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2009

The year in review

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BULLETIN

Cover: Type by Jane Fitzgerald; image from space shuttle Columbia, 2003.

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AIAA
American Institute of Aeronautics and Astronautics

Editorial

Inching toward reform

As the new year began, a new administration and a new Congress opened a door to long-sought efforts to rewrite the tangle of controls governing U.S. exports.

The International Traffic in Arms Regulations were enacted in 1976 and closely mirrored laws in place in eastern bloc nations. Over the subsequent 30+ years, political winds have shifted, both domestically and internationally, and those rules have been reinterpreted, refocused, and, in many cases, made even more restrictive.

But recently many, particularly in the aerospace industry, have come to recognize that the very regulations designed to protect the nation's technological edge and asymmetrical advantage over potential foes have, with their restrictions on the export of possible dual-use technologies, also hamstrung the ability of the U.S. to participate in international trade in many areas only marginally related to defense.

International aerospace companies loath to endure the months of red tape and deliberations required for the purchase of simple parts instead developed their own capabilities. The rise of the "ITAR-free satellite" was not a one-off.

But with the new administration, there seemed to be genuine interest in reexamining ITAR issues. Members of both houses of Congress began holding hearings, and many who had been adamantly opposed to change came to understand the damage being done to trade and now simply urged caution in moving forward. The House bill authorizing appropriations for the Dept. of State, where ITAR issues reside, and containing a section on reform of export controls was passed in June. (Unfortunately, its Senate equivalent remains stalled.) And in August, President Obama announced a comprehensive review of export controls.

This all might suggest a looming overhaul of the most trade-restrictive parts of the laws. However, there are other troubles weighing heavily on the president and the Congress. For example, even as the economy appears to be turning around, unemployment is still rising. And the world clock is ticking on climate change, as the longer we wait to act, the more damage will be done and the more mitigation will be necessary.

But these issues do truly tie together. The longer it takes to modify the antiquated sections of the export controls, the smaller the U.S. export market will become. As more and more of those who were once our customers become our competitors, that market shrinks, manufacturing numbers diminish, and the workforce required declines.

Export controls also hamper U.S. participation in GEOSS, the Global Earth Observation System of Systems. Climate change mitigation can only happen when action is taken on a global scale. But according to a report issued in 2008 by the Center for Strategic & International Studies, "Export control regulations are a fundamental disincentive and significant structural impediment to U.S. participation in international systems, to foreign cooperation with the United States, and to the development of GEOSS."

There are those who argue that ITAR reform must take a back seat as our government grapples with the larger issues of the day. But a closer look would suggest the opposite, that major strides in repairing what is broken or out-of-date in ITAR would go a long way in helping solve those issues.

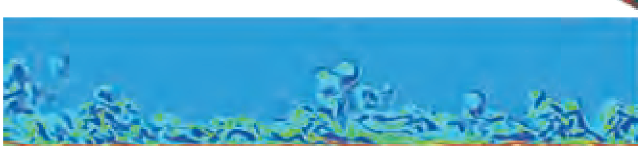
Elaine Camhi
Editor-in-Chief

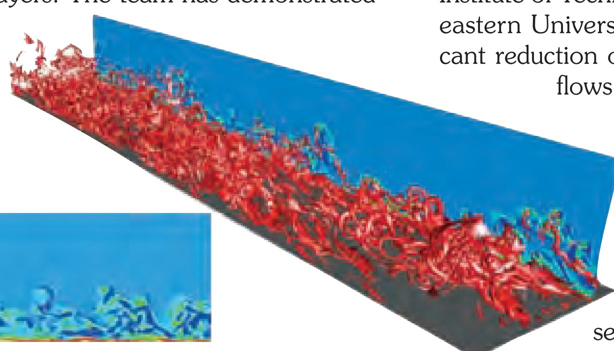
Fluid dynamics

The year has brought many significant and exciting developments in the study of fluid dynamic phenomena with a breadth of activities spanning from hypersonics to low Reynolds number regimes.

A significant development has been the establishment of three national hypersonics centers, overseen by NASA and the Air Force Research Laboratory (AFRL) Office of Scientific Research, to help forge a national direction for studying hypersonic flight. One center, led by Texas A&M University with several partners, is called the National Center for Hypersonic Laminar Turbulent Transition. It will specialize in boundary-layer control research.

AFRL, Caltech, and the University of Minnesota have collaborated in a numerical and experimental study on control of high-speed boundary layers. The team has demonstrated significant delays in transition through the suppression of instabilities with the injection of CO_2. Researchers at the University of Minnesota, CUBRC, NASA Langley, Purdue, and AFRL used a combination of stability analysis and ground test data to identify crossflow instability as a likely mechanism for transition on the leeward side of the X-51 demonstrator aircraft.





Complete transition to turbulence was initiated by one particular transition mechanism for a flat-plate boundary layer at Mach 3. (Left) Isosurfaces of the vortex identification criterion "Q" and contours of spanwise vorticity at one spanwise position illustrate small-scale structures close to the end of the computational domain. (Right) A close-up view shows contours of the spanwise vorticity (simulations carried out by the University of Arizona).

Additional efforts involving highly resolved numerical studies include a University of Arizona program examining the entire process of transition to turbulence in supersonic and hypersonic flows. The goal is to enable improved engineering and physical models for transition during high-speed flight.

On space shuttle Discovery's STS-119 and -128 missions, NASA flew a specially modified tile and instrumentation package to monitor heating effects from boundary-layer transition during reentry. The airflow on the port wing was deliberately disrupted by a protuberance built into a modified tile, enabling the effects of a known roughness geometry on the orbiter surface boundary layer to be quantified for the first time. Regular orbiter instrumentation was augmented by high-resolution calibrated imagery obtained by a Navy NP-3D Orion aircraft using a long-range infrared optical package known as Cast Glance.

In low Reynolds number aerodynamics, work continues on unsteady flow phenomena and control. Researchers at the University of Michigan found that for low-aspect-ratio flapping wings, tip vortices can increase lift by creating a low-pressure region near the wing tip and delaying the shedding of the leading-edge vortex (LEV). AFRL/RB researchers have demonstrated, with a high-order implicit large-eddy simulation (ILES) approach, that stall suppression can be achieved with small-amplitude high-frequency oscillations. The resulting new flow regime has no LEV shedding or thrust generation, and features the dramatic spanwise breakdown of the dynamic-stall vortex system. A joint effort by Caltech, Illinois Institute of Technology, Princeton, and Northeastern University has demonstrated significant reduction of lift fluctuations in unsteady flows through flow control, with applications in gust alleviation. Balanced POD (proper orthogonal decomposition)/observer models were shown to stabilize vortex shedding using only two velocity sensors, with important benefits for small autonomous air vehicles.

Control of the flow over a hemispherical turret for aerooptic applications is an important application of control of 3D flows, and has received considerable attention this year. Studies involving hybrid Reynolds-averaged Navier-Stokes/ILES simulations by researchers at AFRL, and experiments at AFRL, Syracuse University, Notre Dame, Georgia Tech, and the University of Florida demonstrated an array of actuation strategies in both open and closed loops.

Researchers at the University of Vermont have teamed with NASA to study micropropulsion and control of nanosats, to enable new propulsion technologies for these very small spacecraft using microfluidics.

Purdue and George Washington University, under FAA funding, conducted studies of air circulation patterns and particle transport in model aircraft cabins. A key finding is that people walking in the aisles disrupt the designed ventilation flow patterns and can promote the spread of airborne contaminants over 10 rows.

by **Lawrence Ukeiley**

Aeroacoustics

The development of civil supersonic aircraft capable of operating within the threshold of community noise regulations is continuing on different fronts. Wyle Laboratories, in collaboration with Penn State University and Eagle Aeronautics, has made significant strides in calculating sonic boom footprints from supersonic flight vehicles. Enhancements include sonic boom predictions over georeferenced terrain encompassing varying ground impedance, as well as distortions imposed by atmospheric turbulence.

Meanwhile, scientists at Stanford University, with support from NASA, are developing large eddy simulations (LES) capable of predicting the radiated sound from heated and unheated supersonic jets with complex geometries. Databases obtained at the small hot jet acoustic rig facility at NASA Glenn are being used to validate these models. Similar efforts at Boeing, under way since 2004, have demonstrated continued progress in the development and application of LES methodology. Accurate spectral predictions of jet noise, to within 2-3 dB over a meaningful range of frequencies, have been achieved from complex single-stream and dual-stream nozzle geometries and a wide range of jet operating conditions with the developed methodology.

Researchers at the University of Illinois at Urbana-Champaign are developing new theories for the dominant mechanisms responsible for the sources of core noise in aircraft engines. This effort is part of an NRA from NASA's subsonic fixed-wing program. The mechanism, often called "indirect combustion noise," is believed to be caused by thermodynamic interactions (entropy fluctuations) with the engine's turbine blades. Nonlinear simulations of the flow and acoustic radiation over an idealized turbine blade support the new theory.

Other activities in computational aeroacoustics and advanced measurement methods were sponsored this year by the Aeroacoustics Research Consortium. Managed by the Ohio Aerospace Institute, the consortium is a partnership among NASA Glenn, Boeing, General Electric Aircraft Engines, Honeywell International, Pratt & Whitney, and Rolls-Royce. Its programs include assessing the effectiveness of using phased microphone arrays to identify engine noise sources, the development of computational methods to predict high-speed jet noise, and the application of LES to acoustic liners.

The FAA sponsored an aircraft taxi noise study performed by Wyle Laboratories.

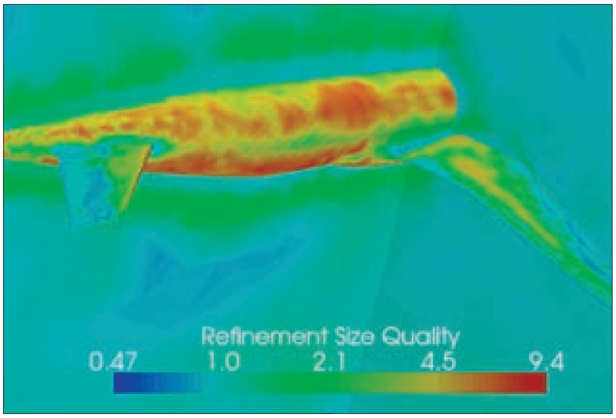
A collaboration between GKN Aerospace and Honeywell Aerospace brought continued progress in reducing engine fan noise. The two companies designed, fabricated, and tested a seamless double-layer engine inlet liner using a Hexcel HexWeb Acousti-Cap honeycomb core with a perforated composite facesheet. Far-field acoustic surveys on a full-scale demonstrator engine at Honeywell's Acoustic Test Facility demonstrated comparable results over a substantial range of engine speeds for the new design when compared to traditional liners. Testing also confirmed improvements in sound attenuation at high engine power settings using the seamless liners.

The counterrotating open fan engine architecture, successfully developed and flight tested by GE in the 1980s, is a candidate for the next generation of narrowbody aircraft. To meet community noise regulations, CFM International (a 50/50 joint partnership between GE and Snecma) has developed modern open rotor fan system designs using computational aeroacoustic prediction tools. Joint GE/NASA testing is scheduled to continue through early 2010 to demonstrate these concepts and validate the design tools.

In the area of space-based launch platforms, existing liftoff acoustic models used by NASA Marshall are being updated with new empirical data. One such set of experiments, conducted under a joint effort of NASA, Wyle Labs, and ATK Launch Systems, comprised three static firings incorporating more than 60 acoustic free-field microphones. The new acoustic models will be used to predict the liftoff acoustic environments of the Ares I and Ares V launch vehicles.

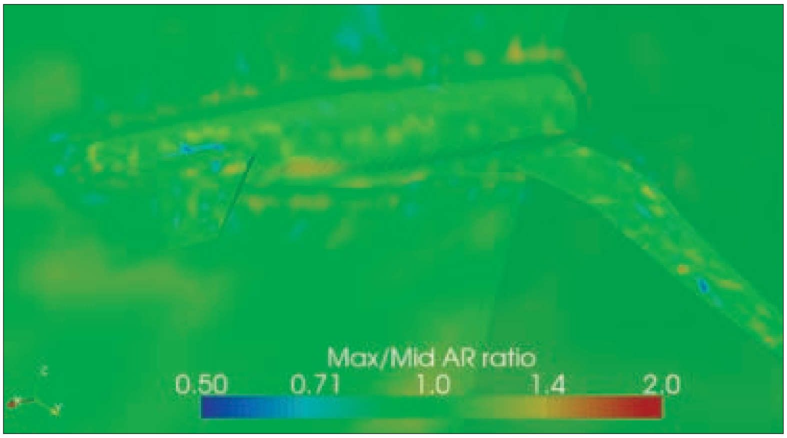
by **Charles E. Tinney**

Meshing, visualization, and computational environments



The length scale ratio for the coarse and medium meshes in the Langley cell-centered sequence is normalized by mesh size so that the expected value is one; the analysis suggests that the medium mesh has cells that are too large on the surface of the fuselage.

The overall problem of elucidating the interaction between mesh and solution is large and complex. Recent work by Carl Ollivier-Gooch of the University of British Columbia seeks to address a small but important part of the problem, that of determining whether a sequence of meshes truly constitutes a mesh refinement sequence for a mesh convergence study. Two meshes are said to form an ideal refinement pair if their cell sizes are uniformly proportional across the entire domain, and if cell aspect ratio and orientation are the same in anisotropic regions of the mesh. The size, shape, and orientation of a cell in an unstructured mesh can be computed in more than one way; one viable approach is to compute the moments problem to find the size, aspect ratio, and principal directions of the cell.



In a comparison of one of the two cell aspect ratios (roughly spanwise to streamwise) for the coarse and medium meshes in the Langley cell-centered sequence, with the exception of a few small regions on the wing and at the base of the tail, the aspect ratio is nearly the same for both meshes, as expected.

Once these quantities are known, a comparison between meshes can be accomplished by projecting data from one mesh to another. Although this is still a research tool, meshes from a Drag Prediction Workshop held this summer were analyzed successfully.

CRAFT Tech and CEI have jointly developed a computational environment that allows users to predict, visualize, and reduce grid-induced errors in CFD simulations. Through a custom interface, the software system combines an error quantification and unstructured mesh adaptation code, CRISP CFD, with the rendering capabilities of EnSight.

A variety of methods may be used to visualize predicted errors obtained from the solution of error transport equations. Techniques for simultaneous visualization of flow variables and their associated errors include multiple contours, multiple vectors or streamlines, texturing, and error bubbles. Error sources may be used to drive local adaptive mesh refinement, directly from the user interface. The system has been demonstrated for practical turbulent flows on 3D unstructured meshes.

Mesh generation developers worldwide came together to share technical information related to their research at the International Meshing Roundtable (IMR), a yearly conference devoted to mesh generation and general preprocessing techniques. Started by Sandia National Laboratory in 1992, the meeting continues to be one of the premier events focusing on mesh generation for field simulations and graphical display. The AIAA began cosponsoring the conference starting with the 18th IMR held in Salt Lake City in October.

An award given each year by the AIAA MVCE Technical Committee was renamed the Shahyar Pirzadeh Memorial Award for the Outstanding Paper in the discipline. The award was renamed in memory of a valued contributor to the field of unstructured numerical mesh generation. Pirzadeh, who died on March 18, was best known for his work with the VGRID unstructured mesh generator. His many innovations included the advancing layers method and early adoption of the Cartesian background grid to control mesh spacing. He was also the award's first recipient.

by **Anthony C. Iannetti**

Guidance, navigation, and control

Rockwell Collins demonstrated a damage-tolerant flight control system for DARPA's Joint Unmanned Combat Aircraft Systems program using an unmanned F/A-18 subscale aircraft model with 60% wing loss. The flight controller demonstrated automatic recovery and autonomous landing.

Aurora Flight Sciences demonstrated autonomous vertical takeoff, hover, and landing of the Excalibur unmanned combat aircraft, which combines high-speed flight with vertical takeoff and landing (VTOL). Its VTOL system gets its primary propulsion from a tilting jet engine and supplemental thrust and pitch control with electric lift fans.

An X-plane pushing the limits of flight control software is the tailless, X-48B blended wing body built by Boeing with NASA and the Air Force Research Laboratory (AFRL). The X-48B's flight controller is responsible for allocating the autopilot commands among 20 movable surfaces. The control surfaces are all independently actuated and clustered along the trailing edge. The centralized, highly coupled, nonlinear flight control system also incorporates envelope protection algorithms via limiters. More robust alpha and beta sideslip limiter algorithms are being developed to provide better envelope protection against unexpected lateral-mode oscillations seen in stall tests at high angles of attack.

NetFires completed the first moving target test flight of the non-line-of-sight launch system's precision attack missile in July. Raytheon's AIM-9X Sidewinder missile demonstrated surface-to-air capability when it engaged an unmanned air target in May. The AIM-9X is a fifth-generation, high off-boresight infrared-guided missile developed for the air-to-air mission.

Lockheed Martin launched DAGR rockets from an airborne AH-6 Little Bird helicopter and hit the targets in two trials in July. Lockheed Martin and the Missile Defense Agency demonstrated the ability of the Terminal High Altitude Area Defense weapon system to detect, track, and intercept a separating target inside Earth's atmosphere in March.

A Boeing Harpoon Block II missile equipped with a redesigned guidance control unit hit its land-based target in its first test flight in September. The Arrow II interceptor, produced by Boeing and Israel Aerospace Industries, shot down a ballistic missile target in April in an operationally realistic test conducted in Israel by the Israel Ministry of Defense and the Missile Defense Agency.

A Sidewinder missile demonstrated surface-to-air capability when it engaged an unmanned air target.

Shuttle mission STS-126 delivered ISS component modules that doubled the space station's crew capacity with new living quarters, regenerative environmental controls, and enhanced life support system. Follow-up STS missions installed the final pair of solar panels, several new multinational science laboratory modules, and a new astronaut treadmill. On July 30, two 5-in.-cube picosatellites, AggieSat2 (Texas A&M University) and Bevo-1 (University of Texas-Austin) were released from STS-127 Endeavour. They are the first of a series of test satellite pairs that will eventually demonstrate autonomous rendezvous and docking.

On June 18, NASA launched LCROSS (Lunar Crater Observation and Sensing Satellite) and LRO (Lunar Reconnaissance Orbiter). In an effort to detect water ice traces in a lunar polar crater, the LCROSS satellite flew into a heavy debris plume created when its spent upper-stage Centaur rocket impacted the Moon's Cabeus A crater on October 9. It collected and analyzed debris samples and relayed the data to Earth. LRO's one-year lunar surface mapping mission for subsequent lunar expeditions began when it entered its mapping orbit September 17 and started relaying high-resolution topographic imagery.

In October 2008, India launched its first lunar probe, Chandrayaan-1, which demonstrated launch to Earth orbit, departure, transfer, and insertion into low lunar orbit, finally releasing a lunar impactor for surface analysis missions. Chandrayaan-1 carried science payloads for NASA and ESA, among others, and completed its mission in June.

An AFRL experimental small satellite, TacSat-3, launched and deployed on May 19. TacSat-3 hosts a hyperspectral sensor that can be directly controlled by troops in the field, an ocean data telemetry microsatellite link, and a plug-and-play avionics package.

by **Leena Singh, Daniel J. Clancy,** and **Brett Ridgely**

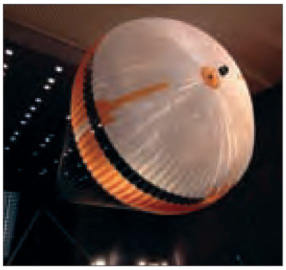
Aerodynamic decelerator systems

2009 was a very productive year for parachute development. Notable accomplishments include testing of the Mars Science Laboratory (MSL) parachute, the Ares I recovery system, and the Max Launch Abort System (MLAS), as well as significant work in the area of autonomous payload delivery.

The Ares I recovery system will require parachutes that are much larger and stronger than those used for the space shuttle.

The MSL parachute finished its final testing, successfully completing structural qualification and flight lot workmanship verification tests. The testing took place at the NASA Ames Full Scale Aerodynamics Complex 80 x 120-ft wind tunnel. The parachute was deployed at conditions that produced inflation loads 25% higher than the maximum expected flight limit load and included multiple inflations of the flight lot canopy. The final tally resulted in a single canopy withstanding 14 inflations at peak inflation loads ranging from 360 to 290 kN (81-65 klbf).

The Mars Science Laboratory parachute completed testing this year.



The Ares I solid rocket booster, which will launch the Orion crew exploration vehicle (CEV) following retirement of the space shuttle, is much heavier than the shuttle's booster and reenters the atmosphere at a much higher velocity; hence the parachutes must be larger and stronger. The 68-ft-diam drogue parachute will experience a load of 500,000 lb, while the three 150-ft-diam main parachutes will experience 300,000-lb loads. The final drogue parachute basic performance drop test was completed this year, along with a drop test of the clustered three main parachutes. The drogue drop test provided the drag area at various reefing ratios along with the corresponding opening loads and load factors. The cluster test provided the cluster degradation factor for the main parachute's drag area, as well as an observation of the parachute's deployment, inflation, and cluster interaction characteristics.

NASA's Engineering and Safety Center developed and tested MLAS as a risk-mitigation system should problems arise with Orion's launch abort design. The effort culminated in a highly successful July flight test. During the test, two mortar-deployed parachutes separated the coast skirt from the forward fairing, followed 3 sec later by two more mortar-deployed parachutes reorienting the fairing 180°, which placed the boilerplate CEV crew module (CM) in the heat-shield-first orientation. With the fairing stabilized, the boilerplate CM was released from inside the fairing. After a brief ride on two drogues, the boilerplate CM released its simulated forward bay cover and deployed four main parachutes.

This test demonstrated that the fairing could be successfully reoriented and the CM released without detrimental recontact. Thus it showed that the MLAS system is a viable concept should the baseline launch abort system encounter significant difficulties during development.

This year the Aerodynamic Decelerator Systems Center at the Naval Postgraduate School developed Snowflake, an autonomous networking aerial delivery system for a 3-lb payload. Networking capability allows target assignment and tracking from anywhere in the world through the Internet. Snowflake is currently being integrated with the Arcturus T-20 UAV, which will be able to carry up to 12 systems inside the payload bay and two payload containers under the wings.

Aerial delivery remains an increasingly critical and successful method of supply delivery for the military in all types of environments. Airdrops have nearly doubled every year since 2005 in Afghanistan, and are on track to exceed 30 million lb this year. The JPADS (joint precision airdrop system) family of autonomous air vehicle systems provides payload capability ranging from 1 to 42,000 lb, with most already demonstrated or in use. The largest precision airdrop demonstration ever held, conducted by the Army Natick Soldier Research, Development, and Engineering Center, took place in the U.S. October 19-22, 2008, allowing more than 500 U.S. and allied participants the opportunity to witness the capabilities and utility of precision airdrop systems.

by **Elsa Hennings**

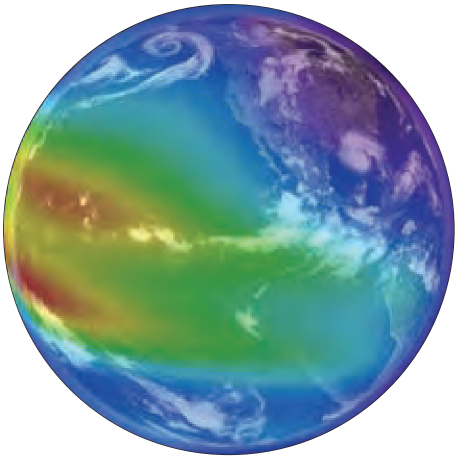
Atmospheric and space environments

Advancements in the areas of atmospheric and space environments continued, and this year saw a wide variety of developments in flight experiments, testing capabilities, terrestrial guidelines, and space weather.

Lockheed Martin Space Systems, NASA Marshall, and Kyushu Institute of Technology are collaborating with the Japanese Aerospace Exploration Agency and the U.S. Naval Research Laboratory (NRL) on a flight experiment scheduled to launch aboard STS-134. The PASCAL (primary arc effects on solar cells at LEO) experiment will characterize the cumulative effects of low-power plasma-induced arcing on the performance of a variety of typical and state-of-the-art space solar cell technologies. PASCAL is part of the MISSE-8 (materials ISS experiment-8) and the first PRELSE (platform for retrievable experiments in a LEO space environment) program managed by NRL. It will be an active experiment on the station with a design life of least two years and a goal of being returned to Earth for ground processing. Results will aid spacecraft designers, operators, and insurers responsible for solar arrays operating in a space plasma environment conducive to producing electrostatic discharges on the solar array surface.

The Air Force is currently developing a new testing capability, the space threat assessment testbed (STAT), at its Arnold Engineering Development Center. STAT will enable ground testing of space systems in the complex natural space environment at various orbits and will also provide the ability to induce man-made threats. An interactive connection to satellite operations centers will be included to bridge the gap between development and operational testing of space systems. This connectivity will allow ground station hardware, software, and operators to be involved in realistic test scenarios.

NASA Marshall's Natural Environments Branch has published the latest revision to *Terrestrial Environment (Climatic) Criteria Guidelines for Use in Aerospace Vehicle Development* (NASA/TM-2008-215633). This document provides guidelines for the terrestrial environment (Earth surface to 90-km altitude) that are specifically applicable in the development of design requirements and specifications, plus associated operational criteria, for NASA aerospace vehicles, payloads, and associated ground support equipment.



Google Earth displays an image of the global ionosphere.

The document contains considerable information of general engineering and scientific interest concerning the terrestrial environment. It also has information on ground and in-flight winds, atmospheric thermodynamic models, radiation, humidity, precipitation, severe weather, sea state, lightning, atmospheric chemistry, and seismic criteria. It includes a model to predict atmospheric dispersion of aerospace engine exhaust cloud rise and growth. It is available for download at the NASA Technical Reports Server: http://ntrs.nasa.gov.

Beginning this year, Utah State University is hosting a new organization to develop commercial space weather applications, with funding provided by the Utah Science Technology and Research (USTAR) initiative. The USTAR Center for Space Weather (UCSW) is developing innovative applications for mitigating adverse space weather effects in technological systems. Of the space environment domains affected by space weather, the ionosphere is the key region that impacts communication and navigation systems. The UCSW has developed products for users of systems affected by space-weather-driven ionospheric changes.

On September 1, in conjunction with Space Environment Technologies, UCSW released the world's first real-time space weather via an iPhone app. Space WX displays the real-time current global ionosphere total electron content along with its space weather drivers. Also, the global assimilation of ionospheric measurements system is now being run operationally in real time at UCSW with the continuous ingestion of hundreds of global data streams to dramatically improve characterization of the ionosphere.

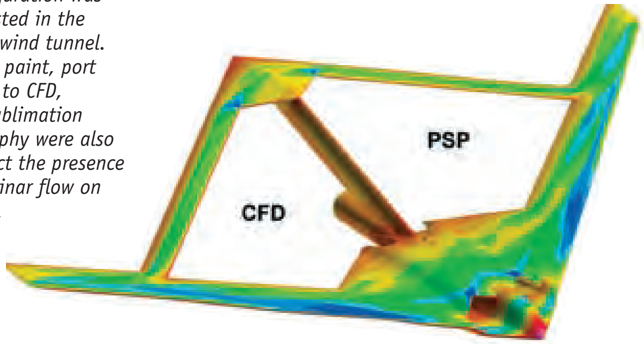
by **Dustin Crider** and the **AIAA Atmospheric and Space Environments Technical Committee**

Applied aerodynamics

Heightened focus on energy and the environment has led to new activities in the aeronautics community. NASA has initiated the Environmentally Responsible Aviation project, which focuses on integrated system-level research aimed at simultaneously achieving national noise, emissions, and fuel burn goals for N+2 (generation after next) civil aircraft. NASA's ongoing N+3 advanced concept studies, involving four subsonic and two supersonic civil missions, will be completed in spring 2010. The Air Force Research Laboratory (AFRL) kicked off an 18-month study of military transports, the Revolutionary Configurations for Energy Efficiency Program, to identify ways of achieving 90% reductions in fleet fuel usage by 2050.

The European Smart Fixed Wing Aircraft Integrated Technology Demonstrator is pursuing active wing technologies that adapt wing shape based on sensed airflow, as well as new aircraft configurations that can best incorporate these novel concepts.

An AFRL/Scaled Composites/Northrop Grumman/university team is maturing swept-wing laminar flow control technologies toward revolutionary ISR (intelligence, surveillance, and reconnaissance) capabilities as part of the SensorCraft concept. A variety of in-flight measurement techniques have been used, including infrared thermography and unique self-contained, in-flight boundary-layer measurement devices, to conduct flight tests of a 30-deg swept-wing test article attached to the White Knight One aircraft.



A 4%-scale Boeing joined-wing SensorCraft configuration was optimized and tested in the NASA Ames 11-ft wind tunnel. Pressure-sensitive paint, port side, is compared to CFD, starboard side. Sublimation and IR thermography were also employed to detect the presence of significant laminar flow on the configuration.

As part of the AFRL Aerodynamic Efficiency Improvement program, Boeing performed CFD-based aerodynamic optimization on a joined-wing SensorCraft configuration to minimize the configuration drag and inlet distortion. With NASA support, a 4% scale model of the optimized geometry was built and tested in the Ames 11-ft wind tunnel.

Preparations continue for Ares I-X flight tests. Development has relied heavily on CFD to predict aerodynamic characteristics on the pad, at liftoff, and during ascent, as well as to predict trajectories of vehicle components to ocean impact.

The Fourth Drag Prediction Workshop centered around the NASA common research model and emphasized trim drag and Reynolds number effects. The model will be tested to flight Reynolds numbers at NASA's National Transonic Facility. A test in the Ames 11-ft wind tunnel will follow.

Northrop Grumman conducted a series of tests to evaluate step excrescence effects on boundary transition in the presence of a pressure gradient. Results indicate that the allowable height of a step excrescence is larger than previously thought, enabling design of full-scale, subsonic, low-sweep aircraft with a better understanding of the tolerance requirements for laminar flow.

NASA and Georgia Tech Research Institute are collaborating on fundamental 2D circulation control experiments to be used for CFD validation. These data will provide the physical characteristics associated with separation and supercirculation flow control and will lead to a refinement of turbulence models, gridding techniques, and test techniques.

AFRL has begun an aggressive multidisciplinary project on micro air vehicle development, to include the flight sciences (aerodynamics, structures, and controls) and constituent subjects such as efficient energy transduction and storage. AFRL engineers are combining wind/water tunnel testing, benchtop testing, computations, and analysis to exploit unsteady aerodynamics for improved flight performance and flight control. These efforts will leverage the Air Force Office of Scientific Research multidisciplinary research on bio-inspired flight as well as the extensive and multidisciplinary research now being performed in the academic community. They include studies of bat flight, led by Brown University, and fundamental physics of flapping wings, led by the University of Michigan.

Operational control units on flight projectiles were tested at the wind tunnel of the Army Armament Research, Development, and Engineering Center (Picatinny Arsenal). Full-scale models of various configurations were tested at near-free-flight Reynolds numbers to validate performance. Testing resulted in a working software fix being implemented for a configuration that had failed during ballistic firing.

by **Gary Dale**, **Andrew McComas**, and the **AIAA Applied Aerodynamics Technical Committee**

Atmospheric flight mechanics

Boeing completed low-speed taxi tests on the 787 Dreamliner. These included evaluation of the ground handling and braking system during taxi speeds of up to 100 kt. The company continues to address wing attachment structural issues before first flight, which is expected by year's end. The latest variant in Boeing's largest aircraft, the 747-8, is scheduled to fly by early 2010. Design changes to the wing and engine have improved fuel efficiency, while the lengthened fuselage has increased capacity by up to 51 seats.

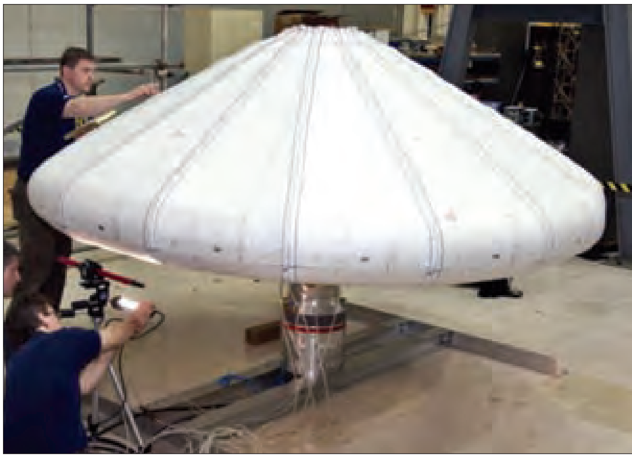
Boeing is also continuing its successful X-48B Blended Wing Body flight test program. As of October 21, 70 flights designed to expand the flight envelope up to and beyond stall and confirm the flight control software's capabilities, were successfully completed. The Boeing X-48C, a low-noise variant of the X-48B, completed a 300-hr test in the 30x60 wind tunnel facility at NASA Langley.

Currently under way are several efforts to develop autonomous and augmented control systems for general aviation aircraft. Hoh Aeronautics and S-TEC have received a supplemental type certificate for their stability augmentation and autopilot unit, called Heli-SAS, for the Robinson R44 helicopter. Flight testing is in progress for Bell's 206-B and 407 rotorcraft models.

For fixed-wing aircraft, Hawker Beechcraft and Rockwell Collins Athena have completed initial flight testing of a fly-by-wire autoland system for the Beechcraft Bonanza. The goal is to demonstrate adapting a UAV autopilot system to a manned aircraft to improve flight safety.

Cessna has flown the first production, single-engine model 162 Skycatcher, which is manufactured in China. Development and production continue despite two incidents with prototype aircraft involving unrecoverable spins. Cessna is reentering the primary training market with the aircraft, its first two-seat design since 1985. Skycatcher complies with the new LSA (light sport aircraft) category.

Roadable aircraft prototypes were announced and debuted, including Terrafugia's folding wing design and Maverick's parachute wing approach. Hybrid air-land vehicles face conflicting design requirements and environmental factors during the drive and flight phases. Both these and other companies say advancements in materials and systems enable a practical, dual-use roadable aircraft.



The IRVE has an inflatable 10-ft-diam heat shield that generates sufficient drag to enable controlled descent through the atmosphere. (Photo by Sean Smith.)

Renewed interest in dirigibles has led one company to offer Zeppelin tours over San Francisco Bay and the USAF to consider it for a long-duration, high-altitude mission. The current design uses a helium-filled hull to provide buoyancy and a solar panel array for propulsion and system power. The USAF vehicle is expected to hover at 65,000 ft for 10 years providing persistent surveillance.

In an alternate approach to high-altitude persistent loiter, the 61-m-wingspan Solar Impulse vehicle is being prepared for an initial flight late this year. The large wingspan and lightweight structure contribute to coupling between the aerodynamic and structural modes and offer unique handling qualities. An autonomous option is planned for the aircraft, which may compete with vehicles developed for DARPA's Vulture program.

Virgin Galactic conducted the inaugural flight of WhiteKnightTwo, which will be used to drop-test and eventually launch the commercial space tourism vehicle SpaceShipTwo. The spacecraft uses a morphing tail section to reconfigure from a streamlined ascent geometry to a high-drag reentry shape.

The X-48C completed a 300-hr test in the 30x60 wind tunnel facility at NASA Langley. (Photo by Bob Ferguson, Boeing.)

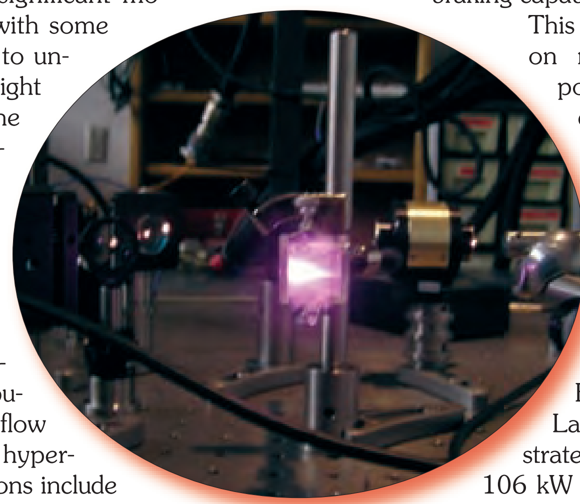
NASA Langley successfully tested the inflatable reentry vehicle experiment (IRVE), whose inflatable 10-ft-diam heat shield generates sufficient drag to enable uncontrolled descent through the atmosphere. Launched to an altitude of 131 mi. using a Black Brant IX rocket, the IRVE initiated inflation during descent while passing through an altitude of 124 mi. This demonstrator's success will lead to larger, more advanced aeroshells designed to withstand higher heat. Ultimately, a shield may be used for safely landing larger payloads to higher surface elevations on Mars.

by **Mujahid Abdulrahim** and **Dwayne F. Kimball**

Plasmadynamics and lasers

by **Ron J. Litchford**
and **Timothy J. Madden**

Development of electrodynamic heat shield technology gained significant momentum this year, with some groups now poised to undertake pioneering flight test experiments. The basic idea is to project magnetic fields into the hypersonic boundary layer surrounding a reentry vehicle and induce strong magnetohydrodynamic interaction effects to manipulate and control flow structure. Potential hypersonic flight applications include active thermal protection systems, guidance and flight path control for endoatmospheric maneuverability, and magnetohydrodynamic power extraction with in-flight energy storage and/or burst power utilization.



Fluorescence emanates from a diode pumped alkali laser experiment. (Courtesy Air Force Research Laboratory.)

The basic technological concept was originally conceived in the 1950s as a potential means of mitigating heat transfer to warhead nose cones but was set aside following the practical demonstration of ablative heat shield materials. However, advancements in superconducting magnet and cryocooler technologies combined with a desire for enhanced capabilities have generated renewed interest in the idea.

Detailed conceptual development has been led primarily by the Institute of High Temperatures in Russia. ESA, EADS Astrium Space Transportation, and DLR have also invested in experimental and theoretical research and recently completed milestone demonstration experiments in the L2K long-duration arc-heater facility at DLR, with clear demonstration of surface temperature reductions (16-44%) and heat flux mitigation (46-85%).

The group's current efforts focus on CFD validation using high-accuracy experimental data and flight test development. Flight tests are necessary to cover the complete environment parameter space, which cannot be precisely simulated in ground-based facilities, and to include the integrated effects of vehicle flight dynamics. The suborbital flight test scenario is based on submarine launch from the Barents Sea using well-established Volna/Volan hardware and infrastructure, with descent phase test article deployment and landing on the Kamchatka peninsula. Additional flight test planning is under way at JAXA's Institute of Space and Astronautical Science, with the aim of enhancing planetary aerobraking capabilities.

This year has seen advances on many fronts in high power-laser technology development. Emphasis is on developing electrically powered laser systems, including bulk solid-state, fiber lasers, and gas-electric hybrid lasers. Northrop Grumman, under DOD's Joint High Power Solid-State Laser program, demonstrated a bulk solid laser with 106 kW of power, claiming the record for the highest continuous wave power produced by this type of laser. As part of this demonstration, Northrop Grumman also showed 19.3% electrical to optical conversion efficiency with a beam quality of approximately 3.0. Similar in orientation to DARPA's High Energy Liquid Laser Area Defense System, these programs are pushing bulk solid-state laser technology to higher powers, better beam quality, and improved specific power performance to enable placement of these lasers on aircraft and mobile ground platforms.

An alternative approach to bulk solid-state laser technology that incorporates the cooling function performed by the liquid into the gain media involves optically pumping a gas with diode sources to drive the lasing action. This approach has the potential to combine the beam quality and cooling advantages of gas lasers with the compactness and logistics advantages of electrically powered solid-state devices. Researchers at the Air Force Academy, teamed with the Air Force Research Laboratory and General Atomics, made significant demonstrations of increases in laser power in laboratory devices with diode pumped alkali lasers. While demonstrating increases in laser power, a critical finding was a decrease in optical input power to laser output power conversion efficiency with increasing input optical power, attributed to mounting losses to heat release and kinetic quenching in the gas. With this finding, it is clear that future development of this technology will involve the application of traditional aerospace technologies for controlling heat release in a gas.

Thermophysics

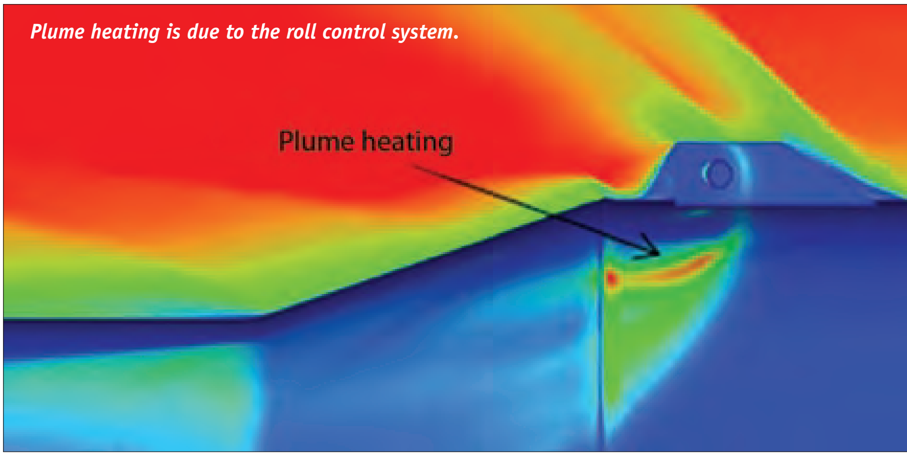
Ares I-X is the test flight for the CLV (crew launch vehicle) Ares I. Its first launch occurred on October 28 from NASA Kennedy in support of NASA's Constellation program. The vehicle's first stage includes a standard solid rocket booster from the space shuttle program. The upper stage and crew exploration vehicle portions of the craft are simulators, with a similar outer mold line to Ares I, but no active propulsion or crewed area in the upper stages. Thermal modeling was performed for Ares I-X to show that the vehicle design is thermally robust, and that all components and materials survive the expected conditions.

Several integrated product teams have come together to develop the Ares I-X first stage, upper stage simulator, crew module/launch abort system, avionics, and roll control system.

The Ares I-X achieved roughly Mach 4 before the separation of the upper stage from the first stage. Thus the amount of aerodynamic heating is relatively minor on most of the craft. The highest aerodynamic heating is at the pointed nose, where there is a probe installed to capture airspeed and angle of attack. This probe is manufactured from stainless steel to withstand the heating. Other high heating on the vehicle is from the roll control system, which will fire during ascent to maintain the vehicle in the proper orientation. Because of the velocity, the plumes from these roll control engines blow back along the vehicle, producing locally high heating. Thermal protection system materials are used in those locations to protect the vehicle skin.

Another thermal challenge for Ares I-X is to maintain the vehicle and avionics temperatures while on the launch pad and during rollout; there is no active environmental control system during rollout or for several hours before launch. The vehicle is painted white to limit absorbed solar heat flux, and fans and conductive thermal grease are used to maintain the avionics temperatures within limit.

The vehicle thermal model has been developed with input from four NASA centers and three contractors. The full model includes all parts of the 350-ft, 2-million-lb vehicle and the pad structures, as well as all physical effects, such as solar heat flux, radiation exchange with ground, sky, vehicle components, and pad, natural and forced convection, contact conduction, and avionics self-heating. Over 40 cases are run within the model and include everything from testing in the Vehicle Assembly Building, rollout, and on-pad sequences (nominal as well as extended hold and abort), through ascent and descent.



Plume heating is due to the roll control system.

Complex timelines of the avionics startup are captured during the on-pad sequence cases, and full mapping of skin-temperature dependent aerodynamic heating on the vehicle skin is done during ascent and descent. This vehicle includes the largest vented air volume ever launched by NASA. The behavior of that air, including venting on ascent, is also captured in the model. The thermal modeling shows that all components and materials are expected to remain within their specified thermal limits during all phases of the mission.


A bow shock forms around the Ares I-X traveling at supersonic speed. The rocket produces 2.96 million lb of thrust at liftoff and goes supersonic in 39 sec. Liftoff occurred on October 28.

Lessons learned on this program about large thermal model integration, analysis of on-pad conditions, and application of aerodynamic heating should prove useful to future programs.

by **John A. Dec**
and **Ruth M. Amundsen**

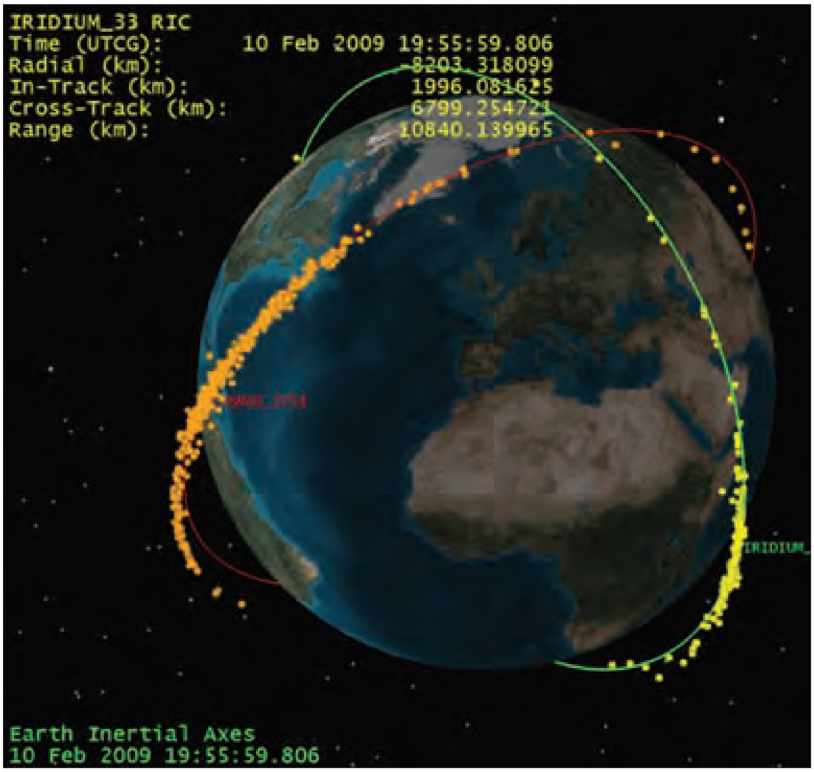
Astrodynamics

by **L. Alberto Cangahuala**

On February 10, Iridium 33—an operational U.S. communications satellite in LEO—was struck and destroyed by Cosmos 2251, a long-defunct Russian communications satellite. The debris fragments generated by this event, and by earlier on-orbit breakups, explosions, and use of antisatellite weapons, will be a growing hazard to much of the LEO satellite population for many decades to come. With a great increase in the number of expected close approaches, it is more important than ever to have widespread participation in sharing the highest fidelity orbit data in order to improve predictions of possible collisions.

There was significant activity related to flight dynamics at the Moon over the past year. The Chinese Chang'e spacecraft and the Japanese Selenological and Engineering Explorer spacecraft made planned impacts to the lunar surface in March and June, respectively. The Indian spacecraft Chandrayaan-1 arrived at the Moon and delivered a lunar probe in late 2008, and conducted science operations until it fell silent at the end of August. It was joined in orbit by the Lunar Reconnaissance Orbiter (LRO) in late June.

A view of Iridium 33 and Cosmos 2251 shows orbits and debris 180 min after the two communications satellites collided. (Credit: T.S. Kelso.)



Three spacecraft began low-energy transfers from the Earth to the Moon in 2009: the Lunar Crater Observation and Sensing Satellite, which observed the impact of its upper stage and then impacted itself on October 9, and the two outermost THEMIS/MIDEX probes, renamed ARTEMIS, which will achieve lunar orbit in 2011.

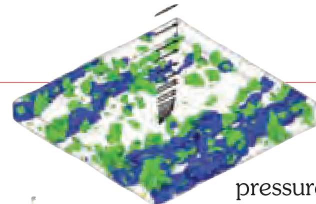
The National Academies put out a call for white papers focusing on how understanding of the solar system may be advanced in the future. In response, many members of the astrodynamics community made strong contributions to several papers, advocating research in several related areas (for example, on-board navigation autonomy).

In addition, the community submitted a paper focused on astrodynamics research and analysis. This paper made the case that, while astrodynamics research has both enabled and greatly expanded the capabilities of numerous planetary science missions, including Dawn, Cassini-Huygens, and MESSENGER, funding for this research has been largely limited to the development and operations phases of missions. NASA funding for general research and analysis in astrodynamics would uncover new techniques before the formulation of new mission concepts and could motivate new classes of missions. These new techniques would not only enhance all sizes of missions, but would also expand the feasible set for new mission concepts.

In the area of low-thrust dynamics, the Dawn spacecraft performed the first flyby of another planet (Mars) by a spacecraft equipped with solar-electric propulsion. The Japanese Hayabusa spacecraft began thrusting again in the final leg of its journey back to Earth and is due to arrive in June 2010. Back on Earth, the European Gravity Field and Steady-State Ocean Circulation Explorer launched in March. It is using electric thrusters as part of a compensation system for all nongravitational forces acting on the spacecraft, leading to improved spatial resolution of the Earth's gravity field.

Finally, the Centre National d'Etudes Spatiales hosted the Fourth Global Trajectory Optimization Competition. The objective of this international astrodynamics design contest was to design a rendezvous mission to a given asteroid while visiting the largest number of other asteroids along the way. The winning team for this year was from Moscow State University. A workshop presenting the methods and results from the competitors was held in Toulouse in September.

Aerodynamic measurement technology



Monash University and the LML obtained instantaneous data from 3C-3D PIV. Structures in green represent vortices identified using a high value of the second invariant of the velocity gradient tensor; the blue regions represent low-speed streaks.

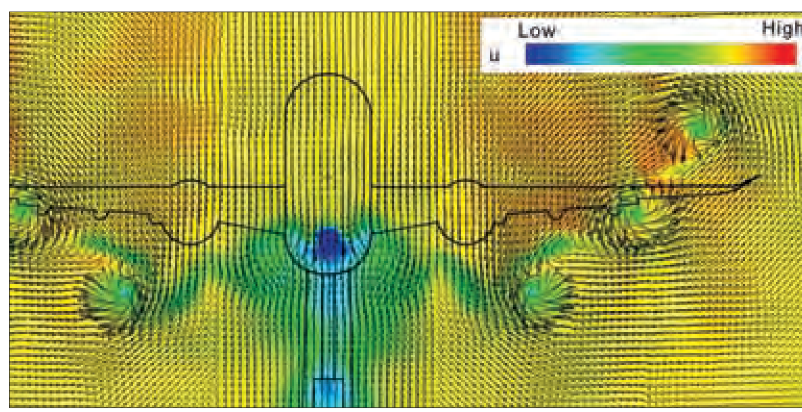
University of Florida researchers presented a microelectromechanical systems-based capacitive wall shear stress sensor for turbulence measurements. It consists of a tethered floating element structure with comb fingers for electromechanical transduction, and employs silicon-micromachining techniques to develop a metal-plated, differential capacitive floating-element-based design. A shear-induced sensor motion results in a proportional capacitance change, measured as a voltage. A simple fabrication process with two lithography steps is used, with deep reactive ion etching on a silicon insulator wafer. The sensor exhibits a linear sensitivity up to the testing limit of 1.1 Pa and a bandwidth of 6.2 kHz. The device has the largest dynamic range and lowest noise floor of any MEMS shear stress sensor to date.

The unsteady pressure-sensitive paint (PSP) technique developed by the Japan Aerospace Exploration Agency (JAXA) was applied to visualize changes in pressure distribution on a wing in flutter. Fast-response anodized-aluminum PSP was coated on a thin aluminum half wing model for flutter measurements. The model was illuminated by a high-power blue laser diode, and its PSP luminescence was measured by a CMOS high-speed camera at 4,000 frames per second. Time-series PSP results revealed a limit cycle oscillation (LCO) in which unsteady pressure behavior was observed. Downward deformation of the wing caused positive angle of attack at the wing tip because of the swept-back angle, so that lambda-shaped shock structure was clearly observed. No shock waves were observed in upward deformation cases where the angle of attack induced by the deformation was negative. Continuous time-series results produced by the unsteady PSP technique are helpful in understanding the unsteady behavior of the global pressure field, including shock waves in the LCO phenomena.

JAXA and Tohoku University jointly developed an innovative technique to measure the spanwise distribution of lift and drag on a wing by stereo particle imaging velocimetry (PIV). The 2D Poisson equation for pressure is solved using PIV velocity data in a measurement plane perpendicular to the freestream direction, yielding the static pressure distribution. Using the wake integral method, spanwise distributions of profile and induced drag and lift are obtained based on the derived pressure data and the three-component velocity data from the PIV.

This technique was applied to wind tunnel tests of a Japanese regional jet, the MRJ (Mitsubishi Regional Jet), to support the aerodynamic design. The technique provides profile and induced drag distributions, which cannot be supplied by conventional balance measurements. The profile drag and induced drag and lift data generated by aerodynamic components (winglets, high-lift devices, engine nacelle, and so on) have proven useful in aerodynamic design studies.

Researchers at the Laboratory for Turbulence Research in Aerospace and Combustion (LTRAC) at Monash University in Melbourne, Australia, led by Julio Soria, and at the Laboratory for Mechanics Lille (LML) at the Ecole Central de Lille, France, led by Michel Stanislas, have undertaken the first 3C-3D (three-component three-dimensional) velocity vector field measurements using accelerated multiple-line-of-sight SMART-based Tomo PIV (developed at LTRAC) of a turbulent boundary layer. The measurements produced instantaneous quantitative 3C-3D velocity vector field measurements in the boundary layer, revealing vortices and other flow structures.



Using stereo PIV, JAXA and Tohoku University obtained three-component velocity distribution around a regional jet model. Lift and drag profiles were computed from the PIV data.

Researchers at Ohio State and Iowa State universities developed a MHz-rate nitric oxide planar laser-induced fluorescence imaging system. The system was demonstrated in the 31-in. Mach 10 wind tunnel at NASA Langley, where it was used to study the time evolution of the transition to turbulence in hypersonic boundary layers. In a separate experiment, Langley researchers have demonstrated non-invasive measurement of 2D oblique-shock strengths (that is, pressure change) with two independent optical methods, Doppler global velocimetry and laser-induced thermal acoustics, finding excellent agreement between the two approaches.

by **Thomas P. Jenkins** and the **Aerodynamic Measurement Technology Technical Committee**

Air transportation

US Airways A320 struck a flock of geese and was forced to ditch in the Hudson River.

The World Geodetic System (WGS) is the coordinate system used by GPS. The current version, WGS-84, was last updated in 2004. To implement worldwide satellite-based communications, navigation, and surveillance systems—a key early component of NextGen initiatives—it is critical that the worldwide air traffic system be referenced to WGS. This year an important milestone was reached as Mexico converted to the WGS-84 standard. In addition, in the U.S. the number of published Wide-Area Augmentation System Category I approach procedures (1,333) surpassed that of the prior-generation ground-based ones.

On January 12, *USA Today* reported a new record for aviation: It had been two years since the last passenger fatality on a U.S. carrier. On January 15, a US Airways A320 struck a flock of geese and was forced to ditch in the Hudson River. Fortunately, no lives were lost. However, in February the string was broken when 48 passengers were killed after a Continental Connection flight crashed near Buffalo, N.Y. In March, a FedEx MD-11 crashed at Tokyo's Narita Airport. In June, an Air France A330 was lost over the Atlantic. Also in June, a Yeminia Airways A310 went down in the Indian Ocean. In July, a Cas-pian Airlines Tu154 crashed in Iran. And in August, a highly publicized crash occurred over the Hudson River between a sightseeing helicopter and a private plane.

Although not atypical from a statistical standpoint, the accident rate worldwide for this year did not decline, and the breadth of the accidents—occurring over all regulatory segments of aviation—has raised safety regulators' concerns.

With the economy on the downturn, air travel has declined, reducing arrival delays but also putting pressure on the industry. The impact has not been uniform, with some industries (the business aircraft market) hit harder than others (the UAV market), and with some airports (Cincinnati, Hong Kong, Munich) hit harder than others (Abu Dhabi, Charles De Gaulle, San Francisco). According to the Air Transport Association, passenger traffic in the fourth quarter of the year was expected to be 12.5 billion passenger miles, down about 13% from the fourth quarter of 2000 and about equal to the 12.1 billion mi. flown in the fourth quarter of 2001 after the downturn associated with September 11.

Because of this drop, airlines are cutting service, focusing more on those routes that cater to business travelers, who tend to pay higher fares. Even some of the low-fare airlines are impacted, like Southwest, whose revenue is down by about 5% and whose schedule for 2010 is slightly reduced.

Efforts to integrate UAVs into the airspace system saw progress this year. In Europe, several projects continued, including the ASTRAEA program, whose goal is to flight test a UAV in nonsegregated airspace in 2012. The FAA has begun a simulation project for investigating UAV operations in the U.S. airspace system, and the Performance-Based Rulemaking Committee has delivered its recommendations concerning small UAVs. Once regulatory barriers to flying UAVs are reduced, the market for commercial applications of these aircraft is expected to explode, as it has for military applications.

The En Route Automation Modernization (ERAM) system, successor to the FAA's Host system, was installed this year in 20 U.S. air route traffic control centers, and software testing has begun. The FAA expects to make a decision on full deployment by year's end. ERAM is considered a key technology platform for a number of NextGen initiatives, including network-centric operations, weather integration, automated conflict resolution, and strategic flow management.

by **Steven J. Landry, Chris Nutter, Frank Frisbie,** and **Dan Salvano**

Aircraft design

Three themes for 2009 are hypersonics, military aircraft, and green aircraft.

In hypersonics, DARPA is developing the Vulcan engine, which is capable of accelerating a vehicle from rest to Mach 4+. Vulcan consists of an integrated constant volume combustion (CVC) engine, a pulsed detonation engine, and a current-production high Mach turbine engine—a Mach 2+ turbojet. The turbine operates from rest to Mach 2; the CVC engine from Mach 2 to Mach 4+. Vulcan will enable reusable hypersonic cruise vehicles for ISR (intelligence, surveillance, and reconnaissance), strike, and access to space.

DARPA plans to fly the Falcon HTV-2 hypersonic vehicle 4,000 n.mi. from the ground at Mach 15-20, validating hypersonic thermal management, guidance, navigation, and control systems. DARPA also plans to fly Boeing's X-51A WaveRider on a 5-min Mach 6 flight to demonstrate scramjet propulsion, advancing sustained-use scramjet technology.

In green aircraft, one important initiative is the hybrid wing body (HWB) configuration, suitable for military transports. NASA, the Air Force Research Lab (AFRL), and industry are developing HWB aircraft that, relative to today, will have 40% reduced fuel burn, noise levels 42 dB below Stage 4, and 75% reduced NO_x emissions. Boeing's X-48B Blended Wing Body is completing low-speed flight testing to evaluate handling qualities and develop a flight control system. Various key HWB technologies are being studied, including lightweight stitched composite structures for noncircular fuselage, hybrid laminar flow control for reduced drag, boundary layer ingesting serpentine engine inlets, ultra-high-bypass engines such as AFRL's ADVENT/HEETE/AD-HEETE engines, landing gear plasma fairings for noise control, low-emissions combustors, and advanced flight controls.

To ensure introduction of HWB aircraft by 2020, NASA's Integrated Systems Research Program will mature, integrate, and test these technologies at the systems level, through simulations, ground testing, and flight testing.

Truss-braced-wing aircraft for commercial transports enable an increased wingspan and thinner wing with less sweep, resulting in reduced induced drag and natural laminar flow. Multidisciplinary optimization is used to determine the proper balance between aerodynamics and structures. A NASA-funded Virginia Tech/Georgia Tech study has resulted in an airplane that uses 32% less fuel for a B-777 mission. Continuing studies include replacing the tail surfaces with thrust vectoring and circulation control.

The Vulcan engine program, HTV-2, and scramjet flight testing are enabling DARPA's vision of hypersonic aircraft.

In military aircraft, Lockheed Martin rolled out the Navy F-35C. The Marines' STOVL F-35B has been undergoing expanded flight testing, with its first vertical landing completed. The Air Force CTOL F-35A is undergoing propulsion and aerial refueling testing. The first joint training wing has been created.

Boeing unveiled the Navy P-8 Poseidon maritime patrol aircraft, a modified B-737-800ERX. Northrop Grumman Navy's E-2D Advanced Hawkeye completed operational assessment and has entered low-rate production. Northrop Grumman's Navy X-47B UCAV is preparing for first flight, completing static and dynamic proof load testing that validated the design and structural integrity.

The fighter-sized Navy X-47B UAV can conduct long-range, high-endurance missions including ISR and precision strikes.

General Atomics flew the Avenger, faster and stealthier than the MQ-1 Predator and MQ-9 Reaper. Skunk Works unveiled an advanced replacement for these vehicles. The stealthy UAV design uses a hybrid propulsion system comprising embedded jet engines for high transit and dash speeds and a turbodiesel driving a propeller located between V-tails for longer, lower speed loiter. Used together, the engines can push the UAV to higher altitudes. The F-22-sized fuselage can be fitted with mission-specific modular wings: a shorter wing for the medium-altitude hunter/killer role and a longer wing for high-altitude, high-endurance ISR missions.

AeroVironment made a breakthrough in nanotechnology, demonstrating controlled hovering flight of DARPA's flapping wing Nano Air Vehicle. They will next build a 10-g hummingbird-like spy vehicle that can travel indoors and outdoors using its flapping wings.

by **Dyna Benchergui** and **Charlie Svoboda**

Aircraft operations

Working closely with the FAA and airline industry partners, NASA continued its research across multiple airspace and operational domains to increase the capacity and efficiency of the National Airspace System. To optimize departure operations, new algorithms were created to assign aircraft to available departure queues and to schedule runway departure times. These algorithms took into account wake-vortex separation criteria, departure fix constraints, and aircraft prioritization. Computational optimization showed improvements in runway throughput when minimizing total airport delay. Total airport delay in a Dallas-Fort Worth traffic study was reduced by up to 30 min over a 15-min scheduling horizon compared to traditional first-come first-served algorithms.

To avoid airspace congestion en route, and to provide an equitable distribution of any required delay among airspace users, NASA developed and tested a generalized approach for evaluating the effectiveness of different traffic flow management strategies at both the regional and national levels. Using this approach, 85 6-hr fast-time simulation experiments examined tradeoffs between alternative optimization schemes, planning horizons, replanning intervals, and control techniques. In the absence of weather constraints, these studies showed that scheduling alone was the most effective strategy for alleviating congestion. In the presence of en route weather hazards, however, tactical rerouting was shown to be the preferred strategy for avoiding sector overload.

NASA furthered development of the EDA (en route descent advisor), used here in a simulation at Ames.

In the arrival domain, NASA furthered its development of the EDA (en route descent advisor) to help air traffic controllers plan operations that maximize throughput while reducing fuel consumption and environmental emissions. New algorithms and human interfaces were developed to provide controllers with idle-thrust descent solutions that prevent traffic conflicts while satisfying time-based metering constraints. Working with the FAA, Boeing, United Airlines, and Continental Airlines, NASA conducted human-in-the-loop simulations of EDA and collected field data during flight operations at the Denver Air Route Traffic Control Center. For large aircraft operating in en route airspace under heavy traffic conditions, simulation results showed reductions in fuel consumption and carbon dioxide emissions of up to 500 lb and 1,500 lb per flight, respectively, with EDA. Results also showed a reduction of over 70% in controller-pilot communications due to EDA's ability to resolve complex arrival problems with a comprehensive trajectory solution that can be issued as a single air traffic control clearance.

For arrival traffic within terminal airspace, NASA conducted high-fidelity simulations investigating the feasibility of conducting closely spaced parallel approaches to three runways—spaced as little as 750 ft apart—under instrument meteorological conditions. Using flight deck displays depicting aircraft locations and wake hazard regions, pilots flew trajectories to the runway in an echelon formation while maintaining precise spacing with one another. Off-nominal events such aircraft blunders and wake encroachments were tested. In the event of an emergency situation, pilots were given aural and visual alerts and shown the breakout trajectory needed on their navigation display.

The pilots successfully completed all simulated approaches with no safety violations and with adequate levels of situational awareness. The minimum separation recorded over all simulated flights was 2,400 ft, well above the FAA separation criterion of 500 ft for such operations.

A Monte Carlo-based optimization model was developed for using the probabilistic forecast of stratus clearing time at San Francisco to achieve benefits in terms of more efficient ground delay programs (GDPs) by better determining GDP end time and scope. Model results indicate reductions of 29% of unnecessary issued ground delay and 39% of unnecessarily delayed flights over the GDPs. This corresponds to a $2.8-million savings per stratus season. The FAA is now funding a field evaluation of this model during the stratus season in 2010 as a cross-organizational effort by the FAA, NASA, Mosaic ATM, and MIT Lincoln Laboratory.

by the **AIAA Aircraft Operations Technical Committee**

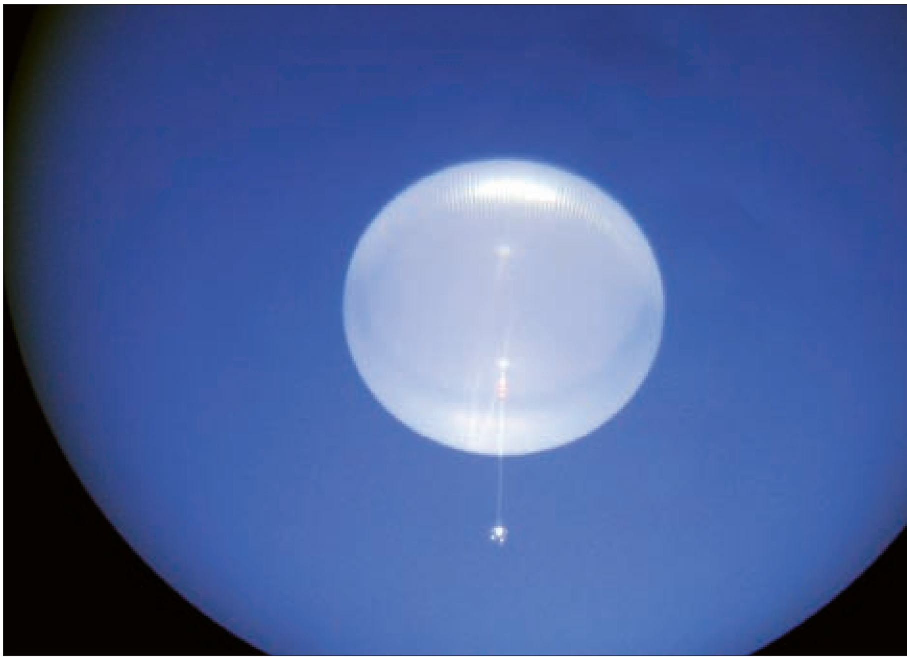
Balloon systems

This year brought progress in balloon design and operational techniques. This included significant successes in large balloon flights, which will increase the usefulness of balloon platforms for scientific and military users. The popularity of small balloons is gaining momentum. Reductions in payload weight and power requirements make it possible to carry out significant science missions using very small hand-launched balloon systems.

NASA's 2009 flight program supported a robust manifest of 16 NASA flights and one technology demonstration. Activities included conventional zero-pressure flights from Fort Sumner, N.M., as well as long duration balloon (LDB) missions and superpressure balloon flights launched from McMurdo, Antarctica, and Esrange, Sweden. The ANITA LDB mission launched in Antarctica achieved its best trajectory thus far for the needed dwell time over the deep ice of the East Antarctic Plateau. This extended dwell time is necessary for achieving the science goal of detecting neutrinos. The CREAM (cosmic ray energetics and mass) mission achieved almost 20 days' flight duration, thus providing over 120 days' cumulative exposure toward the project goal of 1,000 days of flight. The Sunrise instrument launched from Esrange achieved observations previously unparalleled. NASA realized a 100% mission success for the year.

The record-setting flight of a NASA-developed superpressure pumpkin balloon was successfully launched from McMurdo on December 28, 2008. This roughly 201,000-m^3 test balloon was the largest successful single-cell superpressure balloon ever flown. The flight lasted over 54 days, with the balloon flying at a stable altitude of 33.8 km. In the seven-plus weeks at float, it circled the Antarctic continent almost three times with an altitude variation of only about ±170 m, more than an order of magnitude decrease in altitude variation from standard zero-pressure balloons. A roughly 420,000-m^3 balloon was also test flown for a short flight from Sweden in June. A longer duration flight of the same size balloon will take place late this year from McMurdo Station.

These superpressure balloons will ultimately carry large scientific experiments to the brink of space for 100 days or more, and may enable a new era of high-altitude scientific research. The superpressure balloon was highlighted in the National Research Council's decadal survey, *Astronomy and Astrophysics in the New Millennium*, and will play an important role in providing inexpensive access to the near-space environment for science and technology.



NASA's 7-million-ft^3 balloon, at float altitude of 110,000 ft, is 274 ft in diameter. The balloon circled the Antarctic continent for 54 days during December 2008-February 2009. Photo credit: Michael S. Smith, Aerostar International.

A JPL-led team continued to mature the planetary balloon technology required for a future mission to Saturn's moon Titan. Several hours of autonomous flight were accumulated on a low-altitude blimp test bed using the techniques of waypoint navigation, trajectory following, and image-based motion estimation. The team also successfully conducted proof-of-concept experiments to collect small amounts of soil from a low-altitude aerobot using a tethered sample acquisition device. CFD simulations yielded design metrics for double-walled Montgolfiere, or hot air, balloons suitable for use in the cryogenic environment at Titan. A full-scale, 9-m-diam, double-walled prototype Titan Montgolfiere balloon was also successfully floated during an indoor test using a conventional propane burner heat source.

Aerostar International has developed small balloon command and control systems that will allow small university groups and other users to conduct long-duration balloon flights above 100,000 ft with a minimal logistics footprint. The system includes two-way telemetry, ad hoc networking capabilities, redundant flight termination systems, and mission planning software. The systems have been used successfully on university and military demonstration flights. Future developments will include precise altitude control systems and satellite modem communications.

by the **AIAA Balloon Systems Technical Committee**

Flight testing

F-35 STOVL variant BF-2 refuels from a Marine KC 130 tanker, using the Navy probe and drogue system.

The Advanced Composite Cargo Aircraft, based on the Dornier 328 with new composite fuselage and tail, had its first flight out of Palmdale. Modified by the LM Skunk Works, the ACCA is proving the advantages of out-of-autoclave production of large airframe components. Photo: Lockheed Martin/Carla Thomas NASA Dryden.

by **David Brown**

First flying at the end of 2008, Scaled Composites' White Knight Two will carry SpaceShip Two to altitude before its launch into space. Initial changes to the WK2 control system, which is unpowered, included modifications to the rudder aero balances and the addition of vortex generators to the vertical tails. Initial flights expanded the flight envelope to 140 kt and 18,000 ft. Further flights checked pressurization and the electronic control system, and altitude was increased to 52,000 ft. WK2 is now being prepared for initial carriage of SpaceShip Two.

The much-delayed first flight of Boeing 787 ZA 001 had been on track, aiming to fly at the end of June, and the aircraft had completed initial taxi and braking tests when the flight test program was delayed to embody modifications to the wing-fuselage joint area after tests on the static rig revealed delamination of the composite stringers. Following incorporation of fixes, first flight is planned for the last quarter of this year.

The Boeing 747-8 freighter completed power-on checks in August and is expected to enter flight test during the last quarter. A fleet of three aircraft will be used in the test program. With a lengthened fuselage, a new wing with raked wingtips, and GEnx engines (already flown on the GE 747-100 test bed), the -8 will be a quieter, more efficient aircraft.

Several Lockheed Martin F-35s are now in flight test. BF-1 will test initial STOVL flight operations, short takeoffs, hovers, and vertical landings. Hover pit testing involved anchoring the aircraft to a metal grate 14 ft above a sloped concrete floor, eliminating ground effects and so simulating free flight. The specially instrumented hover pit in Fort Worth was used in March. Sensors measured thrust and aircraft response to pilot inputs, in addition to testing all the STOVL systems, and to vector engine thrust. These tests confirmed that the vertical thrust of 41,100 lb was available. Critical performance parameters were measured. Results corresponded well with the computer models for STOVL operations and will lead to the in-flight transitions to STOVL mode and the first vertical landing in the last quarter of the year. However, an engine blade design problem caused the aircraft to be grounded until this fall.

BF-2, the second STOVL aircraft, first flew on February 25. Initial flights were in conventional mode, to be followed by STOVL flights. On August 14, the first air refueling using the Navy probe and drogue system was carried out with a KC-130 tanker. BF-2 will also cover flutter envelope expansion, high-angle-of-attack testing, performance and propulsion testing, and weapons and radar-signature testing. This aircraft will be deployed to NAS Patuxent River, Md., later in the year.

BF-4, due to fly this year after an extensive series of ground tests, is a STOVL variant with full avionics, including the Northrop Grumman AN/APG-81 active electronically scanned array radar, electrooptical distributed aperture system, and integrated communications, navigation, and identification suite, and the BAe Systems electronic warfare system.

CF-1, the first F-35B for the USN, will also fly late this year.

The advanced ballistic laser aircraft YAL-1A, a modified 747-400, has been flying out of Edwards AFB and on August 20 fired its high-energy laser in flight. Further beam control and tracking tests will be completed before it fires at increasingly challenging targets, culminating in the shoot-down of a boosting ICBM.

Lockheed Martin flew the Advanced Composite Cargo Aircraft in June. Based on a Dornier 328, the vehicle features a new composite fuselage, tail ramp, and tail. The out-of-autoclave large composite structure used for the fuselage promises to reduce production costs drastically.

General aviation

Following a slight decline in 2008, general aviation shipments dropped dramatically in the first half of this year. Overall, the number was down 46% over the same period last year, with only 1,037 aircraft delivered. Total billings also dropped for the first time in over a decade to 77% of last year's record first-half figure of almost $12 billion.

Hardest hit was the piston market, down 58% from the high of 1,034 aircraft in the first half of 2008. Also, for the first time in several years, business jet shipments dropped by 38%. This trend was anticipated both from the budget cuts of many industries and from the bad press recently given to the use of business aircraft, perceived by many as perks strictly for executives.

The very light jet (VLJ) boom ended with the bankruptcy of Eclipse, considered the leader in this market. The Embraer Phenom 100 was certificated in late 2008 and began deliveries this year, and the Cessna Citation Mustang continues its deliveries. With gross weight close to 10,000 lb, however, these airplanes are not true VLJs, falling more into the category of light jet. The Piper Jet, a single-engine VLJ, continues in development. Both Cirrus and Diamond are actively working toward certification of their single-engine jets, but consider them personal jets, designed as step-up models from their piston lines.

Production of larger business jets has been cut back, and Cessna suspended work on the Columbus, its largest jet ever. As a result of this move and other cuts, Cessna laid off almost 8,000 people. However, the company still remains the largest producer of general aviation aircraft, both piston and jet, with 321 delivered in the first half of the year. In July, Cessna announced the ASTM (American Society for Testing and Materials) approval of the Model 162 SkyCatcher, its entry into the light sport aircraft (LSA) category, and expects deliveries before the end of the year. Aimed primarily at the training market, this aircraft is expected to boost both Cessna sales and the LSA market overall.

Although a relatively small segment of general aviation, LSA seems to be the one bright spot in this market. With 70 companies now producing such aircraft, new models continue to be introduced. Current U.S. registrations of light sport airplanes now total over 1,600, up about 400 from last year. Many European manufacturers have modified their latest models to appeal to American taste, with features such as toe brakes, modern panels, and leather interiors.

Tecnam this year introduced to the U.S. market the P2006T light twin with economical 100-hp Rotax engines.

The prototype for the Terrafugia Transition, a roadable LSA, flew for the first time in March. The ICON A5, one of the more impressive LSA amphibians being developed, completed the first series of flight tests this year. CubCrafters introduced its Super Sport-Cub, boasting 180 hp from its ECI O-340 engine. This airplane has tremendous performance for an LSA, while still meeting the 1,320-lb gross weight limit.

The production version of the Cessna 162 SkyCatcher was unveiled in July after receiving LSA certification, and deliveries are expected late this year.

A unique airplane introduced to the U.S. market this year by the Italian manufacturer Tecnam, a leading producer of LSA, is the P2006T. This impressive twin high-wing uses two of the lightweight 100-hp Rotax 912 engines that are so popular in LSA. With feathering constant-speed props and retractable gear, ample single-engine performance, and a fuel consumption of under 10 gph total, this aircraft should be a boon to multiengine training.

Following Cessna, Cirrus was the second largest producer of general aviation aircraft, with 121, all pistons. Bombardier/Learjet was the second largest deliverer of jets, at 104, and Diamond shipped 88 aircraft, the third highest number of pistons. Although these numbers show some reasonable activity, overall, the first half of this year was pretty disappointing for general aviation.

by **Hubert C. "Skip" Smith**

V/STOL

UH-60 IBC testing in the Ames subsonic wind tunnel was successfully completed in March. (Photo by Dominic Hart.)

by **E.R. Wood**

This year brought progress in areas across the spectrum of high-technology V/STOL programs, from the F-35B STOVL (short takeoff/vertical landing) Joint Strike Fighter to Sikorsky's X-2 coaxial twin rotor technology demonstrator to V-22 tilt-rotor overseas deployment to DARPA-funded full-scale wind tunnel research on individual blade control.

The F-35B is in final preparations for vertical landing. On September 4, the first Lockheed Martin F-35B Lightning II STOVL variant, known as BF-1, began a final series of flights at the company's Fort Worth plant before its scheduled transfer to the primary STOVL test site at Naval Air Station Patuxent River, Md. There, the test team will intensify STOVL-mode flight operations—short takeoffs, slow landings, and hovers—until BF-1 executes a full vertical landing later this fall. BF-2 is scheduled to arrive at Patuxent River in December, shortly after BF-1. These aircraft will be followed by BF-3, and the first avionics-equipped F-35, BF-4.

In April, BF-1 demonstrated during testing that it produces excess vertical thrust—more than is required for carrying out its missions. "The performance level measured was absolutely exceptional," says J.D. McFarlan, Lockheed Martin F-35 air vehicle lead. "We demonstrated 41,100 lb of vertical thrust against our requirement of 40,550 lb."

In January Bell Boeing was awarded Phase I of a two-phase joint performance-based logistics contract from Naval Air Systems Command. The $581-million contract provides integrated logistics support for both the Marine Corps MV-22 and Air Force CV-22 over a five-year period.

The Air Force declared initial operational capability for its CV-22 aircraft in March. By the end of the summer, Air Force Special Operations Command had deployed CV-22s from its 8th Special Operations Squadron to Iraq for the aircraft's first operational deployment in support of a combatant commander.

April marked the end of an 18-month Iraq deployment for 12 MV-22 Ospreys. The V-22 fleet now has more than 60,000 flight hours. Plans are to ramp up annual V-22 production from 19 aircraft this year to 28 in 2010, and then to 36 in 2011 and beyond.

The X2 completed low-speed flight testing at the Schweizer facility in Horsehead, N.Y. Further flight testing was transferred to Sikorsky's flight test development center in West Palm Beach, Fla. There, tests were resumed and, by the middle of October, Sikorsky's X2 technology demonstrator had achieved a maximum speed of 106 kt. Phase III flight testing was then to begin and the active vibration control system was to be made operational. To date, the aircraft has been flown in both helicopter and auxiliary propulsion mode. The pusher propeller has shown that it can provide the benefits of level flight acceleration and deceleration. Flight testing will continue until the aircraft reaches the maximum speed achievable, currently calculated to be 250 kt.

On March 5, the UH-60A individual blade control (IBC) test team successfully concluded all testing in the NASA Ames 40x80-ft wind tunnel. This wind tunnel test program is a collaborative effort of NASA, the Army, Sikorsky Aircraft, and ZF Luftfahrttechnik GmbH to demonstrate the benefits of IBC for a UH-60 rotor. (IBC is an active rotor concept providing independent control of blade root pitch.) All major test objectives were met, allowing for the evaluation of IBC effects on power, noise, vibration, loads, and flight characteristics.

During a four-week joint NASA/Army experiment in July, flight dynamics and control requirements for large rotorcraft were investigated at NASA Ames in the facility's Vertical Motion Simulator. The purpose of the study was to define response bandwidth and damping requirements in pitch, roll, and yaw in hover for a large rotorcraft.

Lighter-than-air systems

Development of unmanned airships and aerostats continues to dominate the lighter-than-air field in terms of funding and advanced technology. Projects focus on the military requirements of intelligence, surveillance, and reconnaissance. These requirements have forced the development of very lightweight materials for airship and payload structure. They have also led to finding novel ways of incorporating payload and structure to combine their functions, as in DARPA's ISIS project. High altitudes will be used to achieve wide areas of coverage. In April DARPA awarded Lockheed Martin a $400-million contract to proceed with Phase 3, which includes design and construction of a one-third-scale demonstrator airship slated to fly in 2012.

Lockheed Martin plans to fly its long-endurance demonstrator, HALE-D, in 2010. Designed to fly for two weeks in the stratosphere while carrying a 50-lb payload, the craft is a scaled version of the High Altitude Airship, sponsored by the Army Space and Missiles Command. The Army also announced its interest in rapidly acquiring a long-endurance multipayload vehicle with a 2,500-lb package of sensors while on station at 20,000-ft altitude.

Raytheon and TCOM, contractors for the Army's JLENS (joint land attack cruise missile defense elevated netted sensor) project, have completed a $1.4-billion contract to develop a superior airborne sensing system. TCOM provides the 74-m, 650,000-ft^3 tethered aerostats to lift 7,000-lb radars to an altitude of 10,000 ft. Two aerostats are required for each operating system, one carrying a surveillance radar and the other a fire control radar. The system can detect missiles over the horizon 340 mi. away flying at low altitude. Sixteen aerostats equipped with the Raytheon radars are on order. TCOM also has delivered 147 17-m tactical aerostats for the Army's RAID program for force protection.

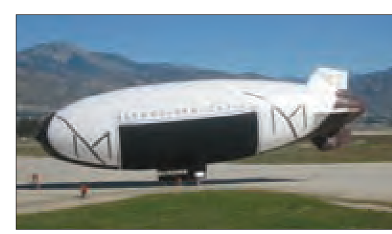
The Polar 400 airship from Guardian Flight Systems (formerly Blackwater Airships) has demonstrated improved broad area persistent surveillance carrying a megapixel compound focal plane camera. The demonstration was sponsored by the Office of the Secretary of Defense, Advanced Systems and Concepts.

Sanswire-TAO has acquired the first envelope for its STS-111 multisegmented nonrigid airship. A lightweight efficient engine has been modified to operate the patented Fuel-Gas design for the midaltitude STS-111 autonomous airship.

The 71M Aerostat Test Balloon is prepared for liftoff from the Aerostat Test Bed at McGregor Range, N.M.

Hybrid Air Vehicles in the U.K. is flight testing its HAV3 scale demonstrator. Test results will be applied to the design of full-scale 20-200-ton payload aircraft.

In July Boeing and Skyhook International reached a configuration freeze milestone on the heavy-lift airship, establishing the aircraft's overall performance and layout. These include an added three-piece tail, integration of lifting and thrusting propulsion systems, and improved aerodynamics on the craft, which combines helicopter and airship components.



American Blimp has delivered two A170s this year for display advertising.

Zeppelin Luftschifftechnik delivered its NT-07 number 4 airship to Airship Ventures in California in October 2008. Passenger sightseeing flights take place at Moffett Field near San Francisco and at various local airports. Longer excursions are flown to Monterey and Los Angeles. Zeppelin's passenger flights also continue to be popular in Germany. A fifth NT-07 airship is under construction.

American Blimp, through its subsidiary The Lightship Group, has delivered A170 airships to the Wind Creek Casino in Atmore, Ala., and to Beijing Advertising in China. Both airships are equipped with 70x30-ft LED video screens.

The 21st Century Airships team in Ontario has developed a 231-ft airship designed for flight at midaltitude (15,000-20,000 ft). The craft is controlled by three vectoring propellers and designed for manned and unmanned flight.

by **Norman Mayer**

Economics

Factors that affected the broader aerospace industry's economic perspectives this year ranged from the economic downturn and the changes influenced by government fiscal realities, to support for current space applications and the promise of future opportunities.

The proposed FY10 DOD budget reflected a shift away from complex, costly, and technologically "exquisite" platforms toward solutions that are more attainable given schedule, budget, and risk constraints.

The economic situation has created challenges across the industry, with aviation particularly affected. Despite lower jet fuel costs, which averaged less than half of the 2008 peak cost of $4 per gallon, the commercial aviation sector has been hurt. The International Air Transport Association is forecasting that the global commercial aviation industry, driven by declining traffic and pricing, will experience a 15% decline in revenues and $9 billion in losses this year. Aviation manufacturers also experienced significant impacts. General aviation airplane shipments fell by 46% during the first half of the year, according to the General Aviation Manufacturers Association. Substantial layoffs resulted, with United Technologies, Boeing, and Cessna announcing layoffs of almost 30,000 workers.

The space industry was not immune to the effects of the financial crisis, with Sea Launch (launch services) and ICO North America (mobile satellite services) filing for bankruptcy because of their inability to obtain needed financing.

Even defense markets reflected the government's new fiscal realities and its need to achieve more with less. The signing of the Weapons Systems Acquisition Reform Act into law marked renewed efforts to eliminate waste and inefficiency in defense acquisition by limiting cost overruns, strengthening oversight and accountability, fostering competition, and reducing conflicts of interest. The proposed FY10 DOD budget reflected a shift away from complex, costly, and technologically "exquisite" platforms toward solutions that are more attainable given schedule, budget, and risk constraints.

Consistent with this perspective, the $26-billion Transformational Satellite program was canceled in favor of building two additional Advanced Extremely High Frequency Satellites, and production of the F-22 Raptor was capped in favor of accelerated development and increased purchases of the F-35 Joint Strike Fighter. In addition, support for unmanned vehicles, particularly UAVs, continued to grow, with proposed spending of $5.4 billion for this year, an increase of over 18% from 2008.

In spite of the difficult economic environment, space applications saw continued progress. Use of GPS is expanding, largely driven by the strong growth of GPS-enabled mobile phones, predicted to reach almost 80 million shipments this year. In capital markets, a number of companies across the space services industry were able to obtain substantial financing, including $1 billion for Dish Network, $738 million for Globalstar, and $526 million for Sirius XM. The commercial remote sensing industry also took strides forward with DigitalGlobe's successful IPO, GeoEye's launch of the world's highest commercial resolution imaging satellite, and the start of operations for RapidEye's innovative five-satellite constellation.

The future for space continues to be promising, as evidenced by the entrepreneurial opportunities being pursued. The privately funded SpaceX achieved its first successful commercial flight, placing the Malaysian RazakSat satellite into orbit, while an Abu Dhabi group invested $280 million in the space tourism company Virgin Galactic. One example of innovative government/commercial partnerships was Intelsat's agreement to host an Australian military UHF payload on its commercial Intelsat-22 satellite. Another was the formation of U.S. Space LLC, which will capitalize on defense market bandwidth shortages by building and operating privately owned communications satellites to be leased only to military customers.

As a year of economic uncertainty and excitement comes to an end, the resilience and creativity that have taken the aerospace industry through previous periods of difficulty appear likely to lead it again to a brighter future.

by **Marilee Wheaton** and **Scott Isara**

History

This year marks the centennial of the birth of the aerospace industry. Today we can look back 100 years to its beginning in 1909, when the Wright brothers set up the Wright Company, to today, when exciting developments range from a new generation of commercial airplanes to sophisticated space exploration activities. In 1909 it would have been hard to project where the aerospace industry would be a century later.

In May of 1909 the Wrights were hailed as heroes upon their triumphant return from demonstration flights made the previous year in Europe and at Fort Myer, Va. On October 4, 1909, Wilbur Wright made a 20-mi. flight up the Hudson River and back in view of a million people. Now, 100 years later, over three million passengers a day travel in airplanes.

On July 25, 1909, Louis Blériot crossed the English Channel, flying from Calais to Dover in 37 min in a Blériot XI Monoplane. The event had implications that would prove devastating during the two world wars: Britain was now vulnerable to air attack. Nevertheless, the flight was hailed as one of aviation's early triumphs. On July 27 of this year, to commemorate the flight's hundredth anniversary, Frenchman Edmond Salis flew a restored Blériot XI across the channel.

Another celebration that took place this year was the 40th anniversary of the Apollo 11 landing. At a widely publicized event marking this achievement, Apollo 11 astronauts Neil Armstrong, Buzz Aldrin, and Michael Collins were reunited, and each was awarded a Congressional Space Medal of Honor.

Meanwhile, NASA's Lunar Reconnaissance Orbiter began its mission to map the lunar surface with high-resolution cameras and return pictures from the Apollo landing sites. Many museums and work sites around the country also celebrated the 1969 landing. A 40th anniversary documentary film, *Moon Beat*, won the 2009 Special Jury Remi Award at the 42nd Annual WorldFest-Houston International Film Festival. In addition, NASA announced the availability of remastered footage of the initial TV broadcasts of the landing.

This year is also the 400th anniversary of Galileo's introduction of the telescope. On August 25, 1609, Galileo gave a demonstration of his new optical device to several prominent Venetian officials. The event was celebrated by a PBS special, *400 Years of the Telescope*, sponsored by Ball Aerospace. Four hundred years after Galileo presented his invention, which he used to discover Jupiter's moons, the Hubble Space Telescope received its final servicing, and on July 23 its lens turned to Jupiter, recording sharp images of the aftermath of a surface impact by a comet or asteroid.

On the eve of the 40th anniversary of Apollo 11's Moon landing,crew-members (from left) Michael Collins, Neil Armstrong, and Buzz Aldrin gathered at the National Air and Space Museum. Photo Credit: NASA/Bill Ingalls.

Fifty years ago, the Mercury Seven—the first astronaut group—were selected to great fanfare. Meanwhile, the X-15 began early flight testing, with pilot Scott Crossfield at the controls. The contrast between the two methods of early access to the edge of space is a subject of continuing discussion.

This year AIAA sponsored the transcription of three important oral histories, those of Sam Iacobellis of North American-Rockwell; Jack Duffendack, who worked at Lockheed from 1937 to 1977 and became its chief engineer; and Les Jonkey, also of Lockheed (1937-1984), where he was head of manufacturing engineering for the Skunk Works. These histories should be available to AIAA members in the near future.

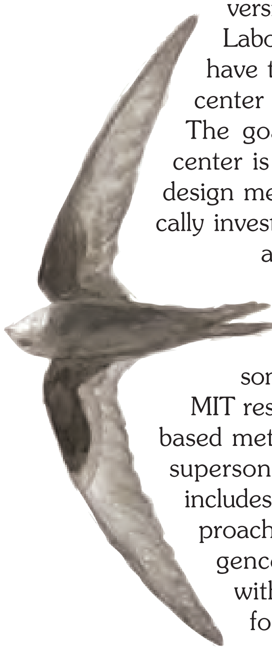
by **Scott Eberhardt**

Multidisciplinary design optimization

Multidisciplinary design optimization (MDO) synergistically considers the interests of multiple, often competing, disciplines in the optimal design of parts, products, and systems. Advances in MDO span industry, government, and academia—with a variety of emphases.

The University of Michigan's Optimal Design Lab extended the analytical target cascading methodology for solving nonhierarchical problems and conducting reliability target allocation (with Eindhoven University of Technology), and developed methods for market simulation-based vehicle design. The lab also investigated the impact of novel vehicle architectures on occupant safety and sustainability, and derived relationships between coupling and controllability in codesign problems.

Virginia Tech, Wright State University, and the Air Force Research Laboratory at Wright-Patterson AFB have teamed to form a collaborative center on future aerospace vehicles. The goal of the Virginia Tech-based center is to improve aerospace vehicle design methods. The center will specifically investigate multidisciplinary analysis and design of several futuristic aircraft such as the joined-wing sensor craft, flapping micro air vehicles, and supersonic long-range strike aircraft.



The swift is one of nature's models for morphing wings, a design challenge for MDO.

MIT researchers are developing MDO-based methods for conceptual design of supersonic and subsonic aircraft. This includes a multifidelity optimization approach that achieves provable convergence to a high-fidelity optimum without requiring derivative information, a multifidelity geometry framework that permits consistent representation of evolving designs for MDO across design phases, and an approach for including more detailed controller design in the conceptual design process.

At the University of Oklahoma, an exergy destruction minimization approach has been used for drag optimization of aircraft using airframe and operational variables. The development of a large multilevel, multifidelity, multiobjective MDO framework also continues.

The Aerospace Structures group at Delft University of Technology is collaborating with aircraft manufacturers Airbus and EADS and with the German Aerospace Institute DLR to develop fast aeroelastic analysis and design tools. These tools will be used for topology design, internal structure layout, and composite skin design of fixed and rotary wings, and wind turbine blades.

Researchers at the University of Illinois at Urbana-Champaign and Caterpillar developed a methodology to efficiently perform stress-based topology optimization. The method allows engineers to design mechanical components via topology optimization by having stress as a criterion instead of stiffness, thus reducing stress concentrations.

The University of Bath has been developing efficient structural optimization capabilities such as topology optimization in a continuum with uncertainties. They are also collaborating with Airbus and QinetiQ in design and analysis capabilities for bistable composites with actuations as a concept mechanism for morphing wings.

The Integrated Design Automation Laboratory at Northwestern University has developed a multiscale design methodology for designing multiscale engineering systems. Their focus is on the design of hierarchical material and product systems with the consideration of random field uncertainty that propagates across multiple length scales. Related research at Brigham Young University has focused on characterizing a mapping between manufacturing process, geometric design, and material microstructure spaces to facilitate multiscale MDO.

Penn State and the Applied Research Lab continue to investigate the benefits of data visualization and visual steering tools that support decision-making. Recent findings demonstrate that novice users—when properly trained to work with higher dimensional visualization tools—perform significantly better than users without training and yield results comparable to those of expert users.

Researchers at the University at Buffalo-SUNY are studying the convergence characteristics of multidisciplinary design process architectures and have developed accurate analytical predictions for certain classes of process architectures.

Iowa State has developed a segmentation algorithm to assist in tumor diagnosis and surgical planning. The algorithm uses adaptive fuzzy rules to extract tumor tissues from healthy tissues in CT scans, and using virtual reality, the segmented tumors can be viewed in context with the original patient data to improve decision-making.

by **Christopher A. Mattson**

Management

Whenever we enter a new era it is important to consider where we have been, what factors have been important, and where we want to be. In the past, management—like other areas of industry—was divided up and specialized. Today it is entering an exciting new era that has almost unlimited potential and is more complex than ever.

Traditionally, management has the right stuff in the right place at the right time. In today's globalized, hypercompetitive world, where knowledge is transmitted literally at the speed of light, this can be difficult to accomplish. Uncertainty abounds. What is the right stuff—the right people, equipment, capital, and other assets? Where is the right place—not just geographically, but economically, technically, environmentally, even socially? When is the right time? The answers are especially important in the aerospace industry, where risk is great, costs are high, and failure can be devastating.

Today many complex issues seem to complement and contradict. For example, many believe aerospace (particularly its defense component) is simply outdated. On the other hand, some say it is simply in the downturn of a cycle. Others point to politicians' lack of engagement on aerospace topics during our last election and conclude that the populace does not view aerospace as relevant to the health of our nation. Yet the role of aerospace is as important today as it has ever been. However, unlike the changes in industries where consumers impatiently wait for new product features, changes in aerospace are not always apparent. For example, people fly on airplanes but do not "see" the new materials that make air travel more viable and economical. This is similarly true for defense.

The ability to take so much for granted creates a real conundrum in discussing what the role of this industry should be. Equally important is how aerospace fits in with and supports other industries. So, how should management meet the requirements of today's aerospace industry?

What is the right stuff? Because of outsourcing, the right stuff includes continuous access to information, goods, and services, many of which are produced in newly industrialized countries, or NICs. Today, NICs provide most of the world's industrial base and have a growing presence in the technological base. So the right stuff becomes sufficient resources (including energy), technology (including knowledge, skills, and abilities), and defense (protection) for an increasing number of countries, including NICs.

Where is the right place? The drive to lower costs has extended industrialized countries' interests literally around the world. Not every developing country will be industrialized. However, for the acquisition or transport of resources, for protection, or for other reasons, the interests of NICs are frequently tied to countries with which no apparent tie to industrialized countries exists. The right place becomes a world in which the flow of information, goods, and services continues uninterrupted.

What is the purpose of expending resources to develop new technologies if they cannot be implemented because nuts and bolts are lacking? What will it mean if stopping development of fighter jet aircraft ultimately reduces the defense of countries we depend on, to the point where we cannot obtain critical goods and services?

When is the right time? The answer is, all the time. To ensure the continuous flow of information, goods, and services today, sustainable development around the world is vital. What is the purpose of expending resources to develop new technologies if they cannot be implemented because nuts and bolts are lacking? What will it mean if stopping development of fighter jet aircraft ultimately reduces the defense of countries we depend on, to the point where we cannot obtain critical goods and services?

Managing sustainable development requires broadening the scope of deliberations well beyond the boundaries of the past. Today, having the right stuff at the right time and place will require a "holistic" approach in which aerospace plays many roles. Correspondingly, an expanded and more comprehensive approach by management will be needed in order to fulfill the aerospace industry's requirements.

by **Marvine Hamner**

Systems engineering

In recent years, defense and aerospace programs have placed growing emphasis on systems engineering as a distinct technical discipline. As a result, there has also been greater emphasis on education and training in the subject. In a Purdue University lecture, former NASA administrator Michael Griffin proposed that "systems engineering is a holistic, integrative discipline, wherein the contributions of structural engineers, electrical engineers, mechanism designers, power engineers, and many, many more disciplines are weighted and considered and balanced, one against another, to produce a coherent whole that is not dominated by the view from the perspective of a single discipline."

The premise that a systems engineer functions in a unique discipline, interacting with and relying on discipline-specific engineers, has possibly led to increasing numbers of universities offering undergraduate degrees in this area. This raises the question of how a student can learn a multidisciplinary engineering approach to problem solving without the benefit of a strong background in a single discipline. For this reason, general opinion, supported by publications, is not in favor of undergraduate degrees in systems engineering.

"Systems engineering is a holistic, integrative discipline, wherein the contributions of structural engineers, electrical engineers, mechanism designers, power engineers, and many, many more disciplines are weighted and considered and balanced, one against another, to produce a coherent whole that is not dominated by the view from the perspective of a single discipline."

To fill the growing number of systems engineering positions made available in part through the much-publicized aging of the workforce, a number of universities now offer undergraduate degrees in this field. These degrees have varied titles and are situated under various departments within the universities. Brief scrutiny of some of the undergraduate systems engineering curricula indicates similarity to general engineering degrees that simply offer a broad but shallow engineering program of study.

Other programs offer studies in engineering economy and scheduling that complement work experience, yet still do not focus on the problem-solving needs that so many systems engineers face at work. The programmatic side of systems engineering is easily overlooked, and while a balance between performance, cost, and schedule is a critical aspect of a systems engineer's job, isolated courses in those subjects may not give a student sufficient background to achieve that balance. Also, a study of risk management, which by its nature quantifies technical risk in terms of cost and schedule impacts, could be of benefit to systems engineering curricula.

Several other publications have noted that about five years after graduation, engineers typically face a choice of continuing in their discipline or migrating to a systems integration job. Employers typically aid the transition to a systems career path with in-house training. There are many workplace opportunities to receive training in systems engineering once formal education has been completed. Corporate universities offer various training opportunities in systems engineering, naturally focusing on the specifics of the organizations they serve. Traditional universities also offer short-term certificate programs in systems engineering.

In addition, graduate degree programs have long been offered in systems engineering, with the degree names varying widely and the major focus being integration of traditional disciplines. The previously mentioned lack of integrated programmatic problem-solving course material still seems to exist at the graduate level.

Every systems engineer operates in a unique program development structure. Each program faces integration challenges specific to its system. In program failure studies, much blame is placed on lack of adherence to recommended systems engineering practices. However, those practices are nearly always subject to tailoring or modification. Such change, although warranted, does leave a lack of structure to impart to systems engineering students. In the future, systems engineering competency will require a variety of fundamentals provided by traditional education, combined with program-specific training to grow the knowledge base for the community as a whole.

by **Michelle Bailey**

Society and aerospace technology

This spring, an interesting social experiment began in space when the ISS attained its first six-person international crew, the largest crew ever to live in space together for a long period of time. While there have been larger crews on space shuttle missions, these only last a couple of weeks, and ISS tours of duty can last up to six months.

Arriving in March aboard a Soyuz spacecraft were two of the crewmembers, Russian Commander Gennady Padalka and NASA physician Michael Barratt. Japan's first full-time crewmember, Koichi Wakata, also arrived in March, on the shuttle Discovery. In May, the three were joined by Russia's Roman Romanenko, Frank De Winne, who represents ESA's 11 member countries, and Canadian Space Agency shuttle veteran Robert Thirsk. For the first time, all five space agencies building the station were represented by a full-time crewmember.

Until now, three-person crews have spent large amounts of time building and maintaining the station. One of the main reasons for having a larger crew on the international lab is to increase the number of hours devoted to science experiments from 20 to 70 hr a week. In addition to increasing the science return, having a larger crew is a tremendous social experiment. The Russians and Americans, who have been rotating crews aboard the station since 2000, have now been joined by a team representing different cultures.

In talking about some of the challenges, the crew have compared it to having in-laws visiting for the holidays, except the crew is living in a space about the size of a jumbo jet and sharing limited bathrooms, food preparation areas, and sleeping quarters that are located in various modules throughout the ISS.

As they live and work together in space, the crewmembers themselves are performing an important set of social experiments, including a formal one called Interactions, which records the crew's feelings and examines the influences of culture on their stay in space. This experiment has been running since the station's early days. Investigators also collect anonymous data from ground control personnel for comparison with the data collected from crewmembers on orbit.

In addition to the station's assigned crew, spacefarers from around the world will be visiting the ISS, temporarily bumping up crew sizes to as high as 13. This will be a test for recently installed sophisticated life support systems. These space travelers will be arriving on vehicles launched from Russia and the U.S., but cargo also will arrive on new transport vehicles designed by Europe and Japan. The ISS has become the first global port for spaceships, involving the hardware needed for spacefaring societies and *people*—the "soft" ware at the heart of human exploration. This reality is the focal point of astrosociological research and clearly points to the need for collaboration between the natural/physical sciences and the social sciences.

Perhaps most important, a space crew now reflects, for the first time, the global nature of our world. Eventually the international crews will staff the station for up to six months, simulating the time periods for longer space journeys. The international partners have indicated they would like to continue ISS operations until 2020, enabling hundreds of astronauts from around the world to staff and visit the global outpost.

Since international cooperation will more than likely make longer space missions possible, the crews and their social interactions may well involve the most important area of research, one that helps pave the way for explorations and settlements farther away from Earth.

ISS Expedition 20 crewmembers share a meal in the station's Unity node with visiting space shuttle Discovery crewmembers. While the two craft were docked during STS-128, 13 people lived on the ISS (NASA photo).

ISS Expedition 20 crewmembers from Canada, Europe, Russia, and the U.S. monitored the unpiloted Japanese H-II transfer vehicle (HTV) in its first approach to the ISS. Once the HTV was in range, they used the station's Canadian robotic arm to grab the cargo craft and attach it to the ISS Harmony node, built by the U.S. (NASA photo).

by **Tracy McMahan** and **Jim Pass**

Intelligent systems

MIT developed an iPhone interface for controlling small UAVs.

This was a year of substantive advances for intelligent systems. MIT's Humans and Automation Lab developed an iPhone interface for controlling small autonomous helicopters in indoor/outdoor urban settings. MAV-VUE (micro air vehicle visualization of unexplored environments) supports a map display, real-time camera imagery with panning capability, health and status monitoring, and novel vehicle control capabilities. Operators with no specialized training use a touch-enabled display to command an unmanned small helicopter through high-level, goal-based waypoints or fine-grained "nudge" gestures leveraging built-in accelerometers.

Researchers in the Vehicle Systems and Control Laboratory at Texas A&M developed an approach for synthesizing adaptive learning flight control laws for morphing air vehicles. They demonstrated the ability to learn the shape-changing policy for an air vehicle with up to 14 independent controllable shape-changing degrees of freedom using a Q-Learning approach with an adaptive action grid and coupling it with structured adaptive model inversion control. Accurate trajectory tracking and stability were achieved while morphing during aggressive maneuvering. The approach is being extended to real-time learning and flight control.

Researchers at Penn State developed the Cognitive Robotics System (CRS) to study the use of a computational psychology method for control of unmanned vehicles. CRS uses a Soar cognitive architecture agent to navigate to a target while avoiding different types of obstacles. CRS realized when simple approaches to avoiding complex obstacles were not working, and employed a more complicated approach to avoid more challenging obstacles. CRS can be expanded with more software systems, additional perceptual capabilities, and more sophisticated agents.

In another effort to use psychological principles to control robotic systems, the Army Research Laboratory developed a Symbolic and Sub-Symbolic Robotics Intelligence Control System (SS-RICS). The system's major thrust has been the integration of knowledge representation and organization theories within the field of cognitive psychology. SS-RICS is a hybrid cognitive system; its continuum of knowledge is intended to represent the complete spectrum of cognition.

NASA's Ares I rocket program has several intelligent systems components. The Ares I-X ground diagnostic prototype (GDP) monitored the first-stage thrust vector control and associated ground hydraulics in the Vehicle Assembly Building and on the launch pad. GDP combines the TEAMS diagnostic tool from Qualtech Systems, the inductive monitoring system (IMS) anomaly detection tool from NASA Ames, and the SHINE rule-based expert system from the Jet Propulsion Lab. GDP was deployed to Kennedy Space Center, where it received live data from the rocket and ground hydraulics. IMS' model-based reasoning, machine learning, and data mining techniques are also used to establish a baseline, then monitor and report abnormal behavior on F/A-18 jet engines and on the space station's control moment gyros and external thermal control.

Finally, JPL is using dynamic landmarking for change detection to autonomously detect transient surface features from orbit, such as dust devil tracks or dark slope streaks on Mars. The approach operates on visually salient landmarks, not pixel-based change detection, to provide a sparse, semantic representation of image content. Automated methods were developed to identify landmarks, classify them using a machine learning classifier, then match landmarks between images using graph matching algorithms. New or vanished landmarks appear as unmatched items on images from the Mars orbiter camera on Mars Global Surveyor and the thermal emission imaging system on the Mars Odyssey orbiter.

by the **AIAA Intelligent Systems Technical Committee**

Digital avionics

As the FAA moves toward the Next Generation Air Transportation System (NextGen), it has defined a transformational program known as Automatic Dependent Surveillance-Broadcast (ADS-B).

ADS-B is the NextGen surveillance technology that allows aircraft and air traffic management to know the location of each participating aircraft. Instead of relying completely on ground-based primary and secondary surveillance radar (SSR) systems to track aircraft, NextGen will rely on each aircraft to broadcast its GPS position periodically.

The FAA Surveillance and Broadcast Services Program Office is the organization responsible for the ADS-B program. ITT is the ADS-B prime contractor that is performing system installation and will be responsible for system operation. ITT is scheduled to have nationwide ADS-B service ready by 2013.

The FAA has mandated two different datalinks for ADS-B. Air carrier and larger general aviation aircraft are already equipped with a 1,030-MHz uplink/1,090-MHz downlink datalink. Smaller general aviation aircraft are more likely to be equipped with the universal access transceiver (UAT) that operates at 978 MHz. Since there are two datalinks, the ADS-B ground system incorporates ADS-R (ADS-B Rebroadcast), which rebroadcasts the transmission on the other datalink.

Nonparticipating aircraft, those that are not equipped with ADS-B, will still be tracked with primary radar and SSR. The position information for nonparticipants is provided to ADS-B-equipped aircraft through Traffic Information Services (TIS) to ensure that the aircraft have a complete picture of other traffic. TIS-B data will be uplinked through the ADS-B datalinks.

Aircraft equipage has been separated into two different capabilities: ADS-B Out and In. ADS-B Out capability requires that an aircraft be equipped for broadcasting its GPS position once a second. With ADS-B Out-equipped aircraft broadcasting their position, the air traffic control system can start relying on ADS-B rather than radar for surveillance. A notice of proposed rule making (NPRM) issued in 2007 mandated the use of ADS-B Out by 2020. Responses to the NPRM were collected in 2008, and publication of a final rule is expected in 2010.

ADS-B In enables aircraft to receive traffic and weather information. It can listen to ADS-B Out reports from other aircraft as well as ADS-R and TIS-B uplinks from the ADS-B ground stations. This allows a flight crew to be aware of other traffic. ADS-B In was not included in the original NPRM. The responses to the NPRM have suggested that a strategy for incorporating ADS-B In should be defined.

ADS-B Out is easier to install than ADS-B In. For Out, aircraft only need a Mode-S extended squitter or UAT radio; there are no significant modifications to the flight deck instrumentation. For In installation, the flight deck needs a cockpit display of traffic information capability, a user interface, and optional interfaces to display weather information.

This ADS-B ground station is located in southern Florida. (Photo courtesy ITT.)

In late 2008, the ADS-B ground system was installed and tested in Miami and southern Florida. This year installations were completed in Louisville, Philadelphia, Juneau, and the Gulf of Mexico. The gulf installation includes 16 total ground stations that will provide the initial operational capability (IOC). These stations are fairly evenly split between nine land-based sites located around the coast of the gulf, and seven oil-platform installations. All of these stations were operational at the end of September 2009 in preparation for a December IOC. Sometime after IOC, an additional five oil platform installations will be added to increase the overall availability of the system in the gulf.

by **James Rankin, Chris Watkins,** and the **AIAA Digital Avionics Technical Committee**

Sensor systems

A University of Colorado-led team deployed an Aerosonde A-20 UAV at McMurdo Station, Antarctica, collecting data on weather conditions and ice coverage.

by **Michael J. Martin, Wei-Jen Su,** and **Stephen Horowitz**

The challenges in designing sensor systems for aerospace applications are complex. The sensor must demonstrate accuracy and reliability, and must be integrated into both the sensor system and the overall vehicle architecture. As vehicles move into more demanding environments, the sensors themselves must become more robust. Recent developments in sensors for military, scientific, and commercial applications show the variety of challenges that must be met. The rewards include greater safety, better vehicle performance, and previously unobtainable scientific data.

Helicopters operating away from paved fields are vulnerable to brownout, a loss of visibility during takeoff or landing due to dirt or sand kicked up by the vehicle. Sikorsky is leading the development of the Sandblaster System. This DARPA-funded effort integrates Sierra Nevada's millimeter-wave radar, Honeywell's data processors and synthetic vision technology, and Sikorsky's flight control systems to allow safe rotorcraft operation under these conditions. A similar system developed by CAE uses laser radar for sensing.

Deploying sensors on UAVs, removing the human presence entirely, is a second option for improved safety. While military UAV applications have become routine, the application of UAVs to other tasks also enhances safety. Using UAVs to take scientific measurements in the harsh polar environment offers better data, with less risk to humans, than using conventional aircraft. NOAA-university partnerships led to progress in both polar regions this year. In May and June, for example, researchers from NOAA's National Marine Mammal Laboratory, working with the University of Alaska's Unmanned Aircraft Program, demonstrated the shipboard use of an Insight A-20 UAV to survey seal populations in the Bering Sea. In September, researchers from the University of Colorado's Cooperative Institute for Research in Environmental Sciences flew an Aerosonde UAV in the Antarctic winter. In spite of temperatures below -35 C, the UAV successfully measured local weather conditions and ice coverage in Terra Nova Bay.

Monitoring of ocean conditions in temperate environments is useful for both climate modeling and routine weather prediction. The Flying Fish UAV, under development by a DARPA-funded team at the University of Michigan, is designed to supplement existing buoys with an autonomous air vehicle capable of repositioning itself as needed. Unlike conventional UAV sensor systems, the avionics sensors are combined with the environmental sensor suite. The integrated sensor package offers greater reliability and lower power consumption than conventional arrangements.

An area that presents sensor systems with another set of challenges is vehicle health monitoring. Sensor systems designed to monitor propulsion systems must function in environments of extreme temperatures, high vibration loads, and corrosive chemicals. At the low-temperature extreme, Accellent Technologies is developing sensor systems to detect structural failures in the cryogenic fuel systems of liquid propellant rocket engines during operation. At higher temperatures, a team at NASA Glenn demonstrated the use of magnetic measurements of tip clearance for the compressor and turbine stages of combustion turbines.

Adapting existing sensors for the space environment requires that the design be reevaluated for the extreme conditions. Lab-on-a-chip microdevices, developed for terrestrial medical diagnostics, offer the capability to search for life in extraterrestrial environments. JPL, NASA Ames, and the University of California at Berkeley are partners in developing the Urey instrument for ESA's 2016 ExoMars mission. Urey includes two microfabricated instruments: the Mars oxidant instrument and the microcapillary electrophoresis instrument. The Mars oxidant instrument uses chemically sensitive solid-state films to detect oxidants. The microcapillary electrophoresis instrument not only detects amino acids, but also determines the chirality, indicating if they have a biological origin. Technical challenges include development of materials for the spacecraft environment, packaging, and ensuring system reliability.

Computer systems

This year saw several notable developments in radiation-hardened electronics, designed to operate through the harsh radiation environment of space. Broad Reach Engineering announced BRE440, a PowerPC 440 implementation using the 0.15µ Honeywell HX-5000 semiconductor technology. BRE440 raises the bar for rad-hard computing through an on-chip L2 cache and enhanced memory access features.

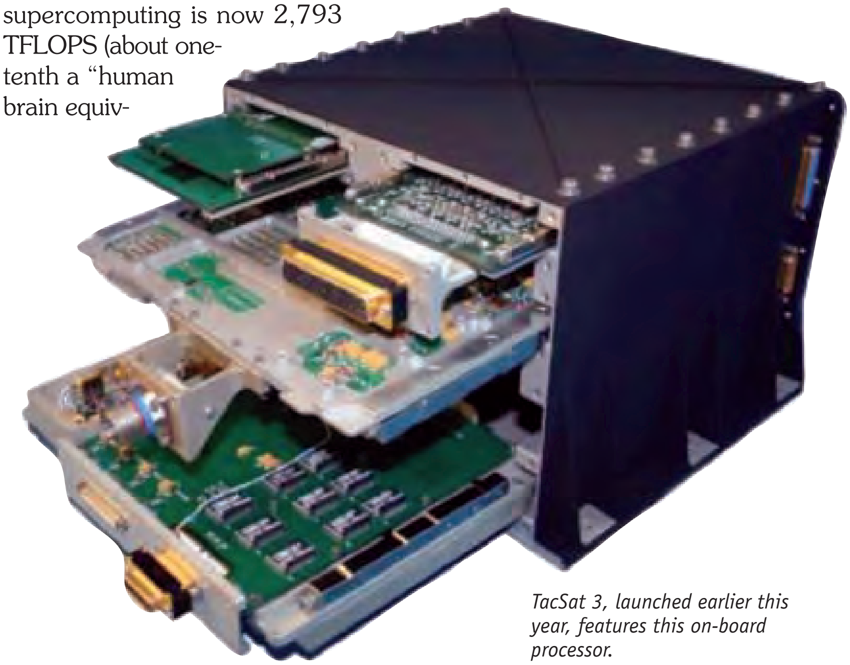
Just as personal computers bolster their central processing units (CPUs) with auxiliary devices such as graphics processing units, more space systems are finding it essential to enhance their CPUs (such as the BRE440 and the Rad 750) with powerful coprocessors. Custom integrated circuits have often fulfilled this need, but more systems are moving to reconfigurable FPGAs (field-programmable gate arrays) for this purpose.

The Air Force TacSat 3 satellite, launched earlier this year, used an array of Xilinx Virtex 4 devices to handle number-crunching tasks for a hyperspectral imager camera. Although such FPGAs were not specifically designed for use in space, under a separate Air Force Research Laboratory program an even more advanced FPGA, based on the Xilinx Virtex 5 (FX130), was created in rad-hard form. At nearly 1 billion transistors, the prototype chips produced this year represent the most complex rad-hard chip ever developed.

Computers without memory are useless. Fortunately, this year brought other breakthroughs in rad-hard memory. BAE announced a 4-Mbit rad-hard nonvolatile memory, based on a (chalcogenide) phase change material. TI debuted a 16-Mbit SRAM, based on a radiation-hardening technique (patented by Silicon Space Technology) that allows existing commercial fabrication lines to build rad-hard chips. This breakthrough is particularly exciting because it may make TI's vast catalog of intellectual property accessible in rad-hard form.

Not only will this year be remembered as one of global struggle with the economic downturn, but also as one of startling changes in acquisition. It was the year the beleaguered $20-billion TSAT (transformational satellite) program was formally canceled. The fate of some of NASA's most significant initiatives remains murky. It was also a year when (at the time of this writing) the purchases of Wind River Systems by Intel and Sun Microsystems by Oracle seem likely to happen, raising concerns over the impacts to VxWorks and the Java programming language, respectively, used in a variety of aerospace computing systems.

We make note that this year the first interplanetary Internet site was established aboard ISS, and the new high-water mark in supercomputing is now 2,793 TFLOPS (about one-tenth a "human brain equivalent" or HBE), thanks to the Berkeley BOINC system. Some still groan at hearing "semantic web," despite Microsoft's hilarious television ads for their revamped Bing search (no, decision) engine. Cloud computing to some may be the answer (what became of "grid computing"?), but some of us are not sure about the question.



TacSat 3, launched earlier this year, features this on-board processor.

We should not, however, remain despondent, when the future holds so much promise. Intel now believes that Moore's Law can truck on to at least 2022, with chips having transistors with 4-nm features. TSVs (through-silicon vias) are now ushering in the possibility of 3D integrated circuits with more than 1 M contacts/cm^2 interconnecting stacked chips. Coffee-cup-sized plug-and-play "designer" Cubesats may crowd the skies (although the unprecedented collision of an Iridium and Russian satellite stresses the need to manage the clutter in space). Finally, DARPA and the Air Force Office of Scientific Research have each launched initiatives in the ultimate computation fabric—programmable matter—in which the line between information and material may itself become blurred in a "Terminator-2"-like future of morphable systems.

by **Jim Lyke**

Software systems

by **Stephen Blanchette Jr.**

Security and privacy issues in aerospace software systems took center stage this year. Other problems and achievements demonstrated that software is as important as any other element of aerospace systems and must receive commensurate attention to ensure success.

Perhaps the biggest story in aerospace software came in April, when it was reported that unknown persons had hacked into the Air Force's Joint Strike Fighter (JSF) program and stolen terabytes of information. Rather than U.S. government computers, it was JSF prime contractor Lockheed Martin's network that was attacked. The compromised information was not critical, and no classified data was accessed. Nevertheless, the event highlighted the increasing threat of cyber attacks. The threat is to civil systems as well: In May, the inspector general of the DOT cited vulnerabilities in the air traffic control system.

Another widely reported security incident occurred late in 2008, when a software worm infiltrated an Army network. Worms are computer programs that replicate themselves across a network to perform malicious actions. In this incident, the worm was introduced via a thumb drive, prompting the Army, followed shortly by the entire Dept. of Defense, to ban the use of all removable media. NASA issued restrictions on personally owned devices a few weeks later. The extent of any damage was not clear.

In November 2008, Airbus announced that its A400M would be delayed by problems with the software for the full-authority digital engine control unit. Then, in May, a software error was noted in some multimode GPS receivers, which might throw off flight deck clocks.

Frequently cited in these reports are inadequate safeguards for networked systems and inadequate controls on commercially developed software products. As aerospace systems increasingly rely on software for their development and operations, software security issues must be placed on a par with aerodynamics and other traditional aerospace concerns. The robustness of products, services, and operations depends on doing so.

Meanwhile, lost in the noise of high-profile security news came a September 2008 report of new software technology being developed at JPL to identify individuals by applying gait analysis techniques to satellite imagery of their shadows. The premise is that a person's normal walking patterns are difficult to fake. Shadows are used because direct imagery records only the tops of people's heads.

While much more development is needed to make the concept operationally useful, privacy advocates undoubtedly will raise concerns that will have to be addressed—recall the outcry over early use of public video surveillance. The aerospace software community must consider its ethical responsibilities in applying recognition technologies.

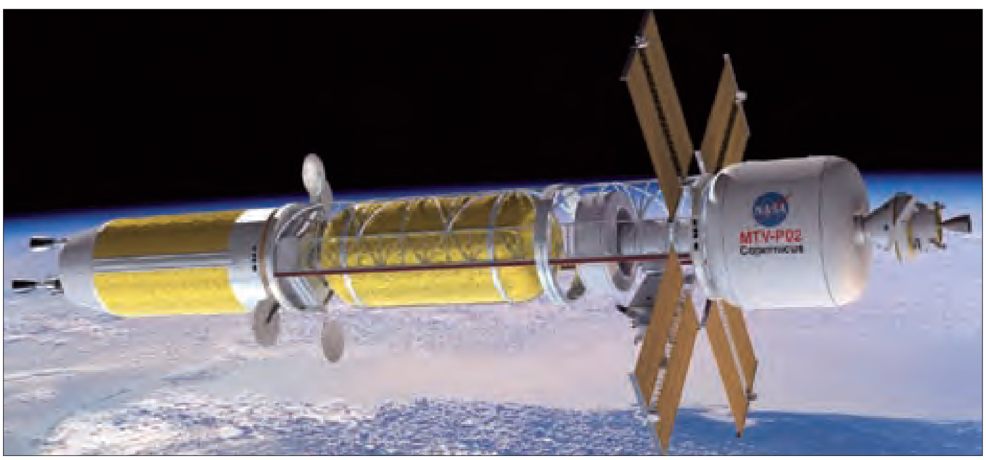
Problems in aerospace software ranged from significant to annoying. In November 2008, Airbus announced that its A400M military airlifter would be delayed nearly six additional months by problems with the software for the full-authority digital engine control unit. In May of this year, the European Aviation Safety Agency noted a software error in some multimode GPS receivers from one manufacturer. This error caused the units to compute a date 512 weeks in the past upon transitioning from June 20 to 21. While no errors in navigation precision resulted, the bug had the potential to throw off flight deck clocks and cause other anomalies.

On a more positive note, data from various Mars probes were incorporated into the Google Earth application in February, providing scientists and lay users a unified view of the red planet. Moon content from Apollo missions was added in July to celebrate the 40th anniversary of the Moon landing. While scientific data sharing is important in its own right, these advances doubtless will inspire a new generation to all manner of aerospace careers, and may even stimulate public interest in, and support for, continued manned spaceflight.

Nuclear and future flight propulsion

Atmospheric mining in the outer solar system was investigated as a means of fuel production for high-energy propulsion and power. A nuclear fusion fuel, Helium 3 (3He), can be wrested from the atmospheres of Uranus and Neptune and used in situ for energy production and/or propulsion.

Five teams from the Case Western Reserve University Dept. of Mechanical and Aerospace Engineering participated with NASA Glenn Research Center in the study. Four teams addressed cruiser-based and balloon-based 3He mining vehicles, and one focused on 3He mining on an outer planet moon.



A nuclear rocket could deliver the crew to the orbiting Mars Transfer Vehicle prior to Earth departure.

Team 1 created a conceptual 3He mining cruiser for Uranus. An inertial-electrostatic confinement (IEC) nuclear fusion reactor was used for propulsion, operating as an air-breathing engine during subsonic cruise in the atmosphere and operating on stored liquid hydrogen as propellant during ascent to orbit. The overall vehicle dry mass was approximately 40,000 kg. The mass was estimated based on past designs and estimates of the IEC engine from Robert Bussard's research. The overall mission delta-V to climb from the low mining altitude to the 5,000-km altitude was 16.23 km/sec. The engine specific impulse was approximately 6,000 sec. The mining time was 28.3 days.

In NASA's recently completed Mars DRA (design reference architecture) 5.0, payload and transportation system options for a human Mars mission after 2030 were examined. Recent work detailed the analysis of a nuclear thermal rocket (NTR) that will reduce the number of Ares V heavy-lift launchers. The NTR was selected over chemical propulsion for in-space transportation because of its higher specific impulse, increased tolerance to payload growth, and lower initial mass in LEO, which is important for reducing the number of heavy lifters.

All three NTR vehicles use a common core propulsion module with three 25,000-lb-thrust "composite fuel" NERVA (nuclear engine for rocket vehicle applications) -derived engines to perform all primary mission maneuvers. NERVA-derived engine features include an exit temperature of roughly 2,700 K, chamber pressure of about 1,000 psia, specific impulse of around 900 sec, and engine thrust-to-weight ratio of about 3.43.) Two cargo flights, using minimum energy paths, deliver a cargo lander to the surface and a habitat lander into a 24-hr elliptical parking orbit where it remains until the arrival of the crew during the next mission opportunity (about 26 months later). The cargo elements aerocapture into Mars orbit and are enclosed within a large triconic aeroshell, which is a payload shroud during launch, then an aerobrake and heat shield during Mars orbit capture and in entry, descent, and landing on Mars.

The gasdynamic mirror (GDM) is a magnetic device where fusion plasmas are heated to ignition by the reaction products resulting from the "at-rest" annihilation of antiprotons in uranium 238. Unlike terrestrial fusion power systems, where large *Q* values (ratio of fusion power to injected power) are required, only modest *Q* values are needed for spaceflight. Recent work at the University of Michigan focused on a bimodal fusion propulsion system in which *Q* values near unity are used and the GDM serves as a neutron source. Fusion reactions are neutron rich but energy poor, while fission reactions are energy rich but neutron poor. This fact led to a system in which the GDM device serves as a fast neutron source surrounded by a blanket of thorium 232, which is used to breed uranium 233 and simultaneously burned to produce energy.

For a reasonable blanket size and deuterium-tritium plasma density, size, and temperature, the hybrid system can produce tens of gigawatts of thermal power per centimeter. When heating hydrogen fuel, a 7-m-long engine can generate a specific impulse of about 59,000 sec at a thrust of about 8 MN at a fuel flow rate of about 130 kg/sec.

by **Bryan Palaszewski** and the **AIAA Nuclear and Future Flight Propulsion Technical Committee**

High-speed air-breathing propulsion

In the area of ramjet/scramjet powered flight, the X-51A scramjet engine demonstrator WaveRider (SED-WR) is poised to demonstrate later this year the first-ever sustained flight beyond Mach 6 of a hydrocarbon-fueled and -cooled air-breathing engine. The SED-WR program team consists of Boeing and Pratt & Whitney Rocketdyne (PWR). The effort is funded by the Air Force Research Laboratory (AFRL) and DARPA.

Also under Air Force funding, Alliant Techsystems (ATK) successfully completed testing for a new class of ramjet propulsion systems that will enable high-speed strike systems and UAVs to travel at Mach 5+. The most recent tests involved flight-weight, fuel-cooled TTRJ (thermally throated ramjet) technology built with conventional materials and manufacturing processes, and burning readily available JP-10 jet fuel. ATK ran the fuel-cooled hardware through multiple 2-min-long test periods to demonstrate full thermal equilibrium, thus ensuring required engine durability and accumulating more than 44 min of hot operating time.

In the area of combined cycle engines, PWR successfully demonstrated the full range of power required for a turbine-based combined-cycle (TBCC) vehicle. The PWR-9221FJ dual-mode ramjet (DMRJ) successfully sustained stable combustion at Mach 3, 4, and 6 in ground tests. Testing was conducted at Arnold Engineering Development Center after a 10-year effort to upgrade a high-speed, high-temperature blow-down ground test facility.

"This test was significant," says Matthew Bond, test manager of AEDC's Aerodynamic and Propulsion Test Unit (APTU). "The Mach-6 run on June 24 was the first-ever scramjet propulsion test at AEDC. It was an actual test of the DARPA Falcon combined-cycle engine technology [FaCET] dual-mode ramjet using APTU's recently acquired combustion air heater, Mach-6 nozzle, and JP-7 fuel heater."

Building on the success of the FaCET DMRJ tests, PWR and Lockheed Martin are working together under Phase 1 of the mode transition demonstrator program, a DARPA-funded activity. This new program will include both the low-speed (turbine) and high-speed (DMRJ) elements of the TBCC propulsion system and will demonstrate the transition between the two modes of operation.

At NASA, the hypersonic propulsion element of the fundamental aeronautics program is helping the nation master the fundamental physics required for routine air-breathing-propulsion-powered aerospace vehicle flight. The TBCC technology development element has progressed significantly, where turbine-to-scramjet transition is being studied. The initial small-scale mode transition study showed high performance for both flow paths during the transition process. NASA Glenn is leading the design and development of a large-scale model capable of accommodating both the turbine engine and the dual-mode scramjet engine. This model is being developed in partnership with AFRL, ATK, Boeing, Williams International, and Spiritech. The large-scale inlet mode transition experimental module has completed the design phase and is being readied for initial test entry into Glenn's 10x10 supersonic wind tunnel facility.

The X-51A SED-WR is poised to demonstrate the first-ever sustained flight beyond Mach 6 of a hydrocarbon-fueled and -cooled air-breathing engine.

The first-ever scramjet propulsion test at AEDC took place when the DARPA FaCET was tested in the center's Aerodynamic and Propulsion Test Unit. (USAF photo.)

In March, JAXA and Hokkaido University conducted flight tests of a rocket-based combined-cycle (RBCC) engine, using a cascaded multistage impinging jet-type hybrid rocket. The RBCC is being studied for an air-breathing launch vehicle. The flight test data will be used for evaluating the ejector system design code. In July, JAXA also succeeded in the ground firing of a precooled turbo-engine model being studied for Mach-5 cruise flight.

by **Tom Kaemming**

Liquid propulsion

In Japan, the LE-8 LOX/natural gas rocket demonstrated its flight feasibility in tests this summer.

It was a good year for liquid propulsion. Although a liquid rocket engine on the Long March 3B failed in August, the U.S., the European Union, and Japan had stellar liquid engine performance and made technology progress on many fronts.

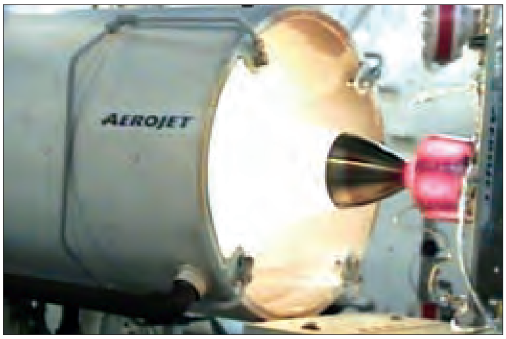
A Northrop Grumman Aerospace Systems TR408 100-lbf oxygen/methane thruster demonstrated pulsed and steady-state performance using a heat exchanger chamber at extreme propellant conditions. At NASA Marshall, the TR202 lunar descent engine with pintle injector demonstrated 10:1 throttling with excellent combustion stability, using liquid oxygen (LOX) and gaseous hydrogen. Further TR202 testing is planned to optimize performance and chamber heat transfer.

Aerojet completed environmental and hot-fire testing of two prototype 600-lbf-thrust monopropellant engines for NASA's Ares roll control system, demonstrating five times mission life. In support of the Constellation program, Aerojet began testing of an advanced 5,500-lbf LOX/liquid methane rocket engine. And for unmanned spacecraft, development testing of the AMBR (advanced materials bipropellant rocket) demonstrated specific impulse of 333.5 sec with 150 lbf thrust using storable propellants.

Orbital Technologies completed initial sea-level tests of its Maelstrom L-3 thrust chamber assembly (TCA). The 3,000-lbf-class, vortex-cooled TCA burns LOX and subcooled propane. Further development of the Maelstrom L-3 under an Air Force contract will lead to flight demonstrations of the TCA in 2011.

AMPAC In-Space Propulsion developed a modular hydrazine subsystem suitable for plug-n-play SmallSat applications. The design incorporates off-the-shelf components with several cost and risk reducing features: a 1-N thruster with adjustable mount (allowing thrust vector tuning any time before launch), an efficient low-cost propellant tank, two-zone thermal control, and electrical/mechanical interfaces designed for ease of integration.

The MR-80 Ares roll control engine undergoes testing at Aerojet.



by the **AIAA Liquid Propulsion Technical Committee**

Separately, AMPAC-ISP demonstrated a small divert engine, attitude control thruster, and aluminum diaphragm propellant tank for use in flight experiments to mature missile defense technologies.

New propulsion concepts and technologies for very small launch vehicles are in development by a joint team from California State University, Long Beach and Garvey Spacecraft. This team conducted the first flight demonstration of a rocket burning LOX and propylene, building on their previous experience with LOX and methane. Such alternative hydrocarbon fuels have the potential to improve performance over conventional RP-1. In parallel, the university collected flight data on aerospike performance in overexpanded, transonic flight conditions—despite an ignition failure of one of the 10 aerospike thrust modules.

On August 21, Ariane 5 accomplished its 32nd consecutive successful flight, delivering two communication satellites to geosynchronous transfer orbit. The previous month, an Ariane 5 lifted the heaviest commercial satellite ever built (weighing 6,910 kg). Meanwhile, ESA continued to evolve its engine designs. The 180-kN upper stage Vinci expander cycle engine accumulated 4,672 sec of test time over 31 hot firings on the P4.1 test facility at DLR/Lampoldshausen, Germany. High-frequency stability margin was demonstrated in "bomb" testing. Separately, ESA engaged EADS/Astrium for development of an in-space engine in the 3-8-kN thrust range; first firing is expected in 2011.

A focus area for ESA's future launcher preparatory program is main-stage propulsion for next-generation launchers. The program is testing a demonstration 40-kN staged combustion subsystem using a coupled preburner/main combustion chamber that can be powered by LOX/H_2 or LOX/methane. EADS/Astrium and Snecma cooperated in hot firing with LOX/methane, achieving combustion pressures of 200 bar in the preburner and 150 bar in the main chamber.

The Japanese 100-kN-class LOX/liquid natural gas engine (to be named LE-8) demonstrated its flight feasibility during the summer. In more than 11 tests, 2,200 sec of on-time were accumulated—including two 500-sec mission duty tests and a 600-sec overduty test. The prototype engine performed flawlessly; altitude testing is scheduled for next year.

Aerospace power systems

Lightweight solar arrays having the highest specific power ever achieved are under development and in use on advanced missions. ATK's UltraFlex solar array contributed to the success of the Mars Phoenix lander. Its 2.1-m-diameter wings achieved a power density exceeding 118 W/kg using Spectrolab 28.3% efficient UTJ solar cells. Larger diameter versions of the UltraFlex wing are being developed, with successful vacuum deployment of a 5.5-m, 175-W/kg wing prototype in a ground demonstration. Further scale-up to 5.9-m-diam UltraFlex wings is envisioned as a planned power platform for NASA's Orion CEV and other missions.

Concentrating photovoltaic arrays are the focus of a DARPA Phase 2 development award to Boeing for design, analysis, and fabrication of a multikilowatt ground demonstration article. Boeing is teamed with DR Technologies, Northrop Grumman, and Emcore to create the Fast Access Spacecraft Testbed (FAST) high power generation system, including solar concentration, power conversion, power management and distribution, heat rejection, and structures, along with necessary deployment, pointing, and tracking mechanisms. When combined with state-of-the-art electric propulsion systems, FAST will form the technological basis for a lightweight, high-power, highly mobile spacecraft platform, with scalability to 175 kW, and at a high system specific power level of 130 W/kg, more than three times those of conventional systems.

The advanced solar cells also have benefits on Earth. Both Boeing and Emcore are offering concentrator systems that reduce the size of the solar cell and the associated cost per watt so that utility-scale systems can take advantage of space quality and performance. This year saw a new world efficiency record set by Spectrolab for a concentrator solar cell converting 41.6% of concentrated terrestrial sunlight to electricity.

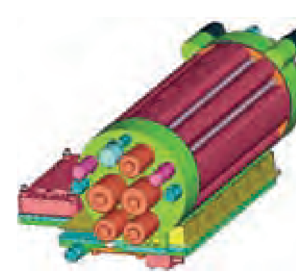
NASA is developing energy storage technology, including fuel cells and batteries, to meet the expected needs of a lunar outpost. "Non-flow-through" proton-exchange-membrane fuel cell stacks and electrolyzers coupled with low-permeable membranes are being developed and integrated with reactants stored at pressures over 2,000 psi. These technologies form the basis for a regenerative fuel cell module providing 3 kW for 10,000 maintenance-free hours, for application to a lunar outpost. Key advanced battery technologies include silicon composite anodes, lithiated mixed-metal-oxide cathodes, and low-flammability electrolytes providing tolerance to electrical and thermal abuse. They are being developed to achieve a specific energy of 150 W-hr/kg and 320 W-hr/liter. With 80% capacity retention after 2,000 cycles, these safety-enhanced cells are ideal for mobility systems such as EVA suits and lunar rovers.

The Mars Phoenix Lander uses ATK's UltraFlex solar array wings.

Lithium-ion battery technology is achieving wide application for spacecraft and launch vehicles, with flight-ready systems offered by ABSL Space Products, AEA Technology, and Saft. ABSL has provided lithium-ion battery technology for over 60 vehicles, including the NASA Kepler space telescope, Lunar Reconnaissance Orbiter, and Lunar Crater Observation and Sensing Satellite, launched this year.

Radioisotope power systems are facing critical challenges to continued efficient use of nuclear power in space, including a U.S. shortage of plutonium-238 for radioisotope thermoelectric generators. Increasing the supply of radioisotope sources and development of higher efficiency advanced Stirling radioisotope generators are being proposed to enable the nuclear power option for missions such as the Outer Planets Flagship 1.

NASA and the Dept. of Energy continue to conduct research and subsystem testing of fission surface power technologies. An initial focus of the joint project is to develop a 40-kWe nuclear reactor that could power the proposed Shackleton Lunar Base and to enhance the potential to power a Mars base. Critical subsystem technology developed at NASA Glenn includes a lightweight composite full-scale radiator panel built by Material Innovations, successfully tested in a vacuum chamber down to –125 C. At NASA Marshall, Stirling engines built by Sunpower were producing over 2 kW of electricity at a gross thermal efficiency of about 32% using pumped liquid metal at 550 C.



A 3-kW non-flow-through fuel cell stack is being designed to help meet the needs of a future lunar base.

by the **AIAA Aerospace Power Systems Technical Committee**

Gas turbine engines

Energy and the environment topped the year's highlights in the field of turbine engines. Efforts focused on improving fuel efficiency and on development and demonstration of alternative fuels, with activities across the federal government and industry.

In May the FAA issued a solicitation aimed at developing CLEEN (continuous lower energy, emissions, and noise) technologies for civil aircraft to help achieve Next Generation Air Transportation System (NextGen) goals. The focus of this effort is to mature noise, emissions, and fuel burn reduction technologies to expedite their introduction into current and future aircraft and engines, and to assess the benefits of alternative "drop in" fuels and advance their introduction. Awards are expected by year's end.

NASA alternative fuels experiments were conducted in a DC-8 aircraft at NASA Dryden.

by the **AIAA Gas Turbine Engines Technical Committee**

Under its subsonic fixed wing project, NASA has partnered with DOD to examine the performance and emissions of the NASA Dryden DC-8 aircraft using a series of Fischer-Tropsch (FT)-derived test fuels. Conducted in January of this year in Palmdale, Calif., the AAFEX (alternative aviation fuel experiment) engaged NASA, DOD, EPA, and FAA researchers. They found that burning FT fuel did not appreciably affect engine performance, but did lead to aircraft and storage tanker fuel leaks due to seal shrinkage from exposure to aromatic-hydrocarbon-free fuels. The greatest effect of the synthetic fuels, however, was to reduce engine black carbon emissions by more than 75% relative to JP-8.

Several projects made significant progress this year in the versatile affordable advanced turbine engines (VAATE) program, a DOD-led effort to develop and demonstrate advanced turbine engine technologies. The ADVENT (Air Force adaptive versatile engine technology) program completed Phase I in September following a number of key component technology demonstrations and detailed designs for variable cycle engines by GE Aviation. The Air Force kicked off Phase II for a full engine demonstration, including a 25% reduction in specific fuel consumption, by 2013. At the same time, the Air Force is pursuing critical components of the HEETE (highly efficient embedded turbine engines) program to demonstrate an improvement of up to 25% in the thermal efficiency of turbine engines.

Also under VAATE, the AATE (advanced affordable turbine engine) program seeks to provide advanced propulsion capability for Army Current and Future Force rotorcraft, with goals including a 65% increase in horsepower-to-weight, a 25% improvement in specific fuel consumption, and more than 35% reduction in production and maintenance costs. The program includes two competing 3000-HP demonstrator engines from GE Aviation and ATEC (Advanced Turbine Engine Company), a joint venture of Honeywell and Pratt & Whitney. Initial design efforts were completed this year, and ongoing rig tests will validate the individual component designs before gas generator testing, with engine demonstrations planned in 2012.

The Navy initiated several activities under the American Recovery and Reinvestment Act, including plans to flight test an F-18E/F on a biofuel JP-5 in summer 2010. The Navy team is working with Canadian and Australian partners to make the biofuel certification of the F-18 an international effort.

Williams International completed testing of alternative fuel in a small gas turbine engine. An FJ44-3 engine was powered by 2,000 gal of coal-based alternative fuel for 118 cycles during 21 hr of testing. The synthetic fuel performed well; engine performance was identical to using Jet-A fuel and required no special engine or test cell modifications.

Combustion and propellants

Efforts to address the challenges of climate change, energy security, and energy-efficient high-speed propulsion brought significant progress in the development of next-generation low-carbon transportation fuels, advanced propulsion technologies, and experimental facilities for space exploration.

An Energy Frontier Research Center for Combustion Science has been established at Princeton University by the Dept. of Energy in an effort to advance fundamental understanding and quantitative modeling of renewable transportation fuels. The ultimate goal is to develop a validated, predictive, multiscale combustion modeling capability to optimize the design and operation of evolving fuels in advanced engines for transportation applications. The investigation will cover all the myriad time and length scales involved in combustion, from the scale of the electron to that of the largest turbulent motion in engines.

The center, funded at $4 million a year for five years, consists of 15 principal investigators from seven academic institutions (Cornell, MIT, Princeton, Stanford, and the universities of Connecticut, Minnesota, and Southern California) and the Sandia and Argonne national laboratories, with expertise in quantum chemistry, chemical kinetics, combustion theory and modeling, and corresponding experimentation.

At Princeton, a next-generation jet fuel project funded by NetJets has identified a sustainable pathway for synthesis of zero net carbon cycle transportation fuels from biomass and coal using carbon capture and storage and coproduction of low-emission electricity. Other activities include system analysis for energy conversion economics and carbon emissions; energy and policy analysis for sustainability; and combustion technology assessment of this and other means of producing renewable transportation fuels.

A DOD multiuniversity research initiative called "Fundamental Mechanisms, Predictive Modeling, and Novel Aerospace Applications of Plasma Assisted Combustion" was awarded to a research team from five universities (Ohio State, Princeton, Drexel, Georgia Tech, and Penn State) to study nonequilibrium plasma-assisted combustion for novel applications in scramjet and gas turbine engines. The objective is to investigate elementary reactions and nonequilibrium kinetic processes using advanced laser diagnostics and experimentation tools in plasma-assisted ignition, and stabilization of flames at extremely high air velocities and elevated pressures.

As the ISS nears completion, studies of fuel and material flammability have now begun on the station under the leadership of NASA Glenn. The goals are to improve fundamental understanding of combustion and enable improvements for fire safety in space and in terrestrial applications.

JAXA astronaut Koichi Wakata, Expedition 19/20 flight engineer, works on the flame extinguishment experiment in the combustion integrated rack on the ISS.

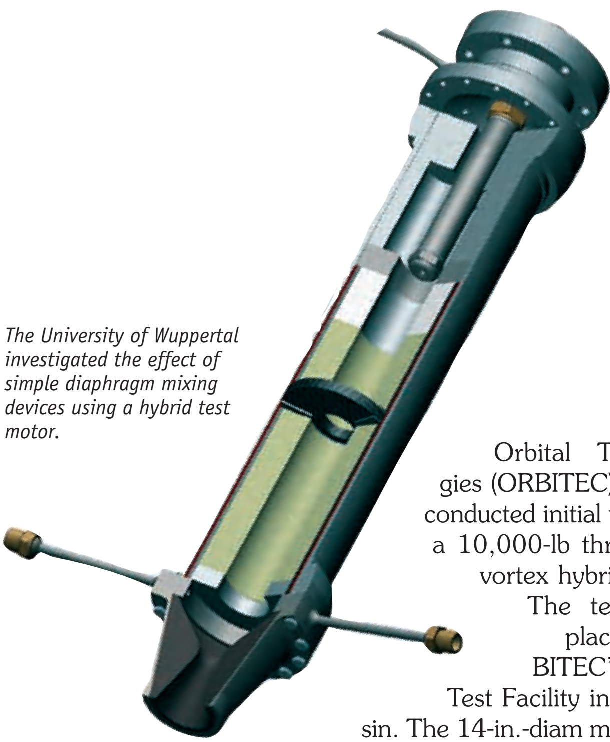
A multiuser facility, the combustion integrated rack (CIR), was installed on the ISS in Destiny, the U.S. laboratory module, in late 2008. This combustion facility provides a gas delivery system, cameras, and a 100-liter chamber into which a variety of experiments can be installed. It can be commanded remotely from a control center at NASA Glenn. Operations with the first CIR effort, the flame extinguishment experiment (FLEX), began early this year. FLEX is a direct successor to the droplet combustion experiment conducted on space shuttle missions in 1997 and 2003. Leading the multiuniversity FLEX research team is the University of California-San Diego. The objective is to evaluate the effectiveness of suppressants on microgravity flames in atmospheres under consideration for future spacecraft. CIR will also be used in ACME (advanced combustion via microgravity experiments) for studies of gaseous laminar diffusion flames.

Combustion research has also been initiated in the ISS microgravity science glovebox (MSG), a general-purpose facility enabling a variety of studies. Early this year, SPICE (smoke point in coflow experiment) became the first combustion experiment to be conducted in the MSG. More MSG investigations are planned for 2010, including studies of flame stability and solid fuel flammability.

by **Yiguang Ju** and **Joanna Austin**

Hybrid rockets

Several organizations made important contributions to hybrid rocket research this year. In May, Scaled Composites successfully completed the first phase of static firing tests of the hybrid rocket motor for SpaceShipTwo. The vehicle, which is under development by Virgin Galactic, will be transported by a new composite aircraft to the upper atmosphere, where the hybrid motor will ignite and propel space tourists, scientists, and payloads into space. Suborbital trajectories to altitudes of up to 65 mi. are expected.



The University of Wuppertal investigated the effect of simple diaphragm mixing devices using a hybrid test motor.

Orbital Technologies (ORBITEC) recently conducted initial testing of a 10,000-lb thrust class vortex hybrid motor. The tests took place at ORBITEC's Rocket Test Facility in Wisconsin. The 14-in.-diam motor uses HTPB (hydroxyl-terminated polybutadiene)-based solid fuel and liquid oxygen. The LOX is injected in a swirling fashion to generate a vortex flow field in the fuel port to drive fuel regression rates that are both fast and axially uniform. The high regression rates allow for a single-port, cartridge-loaded fuel grain approach. The test program aims to demonstrate the functionality of the vortex hybrid design, stable and efficient combustion, high reliability, and the potential for low recurring costs. Additional testing is planned for the near future and will include both HTPB and alternative fuels. ORBITEC also conducted smaller scale vortex hybrid motor development and testing efforts this year using storable oxidizers.

The Purdue hybrid rocket project completed the design and development of a flight weight, 900-lbf-thrust, 90% hydrogen-peroxide/LDPE hybrid rocket motor that was successfully hot-fire tested in vertical configuration five times at the Purdue Vertical Rocket Test Facility. In addition, the first-generation hybrid flight vehicle was launched successfully in June and reached an altitude of 6,100 ft at Mach 0.6. This was an important first step toward flight operations for this series of hybrid rocket technology demonstrators. The Purdue hybrid sounding rocket is the largest hydrogen-peroxide hybrid rocket launched to date. A second-generation high-propellant-mass-fraction flight vehicle is currently being developed for supersonic flights to altitudes exceeding 30,000 ft at Mach 2.

Aerospace Corporation is measuring the structural properties of paraffin-based fuel formulations as a function of temperature. In addition, a small motor evaluation cell has been built and test fired. Regression rate measurements are also planned.

The University of Wuppertal in Germany investigated the effect of simple diaphragm mixing devices, consisting of one- or four-hole perforations located at the beginning or along the fuel grain. The propellants used for the firing of the 225-lb thruster were supercharged nitrous oxide and microcrystalline paraffin. The mixing device increased combustion efficiency up to 12% compared to the control, which had no mixing device. Fuel regression rate downstream of the diaphragm increased up to 80% compared to the tests conducted without a mixing device.

The cryogenic solid propellant (CSP) test motor was developed and manufactured at the Aerospace Institute in Berlin with funding from ESA and the German Aerospace Center (DLR). Cryogenic multilayer internal hybrid combustion was successfully demonstrated with this test rocket motor holding 1 kg of CSPs. The experimental goal of enriching hydrogen peroxide to more than 90% was achieved through the development of a process based on fractionated crystallization. Beginning with 87.5%, hydrogen peroxide greater than 99.4% concentration was successfully produced on a scale of kilograms. This high-concentration hydrogen peroxide was used in combination with different polymer fuels for various lab-scale ignition and combustion experiments under pressure. Current activities focus on the preparation of CSP test motor firings with higher concentration hydrogen peroxide and less subcooled propellant grain.

by **Steven Frolik**

Air-breathing propulsion systems integration

This year NASA collaborated with General Electric Aviation to investigate new open-rotor propulsion systems. Open rotors had been studied by a NASA/GE team in the late 1980s and early 1990s. NASA has rebuilt and modernized a counterrotation propeller test rig used during that campaign with modern data systems and controls technology. In September, this one-fifth-scale open-rotor propulsion rig began a new test campaign in the NASA Glenn anechoic wind tunnel to investigate a series of advanced propeller fan blade designs. A total of seven blade sets will be tested to determine aerodynamic efficiency, and mechanical and aeroelastic stability.

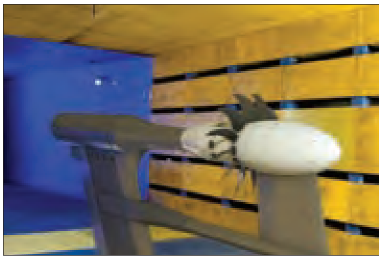
Performance information such as fan thrust and torque, and diagnostic information such as blade loading profiles and flow field turbulence, will be obtained for the baseline configuration. The information will be used to compare and validate computer-based design, analysis, and optimization. This propulsion test rig, combined with modern materials and manufacturing techniques, will be used to produce improved 3D fan blade designs that enhance performance and reduce noise. Open rotors are projected to save 10% in fuel compared to current turbofan engine technology, and ultimately up to 25% with advanced designs.

The F-35 Lightning II Joint Strike Fighter program passed major propulsion/airframe integration milestones this year, highlighted by validation of short takeoff/vertical landing (STOVL) vertical thrust during tests in April. The propulsion system includes an F135 or F136 turbofan engine, a drive shaft leading from the engine face to a gear box and clutch connecting to a counterrotating lift fan, a three-bearing swivel duct at the rear that vectors engine thrust downward and provides yaw control, and a roll control nozzle under each wing. Through testing at a specially instrumented "hover pit" facility, the F-35B STOVL variant demonstrated over 41,000 lbf of vertical thrust and validated the performance of aircraft software, controls, thermal management, STOVL system hardware, and other systems required for vertical flight. This is the final series of ground tests before airborne STOVL testing, to take place by year's end.

This year AFRL, NASA, and Aerojet collaborated on further testing of the advanced combined-cycle integrated inlet, first tested at NASA Langley in 2007 over the Mach range of 2.3-4.6. Subsonic and transonic operation from Mach 0 to Mach 2.0 was investigated in the NASA Glenn 8x6-ft wind tunnel. The test series gave insight into low-speed performance and operability, including contraction ratio limits, bleed effects, and mass flow redistribution characteristics.

In Europe, a study of an environmentally friendly high-speed aircraft featured low-speed wind tunnel testing.

In July EADS Defence & Security successfully tested its Barracuda UAV at Goose Bay AFB in Canada. With a takeoff weight in the 3-ton class, it is currently the largest unmanned aerial system ever designed and built in Europe. Powering the aircraft is a Pratt & Whitney Canada JT15D-5C. The advanced aerodynamic propulsion integration includes a diverterless intake design with low observable characteristics and an ejector nozzle.



In September, a one-fifth-scale open-rotor propulsion rig began a new test campaign in the NASA Glenn anechoic 9x15-ft wind tunnel.

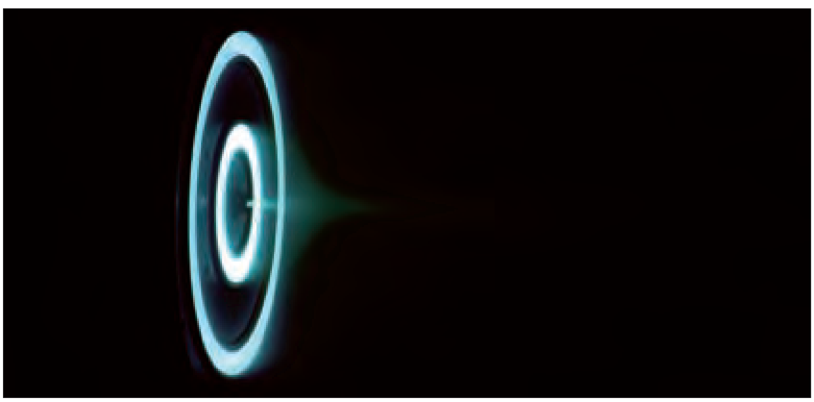
A four-year study of an environmentally friendly High Speed Aircraft (HISAC) within the European Union's Sixth Framework ended in October. The project assessed the technical feasibility of an 8-16-passenger commercial supersonic transport aircraft under environmental constraints. Aerodynamic propulsion integration is among the key technologies that enable a successful design. Configurations featuring afterbody and underwing integrated propulsion systems with ramp inlets were intensively studied in supersonic wind tunnel tests in France and Russia. CFD simulations were performed for a variety of propulsion integration solutions with different inlet types mounted at the fuselage or the wings. Low-speed wind tunnel tests took place in Switzerland.

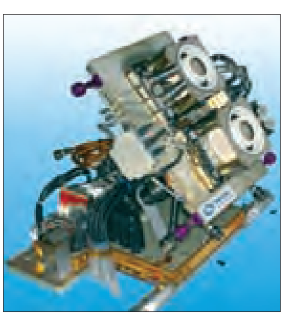
by **Hayden Reeve, Chris Hughes, Keith Blodgett, Jeffrey Hamstra, Roderick Daebelliehn,** and **Thomas Berens**

Electric propulsion

This was an active year for electric propulsion in flight and R&D programs. The 30-cm NSTAR ion thrusters manufactured by L-3 Communications for NASA's Dawn spacecraft have been operated for a total of 8,000 hr and have provided a total impulse of 2.6 MN-sec. Dawn is scheduled to rendezvous with the asteroid Vesta in August 2011. Japan's Hayabusa asteroid explorer restarted its four microwave discharge ion engines for a delta-V maneuver in February. The engines have operated over 35,000 hr in deep space; the satellite is scheduled to return to Earth in 2010. ESA's Gravity Ocean Circulation Explorer satellite was launched in March with a pair of ion thrusters manufactured by QinetiQ.

The University of Michigan and Air Force Research Laboratory developed and operated the first concentric Hall thruster, called the X2 for its two channels. (Courtesy of the University of Michigan.)





Snecma's products include this thruster module assembly. (Courtesy of Snecma, Vernon operations.)

ESA's LISA Pathfinder, scheduled for launch in 2011, will use both colloid and field emission EP for disturbance reduction and attitude control. Busek and JPL delivered colloid micro-Newton thruster flight units to ESA, while Alta will supply the cesium field emission system. Snecma completed acceptance testing of four PPS-1350 stationary plasma thrusters for ESA's Alphasat and was selected to supply eight EDB Fakel SPT-100 thrusters for the ESA Small GEO satellite. An Israeli Hall-effect thruster manufactured by Rafael was integrated onto the joint Israeli and French VENμS spacecraft.

L-3 Communications launched four 25-cm ion thrusters onboard a Boeing 702 satellite, with another four thrusters in satellite integration and 12 in production. Space Systems/Loral launched five spacecraft with stationary plasma thrusters, with another three subsystems delivered and six scheduled for delivery.

NASA's evolutionary xenon thruster (NEXT) long-duration test has accumulated over 24,300 hr of operation, processed over 434 kg of xenon, and demonstrated a total impulse in excess of 16 MN-sec. Plans call for extending the test to demonstrate first failure mode (accelerator grid wear-through), projected at 750 kg at full power. The Japan Aerospace Exploration Agency is developing a 20-mN ion engine for the super-low-altitude satellite. L-3 Communications is developing a throttleable 8-cm XIPS thruster that operates at 100-350 W, with 2-14 mN of thrust. Busek demonstrated three small RF gridded ion thrusters delivering 0.2-, 2-, and 11-mN thrust with specific impulse ranging from 1,300 to 3,800 sec.

Aerojet delivered the engineering model of NASA's high-voltage Hall accelerator. It will begin performance acceptance tests, environmental tests, and ultimately a long-duration test where it is anticipated to operate for more than 15,000 hr. Michigan Tech University demonstrated Hall-effect thrusters using light metallic elements for propellant. A nominally 2-kW thruster was operated on both magnesium and zinc. ElectroDynamic Applications designed a helicon Hall thruster that was then manufactured by Aerojet. It is a two-stage thruster with helicon ionization first stage coupled to a Hall accelerator stage to provide high thrust-to-power operation. The University of Michigan and Air Force Research Laboratory developed and operated the first concentric Hall thruster, named the X2 for its two channels. It is designed to reduce specific mass and maximize power during high thrust-to-power operation.

MSNW demonstrated the ELF (electrodeless Lorentz force) thruster, a new concept for pulsed electromagnetic propulsion that uses rotating magnetic fields to create a high-density, magnetized plasmoid called a field-reversed configuration. Operation on air and xenon from 1,000 sec to 5,000 sec specific impulse at energy levels suitable for 20-100-kW steady-state operation was demonstrated. Ad Astra Rocket operated the first stage, helicon section, of the VX-200 200-kW VASIMR engine at full power with maximum magnetic field. A record power of almost 150 kW was added to the plasma with the second-stage, RF booster. And the Ecole Polytechnique in France is currently developing the PEGASES (plasma propulsion with electronegative gases) thruster. It produces and accelerates both positively and negatively charged ions, which recombine and form a neutral beam. This technique is expected to reduce plasma-spacecraft interactions.

by **Joshua L. Rovey**

Terrestrial energy systems

Eskom is developing wind farms in the Western Cape in South Africa.

Terrestrial energy research activities in the past year have become more interdisciplinary, involving collaboration by government, industry, and academia as well as international cooperation. Considerable efforts have focused on developing green energy resources, using fuels more efficiently, finding alternate fuels to compensate the increasing demand, and reducing aircraft noise.

Among alternate fuels, biofuels offer immediate potential. In particular, instead of producing biofuels from edible plants such as corn and soybeans, or from oils and resources that have other uses, choosing nonedible oils and cellulosic materials will be the most sensitive alternative. To this end, the Office of Naval Research has begun a new initiative on production of biojet fuels from nonedible oil, waste, and cellulosic materials. The methodology created under this effort will be useful in developing biodiesel and other fuels for transportation and power generation. There is worldwide interest in this area, and the Asian nations have large government and industry programs. In South Africa, several private wind farms are now at various stages of development, including a proposed 3-GW venture by Eskom (South Africa's national utility company) in the Western Cape.

In the field of combustion for terrestrial applications, the focus has been on coordinated computation, analytical, and experimental approaches with innovations in CFD and diagnostics. Diagnostic tools with improved temporal and spatial resolution have been researched to enable measurement of the multiphase flows in complex systems such as multitube detonation engines and high-temperature, high-speed exhaust systems for military aircraft. Particular attention has been given to measuring several species or parameters simultaneously.

Research on CFD is taking place at many institutions globally. In the area of terrestrial energy systems there are notable developments at the University of Illinois at Chicago, where chemically reacting flows are studied in dump combustors. Researchers at San Diego State University are studying flow separation and fuel droplet dynamics in liquid-fuel combustors. South African universities are also active in renewable energy research, and in 2006, the Center for Renewable and Sustainable Energy Studies was established at Stellenbosch University as the national hub for graduate studies on green energy. The University of KwaZulu-Natal has a Renewable Energy Research Group focusing on solar thermal applications, broadband radiometry, and wind power. The University of Johannesburg has a similar research group on thin-film photovoltaics.

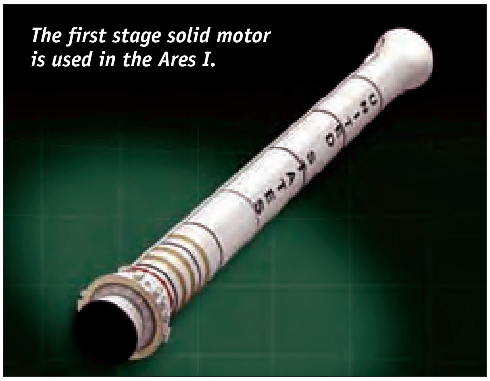
Several novel ideas have been considered for controlling the flow in combustors to increase fuel efficiency and reduce emissions or noise. One idea that has shown some preliminary success involves implementing various fluidic control devices such as countercurrent flow and microjets. These devices are attractive because of their simplicity and low energy requirements. For example, researchers at the University of Minnesota and the University of Illinois at Chicago have obtained preliminary results that indicate injecting high-velocity air through tiny orifices (on the order of 500 µm) could lead to an increase in overall heat release.

Similarly, researchers at Florida State University have used water microjets to manipulate turbulence level and thus reduce noise in exhaust plume. Investigations of bevel nozzle and other innovative technologies such as chevron and internal corrugation have led to unprecedented reductions in noise. Internal corrugation and microjet injection offer immediate potential for reducing noise in the engine exhaust and platforms, respectively.

To reduce the environmental impact of combustion systems, continuing research involves the use of porous inserts in the combustion chamber. Researchers at the University of Maryland are further developing distributed (colorless or flameless) combustion for applications in gas turbine combustion, which can simultaneously reduce emission of hazardous pollutants, energy consumption, CO_2 emissions, and noise, also obtaining a good pattern factor for the quest to achieve a uniform thermal field in the entire combustor.

by **Farzad Mashayek**

Energetic components and systems



The first stage solid motor is used in the Ares I.

The corporate consolidation of the energetic components and systems industry continued this year with the Chemring Group acquisition of Hi-Shear Technology. Once the acquisition is completed, Hi-Shear will join Scot, Kilgore Flares, Alloy Surfaces, and Technical Ordnance in providing a wide spectrum of energetic devices for military and commercial applications. Hi-Shear's decades of experience with initiators, safe/arm devices, and cartridge actuated devices, coupled with the low energy reactive thin film bridge initiators it is now developing, significantly enhances Chemring's existing capabilities in energetic materials and components.

This continues to be a busy year for NASA ELV missions. However, after 55 straight successful NASA launch missions, the agency's Orbiting Carbon Observatory, launched in February on a Taurus XL, crashed into the ocean near Antarctica when the rocket's fairing (a shroud designed to protect the spacecraft) failed to separate and release its payload. The failure investigation identified several potential causes, one of them related to an energetic component. The observatory was a new satellite designed to map Earth's carbon dioxide levels.

The Ares I first stage motor undergoes test firing in Utah.

NASA's "workhorse" ELV has been the Delta II, which has an unsurpassed record of over 99% reliability in 144 launches, with notable payloads including the Mars Pathfinder and Exploration rovers and the Deep Impact spacecraft. Delta began as an improved version of the Thor, and recorded its first successful mission August 12, 1960. The Delta II was developed by McDonnell Douglas in response to an Air Force request for proposals following the loss of the space shuttle Challenger in 1986, as a means of clearing the resulting backlog in the launch manifest. Because it is being phased out as a launch vehicle, there are only four remaining NASA LSP Delta II missions.

All launch vehicles rely on the successful operation of many energetic components for numerous different functions, such as motor ignition, staging, payload fairing and payload separation, gas and fluid management, and, in the case of an unacceptable condition, flight termination.

NASA and industry engineers lit up the sky at ATK Space Systems' Brigham City facility on September 10 with the initial full-scale, full-duration test firing of the first stage motor for the Ares I crew launch vehicle in development for NASA's Constellation program. This is the largest solid rocket motor in the world (154 ft long), holding 1.4 million lb of propellant and producing 370 million lb-sec of vacuum impulse over a burn time of 126 sec. The motor will deliver the Ares I to an altitude of about 35.5 mi. and a speed of Mach 5.7. After this the motor will be separated from the remaining vehicle and fall back toward the ocean.

At approximately 15,000 ft, the aeroshell, a protective heat shield, will be ejected and the parachute recovery system deployed for safe recovery of the booster and motor components, which will be inspected and refurbished for reuse.

Ares incorporates over 400 energetic devices in dozens of different systems.

The Joint Strike Fighter, designated the F-35 Lightning II in July 2006, also enjoyed numerous successes throughout the year, completing first flight for the BF-1 VSTOL aircraft and the 100th test flight of the AA-1 aircraft. This supersonic multirole fifth-generation fighter combines advanced stealth with fighter speed and agility, at lower operational and support costs. The F-35 uses energetic components and systems for many functions, including fire suppression, countermeasure deployment, and crew emergency egress. The ejection seat alone uses over 25 energetic components and systems.

by **Donald Jackson**
and the **AIAA Energetic Components and Systems Technical Committee**

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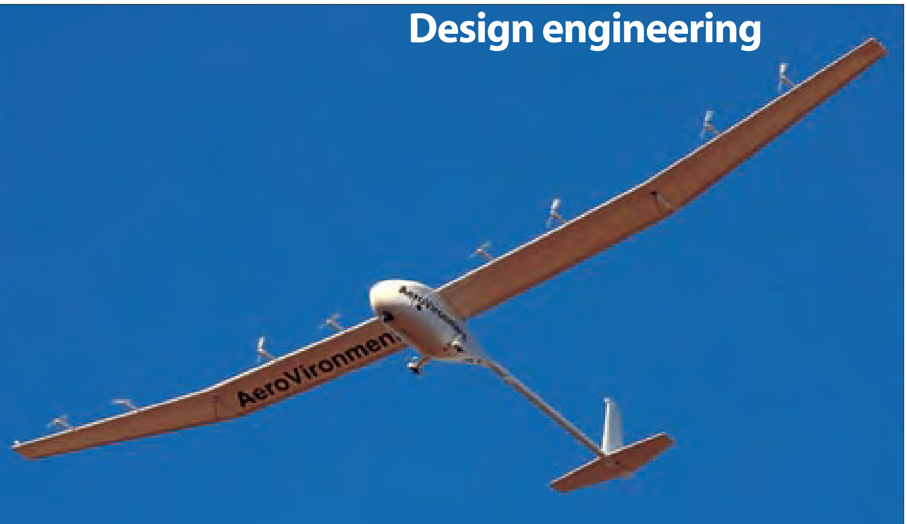
Design engineering



The Global Observer HALE vehicle is under development for the Special Operations Command.

Technology advances in design engineering emerged in many products and design concepts this year. From enhancements in design tools to exciting new aerospace projects to lessons learned from process failures, the year brought noteworthy products and events that continue to advance the design process.

Improved design tools continue to provide the design engineer with more capability to execute the design process efficiently. Human factors are often an important consideration, and there are many computer applications available to assist design engineers with this. These tools can measure attributes such as hand and tool access, dexterity requirements, and ergonomics. They are also critical in developing procedures for the manufacturing process.

Closing the gap between design tools and these manufacturing tools even further, today's CAD applications are now including human models as part of the design space. This allows concurrent design and assessment of human factors issues such as ergonomics and safety and compares the results against industry standards quickly and in real time. In addition, interaction with workstations, machines, and even other people can now be evaluated easily and quickly within the design.

Engineering advances in the design of UAVs continue to evolve at a fast pace as more emphasis is placed on the use and applications of such aircraft. These advances, along with new materials and power plant concepts, allow for larger combinations of payload and duration to create high-altitude, long-endurance (HALE) vehicles.

The Zephyr is a current example of integrating new materials and design ideas in the design and development of a HALE aircraft. By having solar panels integrated into the vehicle structure and using ultra-lightweight materials, the Zephyr is capable of maintaining flight for up to six months without sacrificing aircraft structure or weight. Another example is the Global Observer, under development for the U.S. Special Operations Command. This UAV uses a liquid hydrogen power plant and can carry up to 400 lb of payload with a duration of 5-7 days at 65,000 ft.

Additional advances in guidance electronics and situational awareness information create opportunities for the aerospace design engineer to enhance UAV capabilities further with autonomous flight and even coordinate "swarms" of UAVs to achieve complicated mission objectives.

Several noteworthy process failures have also occurred in aerospace products. The Airbus A380 and Boeing 787 Dreamliner provide high-profile examples of critical process failures that have delayed deliveries of both new vehicles. The design engineer must take note of the lessons learned from these failures and apply appropriate corrective actions as the aerospace design and manufacturing process continues to evolve.

For example, the A380 wiring design created a major problem when it switched to aluminum wire and did not correctly account for the increased bend radii and wire diameter requirements of the two different versions of design software in use at the various design facilities. The 787 recently suffered a structural anomaly that was induced by using the wrong component models in the stress analysis. Neither of these were major design issues, but a lack of configuration management in the design process led to both of these problems and ultimately caused delays in each program. Proper configuration management of designs, models, and processes is critical, especially as the level of design complexity increases.

New materials and design ideas were integrated into the design and development of the Zephyr HALE UAV.

by **E. Russ Althof**

Modeling and simulation

The International Working Group (IWG) formed under the auspices of the Royal Aeronautical Society (RAeS) has completed its revision and expansion of Volume I of the *Manual of Criteria for the Qualification of Flight Simulation Training Devices* (FSTD), Edition 3, International Civil Aviation Organization (ICAO) Document 9625. Published on July 1, it is now available in English from the ICAO Online Store (http://store1.icao.int/documentItemView.ch2?ID=7673).

Volume I of the manual covers the qualification criteria for airplane FSTD. Work continues on Volume II, which will address the criteria for rotary wing FSTD. The rotary group of the IWG expects to present its draft to ICAO and the RAeS in early 2010 to be published late that year. Both volumes contain three parts.

Part I, "Training Task Derived Flight Simulation Requirements," is based on an analysis of airline pilot training needs and lists the features (such as cues) and fidelity levels required to support each task.

Part II, "Flight Simulation Training Device Criteria," lists criteria for standard examples of FSTD derived from Part I, supporting defined training types such as MPL1 (Multicrew Pilot License Phase 1) core flying skills. Volume I defines seven FSTD examples. Volume II is expected to offer three or four helicopter FSTD examples.

Part III, "Flight Simulation Feature and Fidelity Level Criteria," serves to define the qualification and validation testing requirements for feature fidelity levels determined in Part I. It will allow operators and manufacturers to design purpose-built devices that do not correspond to any of the standard examples defined in Part II. It will also permit currently qualified FSTD to be upgraded to meet new regulations by comparing their features with those defined in Part I.

In Volume I, the challenge of defining objective criteria for the evaluation of motion systems leaves this area subject to further study. Similarly, the lack of technical solutions for simulating a full air traffic control environment requires further research. Nevertheless, the document addresses both items.

The challenge for the helicopter group working on Volume II has been evaluating the constraints imposed by the use of collimated visual systems versus the problems arising from direct view visual systems such as dome projected displays. The solution may depend on the type of helicopter and its cockpit layout. The roles of motion and vibration and their integration with visual systems have also received particular attention.

Publication of Document 9625, Volume I, provides the National Aviation Authorities (NAA) with guidance materials for updating their regulations for the initial and periodic qualification and evaluation of airplane FSTD. Several states have indicated an intent to do so in the interest of international harmonization.

In the U.S., 14 CFR FAR (14 Code of Federal Regulations Federal Aviation Regulation) Part 60, Flight Simulation Device Initial and Continuing Qualification and Use, has undergone no changes this year, although the NAA are considering incorporating at least some provision of Document 9625 in the future. On January 12, the NAA finally published 14 CFR Parts 65, 119, 121, and others ("Qualification, Service, and Use of Crewmembers and Aircraft Dispatchers Proposed Rule") to replace FAR Part 121 Subparts N and O. The original comment period was extended and expired on August 10.

The Administrative Procedures Act requires the regulations to be published within 16 months of the expiration of the comment period, with an effective date of one month later—that is, no later than early 2011. As of this writing, the NAA are determining how to expedite this process.

Volume I of the revised manual covers simulators for fixed-wing craft, like this one for the Boeing 737. (Image courtesy 737flightsimulator.co.uk.)

by the **AIAA Modeling and Simulation Technical Committee**

Computer-aided enterprise solutions

At the end of last year there was much discussion of the Aerospace Industries Association's recommendation "that AIA members and companies transition to standards-based interoperability solutions based on the Product Lifecycle Support Standard (PLCS)." At the time, the AIA was also developing "best practice guidelines to help organizations develop their own business cases for transitioning to standards-based data exchange and optimizing their business processes."

Using PLCS within aerospace companies in accordance with the published AIA best practices guidelines is now becoming widely accepted. Boundaries have been crossed to create a consortium consisting of AIA, the European Aerospace and Defense Association, and standards organizations to work as LOTAR International. Its purpose is to investigate and develop approaches using standards for the long-term archiving of digital product data. PLCS will be a key component of this activity and will address the requirement to archive product data in such a way that it is usable decades from now.

PLCS can be seen as the standards glue that allows PLM, ILS, and other specifications to communicate effectively without the high development and software support costs of custom integrations.

What exactly is PLCS and how does it tie in to other standards to advance interoperability within or between organizations and help improve their business? Ask people creating and consuming engineering and CAD data what STEP (standard for the exchange of product model data) is, and 95% of them will correctly state that it is used for translating parts or assemblies between CAD formats. These files are often known as application protocol (AP) 203 or AP214. PLCS represents the portion of the STEP standard addressing product lifecycle management (PLM) data interoperability in addition to lifecycle support of products. As aerospace companies have expanded the use of product data manager/PLM systems for management of highly configured products, PLCS interoperability needs have increased.

Currently, the most widespread application of PLCS is in the area of specification and control of support activities throughout a complex product's life. When you examine the scope of PLCS, also known as AP239, there is the concept of OASIS data exchange sets (DEXs) and other reference data. A DEX is a subset of PLCS capability suited for a particular business process and enables the use of Web-based technology. A sample of existing DEXs for logistics support would include:

•DEX1: Product breakdown defines the PLM product structure relationship to a logistics control number or other structures used to manage support, and provides links to relevant documents.

•DEX3: A task set for the exchange of a set of task descriptions, to support a work plan, or for use in multiple support solution definition.

PLM systems are now communicating via PLCS with systems that extend far beyond the traditional design and manufacture lifecycle management capabilities of PLM systems. PLCS is expanding the definition of product lifecycle to a position long desired—inclusion of the lifecycle portion after production for maintained and supported products.

As affirmed in PLCS DEX1, there are relevant documents or electronic processes that must be linked and controlled between PLM and ILS (integrated logistics systems) for maintenance and support.

PLCS-based repositories often tie together PLM, ILS, and document or international specifications such as these, which are critical to logistics and maintenance of air, land, and sea products:

•S1000D: Technical documentation utilizing a common source database.

•S2000M: Material management and integrated data processing for military equipment.

•S3000L: Activities and requirements governing the logistic support analysis process.

•S4000M: Procedure handbook for the capture of maintenance for military aircraft.

PLCS can be seen as the standards glue that allows PLM, ILS, and other specifications to communicate effectively without the high development and software support costs of custom integrations. PLCS can free organizations from legacy approaches to product lifecycle support and enable them to meet the dynamic technical and business needs of the aerospace world today.

by **Jim Martin** and **Mike R. Jahadi**

Ground testing

The past year has been tumultuous, with continued support for efforts like NASA's Constellation program and the USAF Joint Strike Fighter, and cancellation of other programs such as the hypersonic Blackhawk HTV-3X. Even the continuing programs experienced funding and deployment uncertainties that resulted in schedule stretch-outs. Testing for research continued, although limited budgets for fundamental aeronautics research remained at significantly depressed levels compared with those of earlier decades.

System development for new, "major" weapon system aerospace programs is in decline, although momentum for technology development associated with environmentally responsible aviation has increased. R&D for technologies associated with UAVs has been on the increase, especially at the system and subsystem levels.

The availability of test facilities remained challenging, as owners balanced readiness and uncertain workloads with managing aging infrastructure, static maintenance budgets, and targeted investments in improvements and modernization. Ground testing of aerospace systems encompasses services for a wide variety of products, requiring an equally wide variety of test capabilities.

This year there were several facility and testing highlights:

•Testing in NASA's Ares and Orion programs included launch abort vehicle separation testing in the Langley 14x22-ft subsonic wind tunnel, high-Reynolds-number testing at the National Transonic Facility, Ares I-X and pad testing for ground winds at Langley's transonic dynamics tunnel, and a successful test of the Orion launch abort motor at ATK's Utah facility.

•A 2-Axis Test Facility is under construction at NASA Glenn in support of the Ares I upper stage thrust vector control engineering program to evaluate the TVC integrated hydraulic system, control dynamics, and various failure-mode and off-nominal behaviors.

•The Japan Aerospace Exploration Agency completed a series of firing tests of a hypersonic precooled turbojet engine at its Taiki Aerospace Research Field on Hokkaido Island.

•A NASA Mars Science Laboratory parachute was tested at the Glenn 10x10-ft supersonic wind tunnel.

•Store separation testing of the F/A-18E/F took place at the Arnold Engineering Development Center (AEDC) 16-ft transonic wind tunnel.

NASA and ATK successfully test an Orion launch abort system motor in a 5.5-sec test in the Utah desert at Promontory.

•As part of the series of 787 tests required before flight clearance, Boeing successfully completed a high-pressure airframe static test to 150% of expected maximum service pressure at its Everett, Wash., facility.

•An acoustics research investigation of an ultra-high-bypass fan rig was accomplished at the NASA Glenn 9x15 low-speed wind tunnel, including tests of various fan rubstrips and "soft" vanes for noise attenuation.

•AEDC fielded a new test technique that essentially "flew" an Army projectile model in its 4-ft transonic wind tunnel via continuous measurement, feedback, and remote control that positioned control surfaces based on measured loads.

•In the first customer test since a multiyear facility upgrade at its Aerodynamic and Propulsion Test Unit, AEDC accomplished a successful freejet test on a dual-mode combined ramjet/scramjet hypersonic engine for DARPA's Falcon combined cycle engine test.

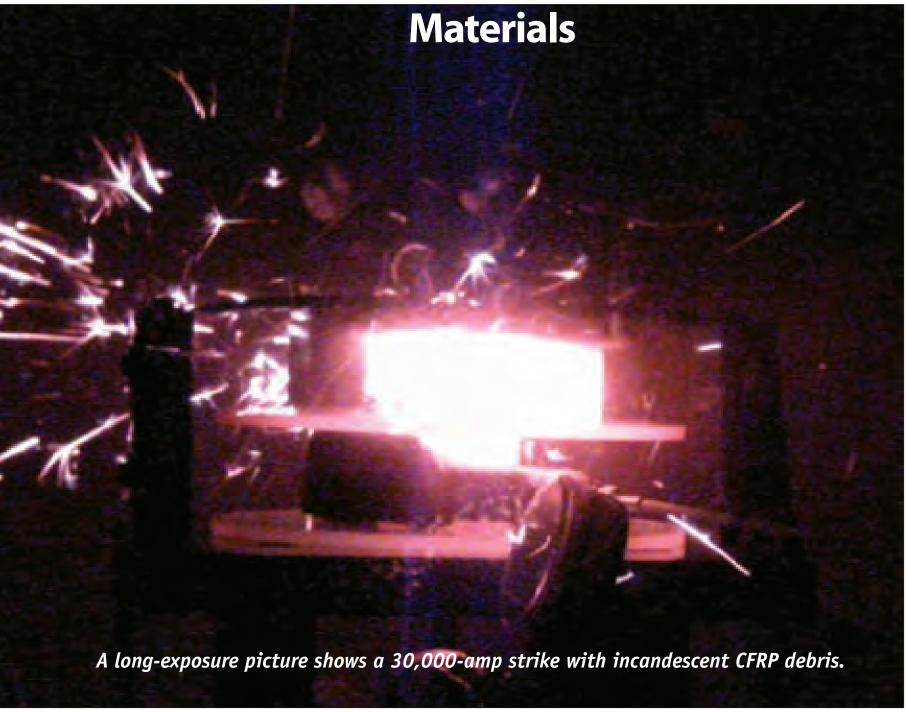
An engineer inspects part of the simulated launch tower between scale model tests of NASA's Ares I-X rocket in the Langley transonic dynamics tunnel.

Additional highlights included a recent successful Ares first-stage motor firing at the ATK Utah facility, continued construction of the new A-3 test stand at NASA Stennis, closing of the Langley full-scale tunnel this fall, continued ground testing of JSF systems (airframe and propulsion systems) as flight testing proceeds, and aviation-safety-related icing research conducted regularly at the Glenn Icing Research Tunnel.

Ground testing growth markets likely include unmanned air systems, environmentally responsible aviation research, commercial space transportation, component and weapons/stores integration for USAF fighter systems, and improvements and research in materials, acoustics, planetary reentry flow physics, and aviation safety.

by **Steven Dunn**

Materials



A long-exposure picture shows a 30,000-amp strike with incandescent CFRP debris.

Recent advances in the manufacturing, analysis, and characterization of materials by NASA, the Air Force, academia, and industry will lead to lighter and more durable aerospace structures.

NASA has initiated an advanced composites technologies project to develop composite materials and structures technologies for Ares V and Altair applications. This effort includes participation from six NASA centers, industry, and universities. The project is working collaboratively with the Air Force Research Laboratory to develop out-of-autoclave (OOA) composite processing technology for large aerospace structures. A demonstration of the potential for OOA technology was part of the Air Force's Advanced Composite Cargo Aircraft (ACCA), which developed an OOA composite fuselage for a Dornier 328J that flew in June 2008. Manufactured by Lockheed Martin, the ACCA had 90% fewer parts and 98% fewer fasteners than the original aircraft.

The effects of lightning strike on aerospace structures made of composite materials are an ongoing concern. Although aluminum airframe structures are highly conductive, carbon fiber reinforced polymers (CFRPs) have very low electrical conductivity because of the dielectric nature of the polymeric matrix. A large amount of energy is delivered very rapidly during a lightning strike, which may cause the ionized channel to expand with supersonic speed and the temperature of the neighboring material to rise dramatically; it may even cause explosive vaporization of the resin. As a result, damage from lightning strikes to CFRPs can vary from degradation of the fiber-resin interface to fragmentation of the laminate.

To address these issues, the Automobili Lamborghini Advanced Composites Structures Laboratory in the Dept. of Aeronautics & Astronautics at the University of Washington has opened a new facility that can simulate the effects of lightning strikes on CFRP. The laboratory's 44-kV generator can generate up to 100,000 amps and can release it in less than 50 microsec. The generator is used to study the fundamental interactions of lightning strike on CFRP specimens, including the effects of material characteristics, lightning strike protection systems, and repair methodologies. The lightning damage tolerance characteristics of CFRP carbon fiber composite structures are being evaluated in a manner consistent with the framework of impact damage characterization, including visibility thresholds and allowable damage limits for repair as well as regulatory agency load requirements.

NASA Marshall has recently manufactured a friction stir welded (FSW) Al-Li 2195 demonstration article for the Ares I rocket. This is the first time a complex curvature dome has been welded using the FSW technique. This innovative process produces high-strength, high-quality welds without melting the alloy. The dome, completed in July, is the first development hardware assembled for the Ares I upper stage liquid hydrogen fuel tank. The assembly took place at Marshall's Weld Development Facility using a specially designed robotic weld tool. FSW will be used for all of the major structural welds on the Ares I upper stage, including welds at difficult angles required for the bulkhead and other large metallic structures.

As part of NASA's subsonic fixed wing project, metallic open-cell foams are being developed for use in aircraft engines because of their ability to reduce engine noise, absorb impact, and reduce structural weight. Work is under way at NASA Glenn to identify and correlate the relationship between key characteristics of the foam microstructure and important acoustic properties such as the noise attenuation parameter. Detailed quantitative measurements are currently under way at Glenn to characterize the microstructures of FeCrAlY and stainless steel foams and to correlate them with the acoustic impedance characteristics and the pressure flow resistance of the foams.

by **Edward H. Glaessgen**

Survivability

The twin-prop, fixed-wing tactical Joint Cargo Aircraft was subjected to triservice live fire test and evaluation (LFT&E) under the auspices of the mandatory Title 10 testing requirement. The Army tested the flight controls, armor, energetic materials, and oxygen systems against ballistic threats. The Air Force tested the engine nacelle fire extinguishing system and made initial evaluations of the wing leading- and trailing-edge dry bays. The Navy assisted by evaluating wing fire, hydrodynamic ram effect, and propeller vulnerabilities to ballistic threats. The Air Force also performed LFT&E on the four-engine fixed wing modernized Super Galaxy C-5M transport aircraft to evaluate its survivability against potential fire initiation and sustainment in the engine pylon areas due to ballistic threats.

After the January 15, 2009, multiple bird strike to the US Airways aircraft resulted in complete loss of power in its two jet engines and an emergency landing on the Hudson River in New York City, bird strike warning devices began receiving more attention for civilian aircraft survivability and safety. The New York Airport Authority is preparing to install and test a bird radar (very much like any other radar) at JFK airport. If it proves successful, LaGuardia and New Jersey's Newark airport will each receive one. The FAA is refining a system at Seattle's airport first, to ensure that the device does not "see" too much or too little. Other avian radars are now also being developed by some vendors.

Space debris is becoming a serious problem. In October 2008, NASA celebrated its 50th anniversary with a proposed vision centered on establishing a permanent manned lunar station as a base for further planetary exploration. This vision must take into account survivability against space debris, an issue that literally exploded into the front pages following several major incidents in 2008 and 2009.

First, the ISS had to use thrusters on August 27, 2008, in a maneuver to avoid a piece of space junk that NASA described as part of the Cosmos-2421 satellite that had separated the previous March. Next, a 30-lb repair tool bag was lost in space on November 18, 2008, by an astronaut of the Endeavour space shuttle during a spacewalk to repair the ISS. The bag orbited for more than eight months before it burned during reentry on August 3. Third, a 1,400-lb refrigerator-sized ammonia servicer jettisoned from the ISS in 2007 burned and disintegrated during reentry more than 15 months later on November 3, 2008. Then, in January of this year, a Russian nuclear-powered satellite, Cosmos-1818, partially disintegrated, posing both debris and radiation hazards. And this February, debris was splashed into orbit from the accidental collision of two communications satellites, one Russian and one U.S., over Siberia. Overall, it is estimated that 19,000 debris pieces larger than 10 cm are floating in orbit (among 300,000 pieces larger than 1 cm). They are monitored closely at NASA Johnson by the agency's Orbital Debris Program Office. NASA, ESA, and the U.N. have held meetings recently to consider formulating regulations to curb collisions and protect satellites and space vehicles.

A tool bag lost in space by an Endeavour astronaut during a spacewalk to repair the ISS solar panel on November 18, 2008,orbited for more than eight months before burning during its reentry on August 3.

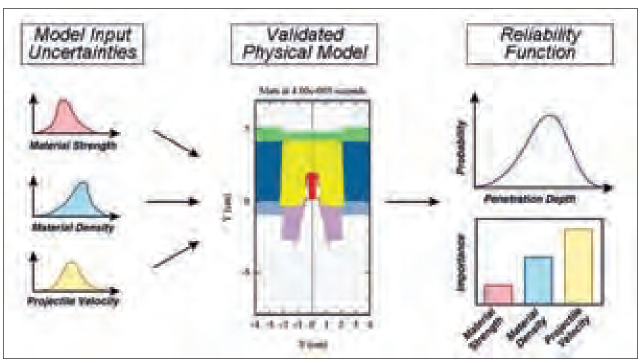
Other survivability-related R&D efforts continued this year. The Air Force is studying the degradation in composite materials due to brief but intense fuel fires. Also, an aircraft fire prediction model is being validated through a series of tests involving ballistic impacts against generic fuel tank and dry-bay configurations. The goal is to enhance fire survivability after impact.

by **Ameer Mikhail, Adam Goss,** and **Dan Cyphers**

Nondeterministic approaches

by **Eric Tuegel**

Nondeterministic approaches (NDA) are essential for the effective application of model-based simulations in engineering. A 2009 World Technology Evaluation Center (WTEC) panel report, "International Assessment of Research and Development in Simulation-Based Engineering and Science" (SBE&S), emphasized the importance of SBE&S for future technical and economic development, and the necessity of NDA both for quantifying uncertainty in SBE&S models and for verification and validation (V&V). The panel noted the strong leadership shown in NDA development by the DOE and DOD, but pointed out the lack of organizational structures in the U.S. for further developing and capitalizing on it. The panel also decried the worldwide lack of graduate curricula in stochastic modeling and simulation.



NDA can be used to propagate uncertainty through a model and compute the sensitivity of the outputs to input parameters.

A critical frontier for development identified by the WTEC panel is the development of sophisticated approaches toward V&V, uncertainty quantification (UQ), and risk assessment to provide confidence in SBE&S. Developments in these three areas occur in islands of excellence at national labs and universities. Sandia National Laboratories has been actively working these areas for years and continues to do so. Techniques for reducing the discretization (mesh) dependence in physics models where results do not deterministically converge with mesh refinement were investigated. In addition, Sandia and partner institutions worked to improve the efficiency of propagating uncertainties in input parameters through models to estimate the uncertainty in output variables.

Universities are responsible for many of the mathematical developments in V&V, UQ, and risk assessment. Improvement of a global, full-field sensitivity analysis method continued at the Naval Academy, together with the Army Cold Regions Research and Engineering Laboratory. This method provides sensitivity information throughout both the spatial and parameter domains of a computational mechanics model based on sampling of surrogate models. Researchers at the University of Arizona are developing techniques for constructing explicit nonlinear limit state functions using support vector machines (SVM), a type of supervised machine learning. The SVM-based limit state functions are developed with both computational and experimental data, and form the basis for an efficient reliability-based design optimization algorithm for problems with competing failure modes.

NDA techniques and nondeterministic SBE&S made headway in real-world applications this year as the desire to lower operating costs drove operators to consider alternate ways of doing business. Nondeterministic service life management tools developed by VEXTEC are being used to establish the warranty periods and maintenance intervals for industrial equipment, automotive fleets, and aerospace vehicles. Southwest Research Institute (SwRI) assessed the impact of condition-based maintenance on the reliability of dynamic helicopter components. In collaboration with the Air Force Research Laboratory (AFRL) and Naval Air Systems Command, SwRI developed a probabilistic methodology to predict the risk of fracture of engine disks subjected to fretting fatigue, a major source of damage in aircraft turbine engine components.

Engineers also looked at NDA to improve the efficiency of products by reducing the weight resulting from overly conservative designs. SwRI and AFRL developed a rigorous probabilistic framework to assess turbine engine reliability when multiple (competing) failure mechanisms, each involving multiple anomalies, are simultaneously active at multiple locations. The purpose was to provide a more accurate estimate of lower bound lives, eliminating the overconservatism that may occur when failures resulting from different mechanisms are lumped together into a single population.

SwRI also worked with NASA and other team members to develop practical guidelines for performing probabilistic fracture mechanics assessments. The ability to identify and catalog overconservative design margins resulting from applying safety factors on top of other safety factors using NDA is being demonstrated by VEXTEC and Vanderbilt University.

Structural dynamics

Every few decades, structural dynamicists get an opportunity to conduct a modal survey test on an integrated launch vehicle to verify the dynamic loads and control models in preparation for the first flight. This summer provided that rare chance. Engineers and analysts from NASA Glenn, Johnson, Langley, and Marshall converged on Kennedy Space Center to perform such a test on the Ares I-X flight test vehicle, a 327-ft-tall, 1.8-million-lb rocket constrained to the mobile launch platform at four hold-down locations. NASA recently completed Ares I-X stack subassembly modal tests, followed by a full vehicle test. The acquired data verify the accuracy of Ares I-X dynamic models for loads prediction and vehicle control analyses.

NASA Marshall is preparing for the Ares I integrated vehicle ground vibration test planned for 2012. The test will verify frequencies, modes, and damping for the Ares I launch vehicle at five points in flight (full stack liftoff, full stack first stage end-of-burn, and three upper stage flight points) to support guidance, navigation, and control as well as loads requirements. The landmark Marshall Dynamic Test Stand (TS4550) has undergone extensive renovations. The access platforms used for the shuttle are being replaced with a "mast climber" for the Ares I test.

Sandia developed new computational tools for massively parallel structural dynamics analysis, and evaluated a novel wind turbine blade design. These tools enable high-fidelity finite-element analysis of structural-acoustic systems. A quadratic eigenvalue solver and mesh tying options for structure-acoustic interfaces were implemented in Salinas, Sandia's massively parallel code, for better coupled analyses. Sandia has been developing innovative concepts for structurally efficient turbine blades. The 27-m STAR (sweep-twist adaptive rotor), developed with Knight and Carver, is one such blade.

First-of-a-kind computations were conducted at NASA Ames for rotor blades using RUNEXE, a C++ based process that facilitates time accurate coupling of CFD and rotor blade CSD (computational structural dynamics) codes. Unlike works that rely on linear aerodynamics codes and the measured thrust coefficient, validations were performed by using only primitive independent parameters: rotating and forward speeds.

The Air Force Research Laboratory com-

The STAR blades on a Zond Z-48 turbine are one example of structurally efficient turbine blades.

pleted a three-year study on the effects of power and signal cables on the dynamic response of large precision structures. The study aimed to discover practical ways of updating dynamical models of cabled structures. Modal models treating cables as nonstructural masses cannot capture high frequencies. Hence a more complex, yet practical, approach to cable modeling was studied. Experimental and computational techniques were developed to extract structural properties of cables used in the space industry and create an extensive database.

Flapping wing micro air vehicles could revolutionize information gathering in areas such as environmental monitoring and homeland security. At the University of Michigan, new computational tools have been created for predicting aeroelastic effects on these vehicles. Using high-fidelity finite-element simulations, these tools can determine the amount of wing flexibility for enhancing aerodynamic performance. A low-order framework, involving nonlinear beam, potential flow aerodynamics, and nonlinear flight dynamics, is used for coupled flight dynamic and aeroelastic simulations.

United Launch Alliance and Ball Aerospace summer interns held their annual high-power rocket launch event in July, launching four rockets that attained above-ground-level altitudes of 4,494 ft, 4,000 ft, 8,809 ft, and 4,632 ft. The third one exceeded Mach 1. The last one, 20 ft 4 in. tall and weighing 137 lb, successfully deployed its main payload at apogee. Then, at 1,700 ft, an egg drop contraption was ejected and deployed a parachute that returned it safely to the ground. In just 10 weeks, the 60 interns built the rocket and payloads, built a load test fixture, and conducted avionics validation tests.

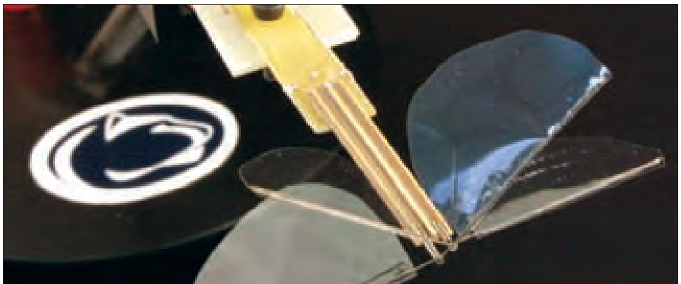
In July, ULA and Ball Aerospace interns launched four rockets to various altitudes.

by **Suresh Shrivastava**

Adaptive structures

Rotorcraft technology was an area of significant activity this year in the field of adaptive structures. The Army and Sikorsky will demonstrate an adaptive rotor system that improves rotor performance, reduces vibration levels, and lowers acoustics. Technologies include active trailing-edge flaps, leading-edge slats, and a hub-mounted vibration suppression system. Full-scale hardware will be tested on the Sikorsky rotor whirl stand and in the National Full-Scale Aerodynamic Complex wind tunnel at NASA Ames.

Eurocopter and EADS Innovation are also investigating active trailing-edge actuator concepts. The actuator is a multimorph bender including piezoelectric ceramics and glass fiber-reinforced plastics. Advantages of the concept are smoothly deflected contours in chordwise and spanwise direction. Eurocopter has built a blade segment for testing. DARPA is leading a mission adaptive rotor program that could enable morphing of the rotor and possibly boost payloads by 30% and range by 40%, reduce sound by 50%, and decrease vibration by 90% compared to the usual fixed rotor blades.



Penn State and the Air Force Office of Scientific Research developed a novel clapping-wing nano airframe

NASA is using adaptive structures technology for airframe noise reduction and engine vibration reduction. Noise produced by unsteady flow around gaps, cavities, edges, and articulation mechanisms associated with multielement airfoils of transport aircraft has emerged as an important contributor to airport community noise. Research is directed at developing practical concepts and prototypes for low-noise transport wing structures. Notional solutions include slat-cove filler, drooped leading-edge, and conformal trailing-edge link concepts.

Vibrations in engines lead to thicker blade design, fatigue, and reduced life. NASA has developed and demonstrated a smart adaptive damping technology to reduce vibrations in fan, compressor, and potentially turbine blades, using piezoelectric materials, plasma-sprayed damping coatings, and high-damping, high-temperature shape memory alloy materials.

The Adaptive Structures Team at the Air Force Research Laboratory (AFRL) has fabricated representative morphing skin concepts to demonstrate single-material shape-memory polymer solutions that allow morphing with minimal strain energy while maintaining outer mold line integrity. They have also investigated thermally activated actuation of a deployable system using available ambient heat caused by high-speed delivery. The concept relies on thermal switches and internal heat storage in phase-change materials before activation of the deployment mechanism.

For micro air vehicles (MAVs), AFRL continues to investigate poststall transient aerodynamics loads for perching MAV concepts, and anticipates mechanism, vehicle, and control design to begin late this year.

Another element of adaptive structures is structural health monitoring. Arizona State University developed an adaptive prognosis model based on improved kernel functions to enhance on-line Gaussian process models and physics-based models. The team is investigating multiscale modeling of woven composites, optimal sensor placement, and sensor fusion. Alpha STAR and the University of California developed a diagnostic prognostic system using optical fiber sensing, wireless strain gauge, and remote data transmission. Software was developed to determine the failure location, failure cycle/load, and the contributing failure mechanisms. University of Michigan research focused on the design of directional transducers for efficient guided wave excitation, emphasizing composite materials. Damage interrogation approaches are using a composite long-range variable-length emitting radar transducer, which is able to inspect a complete structural surface from a central location.

Penn State and the Air Force Office of Scientific Research and have developed a novel 4-cm-wingspan, 1-g clapping-wing nano airframe. The aircraft's four wings are driven by three piezoelectric T-beam actuators monolithically fabricated from bulk 1-mm-thick PZT-5H. A hinge and lever mechanism amplifies the small actuator displacements to produce 60-deg wing motions from DC to 12 Hz using 0.4 V/μm applied electric field. The polymer wings clap together at the end of the stroke to amplify thrust.

by **David Voracek**

Aerospace structures

Advanced flying wing configurations like the blended wing body offer superior operating economics, but such benefits will not materialize until fundamental structural challenges involving pressurization and producibility are solved. NASA Langley and Boeing are developing pultruded rod stitched efficient unitized structure concepts. Complex stitched panel assemblies are built without exacting tolerances, and then accurately net molded in single oven-cure operations. Soft-tooled fabrication methods, where bagging films conform to inner moldline surfaces, eliminate current costly tooling.

At MIT, numerous advances are continuing to drive nanocomposite research upward in scale and complexity to aerospace structural applications. Taking advantage of scale and exceptional properties of carbon nanotubes (CNTs), thin films and hierarchical materials are now being realized. Examples include nanoengineered composites—hybrid composites with 3D aligned CNT reinforcement.

Mississippi State is using multiscale design methodologies to investigate nanoreinforcement effects on primary structure fiber-reinforced composite properties. Critical issues include selection of key combinations of fibers, matrix materials, and nanoreinforcements; fabrication of fine- and coupon-scale testing samples; and multiscale material modeling strategies for assessing high-performance nanocomposites material processing influences.

Arizona State University, in collaboration with the AFRL/RB/Boeing structural hotspots program, is researching structural health management (SHM) and damage prognosis for existing and future structures. A multiscale-modeling framework has been developed for tracking the nucleation of damage in metallic materials from grain level to structural failure. Other efforts include the development of robust online/offline SHM and prognostic tools using system identification and Bayesian statistics.

NASA's integrated vehicle health management program has brought significant accomplishments in multiscale modeling, guided-wave-based damage detection, and novel signal processing techniques for information management. Through the use of machine learning and data reduction techniques, sensor signals and training time storage requirements have been reduced. High-velocity impact research is under way to determine woven and braided composite responses.

The Air Force Institute of Technology conducted impact studies at 108 Joules of titanium and titanium boride monolithic and functionally graded composite plates. A finite-element model was developed to compare with material response using a local random distribution of constituents. Hawk moths have proven to be valuable models for MAV design.

Ball Aerospace is emphasizing high-*g*-level shock testing and analysis for electronic components and assemblies. Its researchers have tested numerous board configurations, creating software tools, engaging experts, and implementing the most current data reduction techniques. The program also focuses on practical uses of "pseudo velocity" techniques, which can bring crucial insight in deciphering test results.

Ares I-X stands on launch pad 39b at the Kennedy Space Center on Oct. 26 awaiting its flight test launch. (Photo Credit: NASA/Bill Ingalls.)

NASA's Orion crew exploration vehicle is a complex state-of-the-art spacecraft that will have more capability, flexibility, and adaptability than any previous vehicle. The full-sized module will be ground tested in vibration, acoustics, and water landing loadings equivalent to flight environments. The initial weld joined an aluminum-lithium 2195 cone panel and AL 2219 longeron using an innovative friction stir welding process.

In June 2008, AFRL and Lockheed Martin launched a new era of aircraft manufacturing technology and performance with the successful demonstration flight of the advanced composite cargo aircraft (a modified Dornier 328J). Lacking traditional rivet fasteners, the composite structure is aerodynamically clean. The fuselage is wider and stronger, and the vertical tail features integrally stiffened skin. Fuselage materials and processes reduced the number of parts by an order of magnitude over metallic designs.

NASA Glenn spent two years designing and building the upper stage Ares I-X rocket simulator (which has since been delivered to the launch pad and had its first test launch). Glenn examined many transportation options because of the sheer part sizes. Twelve tractor-trailer rigs were used to load the 11 18-ft-wide, under 10-ft-tall cylinders, each weighing between 24,000 and 60,000 lb. The 100-yard-long Delta Mariner is designed to navigate both rivers and oceans.

by **Harry H. Hilton**

Missile systems

by **Jeannie Lee Borden, Rick Gamble, Shawn Hertz, Ronald Miller,** and **Randy Sturgeon**

This was an exciting and productive year for new rocket and missile systems and for those nearing completion. The laser-guided Zuni, the LOGIR (low-cost guided imaging rocket), and the HSAD (high-speed antiradiation demonstration) programs all completed significant tests. As a result, there is continuing acceleration toward use of new elements with proven technology to create weapons that meet warfighters' current needs.

The laser-guided Zuni, a high-performance forward-firing semiactive weapon, incorporates a baseline 5-in. Zuni rocket motor with a laser guidance kit attached. In a very successful test, the weapon made a direct hit on a target board less than 1 m from the laser spot.

LOGIR, as its name implies, is designed to provide a low-cost guidance enhancement capability for unguided rockets. Its technology will significantly reduce a pilot's exposure to attack by improving standoff and reducing engagement timelines, as well as enhancing the Navy's ability to deal with asymmetric threats. A LOGIR firing test was conducted this year against a representative fast inshore attack craft target. When the rocket was fired, the inertial measurement unit (IMU) reset as a consequence of pyroshock, and the weapon impacted the sea shortly thereafter. Even so, the test proved invaluable for understanding the launch environment of the rocket motors and the limitations of low-cost IMUs. Based on the findings from this firing, the weapon is undergoing design changes, and a repeat test is scheduled for early 2010.

The HSAD program included the successful flight demonstration of an integral rocket ramjet propulsion system, which incorporates a nozzleless booster and variable flow ducted rocket ramjet technologies. This project's objective was to flight test a near-tactical-configured vehicle with an advanced propulsion and control system. The focus was on increased range and reduced time of flight at critical distances, as well as compatibility with evolving guidance, navigation, and control components. The ultimate goals were performance simulation models and an "as-built" design data package, to be validated starting from the component level all the way through vehicle-level free flight tests.

Arnold Engineering Development Center (AEDC) accomplished testing on the Falcon combined cycle engine technology (FaCET) program. FaCET is a pathfinder dual-mode ramjet demonstrator supporting a turbine-based combined cycle hypersonic vehicle. Over 30 test runs were completed at Mach 3, 4, and 6. The Mach-6 runs were also the center's first hypersonic air-breathing propulsion test of a near-flight scale engine, and thus represent a significant milestone for AEDC.


A laser-guided Zuni impacts the target board.

Joint rocket/missile tests and launches proved to be effective. A USAF Minotaur I rocket launched the Air Force Research Lab's TacSat-3 satellite, and NASA's PharmaSat microsatellite and CubeSat technology demonstration experiments into LEO in May. This mission marked the third launch of a Minotaur I launch vehicle from NASA Wallops and the eighth Minotaur I mission.

The MDA, U.S. Pacific Fleet ships, and their crews successfully conducted an Aegis ballistic missile defense at-sea firing event in July. It was the 19th successful intercept in 23 at-sea firings for the Aegis BMD program. Also completing successful intercept tests this year were THAAD (terminal high-altitude area defense), a mobile system now in development and designed to intercept short-to-medium-range ballistic missiles, and a ground-based interceptor missile.

The Air Force conducted routine operational tests of a strategic missile from Vandenberg AFB as part of a continuing program to evaluate and demonstrate the operational readiness of a ground-based strategic deterrent force. These tests also were used as targets of opportunity for MDA to conduct important exercises and obtain extensive data without incurring the expense associated with launching a test-specific target missile.

Space colonization

Progress toward future space settlement is measured in small ways, mostly as incremental changes in perception and advances in targeted applied engineering that supports infrastructure development. The past year continues this trend.

It has long been recognized that although space settlement/colony development may be technically feasible, it is economically and politically unlikely in the foreseeable future. Several books published just this year indicate a more general acceptance of the concept that space settlements are natural extensions of human civilization. These include *Living in Space* by the Aerospace Technology Working Group, *Lunar Outpost—The Challenges of Establishing a Human Settlement on the Moon* (Seedhouse; Springer/Praxis), and *Space Enterprise: Living and Working Offworld in the 21st Century* (Harris; Springer/Praxis). The recently concluded *Review of US Human Spaceflight* also reports on a strong consensus to "…the ultimate goal: charting a path for human expansion into the solar system."

Evidence of popular acceptance of space settlement concepts is increasing. The AIAA-sponsored International Space Settlement Design Competition involved more than 1,000 high school students worldwide in designing large space settlements in Earth orbit, in lunar orbit, and on the lunar surface. Similarly, the Space Design Contest, a competition organized by the National Space Society (NSS), attracted hundreds of entries, primarily from individual students.

Space settlement concepts and infrastructure supporting future space settlement were featured topics at the AIAA Space 2009 Conference, the 47th AIAA Aerospace Sciences Meeting, and the NSS International Space Development Conference. A Space Elevator Conference provided conceptual design refinements for a transportation system that could reduce costs to GEO to $3,000/kg, although some challenges were identified. These include space debris and the realization that carbon nanotubes may not be as strong as originally thought.

Private and commercial projects press forward toward enabling more people to visit LEO and live above the Earth's atmosphere. Bigelow Aerospace advocated an "Orion Lite" spacecraft to enable tourist visits to LEO. The Mars Society's simulated missions in arctic Canada are becoming more sophisticated—these included UAV flights, remote rover operation, and an in-situ resource utilization demonstration recovering water and plaster of Paris from local minerals.

Automated ISS resupply capability demonstrated by European and Japanese space vehicles are welcome signs of cooperation and cost-sharing in these tough economic times. Similarly, the launch of remote sensing missions to the Moon by other nations new to the space arena is refreshing. Tantalizing evidence of the presence of surface water on the Moon was found recently, and the eagerly awaited results from the NASA Lunar Crater Observation and Sensing Satellite mission may provide a new boost to the Moon-first scenario for space exploration.

As space shuttle operations prepare for another year and start to wind down, work continues on the Ares I and Ares V vehicles, and a test flight has been conducted for the Ares I-X mission. Work continues on the Altair lunar lander and its ascent and descent engines. The year also brought progress in work on evaluating the benefits of a small nuclear reactor to provide surface power on the Moon. Any long-term lunar mission will clearly benefit from augmented power for future lunar surface operations.

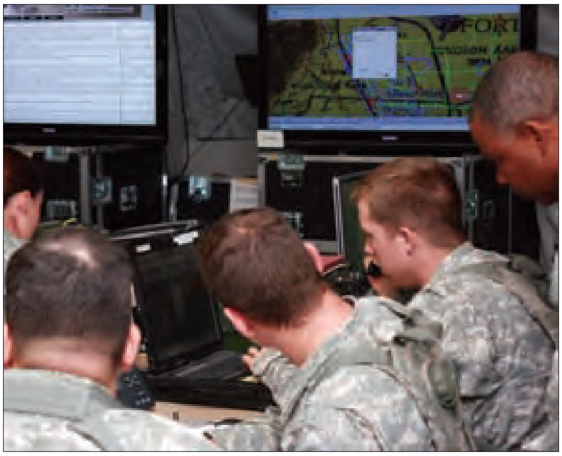
Although space settlement may be technically feasible, it is still economically and politically unlikely in the foreseeable future. (Image produced for NASA by John Frassanito and Associates.)

In the short term, the most significant influences on U.S. national space policy will likely come from responses to recommendations by the Augustine commission, which have had a mixed reception in the public forum. The one consistent theme in the commission's work—that NASA budgets are insufficient to do everything the agency is presently attempting, and only barely enough to do useful parts of it—is right on target. These discussions are of critical interest to the space settlement community: Space infrastructure is an initial condition for establishing space settlements, and decisions made today establish the foundations of tomorrow's space infrastructure.

by **Anita Gale** and **Narayanan Ramachandran**

Weapon system effectiveness

Topics of emerging interest are the network and networks of networks, often falling under the heading of network-centric warfare. Military systems have been developed that handle large amounts of information, and work is ongoing to link these various systems together in a usable fashion. On the positive side, these networks of networks can convey more information at a faster rate than ever before. It is these networks, for example, that enable the significant success of UAVs in the battlefield, from supporting their flights through command and control to distributing the collected information to soldiers. It is the networks that enable requests for battlefield support and calls for air strikes—and that are allowing soldiers to maintain contact with their homes and families during their deployments.



A Battalion Tactical Operations Center relies on constantly updated information. The tactical readouts are vital for today's Army. (Photo courtesy USA.)

There are great hopes for networks of networks and the ability to provide even more information. This year U.S. Army Natick announced its Future Soldier 2030 Initiative, with 25% of the described program goals falling under the headings of "network" and "sensors." In the current theater, pilots are asking for iPhones in the cockpit so that they can be updated continuously regarding developments on the ground to assist in close-in air support. They would like to see what is happening on the ground and have clear identification of targets in dynamic, adverse environments, and these needs for information can only be achieved by having more bandwidth and data handling capabilities. In other words, by having improved networks.

Networks have a number of downsides, however. One is cost. This year, the Future Combat Systems, a system of systems including networks linking vehicles and soldiers together on the battlefield and with command centers in theater and stateside, had its procurement phase canceled by Secretary of Defense Gates due to cost. The follow-on program, Brigade Combat Team Modernization, will hopefully include some of the information technology and network elements, but many of the platforms will no longer be procured in their originally planned design.

Another downside of networks is their vulnerability to either disruption or other forms of breakage. Research is ongoing into the survivability of networks of networks and understanding critical paths and how information crosses networks of networks. Included in these networks are not just the dedicated military hardware but also civilian and commercial networks over which the military passes information. To better understand some of the weaknesses, this year the military held several "day without space" exercises to examine the ability of information to be transferred if the physical networks of certain space assets were no longer effectively passing information.

Given the importance of communications and other information processes typically handled by spacecraft, there are a number of operational thrusts aimed at making these portions of the networks more robust. Operationally Responsive Space (ORS), a joint program office, is coordinating the development of satellites with common spacecraft components that can be quickly assembled and placed in orbit to address specific needs in a very short time.

On May 19 an Orbital Minotaur I rocket launched Tactical Satellite-3 from Wallops Island as part of the ORS initiative. TacSat-3 included a hyperspectral imager, a communications package, and an avionics experiment. Also, work is ongoing looking at blimps, airships, and high-altitude UAVs to act as relays or otherwise replace the information creation and handling roles of various space assets. These platforms will be able to maintain network links in an adverse environment.

Also of concern are direct, intentional electronic attacks on the networks themselves, not just physical attacks on the various nodes. In November 2008 the military restricted the use of thumb drives due to difficulties in ensuring that they were not propagating viruses and worms. Controlling access into a network is one way to prevent cyber attacks, but as the networks become larger and more interlinked other methods are being explored to make network communications more robust and resilient, regardless of the physical means of transference of information. These ideas and programs are aimed at integrating the networks and ensuring their success and thus fall squarely in the vision and areas addressed by weapon system effectiveness.

by **James D. Walker**

Space resource utilization

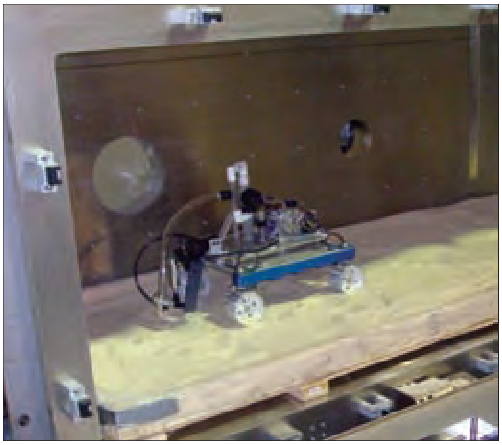
The ability to use local resources will be an enabling technology for future exploration of the Moon and beyond. This year was very exciting and marked important achievements for several lunar resource utilization technologies.

A field demonstration was held at the lunar analog test site on the slopes of Mauna Kea, Hawaii, from November 1 to 16. The test site, operated by PISCES (Pacific International Space Center for Exploration Systems), is located at an elevation of 9,000 ft and serves as a lunar analog in terms of terrain and soil composition. The RESOLVE, ROxygen, and PILOT projects all successfully operated prototype systems during the field demonstration.

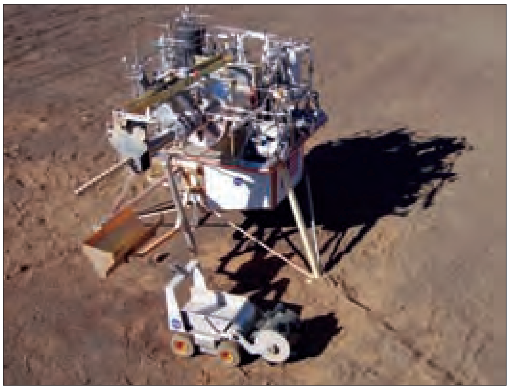
The RESOLVE system combined a rover and a drill to identify and extract water ice and volatile gases such as hydrogen, helium, and nitrogen that may exist in the permanently shadowed craters of the Moon's poles. Equipment from the Northern Centre for Advanced Technology extracted and crushed core drill samples that were then heated in a high-temperature reactor from NASA Glenn. The products released from the samples were analyzed using a gas chromatograph and captured with absorbent beds provided by NASA Kennedy and Johnson. The entire system was mounted aboard a rover built by Carnegie Mellon University. The field demonstration tested the capabilities of all the systems in this lunar prospector in a full end-to-end (roving, drilling, processing) operation.

The ROxygen project conducted by Johnson and Kennedy and the PILOT project from Lockheed Martin both demonstrated prototype systems to extract oxygen from lunar regolith using the hydrogen reduction process at a scale large enough to support a lunar outpost. During the test, Glenn's CRATOS rover was used to collect and deliver soil to the ROxygen system for processing. Lockheed Martin used a bucket drum excavator to collect and deliver soil to the PILOT system for processing. Both projects successfully extracted oxygen from the test site soil.

Two alternative methods to extract oxygen from the lunar regolith were also further developed. ORBITEC demonstrated the first carbothermal reduction of lunar regolith simulant to produce oxygen using direct solar energy. The carbothermal reactor is designed to be operated remotely and is scaled to produce oxygen at a rate of 1 MT/year. Physical Sciences built the hardware to collect and transmit the concentrated solar energy to the reactor through fiber optic cables. The integrated system will be tested at the PISCES lunar analog test site in February 2010.



The Honeybee Robotics/NASA Kennedy pneumatic mining system was tested on a NASA Ames robotic rover in a vacuum chamber with GRC-1 lunar soil simulant.



The PILOT system and the Lockheed Martin bucketwheel excavator were field tested.

Molten Regolith Electrolysis, a joint NASA/ASRC Aerospace/MIT/Ohio State University project, accomplished electrowinning of silica with an inert anode and performed withdrawal of molten ferrosilicon alloy from the reactor.

Five NASA in-situ research utilization projects were awarded reduced gravity aircraft flights under the FAST (Facilitated Access to the Space Environment for Technology Development and Training) program. These projects studied size sorting methods and hopper design assisting regolith flow using a pulsed magnetic field, tribocharged beneficiation of regolith, a pneumatic regolith transport device with electrostatically enhanced cyclone separators, and gas fluidization in a mock reactor. All projects were successfully tested. The data are being analyzed and the results are feeding directly into the next-generation ISRU oxygen production plants.

Honeybee Robotics, partnered with NASA Kennedy, developed pneumatic and percussive approaches to regolith excavation and transport. The pneumatic approach utilizes low-pressure gas to sort and loft regolith particles over long distances, while the percussive approach uses a high-frequency hammer to drive a scoop into regolith or push a dozer blade across the regolith surface. The main advantages of the pneumatic system are its lack of moving parts and high efficiency. The percussive system significantly reduces the excavation force required.

by **Robert Gustafson**

Life sciences and systems

by **Bernadette Luna**
and the **AIAA Life Sciences and Systems Technical Committee**

The life sciences and systems community is conducting numerous aerospace-related efforts, with a major focus on enabling human exploration of space.

At NASA centers across the country, systems needed to maintain breathable air in spacecraft are being developed. Researchers at Johnson have confirmed the functionality of pressure swing amine bed technology intended for Orion, Altair, EVA, and lunar electric rover applications. Complementary development of air revitalization systems for long duration missions is also under way at NASA Ames, where a closed-loop CO_2 removal system is being built incrementally to reduce power associated with water recovery and to integrate CO_2 compression with the CO_2 removal function. NASA Marshall held a loop closure technical interchange meeting, kicking off the effort to "close the air loop" by recovering oxygen from CO_2.

Northrop Grumman is supporting space radiation shielding research critical to vehicle and habitat design as part of mission planning for the Constellation project. Ground-based particle accelerators produce beams of protons and heavier ions characteristic of the most hazardous elements of space radiation. These beams are directed at materials under consideration for use in spacecraft and lunar habitats, including structural applications, dedicated shielding, and lunar soil and regolith. In 2008, researchers measured radiation transport in lunar soil simulants and Apollo samples. Shielding properties of carbon foam and ballistic fiberglass were studied this year.

At NASAJohnson, a simulated crew performs suit loop testing of CAMRAS, an open-loop system for CO_2 removal.

BioServe Space Technologies, a research center at the University of Colorado in Boulder, provided payload support for the ISS National Lab, which was designated under the NASA Authorization Act of 2005. Seven different biotechnology investigations took place this year in BioServe payloads flown on four shuttle flights under the auspices of the National Lab Pathfinder missions. The commercially sponsored experiments focused on vaccine development and control of cellular replication and differentiation processes. The fate of ISS utilization after 2010 remains uncertain; however, NASA and the National Institutes of Health partnered to release a solicitation for proposals aimed at space-based biomedical research on board the ISS.

ORBITEC demonstrated the first carbothermal reduction of lunar regolith simulant to produce oxygen using direct solar energy. The carbothermal reactor, which is designed to be operated remotely, is scaled to produce oxygen at a rate of 1 metric ton a year. Physical Sciences built the hardware to collect the concentrated solar energy and transmit it to the carbothermal reactor through fiber optic cables. The integrated system will be tested at the PISCES (Pacific International Space Center for Exploration Systems) lunar analog test site in February 2010.

This year saw the initiation of two major efforts for evaluation of current national policy. The National Research Council undertook a "Decadal Survey on Biological and Physical Sciences in Space" in response to congressional legislation. The objective of the study is to set clear priorities for microgravity research for the coming decade, incorporating biological, physical, and engineering disciplines to address a wide range of issues in basic and exploration-driven research.

On a broader scale, the Obama administration established a special committee to conduct an independent review of ongoing U.S. human spaceflight plans and programs, as well as alternatives, to ensure that the nation is pursuing a safe, innovative, affordable, and sustainable trajectory for human spaceflight. The life and physical sciences community submitted a public statement to this committee regarding the importance of recreating robust ground and flight programs in biological and physical research.

Space tethers

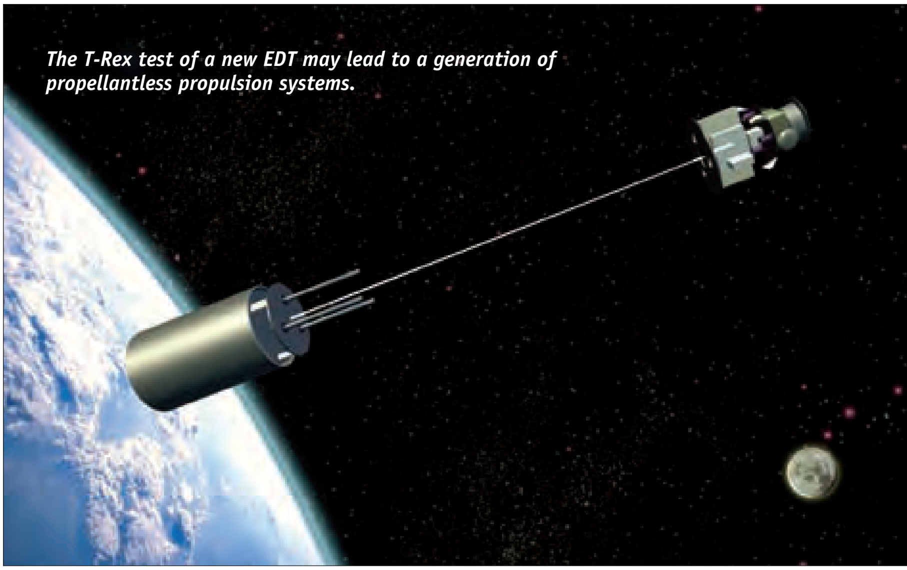
In this past year, the space tethers community has been preparing for several upcoming flight experiments and developing new systems, applications, and technologies.

Early next year, an international team headed by the Kanagawa Institute of Technology/Nihon University, will launch a Japanese Space Tether Experiment called T-Rex (previously Fortissimo) that will be a suborbital test of a new type of electrodynamic tether (EDT) that may lead to a generation of propellantless propulsion systems for LEO spacecraft. T-Rex will launch from Uchinoura, Kagoshima, Japan on an S-520 sounding rocket. During ascent, and above approximately 100 km altitude, the 300-m-long tape tether will be deployed at a rate of approximately 8 m/sec. Once deployed, the tether will serve as an anode, collecting ionospheric electrons that will be expelled into space by a hollow cathode device, thereby completing the circuit and allowing current to flow. The interaction of the tether current with Earth's magnetic field creates a drag propulsive force.

Drag propulsion is also the principle behind the "terminator tape" deorbit module that Tethers Unlimited (TUI) is developing for microsatellites at altitudes above 1,000 km. The module is a "pizza-box"-shaped device that mounts to any face of a satellite. The host spacecraft, once it has completed its mission, will activate the system, which will then deploy a 50-150-m-long conductive tape. The tape significantly increases the aerodynamic drag on the system and also generates passive electrodynamic drag, which deorbits the satellite within 25 years.

The Naval Research Laboratory is also conducting research on spacecraft propulsion using EDTs. NRL has a first flight experiment now in space on board the CP6 CubeSat developed by CalPoly, launched on TacSaT-3 in May. NRL's experiment will demonstrate and evaluate techniques for collection and emission of electrons in Earth's plasma. Planned for flight in 2012, the next experiment being developed at NRL is the use of CubeSats as the end masses for a complete 1-km-long EDT system.

AFOSR has funded a team from Penn State, University of Michigan, and TUI to examine the use of EDTs for energy harvesting on spacecraft. The goal is to develop a better understanding of the power generation capabilities of EDT systems on various scales, and to develop system concepts, key elements, and technology road maps for their use.



The T-Rex test of a new EDT may lead to a generation of propellantless propulsion systems.

A student team from the University of Glasgow in Scotland and the KTH Royal Institute of Technology in Sweden are designing and constructing a tether-based space web structure. The system consists of a central hub that deploys and stabilizes the web, a specially designed reaction wheel with full control, and four daughter units at the web corners providing web tension and containing inertial measurement units for measuring the system's forces acting during deployment and stabilization. The structure will be launched on a REXUS sounding rocket from Esrange, Kiruna, Sweden in early 2010.

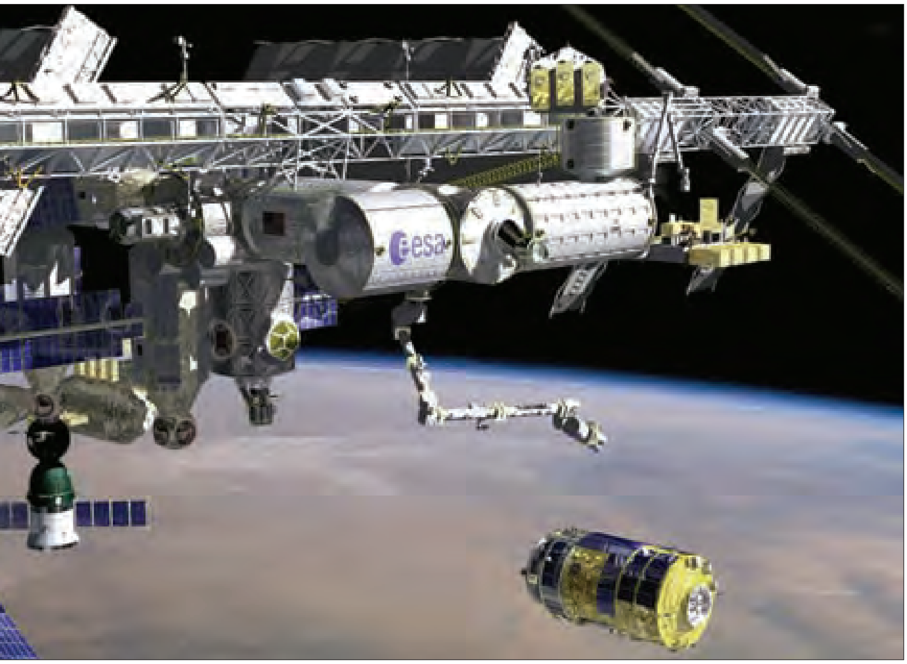
Through proof-of-concept studies and initial experiments, the Jet Propulsion Laboratory has been investigating tethered systems that deploy an end-effector tens to hundreds of meters from a spacecraft, collect a few kilograms of asteroidal regolith, and return the sample to the spacecraft. Utilizing shape memory alloys allows controlled small-body sampling at a much longer distance with lower risk to the spacecraft and longer sampling durations than are possible with existing articulated arms and booms.

North Carolina State University is designing a tether-ballast system for diverting the trajectory of potentially hazardous asteroids (PHAs). By using detailed dynamic computer models, they have determined parametrically the tether length and ballast mass necessary to divert the asteroids currently cataloged in NASA's PHA database. The system works by changing the location of the center of mass of the system and changing the asteroid's trajectory to a non-Keplerian orbit.

by **Sven G. Bilén** and the **AIAA Space Tethers Technical Committee**

Space logistics

This year the most complex space logistics project ever conceived continued to unfold before our eyes. Assembly of the ISS is nearing its 2010 completion date after a multidecadal international design and construction effort. Maintaining this human outpost in a healthy and productive state is an unprecedented logistics challenge. Coordinating flight schedules, cargo manifests, docking port availability, and reverse logistics is an enormous task for NASA and its international partners. Maintaining a robust set of spares and high closure rates for consumables is also a major challenge.



HTV performed its first successful berthing at the ISS on September 17. (Photo courtesy JAXA.)

With just six space shuttle missions remaining and six crew members permanently living on the ISS, excitement is mounting for the maiden flights of the "visiting vehicles" that will soon carry most of the U.S. and international cargo to the station. These vehicles include the Japanese H-II transfer vehicle (HTV), SpaceX's Dragon, and Orbital Sciences' Cygnus. HTV executed its first successful berthing on September 17.

On its first mission, the HTV transported nearly 6,000 kg of supplies to the ISS. Up to 4,500 kg of this was pressurized cargo; the remainder was unpressurized external cargo removable by the ISS robotic arm. HTV will stay berthed at ISS for up to 45 days; undocking ocurred as scheduled on November 1. HTV will undock from ISS with as much as 6,000 kg of waste cargo to be burned up during reentry. The next of the new cargo vehicles scheduled to fly to ISS, the SpaceX Dragon, has three demonstration missions scheduled for 2010. The third mission will be a full ISS rendezvous, berthing, cargo delivery, and return mission. The third new craft slated to fly to the station is Orbital Sciences' Cygnus cargo vehicle. Its demonstration mission to rendezvous, berth, and deliver cargo to ISS is currently scheduled for early 2011.

The high resupply demand associated with maintaining six full-time crewmembers on the ISS means these vehicles, in addition to the Russian Progress and the European ATV, are critical to the success of the ISS beyond 2010.

Much work and logistics research are under way in other areas of the space enterprise. The NASA Constellation program is continuing the process of creating detailed plans for the development of Orion and Ares systems as well as lunar surface systems and a lunar outpost, potentially beginning in 2020. This effort includes the definition of an ILS (integrated logistics system) to populate a single system with data that identifies the entire transportation, habitation, and mobility system. This includes estimates of reliability and maintainability for use in spares and support equipment projections, and time-based data for provisioning planning and consumables management.

On the research front, progress continues in the area of space exploration campaign modeling, with a number of software tools such as CMAT (NASA Langley) and SpaceNet (MIT/JPL) maturing rapidly. Commercial logistics services in Earth orbit and beyond continue to attract interest and draw increasing levels of investment. These activities range from resupply services for cargo to the ISS and potential extension to shuttle services for human crews, to the establishment of fuel depots in Earth orbit, to futuristic plans for resource mining of the Moon and other locations.

The Air Force and other military services continue to invest in space-related assets and capabilities, with logistics (including supportability) over the life cycle playing a major role. Among the areas of particular interest to DOD is the development of a partially reusable launch vehicle as part of an operationally responsive space capability. Researchers at the Air Force Institute of Technology and the Air Force Research Laboratory have made significant progress in simulating flight performance and integrated ground operations, including manpower requirements.

by **Olivier de Weck**

Space systems

In an otherwise tumultuous year of financial crises, space systems quietly provided enabling capabilities to ensure mission success on hundreds of platforms throughout the solar system. As the economic downturn of the last year forced many to downsize where possible, it seemed appropriate to highlight some "downsized" advances in space systems that offer huge "upsize" capabilities.

Demonstrating low-cost satellite design and operations, the Aprizesat-3 and Aprizesat-4 microsatellites, built by SpaceQuest, Fairfax, Va., were launched in July. SpaceQuest built, tested, and delivered the 25-lb, 10-in.-cube satellites in only 10 months for Aprize Satellite, a provider of low-cost wireless services for worldwide asset tracking and data monitoring.

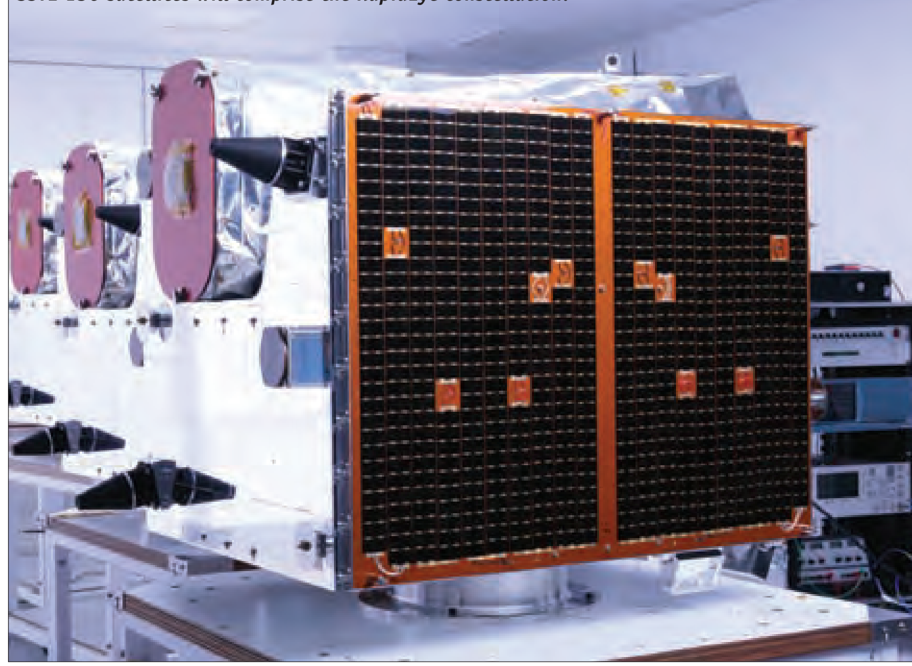
Aprize will offer low-cost satellite data services such as monitoring the fuel level of propane tanks, mobile tracking of shipping containers and rail cars, and space-based automatic identification system (AIS) data services to the global maritime community. The AIS signal decoder operates in real time, in contrast to more costly large satellite systems that require the download of digitized AIS data files that must be postprocessed to recover the user data. Both satellites were commissioned autonomously on first orbit and commenced global AIS operations on the second orbit.

In August 2008 the commercial five-satellite RapidEye constellation was launched, providing multispectral imagery at 6.5-m resolution. The cost of the complete constellation with a "daily imaging" capability is considerably less than that of a single U.S. Landsat satellite. All five satellites were developed by Surrey Satellite Technology, U.K.

To achieve high performance at low cost, the Surrey team leveraged commercial electronics along with materials science such as carbon fiber and silicon carbide structures. In addition, the use of a novel optical design reduced the size and mass of the payload. Use of better detectors on the focal plane incorporating programmable time delay and integration allowed the use of smaller apertures.

Armadillo Aerospace completed the two successful flight tests with their SCORPIUS vehicle in September, using PRESSUREMAXX helium tanks. Scorpius Space Launch of Hawthorn, Calif., sponsored the Armadillo Team in its quest for the Lunar Lander Challenge prize and provided all-composite tanks that enabled them to achieve a factor of two mass reduction. PRESSUREMAXX technology was given the Award for Excellence and Innovation in Composites Engineering by the American Composites Manufacturers Association.

SSTL-150 satellites will comprise the RapidEye constellation.



Developed in cooperation with Microcosm, the technology employs a monolithic linerless unibody construction offering superior performance and significant weight reduction compared to conventional carbon-fiber-overwrapped metal tanks, achieving an unmatched performance index of more than 2,000,000 in.

The Operationally Responsive Space (ORS) Office located at Kirtland AFB is leveraging these types of space system technologies in an effort to corral costs of DOD space systems and shorten their development cycle times to the "speed of need." Established in May 2007, the ORS Office is taking a new approach to risk and mission assurance to rapidly deploy affordable capabilities that are "good enough" to satisfy warfighter needs.

One significant milestone in this daunting effort was the successful launch of the TacSat-3 spacecraft on a Minotaur-I rocket from Wallops Island in May. This small satellite carried a Raytheon-built hyperspectral sensor and a panchromatic imager developed by the Air Force Research Lab. Currently, the ORS Office is collaborating with the AFRL. The Space Development & Test Wing located at Kirtland is operating the TacSat-3 spacecraft while assessing its utility to support combatant commanders.

by **Jerry Jon Sellers**

Space transportation

The global launch community continued to see high success rates.

The space shuttle's STS-119 mission delivered the final set of solar arrays to the international space station. This completes the ISS's solar power system, which will support the station's expanded crew of six. The STS-125 crew made repairs and upgrades to the Hubble telescope. Hubble is now capable of at least five or more years of research. STS-127 installed the JAXA Kibo laboratory complex at the station. STS-128 will carry the Leonardo supply module to ISS, with science and storage racks, a research sample freezer, a new sleeping compartment, and the Colbert treadmill. STS-129 will deliver the first two Express logistics carriers with an array of spare parts.

A United Launch Alliance Atlas V rocket blasted off with NASA's LRO/LCROSS mission from Cape Canaveral Air Force Station, Fla., on June 18. (Photo courtesy ULA/Pat Corkery.)

Shuttle launch pad 39B was turned over to the Constellation program in June. Initial development testing of the new five-segment booster was conducted in September, confirming performance predictions. The Orion crew module passed its preliminary design review. The Ares I-X was moved to the launch pad and was launched on October 28.

The Human Space Flight Plans Committee, led by Norm Augustine, conducted an independent review of ongoing U.S. human spaceflight plans and programs, as well as alternatives. The committee's final report was released on October 22. Key alternatives include, in part: fund shuttle through 2011, when the current manifest will be completed; possibly extend the shuttle to close the human spaceflight gap; or focus on technology plus heavy-lift launch capability. It endorsed commercial crew launch to LEO.

As of September 14, United Launch Alliance had conducted 12 successful launches this year with its Delta II (7), Delta IV (2), and Atlas V (3) rocket systems. Up to 4 missions remain before the end of the year. Notable missions include the final Air Force Delta II flight, launching the GPS IIR-21 satellite; launch of the Lunar Reconnaissance Orbiter/LCROSS by an Atlas V; and launch of the Delta IV Heavy carrying a national security payload.

SpaceX's second successful launch of its Falcon 1 rocket orbited Malaysia's RazakSAT satellite. Falcon 1 is the first all-liquid-fuel commercial vehicle to reach orbit.

In international news, the Ariane V has delivered two astronomical satellites to the L2 Lagrange point, the largest telecommunication satellite (the 6.9-ton TerreStar-1) to a geostationary orbit, and six other communications satellites. Two more launches are scheduled by year's end.

The first Soyuz flight from the Kourou launch site is planned for early 2010. This version of the Soyuz was flight-qualified in Russia in 2008, while the new, smaller Vega launcher completed its third- and fourth-stage ground qualification tests in 2009.

Japan has ground qualified the dual H-IIB LE7 first stage engines. The H-IIB will be used to launch the HTV automatic servicing module to the ISS in September.

NASA announced a plan to invest stimulus funding in the commercial sector toward development of human orbital spaceflight capability. These competitively awarded/funded agreements would be for commercial crew concepts.

WhiteKnightTwo, the carrier aircraft for Virgin Galactic's SpaceShipTwo, made its flying debut for the general public at the annual EAA Oshkosh air show. The eight-seat SpaceShipTwo is expected to roll by year's end.

XCOR has finished a series of wind tunnel tests of the aerodynamic design of its Lynx suborbital launch vehicle. The Armadillo Aerospace Super Mod successfully completed Level 2 of the Northrop Grumman Lunar Lander Challenge, qualifying for the $1-million first prize.

by **Carl Ehrlich** and the **AIAA Space Transportation Technical Committee**

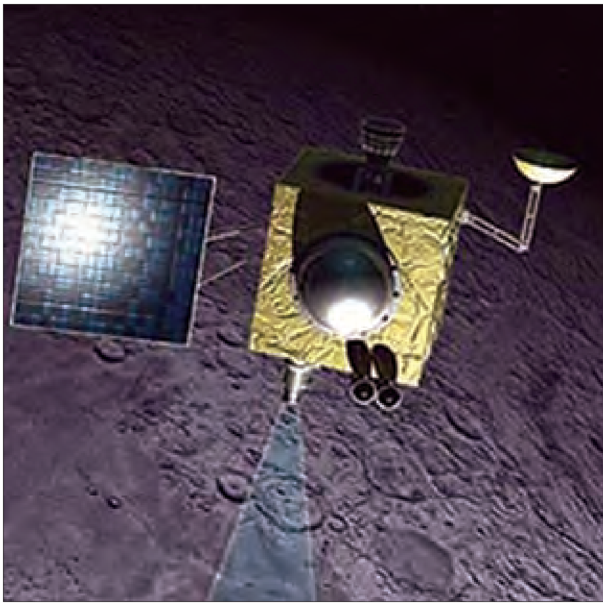
Space operations and support

This year the increasing number of countries making space operations headlines demonstrated clearly that the world now has more than just a handful of spacefaring nations. The greatest number of firsts occurred in the area of satellite launch capability: In February Iran was added to the list of countries confirmed to have this capability; it launched its Omid satellite in April. North Korea's discounted claim to its first successful satellite launch was the most serious attempt to date by that country's regime to perform such a test. Although their spacecraft failed to reach a stable orbit due to a fairing separation malfunction, South Korea joined the list of countries with launch capability, sending its KSLV-1 aloft in August. Asia saw other significant space activity as well, with China's successful launch of its second geostationary navigation satellite and a remote sensing spacecraft; ISRO's successes with radar imaging RISAT-2 and student-built ANUSAT in April; and Malaysia's RazakSAT launch in July, marking the fifth SpaceX Falcon 1 launch and Malaysia's second launch this year, following MEASAT in June.

With more nations participating in the space adventure, and more satellites with no or limited maneuver capability, there is also a growing need to address the issue of safe control and disposal of space assets at the end of their operational life. One incident in particular again highlighted the issue of space debris and the vulnerability of critical orbits to such events, namely, the unprecedented February collision of Kosmos-2251 with Iridium-33, adding a significant debris cloud across low Earth orbits. The event itself called attention to the deficiencies in the world's tracking and reporting mechanisms for space.

NASA's Lunar Reconnaissance Orbiter (LRO) and Lunar Crater Observation and Sensing Satellite (LCROSS) were launched in June on a mission critical to future human lunar operations: the search for lunar water. The LCROSS part of the mission centered on its Centaur upper stage crashing into the Cabeus crater to create a plume through which it could pass to take in-situ measurements. The plume was considerably smaller than predicted—a possible clue to its properties—but LCROSS successfully collected data looking for water.

In August, LRO and India's Chandrayaan-1 flight operations teams attempted to coordinate their respective spacecraft for a radar experiment that could have taken advantage of the unique, bistatic radar response of water ice. The effort was an attempt to increase the chances of detecting the substance on the Moon's polar caps. However, the two spacecraft could not reach the needed alignment, and the experiment failed. One week later the Chandrayaan-1 failed completely because of overheating. Hope for finding water on the Moon, which will represent a quantum leap forward toward a human outpost and eventual settlement, now rests with these three spacecraft. The LRO radar mission is ongoing and continues its search. Post-mortem analysis of Chandrayaan-1 radar data is ongoing. All nine instruments aboard LCROSS successfully captured each phase of the impact sequence, and analysis of its data may yet uncover the signature of water.



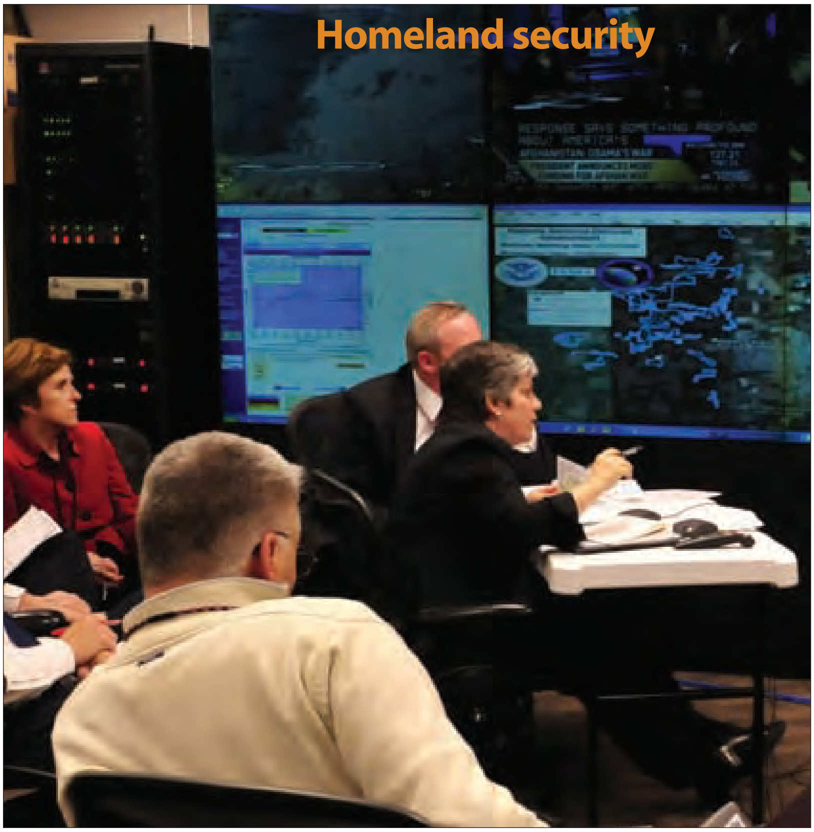
Flight operations teams for LRO and Chandrayaan-1 attempted to coordinate their spacecraft for a bistatic radar experiment to detect water ice on the Moon's polar caps.

Several events that occurred this year, taken collectively, could be seen as the sign of a space industrial revolution. In June, Spaceport America broke ground in Upham, N.M., soon to be home of Virgin Galactic. SpaceX announced the formation of a new Astronaut Safety and Mission Assurance Dept., with former NASA astronaut Ken Bowersox as vice president. The third commercial astronaut corps, after Scaled Composites and Virgin Galactic, was formed this year. Two commercial space operations companies, Galactic Suite (GS) and Excalibur Almaz (EA), announced their intent to offer on-orbit destinations for private space travel. (EA's impressive leadership includes Walter Cunningham of Apollo 7, Leroy Chiao of ISS Expedition 10, and Vladimir Titov, as well as several alliances with space contractors such as United Space Alliance. Both GS and EA are well positioned to make good on their offers.)

In addition, NASA's Commercial Crew Development contract was awarded. Finally, the Augustine committee has among its options that of pumping $2.5 billion into commercial human transport, and turning the ISS over to a private contractor. These events could well mark a new paradigm for commercial human spaceflight.

by **J. Paul Douglas** and **Franz Newland**

Homeland security



On March 27, 2009, Thomas Muir briefed DHS Secretary Napolitano about the flooding in North Dakota and Minnesota at the National Operations Center. (DHS Photo/Barry Bahler.)

The Dept. of Homeland Security (DHS), with its prevention and response goals, continues its aggressive pursuit of the tools it needs to meet these responsibilities. From geospatial to man-portable air defense systems to critical infrastructure risk assessments, DHS is leaning hard within the aerospace domain to equip its fledgling agency with both the understanding and the technology it needs to fulfill its mission. The quest spans the spectrum of academia, DOD, and the public sector contractors for these needs. DHS needs extend far beyond aerospace, requiring flexible teaming among aerospace, systems, maritime, and communications experts.

To support the component agencies within DHS, providing technology solutions to meet these complex needs, DHS has established the DHS Directorate of Science and Technology (DHS S&T). The directorate is organized under three directors and six division heads. The director of research oversees long-term research needs to support DHS mission areas that will provide the nation with an enduring capability in homeland security. The research portfolio includes the Office of National Labs, the Office of University Programs, and the Program Executive Office—Counter Improvised Explosives Devices.

The director of innovation is responsible for putting advanced capabilities into the hands of DHS agencies/operators via the Homeland Security Advanced Research Projects Agency, which concentrates on homeland security research and development that could lead to significant technology breakthroughs and greatly enhance departmental operations. Within the innovation portfolio is the Small Business Innovation Research Office and Homeworks.

Finally, the director of transition focuses on delivering capabilities that department components and first responders can rely on to meet their operational needs. The transition portfolio includes the Commercialization Office, Tech Clearinghouse, and the Safety Act Office.

Among the six divisions, five apply directly to aerospace. The Borders and Maritime Security Division develops and transitions tools and technologies for the largest civilian air force in the world. The Command, Control, and Interoperability Division concerns itself with interoperable communication for operators, transmission and control of images and data from air- and space-based platforms, and automated capabilities to recognize and analyze potential threats. The Explosives Division develops the technical capabilities to detect, interdict, and lessen the impacts of non-nuclear explosives used in terrorist attacks against mass transit, civil aviation, and critical infrastructure.

The Human Factors Behavioral Sciences Division applies the social and behavioral sciences to improve detection, analysis, and understanding and response to homeland security threats. The Infrastructure and Geophysical Division focuses on identifying and mitigating the vulnerabilities of the 17 critical infrastructure assets that keep our society and economy functioning, including our air transportation and shipping infrastructure.

Besides the directors and divisions, additional DHS S&T offices dealing with aerospace include the Homeland Security Institute, Interagency Programs, International Programs, Operations Analysis, Special Programs, Test & Evaluation, and Standards.

Within the new administration and DHS leadership, one primary focus is mission integration. This focus is of utmost importance in order to draw together the various agencies and technologies/capabilities that must work together when responding to crises/emergencies. These interagency imperatives contribute strongly to integration efforts.

by the **AIAA Homeland Security Program Committee**

Space station

The past year has seen tremendous achievements and progress in the capability, function, and use of the ISS. There is now less than one year remaining before assembly is complete and full utilization begins. The ISS is a collaborative international space venture that includes partnerships between NASA, the Canadian Space Agency, ESA, Roscosmos (Russian Space Agency), and JAXA (Japan Aerospace Exploration Agency). These partners have been responsible for the assembly that has taken place in space for the past 11 years. Besides demonstrating long-term multinational collaboration and commitment to building the largest and most complex occupied space station to date, the ISS is a laboratory that allows for expanding knowledge of how the space environment affects biological and physical systems, and for testing the tools needed to expand human exploration and settlement of space.

In 2008 the addition of ESA's Columbus and JAXA's Kibo scientific modules to the U.S. Destiny and Russian segment modules tripled the station's laboratory space and research facilities. NASA is currently working on launching and installing the remaining major research facilities that will be housed in the Destiny, Columbus, and Kibo modules. These facilities will include physical sciences hardware for combustion, fluid physics, and materials science research, as well as additional multipurpose and supporting infrastructure. The ISS also had its crew size doubled to six members in May. These changes are already contributing to a major increase in the number of research experiments conducted on the station. From September 2000 through April of this year (Expedition 18), more than 400 investigations have taken place on the ISS, with participation by more than 600 scientists from nations across the world.

ISS science and technology facilities are designed to accommodate a broad range of experiments, from cell biology to human physiology to materials and physical science studies, as well as tests of technologies and systems support for human exploration.

Among the most exciting biological results reported from ISS research is the confirmation that common pathogens change and become more virulent during spaceflight. The space environment has been shown to induce key changes in microbial cells that play a direct role in infectious disease, including alterations of microbial growth rates, antibiotic resistance, microbial invasion of host tissue, organism virulence (the relative ability of a microbe to cause disease), and genetic changes within the microbe. Understanding how the space environment affects microorganisms is critically important for understanding the risks they pose for future spaceflight missions.

During ISS Increments 18, 19, and 20, numerous physical and life sciences experiments have taken place. The major NASA-developed physical science facilities, namely the combustion integrated rack, the fluids integrated rack, and the materials science research rack, now are also installed on the ISS. These facilities will enable the conduct of significant experiments for the life of the station.

Astronaut Michael Barratt tends to science hardware in the U.S. Laboratory. (NASA photo.)

The ISS also promotes the commercialization of space through programs such as NASA's COTS (commercial orbital transportation services) and the U.S. ISS National Laboratory designation. As the era of the space shuttle comes to an end, commercial resupply vehicles will be key to the launch and return of samples from this unique laboratory. Although constraints on up-mass to orbit and crew availability on the station have limited the scope of research during assembly, the science return to date provides strong evidence for the high potential of ISS science return after assembly is complete.

by **Jacob Cohen**, **Julie Robinson**, and the **AIAA Microgravity and Space Processes Technical Committee**

Energy optimized aircraft and equipment systems

The Boeing 787, with its bleedless architecture, is evidence of the reality of the more-electric aircraft.

The search for aircraft with better efficiencies has never been more vital than it is today as fuel prices rise and environmental constraints tighten. That search for efficiency has led aircraft manufacturers and their suppliers to reconsider traditional systems architectures and seek alternative equipment technologies.

Hybrid hydraulic/pneumatic/mechanical/electrical energy architectures are deeply entrenched in today's aircraft designs. This traditional approach is nearly tapped out, making it increasingly difficult to improve capacity and efficiency. "More-electric" technologies, on the other hand, have the potential to be more efficient due to fewer losses, being "on-demand" in nature, and more dependable since they are easier to maintain. It is important to note that more-electric technologies and architectures continue to evolve and show potential, although not yet achieved, platform benefits for modern highly integrated platforms that conventional/mature methods cannot offer.

More-electric equipment systems are already in use for aircraft flying today. The Airbus A380, for example, includes electrohydrostatic flight control actuators, powered and controlled electrically with only local hydraulics, as well as electromechanical actuation of its thrust reverser. But this consists of no more than a conventional aircraft equipment system layout with a few hydraulic users replaced by electrical ones. Indeed, the conclusions reached by the Power Optimised Aircraft project, sponsored under the 5th EU Framework Programme that concluded in 2006, indicate that within conventional architectures, electric technologies yield only a fraction of potential benefit, and functional thinking is needed for true integration.

The need for integration and the importance of architectural choices were highlighted again this year during the TEOS III (technologies for energy optimized aircraft equipment systems) Forum and the MOET (more open electrical technologies) Project Consortium meeting, both held in Barcelona this September. The TEOS Forum included a presentation from the USAF regarding its INVENT (integrated vehicle energy technology) Program, which seeks to enable an energy optimized aircraft in the short term and revolutionary more electric aircraft in the future.

INVENT seeks to accomplish this by focusing on five main areas of research:

- High-performance electric actuation systems to ensure fault resistance and an appropriate treatment and eventual reuse of regenerative power.
- Robust electrical power systems less sensitive to external conditions and power quality issues.
- Adaptive power and thermal management taking advantage of the potential versatility of electrical systems.
- Smart integration of these aircraft subsystems with advanced propulsion systems.
- Integrated modeling and simulation environment with hardware in the loop.

The integration approach using both modeling and simulation and hardware test facilities was echoed by the MOET Project consortium sponsored by the EU under the 6th Framework Programme and including over 62 industrial and research partners. While much of the project was dedicated to the exploration of enabling technologies, cross-cutting working groups were also organized to consider system architectures and modeling and simulation concerns. Two integration test rigs were built as part of the project: one for larger aircraft at Airbus that "powered on" in March, and one for smaller aircraft at Alenia.

The preliminary conclusions from the MOET Project, which will end this year, highlight the criticality of architectural choices in intermediate hybrid more-electric solutions, and the need for further technological development in the weight and thermal efficiency of system components.

The MOET conclusions see the all-electric aircraft as a relevant long-term trend, especially in light of tightening environmental regulations. For now, more-electric aircraft are indeed a reality, with the F-35 JSF currently undergoing flight test, and the Boeing 787 with its bleedless architecture scheduled to fly by the end of the year.

by **Elena Garcia**

Unmanned systems

The exploitation of unmanned air systems (UAS) in military operations abroad, especially in southwest Asia, continued to expand, as did reliance on these systems for intelligence, reconnaissance, and surveillance (ISR) information. Global Hawk, the premier unmanned ISR platform, surpassed a milestone of 25,000 flight hours.

At home, access to the National Airspace System (NAS) remains the major challenge for the development of a viable "beyond-military" UAS market in the U.S. This year saw an increasing emphasis on addressing the integration of nonmilitary UAS operations into the NAS. For small UAS, this was highlighted with the FAA Small Unmanned Aircraft System Aviation Rulemaking Committee recommendations for the operation of civil (commercial) unmanned aircraft with gross takeoff weight of 55 lb or less. FAA anticipates that the recommendations will provide a framework for regulatory changes that enable the safe operations of unmanned aircraft in the national airspace.

FAA and AAI announced a cooperative research and development agreement for a simulation test bed that will include AAI's Shadow with a GE Aviation advanced flight management system to simulate the interactions of manned and unmanned aircraft in the NAS.

After last year's purchase of ScanEagle manufacturer Insitu, Boeing Integrated Defense Systems announced its new Unmanned Airborne Systems Division. The acquisition of small UAS manufacturer Advanced Ceramics Research (ACR) by BAE Systems continued this trend of acquisition of successful small UAS manufacturers by large airframe and systems companies. ACR manufactured three small unmanned aircraft systems for military and civilian agency customers—the gas/electric Silver Fox, the gas-powered Manta, and the Coyote, an electric mini aircraft designed to be deployed from a sonobuoy tube or from a helicopter in flight.

The U.S. Customs and Border Protection (CBP) Unmanned Aircraft Operations Center of North Dakota officially opened in February in Grand Forks. Predator B UAS continue to operate from this center to conduct patrols along the Canadian border. The arrival of a CBP Predator B at the Oshkosh air show this year marked the first time a UAS of this type had been flown to a nonmilitary air show, possibly a bellwether for the operation of civilian UAS in the NAS. Predator B manufacturer General Atomics rolled out the Predator C Avenger, the company's first turbofan-powered unmanned aircraft.

The Air Force presented its Unmanned Aircraft Systems Flight Plan, which lays out a roadmap to the year 2047, the 100th anniversary of the Air Force, while the second edition of the DOD 2009-2034 Unmanned Systems Integrated Roadmap "…represents the department's first truly synchronized effort that increases the focus on unmanned systems, and through interoperability with manned systems, establishes a vision of support of our warfighters."

As an example of efforts to coordinate UAS development for the armed forces, the Navy reportedly announced that it will award a sole-source contract to Northrop Grumman for the development of a sense-and-avoid capability with a common autonomous system for its high-altitude, long-endurance Air Force RQ-4B Global Hawk and the Navy derivative, the RQ-4N Broad Area Maritime Surveillance aircraft.

The Predator B that flew at the Oshkosh air show this year was the first UAS of this type to be flown to a nonmilitary air show.

After receiving two Global Hawks, NASA, in partnership with NOAA, unveiled the first of these systems to be transitioned to nonmilitary use, with initial flights over the Pacific now planned for next year. On the opposite end of the size scale, after demonstrating its hurricane penetration capabilities that included probing of the eyewall of Hurricane Noel in 2007, AAI announced a blanket purchase agreement with NASA to provide aerosonde systems and crews for time-sensitive missions.

by the **AIAA Unmanned Systems Program Committee**

Air traffic management

by **Frank L. Frisbie**

The Next Generation Air Transportation System (NextGen) and Single European Sky ATM Research (SESAR) continue to dominate the air traffic management landscape. The technologies—satellite navigation, dependent surveillance, digital communications, and netcentric operations—are the focus of the industry and of the academic communities concerned with air transportation. The U.S. deployment of ADS-B (Automatic Dependent Surveillance-Broadcast) is well under way, with the immediate prospect of lower altitude surveillance coverage of equipped aircraft over the Gulf of Mexico and the Rocky Mountain west.

In the cockpit display for the Traffic Information Service-Broadcast in the Anchorage Bowl area, round nosed targets are radar targets, arrow nosed targets are ADS-B equipped aircraft.

Less promising is the issue of broad user equipage that requires aircraft operators to make the investment in money and down time to fit their airframes with NextGen avionics and to train pilots/crews in the operation. This hesitancy is not restricted to general aviation but is also manifest in the behavior of commercial carriers and the military, for whom the business case has not yet proved persuasive. Thus there appears to be growing recognition that some form of rule making will be needed to accelerate compliance.

Another challenge to the world's aircraft navigation service providers (ANSPs) is the proliferation of unmanned aircraft systems (UAS) of all shapes and sizes. Spurred by their utility for military uses, these vehicles are now being proposed for missions in the civil arena. Generally the proposed uses are for missions that would be risky or boring for human pilots: fire fighting, pipeline surveillance, border patrol, volcano monitoring. With safeguards, the latter applications can be viewed as nonintrusive by civil aviation authorities because they would take place where other flights either would not operate or where the activity of manned aircraft operations is very low. However, there is growing recognition that UAS have commercial potential for high-value or urgent cargos.

The net result of all of this activity is that the FAA and ANSPs around the world face the prospect of UAS flights sharing the airspace with planes whose pilots are on board. This is a technical challenge in that, to be fully integrated, the UAS must be able to "see and avoid" other traffic and to collaborate with air traffic control. More significant, however, is the psychological barrier to making concessions to technology in an area where the human pilot has always had the preeminent role.

On the safety front, several commercial accidents—most notably the miracle landing in the Hudson River off Manhattan—have raised concerns about safety issues. In the US Airways crash, birds were ingested by the engines on takeoff, causing the loss of power and subsequent controlled water landing. The issues raised ranged from bird control at airports to operational control and emergency procedures in the metroplex area.

Other accidents raised concerns over automation complexity and pilot proficiency. The common concern is to question our ability to foresee problems and take effective action before an adverse event. These issues will only become more relevant as NextGen and SESAR bring into reality the system of systems era, where ground and airborne automation are closely linked to achieve capacity improvements.

Hypersonic technologies and aerospace plane

Plans for four Air Force/DARPA X-51A flight tests are under way. Each X-51A vehicle is built and mated with a flow-through interstage and a modified ATACMS booster. The X51-A stack has been ground tested, and its compatibility with a B-52H is being checked. The first captive flight on the B-52H over the Edwards AFB flight range and a dress rehearsal flight over the Pacific were planned for this fall, before the X-51A's first powered flight.

The DARPA/Air Force Falcon hypersonic technology vehicle (HTV-2) program has developed several key technologies: efficient aerodynamic shaping for a high lift-to-drag ratio; lightweight and durable high-temperature materials; thermal management techniques; and advanced autonomous navigation, guidance, and control. These technologies will be demonstrated and evaluated with two HTV-2 vehicle hypersonic flight tests. After overcoming numerous challenges in the process of fabricating the HTV-2 aeroshells, the first one was completed, for first flight before the end of this year.

The DARPA FaCET (Falcon combined cycle engine technology) program developed and ground-demonstrated elements of a turbine-based combined cycle (TBCC) propulsion system. The freejet engine ground test used an approximately 70%-scale propulsion system model. Freejet engine tests were completed first at Mach 3, 4, and 6. Preliminary test results at Mach 4 indicated that the overall measured engine performance matched pretest predictions.

DARPA's MoTr (mode transition) demonstration program is for ground testing a TBCC propulsion system. MoTr will demonstrate transition from low-speed turbojets to high-speed scramjets in a single flowpath.

MoTr takes advantage of the single TBCC flowpath developed under FaCET and high-Mach turbine engines from the HiSTED (high-speed turbine engine demonstration) programs. A facility survey was completed, and the Propulsion Systems Laboratory at NASA Glenn was selected. Modifications needed to execute the ground demonstration were identified. The program conceptual design review was completed successfully.

DARPA's Vulcan program is changing direction radically for the demonstration of a TBCC propulsion system. In Phase 1, design reviews were successfully completed to enable hypersonic aircraft with a TBCC engine, consisting of a constant-volume combustion (CVC) engine and an aviation turbine engine. Based on compelling outcome from a business-case analysis, Phases 2 and 3 of the program will focus on demonstrating a TBCC system consisting of a CVC combustor and a marine turbine engine. This system is expected to cut specific fuel consumption significantly and generate additional electrical power for Navy ships.

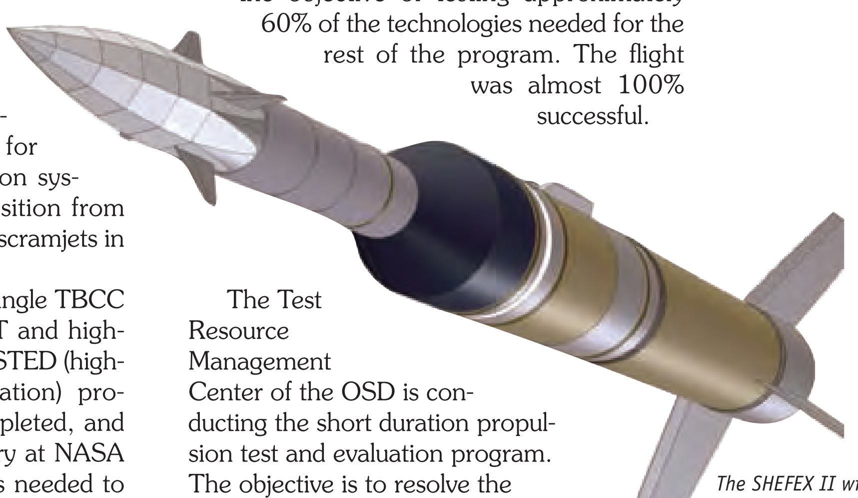
The X-51A stack is mated to a B-52H with a JDAM interface.

The European Commission is pursuing LAPCAT II to develop and validate engine-airframe integration and cycle analysis tools, to experimentally evaluate the design, and to study off-design performance of engine and airframe.

SHEFEX (sharp edge flight experiment) II represents DLR's next step toward development of technology for atmospheric entry and hypersonic flight. The critical design review was finalized for all subsystems. The flight test is planned at Woomera in Australia.

MBDA and Rosoboronexport signed a contract to flight test the LEA hypersonic experimental vehicle, jointly developed by MBDA and ONERA. The test will use an existing Russian supersonic bomber, liquid rocket booster, and test range.

A total of nine flights are planned under the joint Australian DSTO and USAFRL HIFiRE (hypersonic international flight research experimentation) program. The first, HIFiRE 0, flew at Woomera in Australia, with the objective of testing approximately 60% of the technologies needed for the rest of the program. The flight was almost 100% successful.



The SHEFEX II will perform a controlled hypersonic flight up to a Mach number of 11.

The Test Resource Management Center of the OSD is conducting the short duration propulsion test and evaluation program. The objective is to resolve the consequence of the duration of the test flow and the effects of the test medium on dual-mode scramjet engine performance. The program will use numerous facilities to address this objective.

by **Unmeel Mehta**

Out of the

25 Years Ago, December 1984

Dec. 13 Piloted by Chuck Sewell, the experimental forward-swept-wing Grumman X-29 flies for the first time, from Edwards AFB, Calif. The inherently unstable aircraft features digital fly-by-wire controls and the unique wing to test the validity of the forward-swept-wing concept for highly maneuverable combat aircraft. Use of such wings was not possible before the advent of extremely stiff graphite composite structures, because conventional metal structures would deflect too much. The aircraft is essentially a Northrop F-5 fighter with the new wings and flight control system installed. The test program is successful, although the design is not adopted. NASA, *Astronautics and Aeronautics 1979-84*, p. 522.

Dec. 15 The USSR launches Vega 1 in a heliocentric orbit toward Venus. The craft is also to perform a flyby mission to observe Halley's comet using a scanner. Upon encountering Venus, Vega's aeroshell opens and releases a lander, while a French-built balloon carrying an instrumented probe transmits meteorological and other atmospheric data back to Earth. *NASA, Astronautics and Aeronautics, 1979-84,* p. 681.

50 Years Ago, December 1959

Dec. 2 BOAC inaugurates its Comet service to Johannesburg, with stops in Khartoum and Nairobi. *The Aeroplane,* Dec. 11, 1959, p. 589.

Little Joe

Dec. 4 The third all-solid-propellant Little Joe test vehicle, which uses the rocket cluster principle, is successfully launched at NASA's Wallops Island, Va., facility. The vehicle carries a 7-lb rhesus monkey named Sam to an altitude of 55 mi., then recovers the animal from the ocean after the capsule lands by parachute. The Little Joe is normally used to test the launch escape system and other elements on boilerplate models for the Project Mercury manned space program. *Flight*, Dec. 18, 1959, p. 741; *Aerospace Year Book 1960,* p. 457.

Dec. 7 A Navy McDonnell F4H Phantom II twin-engine all-weather long-range supersonic jet interceptor fighter/fighter-bomber, flown by Cmdr. Lawrence E. Flint, sets an unofficial altitude record of 98,558 ft. *Aerospace Year Book 1960,* p. 23.

Dec. 7 At The Hague, Netherlands, nine countries including the USSR approve a new charter for COSPAR (Committee on Space Research), in which membership is opened to all national academies of science engaged in space research. E. Emme, ed., *Aeronautics and Astronautics 1915-60*, p. 115.

Dec. 9 A Kaman H-43B Huskie sets a new world record for helicopters, at 30,100 ft. E. Emme, ed., *Aeronautics and Astronautics 1915-60,* p. 115.

Dec. 11 NASA announces the cancellation of the Vega rocket, stating that other vehicles will be used to launch satellites and space probes originally planned for Vega. Replacing it will be the Atlas-Agena, the Atlas serving as the first stage and the Lockheed Agena, incorporating the Bell Hustler rocket engine, as the second. *Flight*, Dec. 25, 1959, p. 772.

Dec. 12 The second stage of the Titan ICBM is launched successfully from the Atlantic Missile Range at Cape Canaveral, Fla. The first and second stages delivered 300,000 and 80,000 lb of thrust, respectively. E. Emme, ed., *Aeronautics and Astronautics 1915-60,* p. 115.

Dec. 15 A Lockheed F-104C Starfighter, flown over the Mojave Desert in California by Capt. Joe B. Jordan, establishes a new world altitude record of 103,395.5 ft. This beats the previous record of 98,558 ft, set by a Navy McDonnell F4H Phantom II on Dec. 7, and a previous mark of 94,658 ft set on July 14 by Vladimir Ilyushin flying a Russian Tu-431. *The Aeroplane,* Dec. 25, 1959, p. 648; *The Aerospace Year Book 1960,* p. 23.

F-104C Starfighter

Dec. 30 The USS George Washington submarine,using the all-solid-fuel Polaris fleet-ballistic missile, is commissioned. Originally named the USS Scorpion, the ship was lengthened during its construction by the insertion of the 130-ft-long missile section and then renamed. On July 20, 1960, while submerged, it will successfully launch the first Polaris missile. E. Emme, ed., *Aeronautics and Astronautics 1915-60,* p. 116.

Past

An Aerospace Chronology
by Frank H. Winter, Ret.
and Robert van der Linden
National Air and Space Museum

And During December 1959

—The first successful firings of the liquid oxygen-liquid hydrogen LR115 rocket engine, developed by Pratt & Whitney, are announced. Two of the engines will power the Centaur upper stage. *Flight,* Dec. 18, 1959, p. 741; *The Aeroplane,* Dec. 11, 1959, p. 588.

75 Years Ago, December 1934

Dec. 4 The first Australian rocket mail experiment takes place at Brisbane, conducted by Alan H. Young under the auspices of the Queensland Air Mail Society in connection with a visit by the Duke of Gloucester. The solid-fuel rocket, propelled by gunpowder and carrying about 900 souvenir letters, is launched from the deck of the Canonbar toward Pinkenba on the Brisbane River. J. Ellington and P. Zwisler, eds., *Ellington-Zwisler Rocket Mail Catalog,* p. 1.

Dec. 16 Giulio Macchi, 67, famed Italian airplane designer, dies at Varese, Italy. Macchi was known for the outstanding performance of his racing seaplanes in the Schneider Trophy races. The Macchi M-39, which won the Schneider Cup in 1926, is considered the prototype of the modern high-speed machine of the era. A low-wing monoplane, it featured floats as part of the wing-bracing system and has a very powerful engine. *The Aeroplane,* Dec. 19, 1934, p. 755.

Dec. 25 Raymond Delotte celebrates Christmas by setting a new international speed record at Istres Airport, France, when his low-wing Caudron monoplane, fitted with a new 370-hp Renault six-cylinder in-line air-cooled engine, flies at an average speed of 314.3 mph over a regulation course. The previous record was 305 mph, set a year earlier by U.S. pilot James Weddell, who flew an 800-hp supercharged Wasp-powered racer of his own design. *Flight,* Jan. 3, 1935.

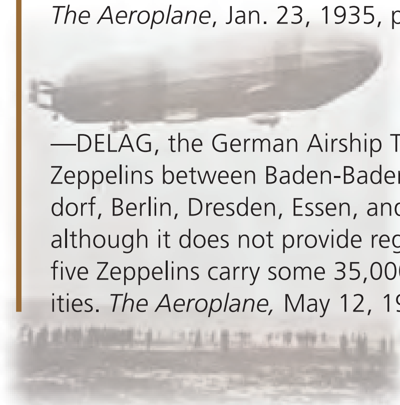
Dec. 28 A record long-distance air mail delivery is made when a de Havilland D.H. 88 Comet carrying 300 lb of Christmas packages and letters returns to Brussels after having left that city on Dec. 20 for Leopoldville, Belgian Congo. The 8,000-mi. trip is covered in less than 45 hr of flying time at an average speed of 195 mph. The British pilot, Ken Waller, and the Belgian pilot, Maurice Franchomme, receive congratulations from the Belgian king and queen. Waller receives the Order of the Lion of Africa, Belgium's highest honor. *Flight,* Jan. 3, 1935, p. 7.


De Havilland Dragon

Dec. 31 Edward Henry Hillman, the British air transport pioneer who founded Hillman's Airways, dies at age 45. A farmer's son, he was a cavalryman during WW I, a chauffeur, and a bicycle repairman. In 1928 he started a motor coach service and raised enough funds to begin his air transport company in 1931 with two de Havilland Puss Moths that he offered for charter. At his suggestion, the economical two-motor de Havilland Dragon biplane with a comfortable passenger cabin was developed and successfully used for air transport. *The Aeroplane,* Jan. 2, 1935.

And During December 1934

—The new Martin M-130 flying boat, three of which have been purchased by Pan American Airways for its proposed transpacific mail and passenger service, undergoes its initial tests. The all-metal seaplane, which features four 800-hp Pratt & Whitney Twin Wasp radial engines, has accommodations for 50 passengers and a crew of six with a 1,200-mi. range, or 14 passengers and 2,000 lb of mail for a 3,000-mi. range. The aircraft subsequently becomes Pan American's regular Pacific transport. The maximum speed of the 51,000-lb seaplane is 180 mph, with a cruising speed of 163 mph. *The Aeroplane*, Jan. 23, 1935, p. 98.



100 Years Ago, December 1909

—DELAG, the German Airship Transport Corp., is formed to carry passengers on Zeppelins between Baden-Baden, Mannheim, Munich, Leipzig, Cologne, Düsseldorf, Berlin, Dresden, Essen, and Frankfurt. In effect, it is the world's first airline, although it does not provide regularly scheduled service. From 1910 until 1914, five Zeppelins carry some 35,000 passengers over 170,000 mi. without any fatalities. *The Aeroplane,* May 12, 1915, p. 474; C. Gibbs-Smith, *Aviation,* p. 152.

Subjects

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INTERVIEWS

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Mechanical, Materials and Aerospace Engineering
University of Central Florida, Orlando, FL 32816
TENURE-TRACK FACULTY OPENINGS

The Department of Mechanical, Materials and Aerospace Engineering (MMAE) of the University of Central Florida (UCF), Orlando, Florida, invites applications for several tenure-track faculty positions at the Assistant Professor level to start August 2010. Of particular interest are candidates who can support our teaching mission in established curricula while building an experimental/theoretical research program in the general areas of Mechanical, Materials, and Aerospace engineering. A doctoral degree in Mechanical, Materials, or Aerospace Engineering is required in addition to an established record of research in Energy and Biomechanics/Biomaterials with strong grounding in any of the broad areas of Mechanics and Materials. We are seeking exceptional candidates nationally to establish strong research programs in the above mentioned areas. The search committee will pay special attention to research background, publications, external funding and other related credentials that will further strengthen the department. We expect the candidate to (1) establish a robust externally funded research program, and (2) be an outstanding teacher for undergraduate and gradute courses. Evidence of prior funding is a plus.

With more than 1,600 undergraduate and 200 graduate students, the Department offers doctoral programs in Mechanical Engineering (ME) and Materials Science and Engineering (MSE), master's programs in ME, MSE and Aerospace Engineering (AE), and bachelor's programs in ME and AE (both ABET-accredited). The instructional and research activities are conducted by over 30 tenured/tenure-track faculty members, many of whom have joint appointments with UCF's research units, including the Institute for Simulation and Training (IST), the Advanced Materials Processing and Analysis Center (AMPAC), the NanoScience Technology Center (NSTC), the Center for Research and Education in Optics and Lasers (CREOL), and the Florida Solar Energy Center (FSEC).

The Department's annual research funding exceeds $5M, and five of its faculty members have received NSF CAREER awards during the past six years. Recently the Department took leadership roles in multi-campus energy initiatives that led to federal and state funding. The Department is one of the partners of Florida Center for Advanced Aero-Propulsion (FCAAP). UCF is near the Kennedy Space Center as well as major facilities of Lockheed-Martin, Siemens Power Corporation, Boeing and Harris Corporations. The Central Florida Research Park is located adjacent to the UCF campus and is home to the nation's largest cluster of government agencies and industries specialized in training and simulation R&D. Located in the heart of the I-4 high tech corridor, UCF has one of the largest enrollments among U.S. universities. For more details regarding the department, visit www.mmae.ucf.edu or e-mail mmae-dept@mail.ucf.edu.

Review of candidates will begin on December 15, 2009 and will continue until the position is filled. Candidates should submit (a) a cover letter, (b) curriculum vitae, (c) a brief description of research and teaching plans, (d) the names and contact information of three referees, and (e) an application online at www.jobswithucf.com/applicants/Central?quickFind=74357.

The University of Central Florida is an equal opportunity/affirmative action employer.

PURDUE
UNIVERSITY

Faculty Openings
Aeronautics & Astronautics
PURDUE UNIVERSITY

The School of Aeronautics & Astronautics (AAE) at Purdue University seeks outstanding individuals with a Ph.D. and a strong background relevant to aerospace engineering. Currently, AAE faculty members conduct research and teaching in the broad disciplines of Aerodynamics, Aerospace Systems, Astrodynamics and Space Applications, Dynamics and Control, Propulsion, and Structures and Materials. Candidates with interests in these areas are encouraged to apply. Details about the School, its current faculty, and research may be found at the Purdue AAE website (https://engineering.purdue.edu/AAE).

Candidates should have a distinguished academic record, exceptional potential for world-class research, and a commitment to both undergraduate and graduate education. Tenure-track positions are available at the assistant and associate ranks. For consideration, please submit curriculum vitae, statement of teaching and research interests, and the names and addresses of at least three references to the College of Engineering Faculty Hiring website, indicating interest in AAE. Review of applicants begins 2/15/10 and continues until the positions are filled.

Purdue University is an Equal Opportunity/Equal Access/Affirmative Action employer fully committed to achieving a diverse workforce.

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THE UNIVERSITY OF MARYLAND

The **Department of Aerospace Engineering** in the A. James Clark School of Engineering at the University of Maryland, College Park is a vibrant and growing department with research in hypersonics, microsystems, rotorcraft, smart materials and structures, and space robotics. It has 20 faculty, six chaired faculty positions, an annual research expenditures of over $19M, and highly ranked undergraduate and graduate programs ("top ten"). While the department is looking for highly qualified tenure-track faculty starting in June 2009 or thereafter in all areas related to Aerospace engineering, applicants in the following areas are particularly encouraged: 'Green' Aviation, Energy, Autonomous Systems, Structural Health Monitoring, Low Reynolds Number Aerodynamics, Hypersonics, and Space Robotics.

Candidates should have an earned doctorate in aerospace engineering or a closely related field at the time of the appointment. Applicants are being sought primarily at the Assistant Professor and Associate Professor level, but extremely qualified candidates at the Full Professor level are also invited to apply. Candidates should have, or must have shown, a high potential for both teaching and research excellence.

For best consideration a cover letter, curriculum vitae, research and education plan, and the names of at least four references should be submitted to the chair of the search committee no later than January 15, 2010:

Dr. Inder Chopra (chopra@umd.edu)
Chairman Search Committee
Aerospace Engineering Department
Department of Aerospace Engineering
University of Maryland, College Park, MD 20742

Information on the Department is available at the following website: www.aero.umd.edu. This is an ongoing search for highly qualified faculty members. The University of Maryland and the Department of Aerospace Engineering are an equal opportunity, affirmative action employer with a strong commitment to the principle of diversity. In that spirit, applications from members of minority groups and women are especially invited.