Applied aerodynamics

This year saw significant progress in industry, research labs, and academia in the development of flow-control concepts, novel configuration aerodynamic concepts, and aerodynamic improvement technologies for enhancing the fuel efficiency and performance of aircraft and surface vehicles. Progress in applied aerodynamics included wind tunnel and flight testing combined with CFD optimization methods under constraints from fluid dynamics, structures, controls, flight dynamics, and other disciplines.

Aerodynamics of commercial aircraft

In the U.S., Boeing rolled out its first 787-8 aircraft in preparation for flight testing. The 787 is an all-new, technologically advanced and environmentally progressive airplane scheduled to enter service in 2008. Significant improvements in 787 fuel efficiency are partly due to enhanced aerodynamic performance afforded by large wingspan (enabled by carbon-fiber composite structure) and advanced wing-tip and fuselage shapes, together with large-scale optimization using CFD and testing methods. The composite structure allows smoother aerodynamic surfaces. The Mach-0.85 aircraft has a compact trailing-edge high-lift flap system with small flap-track fairings. The highly integrated nacelles are shaped for minimizing drag and noise.

In Europe, Airbus delivered the first A380 for use in passenger revenue service, while aerodynamic design and wind tunnel studies are progressing toward definition of the new Airbus A350-XWB aircraft (also incorporating a composite wing). Both cruise at Mach 0.85.

Aerodynamics of new configurations

The innovative Blended Wing Body (BWB) X-48B scaled research aircraft flew for the first time in July at NASA Dryden. The 21-ft-span unmanned test vehicle was developed by Boeing Phantom Works in cooperation with NASA and the Air Force Research Laboratory (AFRL) to gather information on stability and flight control characteristics, especially during takeoffs and landings.

The Silent Aircraft Initiative, a collaborative study by Cambridge University, MIT, and several industry and government partners, disseminated the SAX-40 conceptual design, a quiet aircraft concept with novel centerbody aerodynamics and boundary-layer-ingesting distributed propulsion. These highly integrated BWB concepts have the potential to yield a step change in noise emission and fuel burn compared to existing aircraft.

Next-generation tactical transport

AFRL, NASA, and industry partners are developing technologies for aircraft configurations to enable efficient flight at low speed (90 kt) as well as at transonic cruise speeds (Mach 0.8 or higher). This would enable future transport aircraft to take off and land in short distances while providing fast transportation for intratheater missions.

Wind tunnel tests on high-lift configurations have been conducted to validate system architectures, to study flow fields of blown flaps, and to gather an aerodynamic database for simulations. Also being investigated are transonic drag reduction technologies, including bumps and blowing mechanisms to reduce wave drag.

Applied aerodynamic flow control

Advances in lightweight materials, actuator technology, and aerodynamics are coming together in attempts to improve flight and control characteristics of swept-wing tailless UAVs. West Virginia University and NASA Dryden cooperated on an adaptive washout morphing mechanism for control of tailless aircraft. Control was achieved by using five morphing "feathers" on the outer portion of the wing to provide adaptive washout.

Feasibility of this morphing mechanism was demonstrated by flight testing a 7-ft-wingspan swept-wing tailless scaled aircraft. Wind tunnel, CFD, and free-flight data were in good agreement in the range of test conditions.

Progress was made in the application of plasma flow-control concepts to practical actuators. Under an Air Force Small Business Innovative Research program, researchers at Orbital Research and the University of Notre Dame investigated a plasma enhanced wing for aerodynamic control without movable surfaces. Distributed wing surface-mounted dielectric barrier discharge (DBD) plasma actuators were installed on a 47-deg sweep 1303 UCAV model in wind tunnel tests with a mean-chord Reynolds number of 0.4 million.

The DBD plasma actuators in the leading edge altered the flow field over the lee side of the wing to impart longitudinal and roll control at angles of attack between 15 and 35 deg. Ac-

West Virginia University's 7-ft-span swept-wing tailless demonstrator used wing-tip morphing for control.

tuators applied on the windward side near the trailing edge with a separation ramp produced lift control from 0 to 20 deg. Orbital Research and Notre Dame have applied similar actuators to wind turbines for PACE (plasma aerodynamic control effector) flow control that allows virtual shaping of turbine blades to increase energy capture and reduce noise and vibration.

Aerodynamic flow control has potential synergistic benefit for active load control in the design of slender lifting surfaces such as wings and blades for helicopters or wind turbines. One concept for active load control is an actively controlled trailing-edge tab where the tab slides out of the surface side near the trailing edge of an airfoil to enhance (or mitigate) lift. Unsteady numerical flow simulations of the sliding-tab concept have been conducted, and its effectiveness has been demonstrated in wind tunnel tests at the University of California, Davis. The change in lift coefficient for this concept is approximately ± 0.2. The advantages of a sliding tab configuration are the small force needed for tab deployment and the short deployment times for rapid load control.

Configuration improvements

AFRL researchers, in conjunction with Snow Aviation, performed flight tests on a modified C-130E aircraft fitted with functional tip tanks to determine their effects on the performance and flight characteristics of an aircraft modified with improved eight-bladed propellers and with extended dorsal and rudder surfaces. The tip tanks could replace traditional fuel tanks and may improve aileron effectiveness while reducing drag.

Using Snow Aviation's instrumentation, tests of the modified aircraft showed significant improvement in takeoff/landing distances, stall speed, and minimum control speed in comparison with a "stock" C-130E, as well as in ceiling, specific range, and noise in audible range.

Surface vehicles and wind turbines

Industry, academia, and governments continued to make important contributions toward practical geometry and/or flow-control modifications to reduce drag of surface vehicles. For example, Georgia Tech Research Institute personnel continued development of pneumatic aerodynamic concepts for drag reduction of tractor trailers and SUVs.

Wind tunnel investigations have shown up to 32% drag reduction on scaled long-haul truck models, while full-scale road tests have demonstrated a 12% increase in fuel economy with pneumatic flow control. Active pneumatic

The X-48B scale model flew for the first time at NASA Dryden in July.

control could also provide increased safety from yielding increased drag (when desired) for braking and for increased lateral/directional stability. Researchers at Delft University in the Netherlands plan road testing with fixed-geometry fairings added to the blunt aft-end of tractor trailers to passively reduce flow separation.

Thick airfoils have been pursued for various applications, including section shapes for inboard regions of blades on wind turbines. Recent research has demonstrated that blunt trailing edges may significantly improve the lift characteristics for such airfoils with maximum thickness/chord ratio greater than 25%. Thick airfoils typically have poor lift characteristics when boundary-layer transition occurs near the leading edge because of surface contamination. Incorporating a blunt trailing edge without modifying the camber distribution has been demonstrated in wind tunnel tests by the University of California, Davis, to significantly reduce the sensitivity of thick airfoils to leading-edge transition.

Space vehicles in atmospheric phase

NASA is developing the Orion spacecraft to carry astronauts into orbit, to the Moon, and beyond. Based on Apollo, the Orion command module is a blunt body that achieves lift with an offset center of gravity. An effort is under way to characterize the dynamic stability of Orion during reentry and launch abort scenarios. In wind tunnel testing, NASA Langley is working to obtain free-flight data without sting effects while matching flight lift-to-drag values. This has not been possible over long distances in indoor ballistic range.

The Army Research Laboratory performed free-flight experiments in an outdoor range with telemetry instrumented Orion scaled models. This technique combines the gun-launch of a projectile using a double-length 120-mm gun with an instrumentation package contained inside the test article. Aerodynamic coefficients were extracted from on-board instrumentation and position/velocity histories tracked by radar.

by **Paul Vijgen**
Gary Dale

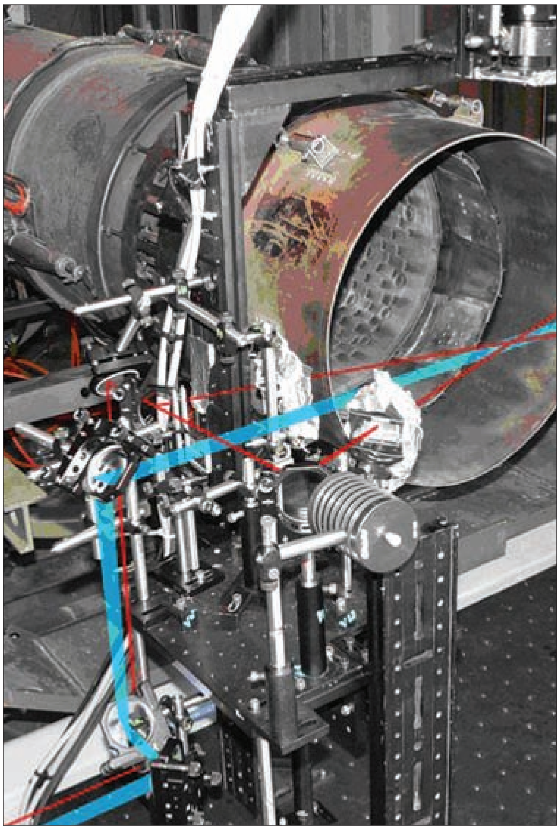
Aerodynamic measurement technology

Researchers at Michigan State, in collaboration with MIT and Iowa State, have introduced the use of quantum dot (QD) nanoparticles for measurements in fluid flows. Measurement capabilities include characterization of scalar concentration and temperature distributions using QD tracers, in addition to imaging single QDs for near-surface velocimetry.

NASA Langley researchers are using high-resolution, 1-kHz-rate video cameras to track the motion of falling crew exploration vehicle (CEV) test articles in support of the Orion Constellation program. A frame-by-frame object-to-image-plane scaling procedure is being applied to help capture the dynamic impact of the vehicles before, during, and after ground contacts. Calculations are furnished for vehicle displacement, pitch and yaw angle changes, and vertical and horizontal velocities of the CEV models. Photogrammetric data obtained during testing, along with other instrumentation onboard the drop vehicles, helps validate computations.

Stanford University is investigating two new classes of diode-laser-based sources for wavelength-tunable light in the mid-IR. The wavelength-tunable 3.30-µm lasers are based on difference-frequency conversion of two fiber-amplified diode lasers in periodically poled lithium niobate. The wavelength tunability enables diverse new strategies to suppress noise and background signals in harsh combustion and propulsion environments. Advances in optically active materials have also enabled extension of tunable diode lasers to wavelengths in the range 2.3-2.7 µm, enabling extension of diode laser sensing strategies to the stronger absorption features of the CO_2 and H_2O combustion products. These stronger transitions offer potential for precise measurements of lower concentrations, shorter optical paths, and improved time resolution.

J85 engine at UTSI shows HTV laser flow tagging optics at exit. The red lines indicate grid-writing laser path; blue indicates PLIF "read" laser sheet.



Also at Stanford, research into the ignition chemistry of practical fuels and propellants, such as JP-8, JP-10, and DF-2, requires specialized laboratory test facilities to overcome the low room temperature vapor pressures of these substances, where the real possibility of pretest decomposition and oxidation of the fuel exists. To circumvent this problem, a new method for studying low-vapor-pressure fuels has been developed. A liquid fuel aerosol is introduced into a shock tube, and the heat-rise from the incident shock wave vaporizes the aerosol, rapidly producing a controlled mixture of fuel vapor. The high-temperature-ignition chemistry of the fully vaporized fuel can be studied behind the subsequent reflected shock wave.

This method provides complete and rapid conversion of fuel to vapor phase *without pretest fuel decomposition and oxidation, and complete control of the mixture* and test conditions—pressure, temperature, and equivalence ratio. Laser absorption is used to measure time-histories of the concentration of a wide variety of chemically important species: fuel components (alkanes, aromatics) are measured in the mid-IR using difference frequency generation lasers; transient radical species (OH, CH_3) are measured in the UV using frequency-doubled and -quadrupled lasers; products (CO, CO_2, and H_2O) are measured using near-IR and mid-IR tunable diode lasers; and aerosol droplet loading is measured with nonresonant near-IR laser extinction. Using the aerosol shock tube and its laser-based diagnostics, fundamental chemical processes of jet fuels, jet fuel surrogates, and new synthetic fuels such as Fischer-Tropsch fuels can be studied at elevated temperatures and pressures.

Vanderbilt University, Arnold Engineering Development Center, and the University of Tennessee Space Institute conducted the first demonstration of hydroxyl tagging velocimetry (HTV) in a gas turbine exhaust, operating a GE J85 engine from idle to full throttle. HTV is a laser-based nonintrusive technique that photodissociates water vapor (H_2O) in the exhaust into OH and H using a grid of ultraviolet pulsed laser beams.

The resulting OH grid "written" in the flow is subsequently "read" by imaging the grid's OH fluorescence utilizing another ultraviolet pulsed laser sheet. Flow displacement measurement through grid image comparisons and knowledge of the write-read delay time provide instantaneous velocity field data. Exhaust velocities up to 500 m/sec (1,100 mph) were measured.

Atmospheric flight mechanics

There were a number of firsts to note in the field of atmospheric flight mechanics over the past year. To begin with, the first flight of the F-35 Lightning II took place on December 15, 2006. This marked the beginning of a 12,000-hr flight test program that will also include Navy and V/STOL variants. The second first occurred on March 19 with two nearly simultaneous landings of the Airbus A380, one in New York and one in Los Angeles. Finally, on the carefully selected date of July 8, Boeing rolled out the 787 Dreamliner from its factory facility in Everett, Wash. The first flight of the 787 is scheduled for the first quarter of 2008, as part of an ambitious flight test program slated to conclude with FAA certification later in the year.

In an attempt to unlock some of the secrets that allow birds to achieve agile flight, engineers working with zoologists are attempting to quantify the flight performance of large birds. What began as an interesting foray has now become an active area of research for the Air Force Research Laboratory (AFRL). The program involves mounting cameras on large birds to observe various aspects of animal flight. The development of microcameras and wireless technology has allowed researchers to place wireless camera packs on birds for purposes of carrying out these studies.

Initial observations of an eagle's wing in flight showed the deployment of the bird's "covert feathers" during certain maneuvers, similar to an aircraft's deployment of leading-edge slats. What was remarkable about this was that it happened so quickly, and only at certain flight conditions. Other observations were also noted, such as wing morphing (or bending) for flight control, and head movement in coordination with turns.

AFRL is now teaming with Oxford University on a project that entails outfitting the birds with a high-quality instrumentation package to record accelerations, Euler angles (the bird's flight path angle with respect to the Earth), and angular rates. These data, coupled with camera observations, will allow engineers to correlate the motion of the bird with changes of the wing.

This has been an important year for the V-22 Osprey as the aircraft moved from development testing to full-scale operational testing. In February and March, VMS-22 (Marine Tiltrotor Test and Evaluation Squadron 22) logged 185 flight hours with four aircraft in just 18 days, operating in the California and Arizona deserts. In June, the aircraft was pronounced fit for operational deployment, and a fleet of 10 Ospreys was scheduled to deploy to Iraq in September. Developmental testing for envelope expansion and operational capabilities continues at NAS Patuxent River, Md., and Edwards AFB, Calif.

In other news, the UCAS-D program was awarded in August and will demonstrate for the first time unmanned operations of a large aircraft from a Navy aircraft carrier.

This also has been an eventful year for the space shuttle fleet. In-orbit reviews of the integrity of the shuttle tiles continue to uncover damage associated with the ascent through the atmosphere. On the June flight of the space shuttle Atlantis, the mission was extended by two days so that the astronauts could repair an insulation blanket on the aft rocket pods. Repairs went without incident, and the shuttle landed safely at Edwards AFB. On the August flight of Endeavour, foam shed from the external fuel tank again damaged the critical tiles. In this case the aluminum skin below the tile was not exposed or compromised. After much deliberation, risky in-orbit repairs were deemed unnecessary, and on August 21, Endeavour landed safely at Kennedy Space Center.

Instruments mounted on a bird of prey will make observations of various features during flight. (Photo courtesy Gregg Abate.)

by **David H. Klyde**
Gregg Abate
David Mitchell

Fluid dynamics

Exciting research developments have been reported in the past year in the various subfields of fluid dynamics. A snapshot of some of these developments is provided below.

CFD methods and applications

The application of hybrid Reynolds-averaged Navier-Stokes (RANS)/large-eddy simulation (LES) methods to aerodynamic flows continued to be an active area of research in the U.S. and abroad. Symposia held in London, England, and in Kerkyra, Greece, highlighted the successes and shortcomings of these techniques. In addition to the canonical separated-flow applications, the method is being used increasingly for wall-modeled LES and for zonal simulations.

Research continued in the development of techniques that improve the solution behavior at the interface between RANS and LES. Boeing and TTC Technologies independently improved and applied high-order-based hybrid RANS/LES procedures to accurately simulate the flow and fluctuating pressure fields required for jet noise prediction in a coupled nozzle/jet plume model.

In other developments, Stanford University researchers demonstrated remarkably accurate LES predictions of turbulent separation and its control for flow over the wall-mounted hump, first used in the 2004 NASA Langley Workshop on CFD Validation. Their results, obtained using nondissipative numerics and the dynamic subgrid-scale model, demonstrated that predictions of separation control can be achieved without resorting to direct numerical simulation, reducing computational costs by orders of magnitude.

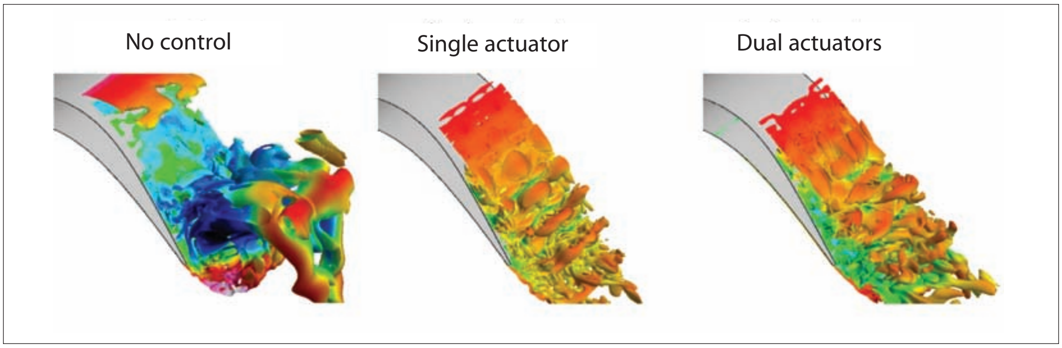
The Direct Simulation Monte Carlo (DSMC) method is currently the most common tool used to simulate nonequilibrium flows at finite Knudsen numbers. Recently, gas-kinetic schemes based on the BGK approximation to the Boltzmann equation have been applied by researchers at the Hong Kong University of Science and Technology, and at Old Dominion University to simulate nonequilibrium flows. By making the relaxation time parameter from the BGK approximation a function of the flow gradients, resolution of shock structures with accuracy comparable to DSMC was demonstrated at a significantly lower computational cost.

Flow control

Flow control continues to be an active area of research, with electromagnetic energy addition receiving significant attention. The computational plasma program at the University of Florida, in collaboration with the Computational Sciences Center of Excellence at the Air Force Research Laboratory (AFRL), has successfully predicted plasma-based stall control for NACA airfoils and turbine blades at high angles of attack. Also in the past year, simulations at the AFRL center explored the use of asymmetric dielectric-barrier-discharge plasma-based actuators to control the flow over blades of transitional, highly loaded low-pressure turbines, commonly employed as the propulsion systems for UAVs. The blades are susceptible to separation in high-altitude cruise, resulting in blockage of the flow passages, transition to turbulence, wake total pressure losses, and a decrease of turbine efficiency.

Various aspects of control strategies for an isolated turbine blade were investigated using high-order CFD combined with a phenomenological model to represent plasma-induced body forces imparted by the actuator on the fluid. The AFRL researchers completely eliminated separation with minimal plasma power requirements. They observed an 85% reduction in the wake total pressure loss coefficient. The flow physics by which this efficiency improvement was achieved were also identified.

Rutgers University has reported significant progress in the use of microwave energy deposition, expanding the possible regimes for flow



Isosurfaces of vorticity magnitude, which are colored by the streamwise velocity component, show the effects of plasma-based techniques to control separation on transitional, highly loaded, low-pressure turbine blades.

by **Foluso Ladeinde**
Tom McLaughlin
Meelan Choudhari
Ugo Piomelli

control in high-speed flows. A series of experiments and theoretical analyses was performed jointly with Russian collaborators from the Institute for High Temperatures to quantitatively evaluate the effect of a laser spark precursor on the breakdown voltage required for microwave energy deposition in air, at subatmospheric to atmospheric pressure. The microwave generator employed has a maximum power of 700 kW operating at 13 GHz. The electric fields of the laser and microwave are mutually perpendicular. The results imply the potential for creating microwave discharges at arbitrary locations in the vicinity of an aerodynamic body.

Likewise, researchers at the University of Illinois Champaign-Urbana are investigating laser and microwave energy deposition methodologies and actuators with an eye toward uncovering opportunities for exploiting instabilities that can be controlled with the techniques. The experiments have resulted in the successful forcing of large-scale structures in a supersonic cavity shear layer using energy deposition. Princeton University has demonstrated nanosecond pulse, sustained high-velocity dielectric barrier discharge surface jets, and "snowplow arc"-driven separation control.

In the emerging research area of feedback flow control, a major problem has been the availability of suitable (meaning simple enough to solve) mathematical descriptions of the flow. Traditionally, low dimensional dynamic models of flow fields have been fraught with mathematical stability problems as well as a limited range of validity.

However, over the past year, several promising approaches have emerged. Trust-Region POD (CNRS, France) as well as Balanced Truncation (Princeton University) have been shown to improve the range of validity, or the numerical stability, respectively. A method combining Double POD and system identification based on neural networks (DPOD-ANN-ARX) improves stability, range of validity, and models actuation effects for both open-loop and closed-loop flow states (Air Force Academy). These developments can be expected to lead to greatly improved understanding of open-loop controlled-flow physics and practical feedback controllers in the near future.

Transition

Several exciting developments highlighted the continued pace of research in laminar-turbulent transition, especially in high-speed boundary layers.

NASA's computational analysis of the Pegasus flight experiment from 1998 provided the first flight validation of stability-based prediction methods for crossflow-dominated transition in high-Mach-number 3D boundary layers. Specifically, the correlation of disturbance growth factors with in-flight transition locations via the e^N method indicated that the same range of N factors as found earlier for low-speed flows also correlates observed transition characteristics over both the cold wing glove and the inboard, hotter tile region of the Pegasus wing.

Extensive analysis and ground tests were performed by an AFRL-led team in preparation for flight one under the HIFiRE (Hypersonic International Flight Research and Experimentation) project. HIFiRE will use a series of flights with low-cost sounding rockets to develop and demonstrate fundamental hypersonic technologies deemed critical to the realization of next-generation aerospace weapon systems. Flight one will test high-frequency instrumentation in a flight environment, with a focus on boundary-layer transition and shock-boundary layer interaction. The preflight effort has shown that hypersonic smooth-body transition should be achievable with the proposed configuration consisting of a 7-deg half-angle cone with 2.5-mm nose radius. However, one side of the vehicle will be tripped to ensure transition and to obtain rough-wall data.

To gain fundamental insights into the dynamics of hypersonic shear flows, NASA Langley researchers have begun using the nitric oxide planar laser-induced fluorescence, or NO-PLIF, technique. In one experiment, NO was seeded into a Mach 10 laminar boundary layer that passed over discrete triangular and rectangular trips and became turbulent downstream. The shape of trip-induced flow instabilities appears to be consistent with the hairpin-shaped vortices observed in lower speed regimes.

In subsonic flow, as part of technology development for low-weight, high-efficiency airframes to allow persistent loiter capability for AFRL's SensorCraft program, Texas A&M University demonstrated the efficacy of distributed roughness elements (DRE) in extending the length of laminar flow from 30% to 60% chord on a subsonic swept wing at chord Reynolds number up to 8.1 million. The flight test of the 37-deg swept wing was accomplished on a Cessna O-2 with the test article mounted to a hard point of the Cessna's port wing. Infrared thermography was used to measure the extent of laminar flow. A surprisingly strong correlation between transition location, DRE height, and test article surface roughness was observed, which was also confirmed via nonlinear parabolized stability computations.

Aeroacoustics

Tangible reduction of aircraft noise to meet the public's expectations remains a challenge. Research this year concentrated on gaining better insights into the noise source mechanisms and on developing metrics that better capture the impact of aircraft operations on communities located near airports.

In a joint effort, NASA and Pratt & Whitney demonstrated the noise reduction benefits of an advanced ultra high bypass (UHB) cycle fan concept called the geared turbofan. This new engine cycle has been designed to obtain peak performance and reduce propulsion noise using a slower, lower-pressure-ratio, geared fan. In wind tunnel tests, the 22-in.-scale model version of the fan demonstrated measured noise levels that were consistent with the predicted levels for a low-speed, low-pressure-ratio UHB fan.

A 22-in. scale model of a NASA/Pratt & Whitney geared turbofan was tested in the NASA 9x15-ft Acoustic Wind Tunnel.

Many airports are using alternate noise metrics to supplement the Day-Night-Level to better communicate noise exposure to the public and to assess sleep disturbance and speech interference effects. Case studies by Wyle show that the NA (Number-of-events Above) metric, which is the frequency of aircraft operations at or above a selected threshold level, has clearly emerged as the best metric to assess these effects. It is now the most widely used supplemental metric in aviation noise analysis.

As part of a project funded by the Office of Naval Research to reduce the noise from tactical fighters, a team of researchers from Florida State University, the University of Mississippi, Boeing, and CRAFT developed a suite of noise reduction concepts. Detailed aeroacoustic measurements carried out at the Boeing wind tunnel facility revealed significant noise reduction in all the noise metrics without performance penalty. These concepts are currently being evaluated for a twin-podded engine configuration.

Under NASA's Supersonic Fundamental Aeronautics Project, a NASA F-18 research aircraft flew unique profiles at Edwards AFB to present sonic booms of overpressures from 1.0 to 1.4 psf to a house constructed with modern methods and materials, and instrumented to measure both pressure and vibration. The primary goals of the test were to collect data on the house's structural response to sonic booms and to compare these results with data collected in 2006 during a test using an older house slated for demolition.

Advanced experimental techniques and numerical simulations have furthered our understanding of noise sources. Honeywell Aerospace, as part of NASA's Engine Validation of Noise and Emission Reduction Technology program, led and completed a static test for the characterization of the engine noise sources. The fan of Honeywell's Tech977 engine was removed, and the engine was successfully operated using a water brake dynamometer, to isolate engine core noise sources.

The Curved Duct Test Rig has been developed for study of sound propagation and evaluation of noise control techniques in ducts approaching the scale of the aircraft engine aft bypass. This new tool in NASA Langley's liner technology effort has been used in conjunction with a finite-element analysis to investigate the effect of higher mode order and flow on the acoustic performance of a locally reacting liner sample.

The definition and measurement of the source of turbulence-generated jet noise attracted significant effort from numerous researchers. Time-resolved particle image velocimetry flow data from heated jets acquired at NASA Glenn helped establish the effect of temperature on various turbulence statistics, including fourth-order space-time correlations. A team of investigators from Florida State University, Boeing, Georgia Tech, and the Ohio Aerospace Institute presented a comprehensive experimental study using four types of measurements. All the results strongly indicate the presence of two distinct noise sources: the noise from the fine-scale turbulence and the large coherent structures of the jet flow.

by **Krishna Viswanathan**

Astrodynamics

Spacecraft encounters of various forms dominated astrodynamics news this year. In January the People's Republic of China demonstrated its antisatellite weapons technology by launching a direct-ascent vehicle from the Xichang Launch Center against one of its old polar-orbiting weather satellites, FengYun 1C.

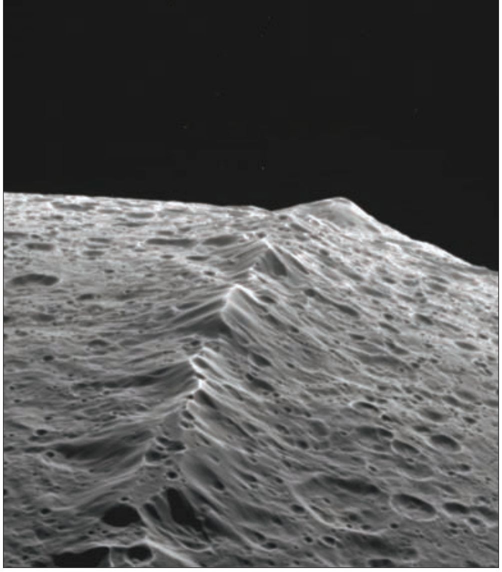
The result of that impact produced a cloud of debris comprising over 2,000 pieces large enough to be tracked by the U.S. Space Surveillance Network. NASA's Orbital Debris Program Office estimated that over 35,000 pieces of debris larger than 1 cm were created. Analysis of the orbital lifetimes of the larger debris fragments shows that they will remain a hazard to much of the LEO satellite population for many decades to come.

Elsewhere, spacecraft flybys enabled, extended, and enhanced a variety of scientific missions throughout the year. In January, the STEREO (Solar Terrestrial Relations Observatory) mission performed its second lunar swingby, completing the setup of its two observatory spacecraft in Earth-leading and Earth-trailing heliocentric orbits. The European Rosetta spacecraft, continuing its odyssey to the comet 67P/Churyumov-Gerasimenko, swung by Mars in February, followed by the New Horizons flyby of Jupiter and its magnetotail a few days later.

The MESSENGER (Mercury surface, space environment, geochemistry, and ranging) spacecraft performed its second of two Venus flybys in June, setting up for its first flyby of Mercury, to take place in early 2008. And throughout the year the Cassini spacecraft performed 17 flybys of Titan, as well as flybys of Tethys, Rhea, and Iapetus. Cassini also completed a 180-deg rotation of its orbit, known as a pi-transfer, within the Saturnian system, placing the subsequent apoapses in between the Sun and Saturn to enable atmospheric and ring observations.

New spacecraft departing Earth orbit included Phoenix, which will deliver a lander to the Martian polar latitudes in May 2008; Dawn, which will ultimately orbit the Main Belt asteroids Ceres and Vesta; and SELENE (Japanese Selenological and Engineering Explorer), which will deploy relay and gravity subsatellites from lunar orbit.

In June, DARPA's two Orbital Express spacecraft performed a rendezvous, conducted proximity operations and stationkeeping, and accomplished the first-ever autonomous capture of a satellite by another satellite using a robotic arm. This enabled the first unassisted in-space exchanges of propellants and components (batteries) in history. In the future these capabilities will extend spacecraft performance and lifetime and reduce the workload of human-piloted missions.

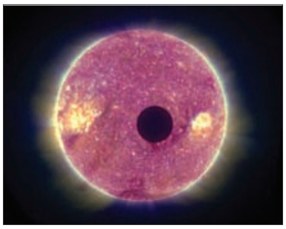


Cassini completed its closest flyby of the odd moon Iapetus in September.

Back on the ground, JPL hosted the Second Global Trajectory Optimization Competition. The objective of this international astrodynamics design contest was to optimize the trajectory of a "Grand Asteroid Tour." A hypothetical spacecraft employing electric propulsion was to be launched from Earth to rendezvous with one of each of four different types of asteroids. The design challenge was to find the "best" low-thrust trajectory using an objective function that rewarded both low propellant consumption and total flight time. The winning team for 2007 was from the Politecnico di Torino in Italy. A workshop presenting the methods and results from the competitors was held at the AAS/AIAA Space Flight Mechanics Meeting in Sedona, Ariz., in January 2007.

Elsewhere on Earth, the 10 antennas of the VLBA (Very Long Baseline Array), spanning baselines up to 10,000 km in length, were used for the first time to track a radar-illuminated asteroid (in this case, the binary system 2006 VV2). These observations provide precision measurements of the objects' angular position and permit an unambiguous three-dimensional shape reconstruction.

The year ended with two more Earth flybys: Rosetta on November 13 and Deep Impact (currently targeted to fly by the comet Boethin) on December 31.



A lunar transit of the Sun was seen from the STEREO spacecraft.

by **L. Alberto Cangahuala**

Aerodynamic decelerators

In a particularly busy year, the aerodynamic decelerator systems community touched a broad range of disciplines and attained several major milestones.

DOD airdrop programs

Airdrop systems such as JPADS (Joint Precision Airdrop System) have saved lives and had an enormous impact on current operations, while the push for increased accuracy, higher reliability, larger and lower payload weights, and lower cost systems continues. JPADS encompasses a family of systems being created through numerous efforts, partners, and funding sources. All efforts are managed and executed by a joint team from the NSRDEC (Army Natick Soldier Research Development and Engineering Center), Product Manager Force Sustainment Systems, Air Force Air Mobility Command, Deputy Under Secretary of Defense for Advanced Systems and Concepts, Joint Forces Command, Transportation Command, Marine Corps, Special Operations Command, and others.

The JPADS family consists of "self-guided" cargo parachute systems, a common mission planning and weather system, and navigation aids for Military Free Fall parachute systems. The 700-2,400-lb variant entered Milestone B in March; the 5,000-10,000-lb variant transitioned from a very successful advanced concept technology demonstration to a formal Program of Record (POR), with MS-B approved in August. The formal Capability Development Document for both increments was approved by the Joint Requirements Oversight Council in March. The 2-klb POR is developing the Firefly system from Airborne Systems of North America and will be entering developmental testing by year's end. The 10-klb system will be chosen after the submission of this annual report.

The JPADS Mission Planner provides computed aerial release point calculations for updating missions to the SCREAMER system, which has been used in Afghanistan since 2006.

The USAF and USA have been using JPADS in Afghanistan and Iraq. Primary airdrops are using the JPADS Mission Planner developed by Planning Systems and the Charles Stark Draper Labs. The system is providing improved computed aerial release point calculations for traditional "dumb" parachutes for Army high-altitude airdrops and for updating missions to the Strong Enterprise SCREAMER system, which has been used in Afghanistan since 2006. JPADS airdrops have been documented as saving warfighters' lives in emergency resupply missions and are being used at a rate of approximately 500,000 lb per month.

Continued use of JPADS for logistics resupply is expected as the systems have reportedly eliminated the need for hundreds of convoys and thousands of soldiers from the roads (which pose IED exposure risks) and many helicopter resupply missions. Large quantities of JPADS-type systems and capabilities are expected to be rapidly fielded for use in theater operations in the near future because of their demonstrated positive impact and rapidly improved technology readiness level.

The Low Cost Airdrop System is a rapid fielding program that explored and fielded numerous low-cost, one-time-use, very-low-altitude airdrop systems weighing from 50 to 450 lb. This system was fielded to theater and is also being used extensively to support small-sized units with enormous success. Systems are being utilized from as low as 150 ft above ground level, and thousands of pounds of supplies have been airdropped.

NSRDEC is executing a 30,000-lb Army Technology Objective and has demonstrated deployment and autonomous control of the largest parafoil system ever deployed (9,000 ft^2), with Airborne Systems North America, Wamore, and Draper Labs. This system was scheduled to be demonstrated to an international audience in October.

NSRDEC executed a Precision Airdrop Technology Conference and Demonstration (PATCAD) in October at the Army Yuma Proving Ground. PATCAD 2007 demonstrated 23 different systems utilizing five aircraft with 14 lifts over three days. More than 140 cargo airdrops took place, with weights ranging from 5 lb to 30,000 lb, for a total of over 300,000 lb dropped. Numerous Special Operations military free-fall systems were demonstrated.

NATO was a sponsor of PATCAD 2007,

by the **AIAA Aerodynamic Decelerator Systems Technical Committee**

and the NSRDEC continues to act as the DOD lead for the NATO Precision Air Drop (PAD) Technology for Special Operations Forces (SOF) Defense Against Terrorism (DAT) project, for which the U.S. is lead nation. "PAD for SOF," one of 10 NATO DATs, is being executed through a NSRDEC-chaired Joint Precision Airdrop Capability Working Group. The group is executing PAD concepts of operation and demonstrations and working to ensure interoperability of PAD systems between NATO nations.

Mars Science Laboratory

The Mars Science Laboratory (MSL) is NASA's next rover mission to Mars, scheduled to reach the red planet in 2010. MSL is designed to gather detailed information on past and present environments that might have supported, or currently support, microbial life. MSL will deliver the largest, most capable rover ever developed by NASA, enabling in-situ analysis of Martian rocks and soil. The entry, descent, and landing (EDL) system of MSL will enable access to previously unattainable landing sites with greater precision than any previous extraterrestrial landed mission.

The MSL parachute decelerator system (PDS), a key component of the EDL mission segment, will be the largest and highest load extraterrestrial parachute ever flown. The PDS is to be deployed at Mach 2.2 and 750 Pa, achieving a peak inflation load of 286 kN. Its supersonic trajectory is similar to that of BLDT (Viking Balloon Launched Drop Test), enabling direct comparison of BLDT flight tests for the determination of drag and peak inflation load.

To support this effort, the MSL parachute team is leveraging and expanding on the design and construction techniques developed for the MER and Phoenix parachute programs and the supersonic qualification of the Viking-era parachute development efforts. A supersonic delta qualification program is also under way, to address the large size of the MSL parachute relative to the Viking BLDT heritage supersonic qualification dataset. The delta qualification program, led by JPL, NASA, University of Minnesota, and University of Illinois, is developing and validating fluid structure interaction (FSI) tools to provide insight into the fundamental physics of supersonic parachute operation and quantify parachute performance and health during its supersonic transit.

The preliminary design of the parachute and mortar system is complete. The parachute is an 80-gore continuous-line construction disk gap band (DGB) with nylon broadloom fabric and a kevlar structural grid. The mortar system uses a precision-machined canister with an integral blow-down, MER-scaled gas generator at the base. Several prototype parachutes have been built and tested in an aerial drop test program demonstrating the inflated shape, construction techniques, and structural design. Development mortar tubes and gas generators have been fabricated and tested with static function and close volume tests. A 2%-scale rigid parachute supersonic wind tunnel test program was conducted at NASA Ames to validate the CFD solvers being used in the FSI tool development.

Activities to come before year's end include a structural qualification program in the National Full Scale Aerodynamics Complex, where the parachute will be deployed in 80x120-ft subsonic wind tunnel and 5%-scale supersonic wind tunnel test program in the NASA Glenn Research Center 10x10 unitary tunnel to explore supersonic performance at MSL deployment conditions.

The Orion program has chosen a parachute recovery system to land the CEV.

Crew exploration vehicle

The Orion program has chosen to baseline the use of parachutes for landing the next generation of NASA human-rated spacecraft. The crew exploration vehicle (CEV) will implement a parachute recovery system architecture very similar to that used during the Apollo program. Once the command module has achieved subsonic flight, a pair of mortar-deployed drogue parachutes will decelerate and stabilize the capsule. After the drogues are released, a cluster of three mains will be individually deployed by mortar-deployed pilot parachutes. The CEV parachute assembly system has been chosen as a Government Furnished Equipment project to CEV prime contractor Lockheed Martin.

Development testing of the component-level parts, including air drop tests of the pilots, drogues, and mains, began in January. The development parachutes, called Generation 1, are designed to recover a 14,400-lb suspended mass and nominally deliver a rate of descent of 26 ft/sec and 33 ft/sec for a single main failure at a landing zone elevation of 4,000 ft MSL. Development testing will culminate in spring 2008 with a demonstration of the entire system assembled onto a boilerplate test article extracted out of a C-17. All development parachute testing is being conducted at the Army Yuma Proving Grounds and the Naval Weapons Center. The development parachute system will be integrated into the first pad abort test, scheduled for September 2008.

Thermophysics

Major activities in the field of thermophysics this year focused on the MEDLI (Mars Science Laboratory Entry, Descent, and Landing Instrumentation) project and on materials for thermal protection systems.

MEDLI

The MEDLI project's main objective is to measure aerothermal environments, subsurface heat shield material response, vehicle orientation, and atmospheric density for atmospheric entry during the entry and descent phases of the Mars Science Laboratory (MSL) entry vehicle. The flight science objectives directly address the largest uncertainties in our ability to design and validate a robust Mars entry system, including aerothermal, aerodynamic, and atmosphere models and thermal protection system (TPS) design. Therefore, although MSL will not directly benefit from this data set, all future Mars entry and aerocapture missions will benefit from the model validation and improvements enabled by the MEDLI data.

By design, this development effort is independent of MSL, will not significantly impact its mission schedule, and will engage MSL at well-defined entry points.

A PICA coupon undergoes testing at the Arnold Engineering Development Center.

MEDLI consists of seven pressure ports and seven integrated sensor plugs (containing four thermocouples and a recession sensor) that are installed in the forebody heatshield of the MSL entry vehicle. The sensors are wired to a sensor support electronics (SSE) box that provides power and conditions and digitizes the sensor signals. The digital data stream is sent to MSL's descent stage power and analog module (DPAM), which then relays the data to one of MSL's rover compute elements over the MSL EDL-1553 bus for storage until the data are sent to Earth after the landing.

The project instrumentation consists of three main subsystems: the MEDLI integrated sensor plugs (MISP), a series of plugs in the TPS that contain embedded thermocouples and recession sensors; the Mars entry atmospheric data system, a series of through-holes, or ports, in the TPS that connect via tubing to pressure transducers mounted on the heatshield interior; and the SSE, an electronics box that conditions sensor signals, provides power to the sensors and transducers, and connects to MSL's data acquisition system.

Each integrated sensor plug includes four thermocouples and a recession sensor. The stacked thermocouples will record heating data at varying depths in the heat shield. The recession sensors will measure the thickness of the TPS as it ablates during atmospheric entry. The pressure ports are arranged to provide a flush atmospheric data system from which aerodynamic data can be computed.

After signal conditioning, the analog signals from the sensors will be digitized and transferred via a 1553 bus to the DPAM system located in the MSL descent stage. The additional mass, volume, and channels required by MEDLI are subject to constraints from MSL.

Mission description and project organization

MEDLI will fly on the MSL mission scheduled to launch in September 2009. The data from the instrumentation will be recorded during the entry, descent, and landing (EDL) portion of the mission and stored on the MSL rover. After landing, the data will be transmitted back to Earth. Collected data will be analyzed and processed by the project science team, and the data products will be made available to the engineering community.

Development of EDL instrumentation is of significant interest to NASA's Exploration Systems Mission Directorate, which funds the project. NASA's Science Mission Directorate (SMD) is responsible for the MSL project and spacecraft. Because MEDLI modifies the heatshield of the MSL entry vehicle, SMD has significant interest in and oversight of MEDLI via the MSL Project Office. The MEDLI Project Office, located at NASA Langley, is responsible for project implementation and management under the center's Exploration and Flight Projects Directorate. The project has direct commitments with other NASA centers, including Ames and JPL, and a contract with Lockheed Martin Space Systems.

Coated and self-coating carbon-carbon

Researchers at Sandia National Laboratories are developing coated and self-coating carbon-carbon thermal protection materials for an emerging new generation of flight. These materials, which are protected by a combination of siloxane-based infiltrates and ceramic and inorganic coatings, must remain intact under intense heating rates for short durations followed by long durations at moderate heating rates.

Sandia screens candidate materials in the radiative heating environments of its National Solar Thermal Test Facility (NSTTF) and solar furnace, which provide heat fluxes up to 700 W/cm². Materials have also been tested in the LHMEL laser heating facility at Wright Patterson AFB and the arc jet facilities at NASA Ames. Current efforts include computer simulations of these novel materials in both flight and arc jet environments.

Orion TPS

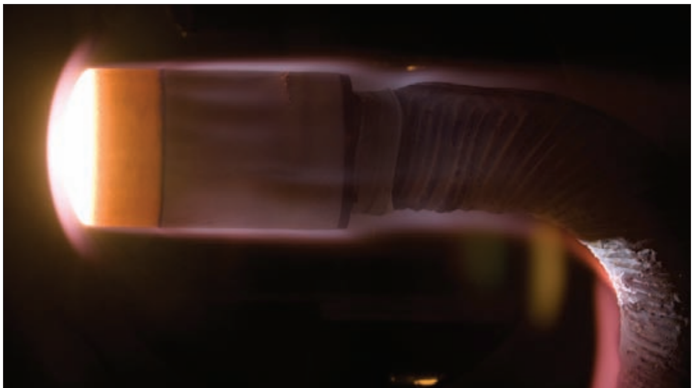
For the past two years researchers and engineers at several NASA centers (Ames, Langley, Johnson, Kennedy, Glenn, and JPL) have been developing the next generation of manned spacecraft thermal protection systems. The goal of the TPS Advanced Development Project (ADP) is to reduce the performance risks associated with a lunar direct return-capable heat shield and help the Orion prime contractor develop, design, and build the heat shield. The Orion lunar-direct return entry velocity is on the order of 11 km/sec, and the heat shield must be capable of withstanding a peak heat rate of over 750 W/cm².

Compared to returning from LEO, where the velocity is on the order of 7.5 km/sec and the peak heat rates are less than 150 W/cm², the new lunar-return-capable heat shield represents a significant jump in performance requirements relative to the space shuttle. The TPS ADP is responsible for developing the entire heat shield system, including the heat shield acreage TPS material, carrier structure, compression pads, and separation system, and the main seal between the forebody aeroshell and the backshell. The TPS ADP is also responsible for developing the overall TPS margin management plan for the heat shield and for providing the prime contractor with a recommended heat shield qualification and certification plan.

The ADP has down-selected from five candidate TPS materials to PICA (phenolic impregnated carbon ablator) as the primary heat shield material. Produced by Boeing and Fiber Materials, PICA is a low-density carbon-fiber-based material impregnated with phenolic resin and made in blocks measuring up to 42x24 in. These are then machined into panels and attached to the carrier structure. The design details of boundaries between the PICA panels are under development and will require either a gap or seam.

The TPS ADP, in partnership with Boeing and Textron, is also developing alternate lunar return-capable heat shield materials. Currently under evaluation are the Apollo heat shield material Avcoat 5026, 3DQP, and BPA.

Avcoat is a mid-density syntactic (silica-phenolic) foam packed into honeycomb matrix that is attached to the carrier structure. The material is cured as a single monolithic article and thus has no gaps and seams. The 3DQP dual-layer material consists of a thin outer layer made of a high-density quartz phenolic and an inner low-density syntactic foam insulation layer.


A PICA coupon is arc jet test in NASA Ames' Interaction Heating Facility.

3DQP is produced in panels and attached to the carrier structure with fitted joints. Both Avcoat and 3DQP are manufactured by Textron. BPA, or Boeing phenolic ablator, is a mid-density material manufactured by Boeing and made of a phenolic resin with organic and inorganic fibers, as well as organic and inorganic microspheres. Like Avcoat, it is packed into a honeycomb matrix that gets attached to the carrier structure, making it a monolithic heat shield.

By year's end, the TPS ADP will select one of these three alternate lunar-capable materials as the "primary alternate." Both the PICA baseline and the primary alternate material will be presented as the two final candidate systems at the TPS subsystem PDR (preliminary design review) next year. Much of the current TPS ADP efforts are focused on achieving a deep understanding of the TPS material capabilities and on developing comprehensive integrated heat shield designs involving these materials.

Atmospheric and space environments

by **John Prebola, Dale Ferguson, Harold Addy, Andy Broeren, William W. Vaughan, Jenching Tsao**

Numerous advances occurred this year in the areas of atmospheric and space environments (ASE). Progress in space involved new flight instrumentation to verify plasma environments, and ground testing to predict long-duration charge buildup. In addition, NASA released the first in a series of new charging standards.

On the atmospheric side, international partnerships continued in the area of icing research. These studies accomplished multiple goals, including improved understanding of both airfoil and aircraft performance with different ice shapes. Also, NASA completed a comprehensive update of its handbook on the terrestrial environment.

A 6.5%-scale S-3B Viking model was tested in the Bihrle Applied Research's Large Amplitude Multipurpose facility.

New standards

NASA released the long-awaited Low Earth Orbit Spacecraft Charging Design Standard as two volumes, NASA-STD-4005 and NASA-STD-4006. These first-of-their-kind standards, developed by NASA Glenn and NASA Marshall, enable spacecraft designers to prevent and mitigate spacecraft charging by high-voltage solar arrays and other power systems in equatorial LEO. Development has started at JPL on a new NASA standard to treat GEO, polar, and deep dielectric charging. It will take the place of the previous NASA-HDBK-4002 and the old and outdated (1984) NASA TP-2361.

Work has begun in Asia, Europe, and the U.S. on a new ISO standard for electrostatic discharge testing of space solar arrays. These standards reflect the growing maturity of spacecraft charging as a design discipline and the growing interest in high-voltage and high-power spacecraft for all orbits.

New instrumentation

Astronauts installed the floating potential measurement unit (FPMU) on the International Space Station. The floating potential is the electrical potential at which the ISS structure "floats" in the surrounding plasma. It is determined by the electron collection on the high-voltage solar arrays, the ion collection on the ISS structure, and the so-called vxB potential caused by ISS cutting the Earth's magnetic field lines. FPMU measures the plasma parameters through which ISS flies, determines the charging of ISS due to its new solar arrays, and is intended to confirm the measurements and the model for floating potential that resulted from the FPP (floating potential probe) that was previously on ISS.

The FPMU has four separate instruments for measuring the ISS plasma parameters and ISS floating potential. There is good agreement between the measurements of the four instruments. As the ISS changes configuration with added PV arrays, the FPMU will provide data for the charging model development and validation.

Charging effects at low temperatures

NASA Marshall has begun buried-charge testing of spacecraft cable materials at low temperatures, such as will be encountered on the James Webb Space Telescope. At cryogenic temperatures, the conductivity of dielectrics becomes so low that natural space radiation charges may be trapped for months, years, or decades, leading to eventual discharges when the internal electric fields reach breakdown strengths.

Preliminary results have shown that the buried charge concerns are real, and suggest that so-called "leaky" dielectrics (with artificially enhanced conductivity) may be needed for long-term missions in permanent shade, such as the lunar poles or the dark side of the telescope sunshade.

Icing tests

NASA Glenn, in collaboration with the French aerospace research organization ONERA and the University of Illinois, recently completed aerodynamic testing of high-fidelity ice simulations on a full-scale model. This testing took place under a multiyear research effort designed to investigate aerodynamic simulation of ice accretion. The goal of this program is to determine methods and accuracies for which ice accretion can be simulated at small scale and lower Reynolds number to achieve aerodynamic effects equivalent to the full-scale case and to provide full-scale benchmark data for this effort and CFD development.

The aerodynamic testing was carried out in two phases at the ONERA F1 full-scale, pressurized wind tunnel in southern France. The goal of the first phase was to document the aerodynamic performance of the airfoil model with six different ice shape simulations. The goal of the second phase was to acquire detailed flow field data for a single ice simulation configuration. Particle-image velocimetry was used to investigate the separated and reattaching flow field about a large, simulated ice ridge for a subset of angle of attack, Reynolds number, and Mach number. The full-scale data acquired in this program will allow for the continued development of methods for simulating the iced airfoil aerodynamics on subscale geometries and Reynolds numbers. In addition, an excellent database exists for the continued development of computational tools in ice accretion modeling and aerodynamics.

A 6.5%-scale Lockheed S-3B Viking complete airplane model was tested with various simulated ice shapes in the Bihrle Applied Research's Large Amplitude Multipurpose facility in Neuburg, Germany, June 26 to July 10. The objective was to develop a database of complete airplane moments and forces for the non-iced airplane and two iced configurations.

This database will be used to expand the understanding of icing effects on airplane performance, stability, and controllability, and to develop flight simulation models for preflight test analyses of the S-3 iced flight characteristics.

The icing configurations that were tested represented an ice protection system (IPS) failure case and a runback shape that can occur on thermally deiced wings and tails. The IPS failure ice shapes were predicted with the NASA icing prediction code, LEWICE 3D. Runback ice shapes are typically spanwise ridges that form aft of the heated leading edges. In this test, these were simulated with square balsa strips of various sizes. Initial results indicated significant degradations of lift and stall angle of attack, as well as pitch and roll control effectiveness.

Terrestrial environment handbook update

NASA has completed an in-depth revision of the *Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle Development*. First published in the early 1960s, this handbook has been a major source for the development of terrestrial environment inputs for the design and operational requirements used in the development of space vehicles and associated facilities by NASA and other organizations. The handbook provides information relative to the natural environment for altitudes between 90 km and the surface of the Earth for the principal space vehicle development, operational, and launch locations used by NASA and for the associated local and worldwide geographical areas.

The handbook is based on the interactions over the years with design and operational personnel relative to studies, analyses, and engineering questions associated with natural environment information inputs. Given the significance of winds to the design of a vehicle's control and structural system, significant coverage in the document is devoted to wind topics. This new revised handbook is undergoing final review and is scheduled for publication in early 2008. Requests for the handbook can be addressed to the Natural Environments Branch (Code EV44), NASA Marshall Space Flight Center, Huntsville, Ala., 35812. A copy of the handbook can also be downloaded from the NASA Technical Standards Program Website: http://standards.nasa.gov.

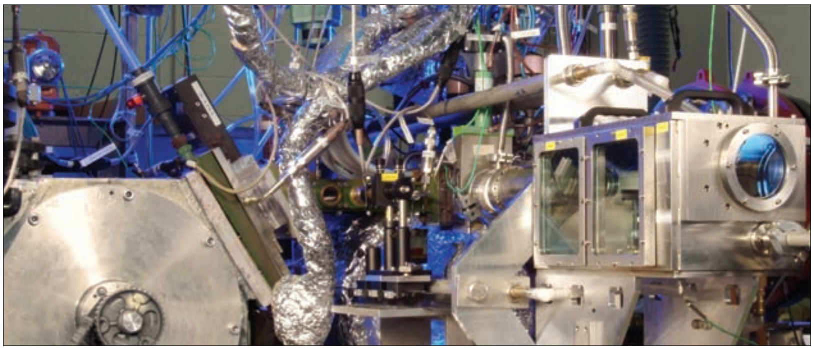
The FPMU was installed on the International Space Station.

Plasmadynamics and lasers

This year saw several noteworthy milestones marking progress toward innovative plasmadynamics and lasers system applications, although investment in long-term aerospace sciences and technology continued trending downward and prospects for an upturn remained bleak.

Plasmadynamics

The Hypersonic Vehicle Electric Power System (HVEPS) program, sponsored by the Air Force Research Laboratory, achieved a major milestone with the successful demonstration of magnetohydrodynamic (MHD) power extraction from the exhaust stream of an NaK-seeded hydrocarbon-fueled scramjet combustor simulating Mach 8 flight conditions. The subscale demonstration experiment, a historic first, employed a diagonal conducting wall generator within a split-coil superconducting magnet to produce 15 kW of electrical power with no adverse impacts on scramjet operation. This collaborative effort by prime contractor General Atomics, LyTec, Pratt & Whitney Rocketdyne, United Technologies Research Center, and NASA Marshall is a remarkable technical advancement and has provided reliable data that firmly establish the technical feasibility of engine-integrated MHD power systems for hypersonic aircraft. By building on this solid foundation, continued progress and advancement toward practical realization may be expected with sustained R&D investment.



The chemical oxygen-iodine laser is operated at the German Aerospace Center (DLR) Institute of Technical Physics. Photo courtesy DLR Institute of Technical Physics.

A parallel effort under HVEPS focused on development of a rocket combustion-driven MHD APU concept, and a successful demonstration experiment was recently completed by the University of Tennessee Space Institute. This concept used the energetic plasma produced from combustion of JP/aluminum-slurry fuel and K_2CO_3 ionization seed with oxygen to drive a Hall MHD generator within the common HVEPS split-coil superconducting magnet. The technical feasibility of the rocket-driven configuration had been established in previous R&D efforts, and the experiment was mainly intended to provide detailed measurements on combustion/plasma conditions and generator performance to validate a state-of-the-art 3D MHD generator code under development by Purdue University.

Observed power generation performance was in very good agreement with preliminary analysis projections, and detailed evaluation and validation efforts continue.

In Japan, various institutions contributed additional technology advancements of significance to aerospace system applications. Most notably, the Tokyo Institute of Technology continued construction and development of its continuous-duty high-temperature closed-loop disk generator facility. This facility uses a 300-kW thermal input electrical heater and a recuperation heat exchanger to heat cesium-seeded argon gas to 2,000 K. This is passed through a small-scale disk generator encased within a 4.2-T superconducting magnet.

The facility, soon to attain full operational capability, has attracted considerable interest since it is prototypical of system architectures for low specific mass closed-cycle nuclear space power plants.

The University of Tsukuba and Nagaoka University of Technology also contributed significant developments in computational simulation of high-interaction MHD generator and accelerator systems. JAXA and Shizuoka University obtained important experimental and computational results that clarified underlying mechanistic principles of MHD flow control.

The development of high-pressure arc-heater technology attained a major R&D milestone that developers hope will lead to the realization of a ground test facility capable of accurately simulating an extended range of hypersonic flight conditions applicable to missile-critical thermal protection systems. Specifically, the Aerospace Testing Alliance's aerothermal testing group at the Air Force's Arnold Engineering Development Center recently succeeded in operating the center's large H3 arc-heater at 167 atm, setting a new world record.

Previously, reliable arc-heater operation was constrained to chamber pressures less than 120 atm by the occurrence of destructive wall arcing and unsustainable heat flux loads. But through committed long-term technology development efforts, the group was able to overcome these problems and to develop a promising strategy for expanding the operational range to 200-250 atm.

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

Lasers

Efforts directed toward development of high-power gas laser systems saw considerable progress, both in the U.S. and abroad. This was illustrated in presentations by personnel from the German Aerospace Center (DLR) Institute of Technical Physics at the 38th Plasmadynamics and Lasers Conference. One talk discussed the German Ministry of Defense's tactical chemical oxygen-iodine laser (COIL). This tactical-scale COIL laser program, similar to the U.S. Airborne Laser and Advanced Tactical Laser programs, provides a critical push for high-power gas laser technology development and deployment by demonstrating the capability and effectiveness of lasers as weapon systems in a field environment.

This medium-power laser addresses issues such as deployment of fuels, system transportability, and operation in a nonpristine laboratory environment, as well as test range firing and beam propagation. Unique innovations enabling the use of COIL technology were also demonstrated in the DLR presentations, including development of a negative branch hybrid resonator to address the requirements of low-gain operation in rectangular geometries under rugged operational conditions, and a cryogenic storage system for basic hydrogen peroxide that enables long-term storage of this fuel in the field.

Development of electrically powered alternatives to high-power gas lasers continues to intensify, as interest in reducing or eliminating the logistical constraints of chemical lasers remains unabated. Efforts to develop a hybrid electrical-chemical laser in the form of the discharge driven electric oxygen-iodine laser (EOIL) reached a milestone recently with a demonstration of 30% singlet-delta oxygen yield under thermally controlled conditions by Plasmatronics and the AFRL Directed Energy Directorate. A significant attribute of the system in which this was demonstrated is the scale of the device, with a potential lasing power based on the singlet-delta oxygen yield and flow rates in the device of 2.3 kW. A lasing demonstration approaching this power would address questions regarding the scalability of EOIL to high powers.

Another hybrid gas-electric approach utilizes diode sources to optically pump gas-phase alkali metals such as cesium and rubidium. This technology was first demonstrated by Lawrence Livermore National Laboratory in 2004 at 0.23 W, and many technical issues remain to be overcome to demonstrate relevant powers at the kilowatt level. However, DPALs may offer a hybrid solution combining solid-state and gas laser elements bridging the two technologies.

A frozen basic hydrogen peroxide batch is used to demonstrate long-term fuel storage for chemical oxygen-iodine laser operation at the German Aerospace Center (DLR) Institute of Technical Physics. Photo courtesy DLR Institute of Technical Physics.

Solid-state laser technology continues to advance into a power regime formerly the sole domain of gas lasers, replacing them in key applications such as cutting and welding. The Joint High-Power Solid-State Laser (JHPSSL) program, funded by the Joint Technology Office for High Energy Lasers, the Army Space and Missile Defense Command, the AFRL Directed Energy Directorate, and the Office of Naval Research, seeks to demonstrate a 100-kW solid-state laser for military application. Building on a 350-sec, 27-kW lasing demonstration by Northrop Grumman in Phase 2 of the program, Phase 3 looks to achieve 100 kW powers. High-power fiber lasers have also shown considerable promise, with single-mode power per fiber having reached 3 kW as demonstrated by IPG Photonics. As power per fiber increases, advantages such as high heat rejection, single-mode operation, and efficiency may lead to 100-kW high-power fiber lasers in the not too distant future.

The field of aerooptics is focused on development of methods to control aerooptic aberrations and development of coupled optical field to CFD models to provide detailed physical information and aid in the engineering process. Recent work has elucidated the difficulties associated with using conventional controllers with adaptive optics mirrors to correct the optical field for aerooptic aberrations given the 1-kHz and greater frequencies within the shear layer, resulting in system latencies and sensing and response limitations. Lines of investigation to circumvent the difficulties associated with adapting to high-frequency aberrations include the use of plasma or acoustic active flow control to reduce the high-frequency content, and the use of alternate control strategies such as adaptive control.

CFD model development is proceeding away from singular reliance on steady-state simulation with statistical-turbulence models to time-dependent, large-eddy, and direct-eddy simulation, where the spatial and temporal scales of the dominant aberrative structures are directly resolved to more accurately capture the optical field to fluid field interaction.

Guidance, navigation, and control

by **Daniel J. Clancy**
Nijel Granda
Leena Singh

Several milestones in guidance, navigation, and control technologies were achieved this year in the areas of weapons and missiles, aircraft, and spacecraft.

Weapons systems

Advances in modern nonkinetic weapons are combining high-power microwave devices with lasers. These new directed energy weapons rely heavily on sensor fusion and target networking rather than new breakthroughs in electronic warfare. Modern electronic attack focuses on identifying, compromising, and exploiting enemy networks ranging from cell phone communication systems to air defense systems.

BAE Systems is using lasers to multiply the speed and power at which high-power microwave (HPM) weapon pulses can be produced, thereby removing the need for explosives or high-power electrical generators. Example HPM missions include defeating cruise missiles at operational ranges, detecting and detonating visible or hidden improvised explosive devices, attacking mobile antiaircraft missile launchers, and eliminating collateral damage to people and structures by disabling enemy communications and electrical power.

The Sentinel unmanned surface vehicle has optional launching and landing facilities for UAVs such as this GLOV.

In addition, photonically driven technology from BAE Systems could enable production of stealth-detecting sensors for use on aircraft that generate tens of gigawatts of power, thereby enabling the detection of a stealthy object at 160 km with 30-cm resolution. Fly-by-wire aircraft flight control systems limit the use of HPM systems because they can be interrupted or disabled by HPM energy spikes. BAE Systems is designing a fly-by-light flight control system for UAVs. Its actuators are triggered by laser light and therefore are immune to the HPM spikes.

In March the Navy accepted delivery of the first Sentinel, an 11.6-m unmanned surface vehicle produced by Accurate Automation. Designed for riverine operations, the Sentinel has a multiple configuration sensor suite and advanced sensor fusion capability that supports both remote and autonomous operation. The software meets full Joint Architecture for Unmanned Systems requirements with encrypted telemetry, network-centric communication, and data acquisition systems based on UAVs.

The vehicle has optional UAV launching and landing facilities, and work is ongoing to develop a UAV recovery capability. The Sentinel features a patented sensor fusion network that performs target identification and employs a towed, offboard sonar system, onboard real-time optical sensors, a radar system, and acoustic sensors. A GPS with an inertial measurement unit is used by the autonomous navigation system. The Sentinel uses an adaptive control, guidance, and navigation system that features intelligent wave navigation, antiporpoising detection and compensation, obstacle avoidance, and multiship operation. It is also able to support intelligence, surveillance, and threat reconnaissance, mine warfare, antisubmarine, and, eventually, surface warfare.

In June the Missile Defense Agency successfully demonstrated that an Aegis destroyer equipped with a ballistic missile defense system is capable of intercepting a threat missile during the midcourse phase. The USS Decatur, an Aegis destroyer, detected the threat missile, which originated from the Pacific Missile Range Facility in Kauai, and launched a Standard Missile 3 Block 1A interceptor that destroyed the threat missile after booster separation occurred.

Aircraft

In August, the Navy awarded a Northrop Grumman-led team a contract under the Unmanned Combat Air System Carrier Demonstration (UCAS-D) program to conduct the first ever at-sea carrier launches and recoveries with a fixed-wing unmanned air system, the X-47B. The company demonstrated a similar capability in 2006 with its MQ-8 Fire Scout rotary-wing UAV—the first completely autonomous VTOL aircraft to land aboard a Navy vessel under way. The first of two UCAS-D air vehicles is scheduled to fly in late 2009 and will begin a series of detailed flight envelope and land-based carrier integration and qualification events beginning in 2010. The first autonomous at-sea carrier landings are planned for late 2011, with follow-on analysis and program completion expected by 2013.

On July 8, Boeing rolled out the 787 Dreamliner, whose gust suppression system senses pressure differences before inertial motion begins. Sensors around the aircraft measure changes in angular velocity and pressure distribution. Gyros and accelerometers detect the motion caused by external disturbances such as wind gusts. At the same time, pressure sensors detect pressure distribution changes around the skin of the airplane through a selected number of static air intake ports.

During flight, the flight control system takes in the data, applies proprietary software algorithms, and sends the appropriate commands to the rudder, elevators, spoilers, ailerons, and flaperons. As a result, the aircraft autonomously actuates the control surfaces it needs to prevent its own inertial reaction to the wind gusts.

High-flying RQ-4 Global Hawk unmanned aerial systems built by Northrop Grumman completed their 1,000th flight. The fourth production Global Hawk, designated AF-4, flew the milestone mission June 14-15 in support of the global war on terrorism. AF-4 cruised at extremely high altitudes for over 18 hr without refueling. This was the 517th combat mission flight for the Global Hawks, which have logged more than 10,700 combat hours, accounting for 71% of the program's total flight time of 15,135 hr. The aircraft are operated overseas by Air Force pilots from a mission control element stationed at its main operating base at Beale AFB near Sacramento, Calif. The pilots' main interaction with the vehicles and their flight control systems is with a keyboard and mouse.

In December 2006, the Lockheed Martin F-35A Lightning II conducted its maiden flight. The fifth-generation stealth fighter will provide its pilot with unsurpassed situational awareness, allowing full spherical surveillance and tracking, positive target identification, and precision strike under any weather conditions.

Spacecraft

In June, EADS Astrium announced that it had begun preliminary development of a space tourism vehicle that would carry four passengers and fly at suborbital altitudes up to 100 km. The space bus is designed to lift off and land from commercial airports with conventional jet engines, with a second, rocket engine stage that ignites at 12 km altitude to provide sufficient thrust to reach 100 km. Small rocket thrusters to control the space vehicle's trajectory will permit 3 min of flight in orbit before descent into the atmosphere. The company plans to start full-scale development in 2008, with first commercial flight by 2012.

Also in June, Bigelow Aerospace launched the Genesis 2 inflatable space module on a converted Russian ICBM. The spacecraft is controlled from the Bigelow space control center in Las Vegas, Nev. Along with Genesis 1, Bigelow now has two commercial space modules in approximately 480-km orbits.

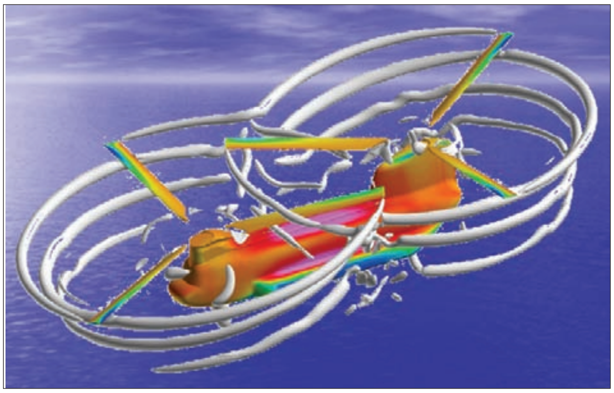
China conducted its first successful antisatellite missile experiment in January this year, colliding a missile with its Fengyun 1C polar-orbiting weather satellite and producing the largest single-event sourced debris field that ranges from below 200 km in altitude up to almost 4,000 km. A NASA Earth observing satellite, Terra, had to maneuver at least once on June 22 to avoid debris from this collision.

Artist's concept shows the X-47B landing on an aircraft carrier.

The Far Ultraviolet Spectroscopic Explorer (FUSE) satellite mission was extended in April when the NASA Goddard/Johns Hopkins University team performed a "brain transplant" by uploading new flight control software for the attitude control, instrument data, and fine-error sensor processor systems. In December 2006, FUSE was nearly lost when two of its reaction control wheels failed. Another part of the attitude control problem fix implemented by the FUSE team was to establish a local electric field by running electricity through the magnetic torque bars, which enables controllers to use the Earth's magnetic field to help point the satellite.

Meshing, visualization, and computational environments

Computational analysis for product design and research is enjoying growth both in the number of projects that are successful and in the size and complexity of the simulations. Automated mesh generation, driven directly from CAD and efficient, economical cluster computing, permits more analyses to be run and can generate huge amounts of data to be postprocessed to provide greater understanding for users.



Unsteady CFD computations have been made of the CH-47 Chinook tandem helicopter in hover. Image courtesy Boeing and the Army AFDD.

With simulation requirements growing ever more complex, a case management environment is needed to provide a solution for users to prepare, submit, monitor, and manage these CFD runs more efficiently to improve the simulation throughputs. To address this need, DOD's Major Shared Resource Center (MSRC) sponsored the development of a computational environment tool called CaseMan, under the User Productivity Enhancement and Technology Transfer (PET) program (Project CFD-KY7-001). CaseMan is a tool designed to make setting up, submitting, and monitoring CFD jobs easier and less complex.

To provide a flexible computational environment for most commonly used CFD solvers and computing facilities, and to give end users an easy way to incorporate more flow solvers and HPC systems into CaseMan, the tool's design allows abstraction on solvers and computing environments. This makes CaseMan solver-neutral and system-independent. The tool eliminates the need for users to edit complex input files, write submission scripts, or learn the intricacies of each solver. CaseMan has been tested on several DOD MSRC and commodity HPC systems under various job-queuing environments.

CAD-centric enterprise product life-cycle management tools came of age this year. The timely rollout of the Boeing 787 was significantly enabled by Boeing's Global Collaborative Environment. A key supplier to this environment was long-time French partner Dassault Systèmes, maker of the CATIA-V CAD software. At the same time, Boeing selected competitor Siemens/UGS's Teamcenter as its enterprise data management system for all its new programs. It seems that multiple sourcing is not just for airlines, but also for aircraft manufacturers.

We also saw the introduction of simulation-centric collaborative engineering software based on enterprise Web application servers such as IBM's WebSphere and BEA's Weblogic. These new tools allow engineers to create and reuse standardized simulation models and share them with partners through Internet, intranet, and VPN clients. Alenia of Italy is deploying MSC Software's SimManager for its ALENET program to improve engineering efficiency. This software's strength is its ability to control and access simulation data and trace project history. Meanwhile, Engineous' iSIGHT-FD/FIPER system is being used by Pratt & Whitney to execute large automated design studies. Distinctive features of Engineous are its open, vendor-neutral approach with respect to data management, grid computing, CAD and CAE integration, and its ability to allow engineers to set up their own projects without programming or IT services.

In the area of large-scale postprocessing, parallel computation on HPC resources is becoming a more common workflow practice. Recently, Intelligent Light was subcontracted to create data extracts and movies for the CH-47 helicopter program. The company's Applied Research Group, contracted by the Army AFDD (through Monterey Technologies), is using NASA's Columbia supercomputer, where the unsteady CH-47 Overflow computation was run. With a model size of 71.1 million grid points, each time step requires 3.1 Gb of disk storage—five revolutions of the rotors produces 2.35 Tb of data.

Intelligent Light's FieldView software, run in parallel batch jobs, is being used to process the results of the computation, creating both movies and highly compressed 3D extract files that are used with the company's ATViewer product. As data sizes for unsteady calculations and solution spaces for parametric studies grow, data management and the use of automated knowledge extraction are becoming increasingly important.

by **Steve M. Legensky**