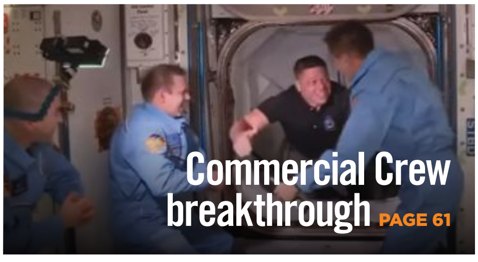
AEROSPACE AMERICA

2020

YEAR-IN-REVIEW Researchers, industry persevere through the pandemic.



Commercial Crew breakthrough PAGE 61

DECEMBER 2020 | A publication of the American Institute of Aeronautics and Astronautics | aerospaceamerica.aiaa.org

AIAA
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A SpaceX Crew Dragon with four Crew-1 astronauts aboard approaches the International Space Station for docking.
NASA

THE YEAR IN REVIEW

The most important developments as described by AIAA's technical, integration and outreach committees

ON THE COVER
Airlines parked hundreds of jets in Victorville, California, when the pandemic forced a shutdown of air traffic.
John Kilmer/AirTeamImages

YEAR IN REVIEW

DEPARTMENTS

What's wrong with a student's prototype of an early aerobatic plane?

AEROSPACE AMERICA

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AIAA
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▲ **A Boeing-FAA crew** tests a 737 MAX aircraft in July.
FAA

Making progress despite pandemic

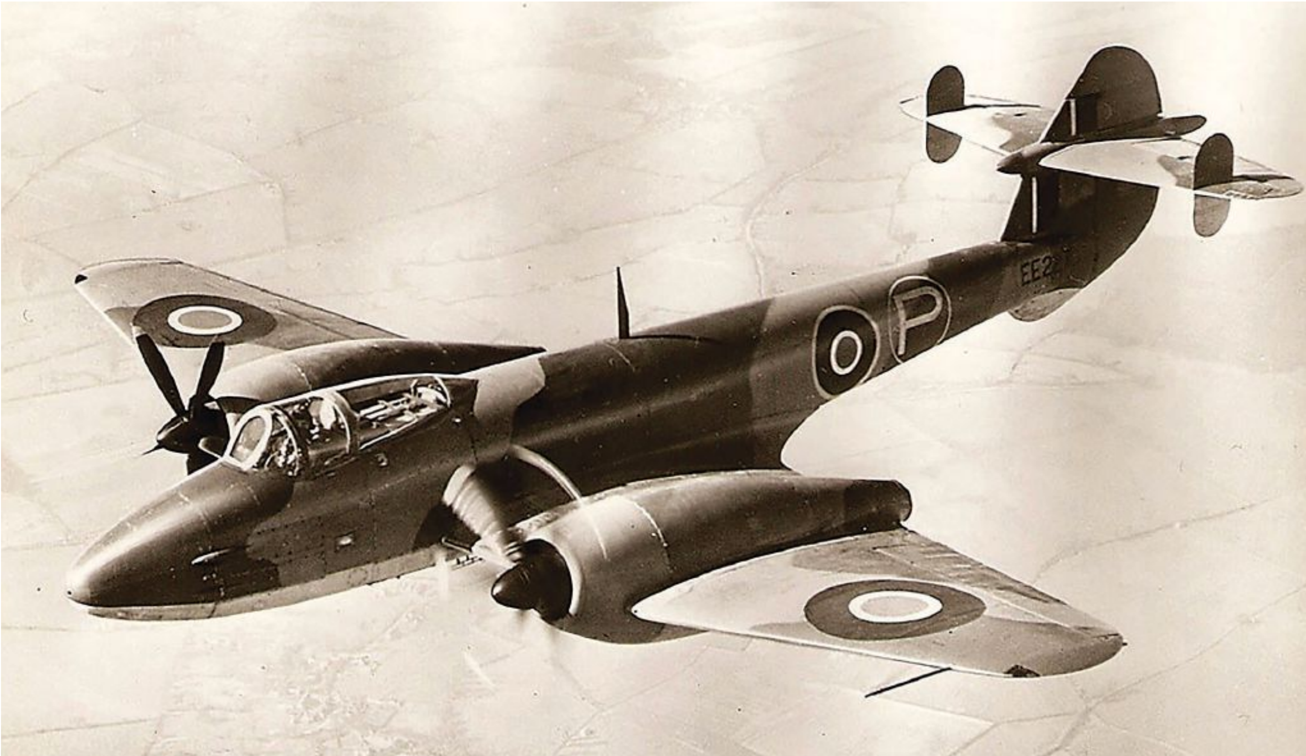
I know this will sound strange, and I don't mean to downplay the hardships many in this industry are facing, but the pages of this special issue are not starkly different from what I might have predicted back in January when the year began with such promise and the term covid-19 had yet to be coined.

Commercial Crew vehicles delivered astronauts to the International Space Station twice. Masked workers at the Lockheed Martin Skunk Works factory continued assembling NASA's X-59 Quiet Supersonic Technology plane. DARPA and Dynetics flew their X-61A Gremlin drones and pressed toward proving the concept of dispatching them from C-130s and recovering them in flight. The U.S. Air Force launched an X-37B spaceplane for the first time in three years. In space exploration, China, the United Arab Emirates and the United States each launched spacecraft toward Mars. A sample of the asteroid Bennu was still collected by NASA. As of this writing, the 737 MAX aircraft remains grounded, but in November FAA completed its 20-month safety review and lifted its grounding order, clearing the way for the airlines to make the required software, wiring and training changes. Behind the scenes, new versions of computational fluid dynamics software were released; exotic propulsion technologies tested; materials studied. Overall, there were literally too many examples of progress this year for me to allude to all of them here.

Peruse this issue of Aerospace America, and you'll sense the perseverance of the aerospace industry in the U.S. and abroad in the face of this global pandemic. Original equipment manufacturers and the airlines innovated to make flying as safe as possible, and in that way moderate the undeniably terrible effects of the pandemic on their businesses. In research and development, those who could not continue their experiments took the opportunity to assess progress, present papers virtually, plan their next experiments and propose architectures for space missions.

As dark as this winter could prove to be, this issue gives me faith that the 2020s will still roar. ★

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



Mike Dowsing Collection

In the September Looking Back column, we ran an incorrect photo to illustrate the Gloster Meteor turbprop prototype. Above is the correct photo.

A teaching moment

Q: It's the early era of aerobatic flight. An aeronautics professor has procrastinated on reviewing the design of his student's aerobatic prototype. Outside, he sees the rogue student climbing into the prototype and preparing to take off. Picking up a stack of papers, the professor sees a chapter titled "Reduction of turbulent flow for optimized maneuverability." He tosses them into the air and sprints out to the flight line. Why?

Draft a response of no more than 250 words and email it by noon Eastern Dec. 9 to aeropuzzler@aiaa.org for a chance to have it published in the January issue.

FROM THE NOVEMBER ISSUE

BUZZING OFF COURSE: We asked you how a voice-controlled Human Maneuvering Unit would respond to an astronaut on the International Space Station who told it to "make a straight beeline" for the nearby Bayer Sustainability Lab, or BSL. Space scientist Laura Forczyk and astrophysicist John Mather reviewed your responses.

WINNER: "We are in orbit, so unless we are constantly firing our thrusters, all orbital paths are made of elliptic curves. We could waste a lot of fuel to straighten out our path, but I would caution that it would be very dangerous for both of us if we ran out of fuel before we could reach the destination and drifted off into an orbit that would never intersect the BSL, or worse, put us on a path toward reentry. Allow me to calculate a maximally efficient burn so that we will get there quickly yet have plenty of fuel for contingencies."

Jeffrey J. Mach
Santa Clara, California
Mach works for Sierra Lobo Inc. as a site manager at the Thermophysics Facilities Branch of NASA's Ames Research Center.

For a head start ... find the AeroPuzzler online on the first of each month at https://aerospaceamerica.aiaa.org/ and on Twitter @AeroAmMag.

Cybersecurity: Inserting Protection at the Heart of the Aerospace Industry

Cybersecurity is an issue of growing prominence within the aerospace industry. It is becoming more and more essential to address cybersecurity on an ongoing basis in the mainstream of our core processes – from the design and development of new space systems to manufacturing and production to operations.

The aerospace industry is on a rapid growth trajectory, evidenced by boosts in private investments, new launch capabilities, and emerging commercial opportunities in low Earth orbit, to name a few. As we continue to drive this dynamic progress forward, we must aggressively protect it with strong cybersecurity practices.

Case in point – our growing satellite constellations. Without robust cybersecurity protocols, hackers could take control, shut them down, deny user access, or jam the signal. Such an invasion could cause major harm to infrastructure dependent on these satellites, such as electric grids, water systems, and transportation networks.

Historically, aerospace has been hesitant to embrace mainstream cybersecurity. The subject has not been emphasized in most undergraduate aerospace curricula nor consistently included in aerospace development and manufacturing processes. Rather, we have seen only small bursts of focus in both areas. We must move toward a more routinized approach from concept development to operations. This is a big task requiring engagement throughout the aerospace supply chain.

There are two real-world factors causing our industry to take a more serious approach to cybersecurity. The fear of an attack or breach of an aerospace company that results in revealing proprietary information always looms. We saw an example of this in late 2019, when ransomware infected a regional airline operator out of Alaska and interrupted operations.

Then there is the more subtle challenge – the emergence of new cybersecurity regulations on the aerospace industry. When similar regulations hit the power grid and commercial nuclear industries over the past decade, the effort of becoming compliant and staying in business under the new guidelines was costly and complex. These companies endured significant organizational stress adapting their people, processes, and technologies to the new regulations. Many incurred unexpected capital and consulting costs to satisfy new cyber audit requirements. The aerospace industry is primed for similar issues.

The DoD's Cybersecurity Maturity Model Certification (CMMC) requires every company that does business with the federal government to comply with a certain level of cybersecurity requirements, based on work provided. Space Policy Directive 5 requires cybersecurity principles and practices currently applied to terrestrial systems be applied to space systems and integrated into every phase of the space system life cycle.

As a result, AIAA has spent the last year bringing cybersecurity front and center. We are committed to bringing you credible resources within four tracks for you to stay abreast of the latest developments.

Track 1 – Events. Cybersecurity content has been added to all AIAA forums. We are coordinating competitive online learning labs, such as hack-a-thons. The most recent one at 2020 ASCEND proved extremely insightful to all attendees. We are also hosting tabletop exercises to share information with senior executives about current trends, best practices, and how to develop their own robust protection programs.

Track 2 – Technical talks and presentations. In May, Matthew Scholl with the National Institute of Standards and Technology shared compelling insights on advancing cybersecurity in space on an episode of the biweekly AIAA Space Policy Pod. There are other examples of technical deep dives on this issue archived on our website.

Track 3 – Ongoing education. We will offer a new industry course by the third-quarter of 2021, designed to inform participants on the major issues regarding the nexus of aerospace and cybersecurity. Our *Daily Launch* newsletter now features several articles a day on the specific role of cybersecurity in the aerospace industry.

Track 4 – Engaging our members. The Aerospace Cybersecurity Working Group has been the driving force behind our increased focus on this topic. So far, they have pursued small projects, but we are empowering them with the resources and guidance they need to make real progress. Our Cybersecurity Steering Group includes senior AIAA members and outside experts who collectively engage and advise the Institute on what we should/should not be doing in terms of cybersecurity. Among their recommendations is partnering with organizations such as the Space Information Sharing and Analysis Center (ISAC). There are ISACs for nearly every major industry. They collect information from an industrial sector and share it with the government. AIAA already has a cooperation agreement with the Aviation ISAC, and will soon have one with the Space ISAC, which will open dialogue and cooperation around this topic.

Most recently, we commissioned a Cybersecurity Findings Report that measured AIAA members' level of concern with cybersecurity. Nearly 75 percent of the members expressed strong interest in each of the tracks mentioned above. This report will soon be released on our website. These steps are just the beginning of our long-term commitment to cybersecurity in our industry.

Everyone in our industry is energized by our growing space economy and promising new aviation innovations. Let us protect that momentum. Join us in truly giving cybersecurity the attention it deserves. Take the time to begin or deepen your knowledge of this new emphasis on aerospace cybersecurity. We must act NOW! ★

Dan Dumbacher
Executive Director, AIAA

On-orbit and wind tunnel tests demonstrate potential of morphing structures

BY JEFFREY L. KAUFFMAN

The work of the **Adaptive Structures Technical Committee** enables aircraft and spacecraft to adapt to changing environmental conditions and mission objectives.

▲ **The SmartX-Alpha** demonstrator (dark vertical structure in wind tunnel) has moveable flaps and piezo-controlled fins to react to changes in wind currents.
Delft University of Technology

The U.S. Air Force Research Laboratory's **Spacecraft Structural Health Monitoring program** concluded experiments in geosynchronous Earth orbit in 2020. It was the third flight in a series started in 2017 on the **Space Test Program-Houston 5**, or **STP-H5**, a NASA-U.S. Defense Department testbed for experiments on the International Space Station. Previous experiments focused on monitoring launch events, **characterizing spacecraft changes in orbit**, **evaluating damage-detection techniques** and cataloging thermal profile influence. This year's experiment focused on **radiation effects**, which are most noticeable in low-Earth orbit and corrupt measurement data on stored volatile memory. Long-term data storage in non-volatile memory also was corrupted in LEO but showed no degradation in GEO.

In January, the Harbin Institute of Technology in China **validated a flexible solar array** in another on-orbit demonstration. A key system element is a pair of shape-memory-polymer composite tubes for clamping and releasing the solar array. Instead of traditional electro-explosive devices or deployment motors, the SMPC tubes unlocked with minimal shock load. The SMPC solar array then automatically unfolded over the next minute to its designed shape and maintained stiffness once deployed. The team indicated this result will lead to SMPCs being built into larger deployable space structures and new release and locking mechanisms.

Researchers at Texas A&M University and engineers at Arizona-based Paragon Space Development Corp. developed and **tested a shape-memory-alloy-actuated prototype radiator** that used a single-loop, two-phase fluid flow in February. It was the first passively adapting SMA radiator ever built. The test results make researchers think that an SMA torque tube-driven radiator can outperform current two-loop radiators and provide new insight into the potential operation of SMA thermal control devices configured as heat pipes.

The adaptive structures community also performed groundbreaking tests for aeronautical applications. In August, researchers at the Delft University of Technology in the Netherlands hastened the next leap in smart aeronautical structures with wind tunnel tests of the **SmartX-Alpha active morphing wing demonstrator**. The sensor- and actuator-rich demonstrator featured a distributed chordwise and spanwise seamless morphing trailing edge, piezoelectric flow sensors and fiber optics. The SmartX project, conceived in 2016, focuses on integrating existing and newly developed sensing and actuation smart technologies into a wing. In the wind tunnel tests, the researchers optimized the static and dynamic wing shape for real-time optimal high-lift and cruise flight performance, as well as simultaneous active maneuver and gust load alleviation using data fusion control algorithms.

A team at the University of Central Florida tackled morphing on a smaller scale, conducting tests in a towing tank in March and September. Funded by the U.S. Navy's Office of Naval Research, the tests showed **dynamic spanwise airfoil twisting during unsteady acceleration can augment aerodynamic lift**.

Also in March, the first set of acoustic beamforming tests of a slat gap filler configuration were completed in the Texas A&M 3-foot-by-4-foot wind tunnel under the sponsorship of NASA's Langley Research Center in Virginia. These test results will help engineers design and demonstrate **SMA-based self-deploying slat gap fillers** for reducing aerostructural noise in transport-class aircraft.

Researchers at Arizona State University focused on airframe structures, developing a new framework to **accelerate the design of complex nano-enhanced composites**. Funded by the Office of Naval Research, the researchers' atomistically informed damage evolution law links nanoscale phenomena to structural-scale damage and response, and a high-fidelity homogenization technique captures material behavior across multiple length scales. The team validated the framework in March using test data for carbon-nanotube-based polymer composites. ★

Electrification, model-based engineering achieve performance, sustainability design goals

BY LISA SAAM

The **Design Engineering Technical Committee** promotes the development and dissemination of technologies that assist design engineers in defining practical aerospace products.

Electrification of general aviation aircraft became a reality in May when the European Union Aviation Safety Agency for the first time **type certified an all-electric aircraft**, the two-seat **Velis Electro**. The aircraft was developed and manufactured by Slovenia-based Pipistrel.

In the United States, NASA released illustrations in March of the final design of its first all-electric X-plane, the **X-57 Maxwell**. Empirical Systems Aerospace, the prime contractor, has tested the electric cruise motors at its facility in California, while also designing modifications to the wing. NASA plans to share lessons learned on the project to aid FAA in creating certification standards for electric aircraft.

The benefits of model-based engineering combined with data analytics and artificial intelligence became apparent in industry this year. Rolls-Royce generated digital twin support through industrial partnerships and employing its digital strategy with the **Pearl 700 engines** for the **Gulfstream G700**. A **digital twin** is a virtual representation of a physical object that shares data throughout the object's life cycle. The first flight of the G700 occurred Feb. 14 in Savannah, Georgia. The benefit of using a digital twin is that preventive maintenance can be individualized with high-fidelity simulation based on live sensor data. Onboard sensors and simulation data inform engine diagnostics that can be used to improve performance and monitor engine health.

In March, the U.S. Army selected **Bell Textron's 360 Invictus** helicopter and **Sikorsky Aircraft's Raider X** coaxial compound helicopter to proceed to detailed design, build and testing as part of the **Future Attack Reconnaissance Aircraft** competitive prototypes program. The Army assessed performers on the air vehicle capabilities of their preliminary designs from phase one of the program. The assessment also evaluated the vendors' ability to implement rapid prototyping processes and digital engineering interfaces for technical data exchange with the government to speed up competitive prototype flight demonstrations and the total life-cycle sustainment for a potential follow-on acquisition program.

Honeywell said in August it had received FAA certification for the **first additively manufactured flight-critical part**. The part is the No. 4/5 bearing house in the ATF3-5 turbofan engine, which was originally designed and certified in 1967. This certification demonstrates the maturity of additive manufacturing and the viability of 3D-printed parts as a solution to supply system obsolescence for sustaining aircraft. The U.S. Army also recognizes this potential, as demonstrated by a new policy published in September to address airworthiness of 3D-printed parts.

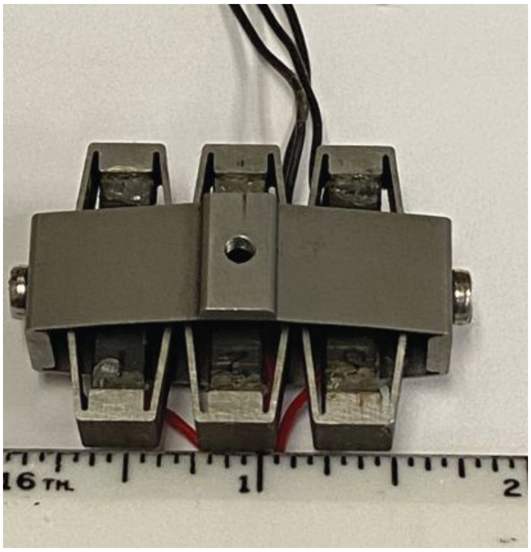
NASA and industry partners accomplished several tests to verify and validate the designs of elements for NASA's **Artemis** program, which aims to put humans on the moon again by 2024. Repeated storms slowed NASA's attempts to complete tests on the **Space Launch System core stage** at Stennis Space Center in Mississippi. Each test incrementally built on the next by increasing the scope of items being tested; the sixth test was in October and simulated countdown procedures that begin 48 hours before liftoff. Another milestone for the Artemis program was the June completion of structural testing of an **Orion structural test article** at Lockheed Martin in Colorado. NASA also completed the SLS rocket's structural testing in June when it tested the liquid oxygen tank to its failure point at Marshall Space Flight Center in Alabama. Northrop Grumman conducted a **full-scale SLS booster test** in Utah in September to evaluate materials and processes to improve the booster's performance. ★

▲ **The European Union** Aviation Safety Agency certified the Velis Electro, the agency's first certification of an all-electric general aviation aircraft.
Pipistrel

Materials tested for new and challenging missions, including space habitation

BY TERRISA DUENAS AND ED GLAESSGEN

The **Materials Technical Committee** promotes interest, understanding and use of advanced materials in aerospace products where aerospace systems have a critical dependency on material weight, multifunctionality and life-cycle performance.



This 34-gram prototype PMN-PT-stacked two-stage cryogenic actuator can drive 5 kilograms of mass with a half millimeter off-resonance displacement at minus 175 Celsius (minus 283 Fahrenheit) for space applications.

Old Dominion University/PolyK Technologies

The aerospace materials community this year sharpened the leading edge of its research for operations in extreme environments. Space flight and habitation led the year, with improved cryogenic actuation efficiencies, higher resolution hypersonic and hypervelocity testing, and advances in high-temperature, space flight and habitation.

In February, Tian-Bing Xu, a professor at Old Dominion University in Virginia, led a group that collaborated with PolyK Technologies in Pennsylvania to demonstrate a **Relaxor piezoelectric Pb(Mg1/3Nb2/3)1-xTixO3 (PMN-PT) single crystal actuator**. It showed excellent cryogenic actuation properties with 80% ultra-high energy efficiency. This design may be a game changer for **cryogenic fuel management for advanced rocket propulsion systems**, space instrumentation and optical system controls and lead to advanced space actuators for NASA missions. The output sustained sufficient stroke and force to drive cryogenic components for broad aerospace applications. In addition, PMN-PT materials may be used to make ultra-high-efficiency cryogenic ultrasonic motors for space drillers and robotics applications.

In April, J.H. Koo, H. Wu and their colleagues at KAI LLC in Texas developed a **cost-effective material screening approach for thermal protection systems.** The traditional methods of manufacturing TPS for spacecraft are labor-intensive. It is difficult for a designer to visualize TPS materials being fabricated and integrated onto a structure with automation. KAI and the Koo Research Group at the University of Texas at Austin have been developing novel high-performance polymer matrix composites for extreme environments. One of the challenges is to obtain reliable material response data under such conditions. KAI has proposed a comprehensive material screening protocol with fast turnaround time. The developed methods include material formulation study using design of experiments, characterization of materials' thermal stability, char yield and flammability, and aerothermal ablation testing using an oxy-acetylene test bed to simulate heat fluxes from 100 to 1,600 watts per square centimeter for exposure times with advanced diagnostics. This methodology allows for rapid comparison of material systems and will **fast track the development of new TPS materials for space missions**. It is being applied to projects funded by the U.S. Defense Department and NASA.

At Embry-Riddle Aeronautical University in Florida, researchers Muhammad Anees, Audrey Gbaguidi and Yachna Gola and professors Daewon Kim and Sirish Namilae collaborated with LUNA Inc. of Virginia on **development of piezoresistive sensors to enable full coverage structural health monitoring and impact detection for NASA's inflatable space habitats**. Two flexible sensor prototypes were developed. One consisted of carbon nanotube buckypaper infiltrated with a mixture of epoxy and graphene. The other was an inkjet-printed device based on conductive CNT ink formulated in-house. In January and March, Gbaguidi led the development, characterization and testing of the inkjet-printed sensors as highly conductive and strain sensitive materials. The sensors were embedded into inflatable structure test articles and tested under hypervelocity impact at 7 km/s to simulate micrometeoroid and orbital debris impact. Both sensors detected the location, depth and severity of the damage. The team developed a computational model (percolation-based) with Monte Carlo simulations to simulate nanocomposites with CNT and graphene. The model was first validated against experimental results and was used to find the optimum microstructures for the two sensors fabricated above. The computational model was finalized in May and can model the electrical conductivity and strain and damage sensitivity of nanocomposites in 2D and 3D.

In July, a **new class of hybrid nanostructured material development for acoustic and thermal isolation** was completed. Researchers from Embraer of Brazil and UFMG/SENAI, a materials company in Brazil, demonstrated that the aero-nanomembranes are 30% lighter than traditional isolation systems and can be tailored for different frequencies. ★

***Contributors:** Antonio F. Avila, Audrey Gbaguidi, Hao Wu and Tian-Bing Xu*

Progress from artificial intelligence to wing structural design optimization

BY DOUGLAS ALLAIRE, JOHN HWANG AND GIUSEPPE CATALDO

The **Multidisciplinary Design Optimization Technical Committee** provides a forum for those active in development, application and teaching of a formal design methodology based on the integration of disciplinary analyses and sensitivity analyses, optimization and artificial intelligence.

This year had important software releases from the multidisciplinary design optimization community. In March, NASA released **Version 3 of OpenMDAO**, an open-source, high-performance computing platform for systems analysis and multidisciplinary optimization, with additional updates published monthly. Version 3 introduces changes to the software interface that improve the accessibility and usability of OpenMDAO. The **OpenMDAO libraries Dymos and pyCycle were released under open-source licenses**. Dymos is a pseudospectral optimal control library, and pyCycle provides a set of thermodynamic propulsion models for engine-cycle analysis.

Also in March, the Systems Optimization Laboratory at McGill University in Quebec released on GitHub a novel relative adequacy framework for multimodel management in multidisciplinary design analysis and optimization for both time-invariant and time-dependent problems.

In May, the University of Central Florida published a **new release of PiNN**, an open-source code for physics-informed neural network modeling. The work extends recurrent neural networks to cumulative damage modeling of wind turbine bearing fatigue and corrosion-fatigue of fuselage panels implementing physics-informed and data-driven layers within one deep neural network.

In June, researchers at the University of Texas at Austin's Oden Institute for Computational Engineering and Sciences released the **scientific machine learning Operator Inference package**, which learns reduced-order models directly from high-fidelity simulation data. By embedding the structure of the governing equations, the Operator Inference reduced-order models have predictive capability not possible with black-box machine learning. This is important for using reduced-order models to accelerate complex physics computations for multidisciplinary design.

The past year also saw important advances in multidisciplinary design optimization methodology and validation. In January, the University of Washington performed integrated engine-pylon structural design optimization at a level of load distribution and stress analysis modeling details that meet current certification requirements. The researchers achieved major weight, cost and schedule gains, and the work lays the foundations for the integrated single-process structural optimization of certification-ready complete airframes.

In February, the Massachusetts Institute of Technology developed an **optimization method for the deflection of incoming asteroids** with destructive potential for Earth using multistage mission campaigns. The method combines orbital dynamics, spacecraft design and planetary science in a common framework that incorporates epistemic uncertainty.

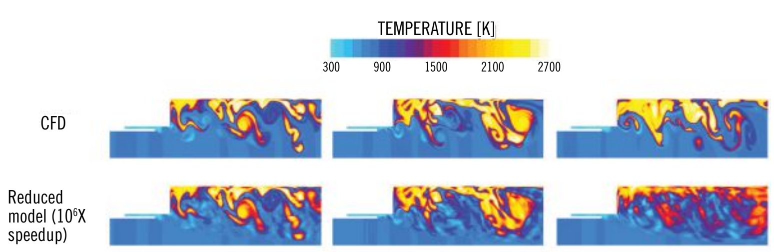
Also in February, the Multidisciplinary Analysis and Design Center at Virginia Tech developed a bilevel optimization framework for the uncrewed research aircraft mAEWing2 to investigate the effect of incorporating active aeroelastic tailoring under the **NASA-funded Performance Adaptive Aeroelastic Wing project**. The researchers demonstrated that this approach reduces aircraft weight by relaxing the flutter constraint while ensuring the flutter mode is controllable, enabling the use of an active flutter controller. In June, the team also developed the Distributed Design Optimization of Large Aspect Ratio Wing Aircraft with Rapid Transonic Flutter Analysis in Linux Operating System, which performs multidisciplinary design optimization of medium- and long-range transonic truss-braced-wing aircraft with nonlinear, transonic flutter analysis in a distributed-computing environment.

Also this year, the U.S. Air Force Research Laboratory **Multidisciplinary Science and Technology Center contracted program EXPEDITE**, short for Expanded MDO for Effectiveness Based Design Technologies, executed by Lockheed Martin, began extending multidisciplinary design optimization beyond engineering quantities (i.e., range, drag) to consider mission effectiveness metrics as response functions. The **Quantifying Utility of Aerospace Derivatives program**, executed by Northrop Grumman and Stanford University and contracted by AFRL MSTC, is aimed at evaluating the utility of high-fidelity, coupled sensitivities on relevant applications (including aeroelasticity and propulsion integration) at industry scale.

Penn State's Applied Research Laboratory completed a DARPA-funded project that demonstrated the use of artificial intelligence to design and optimize boats and unmanned air vehicles with video game simulation engines and no human input; the team 3D-printed vehicles and tested them to validate its approach. ★

▼ Operator Inference reduced-order models provide almost 1 million times computational speedup in predictions of complex flow dynamics for a single-injector rocket combustion example.

University of Texas at Austin Oden Institute



Probabilistic methods gain traction for designing complex systems

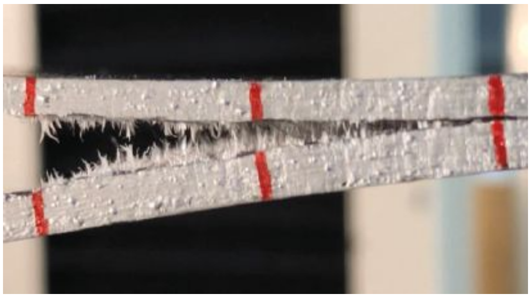
BY SAMEER B. MULANI

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

In July, an AIAA Certification by Analysis Community made up of industry, academia and government/regulatory representatives completed the draft document "**Recommended Practices When Flight Modeling Is Used to Reduce Flight Testing Supporting Aircraft Certification**" to guide commercial applicants when flight modeling is being developed, proposed and used to reduce flight testing relative to traditional aircraft certification practices. The document strongly recommends model verification and validation and uncertainty quantification analysis components.

In May, Sandia National Laboratories released its **Dakota software with multilevel uncertainty quantification and optimization capabilities**. Multifidelity methods for uncertainty quantification and optimization are essential for reducing the costs of computation without sacrificing accuracy compared to exhaustive, high-cost, high-fidelity simulations. Researchers at Sandia investigated the use of these techniques in mission applications that feature complex model ensembles, such as wind and fusion energy, geological waste disposal and cybersecurity. These experiences led to the development of **generalized multifidelity algorithms that support more complex model dependency graphs**. This work, in collaboration with the University of Michigan, has spanned sampling and surrogate approaches.

For noise prediction, DLR, the German Aerospace Center, and Empa, the Swiss Federal Laboratories for Materials Science and Technology, continued research by applying a perturbation approach to carry out spatial and temporal uncertainty quantification of noise. The study revealed **the relationship of uncertainty changes with individual flight paths depending on input data, noise source ranking, specific operating conditions and propagation distance**. Also, a team of DLR, Empa, Technical University Braunschweig and the University of Alabama compared the perturbation approach and higher-order methods for uncertainty quantification in system noise prediction and quantified the effect of dependence or correlation of different variables.



A double cantilever carbon-reinforced composite beam begins to heal itself under the actuation of macro-fiber composites after a Mode I delamination test. The crack propagation rate is decreased (fracture toughness is increased) due to the fibrils formed by thermoplastic particles and shape-memory polymers. The healing is achieved by heat generated due to high-frequency vibrations produced by macro-fiber composite actuators; the same kinds of MFCs are also used as sensors for crack-monitoring.
University of Alabama

The University of Alabama has **developed a novel in-situ self-healing carbon-reinforced thermoset composite system** wherein embedded thermoplastic particles and shape-memory polymers act as healing agents. The healing is activated through high-frequency vibrations using macrofiber composite actuators. This year, researchers achieved repeatable healing for at least five cycles under Mode-I fatigue loading and presented initial results at the AIAA SciTech Forum in January and complete results at the American Society for Composites 35th Technical Conference in September. The healing efficiency, critical loads and crack length are uncertain due to inherent material uncertainties and non-uniform heating during crack healing, and these uncertainties are quantified using different techniques, including machine learning.

Researchers in the Computational Optimal Design of Engineering Systems Laboratory at the University of Arizona developed **a toolbox for aero-structural stochastic design optimization of composite wind turbine blades with fully parametric capability** and shared efficiency and accuracy at the ASC conference in September. The toolbox enables uncertainty quantification to consider the randomness in material, geometric and loading conditions.

Southwest Research Institute continued **developing software to predict the fatigue life of composite bonded and bolted joints**. A model verification and validation framework is used to identify and reduce uncertainties in models and experiments to achieve the required accuracy of predictions of new bonded joint designs. Elder Research Inc. based in Virginia, MESI Technologies of Texas and SwRI have jointly developed a probabilistic damage tolerance methodology to assess the effectiveness of protective coatings for critical rotating aircraft gas turbine components that are susceptible to hot corrosion fatigue. To enhance condition-based maintenance efforts of in-service military aircraft, SwRI developed a novel likelihood-based corrosion rate modeling approach in partnership with the Air Force Life Cycle Management Center. Convergent Manufacturing Technologies US and SwRI, with funding from the Air Force Research Laboratory, developed fast-running response surface models of composite curved beam process models to investigate the relationship between vacuum bagging and part quality. These models predict local flange thickness and porosity development as a function of processing. ★

***Contributors:** Samit Roy and Lothar Bertsch*

Developing technology for smallsat solar arrays and antennas

BY MARK SILVER

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

▲ **The Lightweight Integrated Solar Array and Transceiver**, a combined solar array and Ka-band antenna, stows in a 10-by-10-by-10-centimeter volume for launch and can generate up to 340 watts of power on orbit.
NeXolve Holding Co.

As small satellite capabilities continue to grow, the demand for solar arrays and antennas also grows. Through novel methods of deployment, inflation and in-space construction, the spacecraft structures community is developing new technologies to meet these needs.

In January, NASA announced two contract awards for in-space construction on its planned **On-orbit Servicing, Assembly, and Manufacturing 1 spacecraft, or OSAM-1**, formerly known as Restore-L and scheduled to launch in December 2023. First, Maxar Technologies of Colorado will develop a robotic arm to build a Ka-band antenna in space. Second, Tethers Unlimited of Washington will develop technology to manufacture a 10-meter composite beam.

In February, Colorado-based Blue Canyon Technologies and Florida-based Made in Space announced their partnership in building **NASA's OSAM-2** satellite. The satellite will demonstrate the in-space manufacturing of two, 10-meter booms on opposite sides of OSAM-2 to support solar arrays. As the booms are 3D-printed in space, the solar arrays will unfurl in tandem. These solar arrays will be able to generate up to five times more power than traditional solar panels on similar-sized spacecraft, NASA says. This technology is being developed to help expand solar power generation capabilities for NASA's Artemis program, which aims to put humans back on the moon by 2024 and on Mars.

Roccor Inc. of Colorado completed radio frequency testing of its **Link 16 deployable antenna** in May. Link 16 is the tactical data link used by NATO aircraft, ships and ground forces. Viasat is building the constellation of satellites that will carry the antenna as part of the U.S. Air Force Research Lab's XVI program. Viasat's first XVI satellite is scheduled to launch next year. Roccor's design is a 2-meter-long, helical, L-band antenna that deploys from a 20-by-10-by-10-centimeter volume using a high-strain composite deployable mechanism.

In August, NeXolve Holding Co. completed a design review of the **Lightweight Integrated Solar Array and Transceiver** with NASA's Marshall Space Flight Center in Alabama. The LISA-T deploys from a 10-by-10-by-10-centimeter volume and can generate up to 340 watts of power with simultaneous communication in the Ka-band through its antenna. This review included results from microgravity deployment experiments of the LISA-T performed earlier in the year.

Also in August, Airbus finished ground deployment testing of its 12.3-meter-long **C-band Synthetic Aperture Radar antenna** for the European Space Agency's **Copernicus Sentinel-1C** satellite. ESA will use the Sentinel-1C SAR to map the Earth's surface; collect data on the arctic, marine and forest environments; and help manage humanitarian relief and disasters. During the tests, Airbus measured the mechanical properties of the antenna after deployment, including planarity and shape accuracy. These measurements are critical to predicting performance of the SAR once on orbit. The next step for SAR acceptance is full radio frequency functional testing including the deployed antenna and electronic subsystems. ★

Contributor: *Jim Moore*

X-57 Maxwell leads structural dynamic work

BY NATHAN FALKIEWICZ AND RAFAEL PALACIOS

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

▲ **NASA's X-57 Maxwell** all-electric aircraft is prepared for ground vibration testing at NASA's Armstrong Flight Research Center in California. NASA researchers began correlating data in 2020 from two ground vibration tests.
NASA

Paving the way for a next generation of aircraft, engineers and scientists at NASA's Armstrong Flight Research Center in California and Langley Research Center in Virginia started working in early 2020 on **correlating two finite element models, or FEM, for the X-57 Maxwell**, NASA's first all-electric piloted X-plane. The project is anticipated to validate electrical-powered flight with a five-fold increased cruise energy efficiency through several configuration modifications of the X-57. Researchers have data from two ground vibration tests that were performed on the Mod II aircraft and the Mod III Wing. In June 2019, researchers conducted the first ground vibration test on the X-57 Mod III Wing with the newly designed wing mounted on a loads test fixture. This test gathered the Mod III wing modal data, which Langley used to correlate the wing modes of the Mod III FEM.

Researchers performed a second ground vibration test in November 2019 on the X-57 Mod II aircraft with the aircraft on soft supports to simulate free-free flight boundary conditions. This Mod II test measured the aircraft structural frequencies and mode shapes, which Armstrong used to update and validate the Mod II aircraft FEM. After the FEM correlation, researchers will use the updated Mod II FEM in both the final classical flutter and whirl flutter analyses for evaluating aeroelastic airworthiness for the X-57 Mod II aircraft flights.

In a paper published in May in the Journal of Fluids and Structures, aeroelasticians at Imperial College in London, atmospheric scientists from the National Renewable Energy Laboratory in Colorado, and computer scientists at the Chinese National Supercomputer Center presented **integrated turbulence-resolving simulations of the atmospheric boundary layer with full-vehicle nonlinear aeroelastic simulation**. They had access to one of the world's largest supercomputers, Sunway TaihuLight, to produce physics-based estimates of dynamic loads near the ground of high-altitude pseudo-satellites. Their results indicate that the sizing loads may be at least 50% larger than previously available estimates obtained.

In February and August, the University of Bristol in the United Kingdom performed experimental studies that consider the **effect of floating folding wingtips on aircraft rolling behavior**. They build on previous investigations into the benefits of such devices to enable reduced drag through increased aspect ratio while passively reducing gust loads. These tests showed that the roll rate of high-aspect ratio wing aircraft can be increased by employing such wingtips without the need for an increase in the control surface area. Moreover, the roll rate was shown to be similar to that of a wing without any extension, suggesting retrofitting an aircraft with such a device may be possible.

In launch systems, NASA completed in May early analysis of data from the second rollout of the 4.5-million-kilogram and 120-meter-tall **mobile launcher** transported on top of the crawler transporter from Kennedy Space Center's Vehicle Assembly Building to Launch Pad 39B as part of an integrated **system verification and validation test** in preparation for the **Artemis-1 launch**. Data acquisition systems recorded acceleration time history responses throughout the structure, and operational modal analysis, or OMA, techniques aided in determining the mobile launcher on crawler transporter structural dynamic characteristics. Both time and frequency OMA techniques used together provided a method to understand the data and determine the actual modal responses. Results showed the mobile launcher to have nonlinear characteristics dependent upon the crawler transporter speed and ground winds. Data will be used to improve the accuracy of the mobile launcher finite element model in preparation for the first flight of the Space Launch System, the uncrewed Artemis-1, and subsequent flights. ★

Contributors: *James C. Akers, Jonathan Cooper, Joel W. Sills Jr. and Natalie Spivey*

Supersonic prototype, smart coatings and Orion take shape

BY HARRY H. HILTON, EMILY J. ARNOLD AND CRAIG G. MERRETT

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

Boeing's Renton site is working with Aerion Supersonic of Reno on **Boeing's hypersonic Mach 5 plane** and **Aerion's AS2 Mach 1.4 business jet**. In April, Aerion released an updated AS2 design that would prevent sonic booms from reaching the ground. Manufacturing at Aerion Park in Melbourne, Florida, is scheduled to commence in 2023 ahead of the first test flight in 2025.

University of Central Florida and Boeing Research and Technology collaborated under the National Science Foundation's Partnerships for Innovation and INTERN programs to create **tailorable, smart coatings for noninvasive damage assessments in structures**. With guidance from researchers at the Boeing St. Louis facility, a UCF graduate student at the facility manufactured polymer-based coatings with embedded photo-luminescent and ceramic nanoparticles that act as stress sensors.

Researchers working under NASA's Advanced Composites Project developed technologies to save certification design time. Advancements in manufacturing simulation, nondestructive inspection, and advanced structural design and analysis were completed under the Advanced Composites Consortium, or ACC, public-private partnership and under the NASA Research Initiative's university contracts. In the structural area, ACC made improvements in rapid design tools for preliminary structural sizing, developing detailed static and fatigue strength prediction and high energy impact events in composite structures. **Rapid design tool improvements** are available through Hypersizer software. Over the project's course, approximately 50 publications documenting these improvements were released.

In May, the U.S. Air Force Research Laboratory concluded research to improve the modeling of impact damage on composite aircraft. AFRL, Boeing, North Carolina State University and Virginia Commonwealth University developed simulation tools and high-rate material data for modeling low-velocity impact of runway debris and tool drops. High-rate test data improved predictions of failure initiation and propagation at elevated loading rates. These developments and enhanced material properties prompted creation of a **new LS-Dyna finite element modeling material card, MAT_299**. Under a separate AFRL contract, Boeing continued testing to validate approaches to extend aircraft service life using progressive damage failure analysis, coupled with improvements in assessing service life employing load enhancement factors and fatigue damage severity factors.

In June, NASA completed testing a **duplicate Orion spacecraft, the Structural Test Article**, or STA, needed to verify that Orion is ready for Artemis I, its uncrewed test flight. NASA and prime contractor Lockheed Martin built the STA structurally identical to Orion. These tests verified Orion's structural durability for all operational phases of Artemis I. Lockheed Martin worked around-the-clock to prepare the experiments. During some test phases, engineers pushed expected pressures, mechanical loads, vibrations and shock conditions to 40% beyond most severe expectations.

The year's research at the Air Force Research Institute was directed toward: (1) A lighter-than-air vehicle consisting of a 0.305-meter-diameter sphere constructed with 41 pressurized toroidal small cells designed to resist external pressures. Geometric displacements were evaluated for structural collapse load considering fluid-structure interaction. (2) Lattice cell structural use in projectile designs to determine cell ability to resist high strain rates by evaluating their material properties. (3) Performance evaluations of graphite-epoxy layups where steel foil reinforcements are included in bolt joints was also conducted. This hybrid improves designs up to 15%. (4) This research area concerns a ROM of a pin-on-disc experimental design representing Holloman Air Force Base high-speed experimental system. Heat transfer developed in steel specimens traveling up to 96 meters per second was analyzed with a finite difference technique.

In an unfunded project since 2015, researchers at the University of Illinois at Urbana-Champaign and the Chongqing Institute of Green and Intelligent Technology continued **analyzing 3D/4D printing of temperature-dependent viscoelastic materials**. This study includes analytical formulations and solutions of fundamental coupled thermodynamic-fluid-solid mechanics governing relations, including topology optimization for stress-displacement analyses during deposit and cooling cycles. Absent experimental temperature distribution data, only hypothetical stress-strain-time results will be presented at AIAA's 2021 SciTech Forum. ★

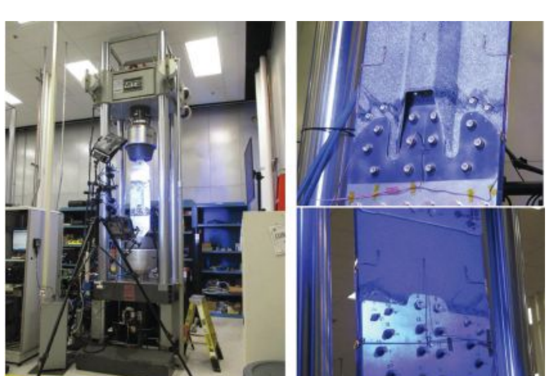


Photo collage of the first type of replicate, tested to failure in the U.S. Air Force Research Lab's Facility for Innovative Research in Structures Technology, or FIRST Lab, established in 2008.

U.S. Air Force Research Laboratory

NASA survivability test paves way for launching astronauts from U.S. soil

BY AMEER MIKHAIL, WILLIAM D. BRYANT AND TEDDY SEDALOR

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

▲ **A SpaceX Crew Dragon** capsule is offloaded from the company's recovery ship at Port Canaveral in Florida after the uncrewed in-flight abort test.
SpaceX

NASA and SpaceX launched a Falcon 9 rocket in January to **test the flight abort system of SpaceX's Crew Dragon** capsule as part of NASA's Commercial Crew program, which has developed spacecraft and launch vehicles to carry crews to low-Earth orbit and the International Space Station. The test validated that the crew and capsule would be protected if the flight needs to be aborted at launch or a few minutes after that. The test flight was aborted 85 seconds after launch. The capsule, which had mannequins but no crew members, splashed down in the Atlantic Ocean nine minutes after launch and was recovered within 32 kilometers east of the Florida coast. The test was the last major hurdle for SpaceX before the Dragon design was approved to carry humans to the ISS. NASA astronauts Bob Behnken and Doug Hurley were launched to the ISS in a reusable Crew Dragon capsule in May for a 64-day mission that included four spacewalks to make repairs. The astronauts returned to Earth in the capsule, splashing down in the Gulf of Mexico in August. Data from that flight cleared the way for the November launch of four astronauts in the Crew-1 operational mission.

Within the military aircraft discipline of survivability from traditional combat threats (ballistics and fire), **a new cyber threat/weapon** considered is the in-flight commanded malfunctions of the aircraft internal computer operations that are running the aircraft systems (e.g., control surfaces, engines, stability, weapons delivery). William Bryant and Robert E. Ball analyzed and formulated this new threat over the past few years and introduced it in the Spring and Summer 2020 issues of the Journal of Aircraft Survivability as an extension of the traditional kinetic energy impact threats (projectiles and missiles). This cyber threat analysis extension follows the same probabilistic approach/methodology of the "hit/kill" survivability analysis for the traditional threats.

From January to March, the U.S. Army Combat Capabilities Development Command Aviation and Missile Center studied and tested the effectiveness of **aircraft lighter-weight, spaced composite armor** (two panels with space/gap in between) against impacting projectiles. Researchers carried out performance characterization for the projectiles' impact speed, impact angle and other parameters. The findings will help in **designing more survivable lighter-weight fuselage and wing structures** for both rotary and fixed-wing aircrafts.

For aircraft composite wing and fuel tank structures, Northrop Grumman started studying a new development concerning the **replacement of fasteners in the composites by bonded composite joints**. Bonded joints produce a distributed stress field and eliminate the fastener bearing stress. However, a drawback for the bonded joint is its lower impact and pullout strengths. Researchers plan to investigate the bonded joint effectiveness against a hydraulic ram event resulting from the high-pressure outcome from the impact of a penetrator projectile with a fuel tank. This high pressure can cause delamination or separation in the bonded joint. ★

Contributors: *Robert E. Ball and Sierra I. Semel*

Systems integration fuels right-first-time launches of historic missions

BY WENJIONG GU AND JEFF NEWCAMP

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

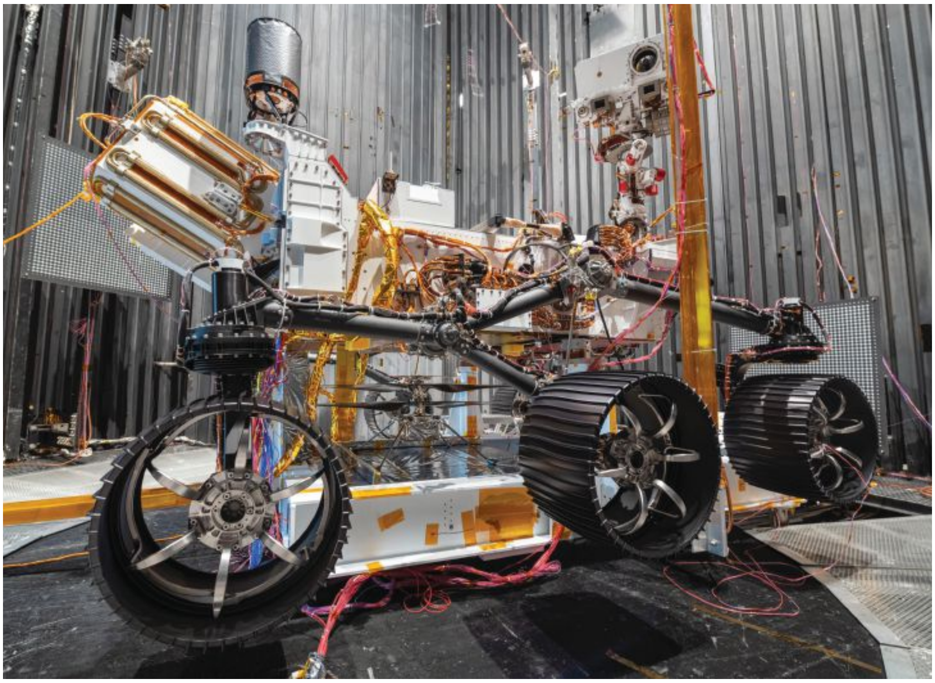
The past year we witnessed important developments for systems integration, the backbone of systems engineering, in renowned, large-scale missions.

In May, **SpaceX's Crew Dragon Endeavour** capsule was launched on the Demo-2 mission with two NASA astronauts to the International Space Station, clearing the way for November's Crew-1 launch. The May Falcon 9 launch, the landing of the first-stage, the docking and the return of the capsule and its two astronauts all manifested years of systems engineering design and integration as well as verification and validation tests. SpaceX built nearly all the components and subsystems, including the rocket, the capsule and the crew spacesuits. This style of all-in-one systems integration amplifies the inherent complexity management for interfaces and interactions necessary to reach an acceptable whole system reliability. Systems integration aims for design errors to be discovered and remedied early during building and accompanying tests, which significantly reduces the overall cost of a mission.

The July launch of **NASA's Mars Perseverance rover** exemplified the benefits of vertical integration of a complex system that is increasingly designed and built by geographically distributed teams. This type of systems integration requires careful definition of functions, interfaces and interactions. Ann Devereaux, the lead spacecraft systems engineer for Mars Perseverance at NASA's Jet Propulsion Lab in California, said, "There is no way any one human being could grasp the totality." Disciplined systems integration on "data architecture and transfer" ensured that the large engineering team managed system complexity. For example, the 1,025-kilogram rover is enclosed in a **Lockheed Martin-built aeroshell capsule** that protects the rover during the launch, deep-space cruise and atmospheric descent toward the Martian surface. Previous systems integration experience with rovers provided increased confidence for what Lockheed Martin said is the largest aeroshell ever built for a robotic mission. "The aeroshell systems engineering team had a big job keeping track of all of the 'big picture' items needing attention throughout the design/test period and kept the entire program on track for an on-time launch," said Angela Adams, systems engineer at Lockheed Martin. Another example is the design and integration of the Mars helicopter, named Ingenuity, with the Perseverance rover. "JPL had only a couple of months to integrate Ingenuity. At the very least, we want it to 'do no harm,'" Devereaux said. JPL built the helicopter and managed requirements and interfaces data so that Lockheed Martin could design, assemble and test the **Mars Helicopter Delivery System**. Adams added, "Systems engineering was important to think through the overall MHDS design and test philosophy and ensured appropriate tests were performed to thoroughly evaluate the MHDS."

In April, **U.S. Space Force** Chief of Space Operations Gen. John W. "Jay" Raymond said that the newest branch of the U.S. military would be the first digital service. "You will build the Space Force as the first digital service and lay the foundation of a service that is innovative and can go fast," he said. The United States established the Space Force in December 2019. Its focus on being a digital service modernizes and streamlines how to process data, how to expose data and how to allow access to and manipulate the data. Such digital data management integrates the overall Space Force system, disrupting and revitalizing the traditional methods of buying satellites and other space systems and connecting the current disjointed space procurement system. Systems integration enabled by digital data will play an important role for the Space Force's success. ★

▼ **The Mars Perseverance** rover and the Ingenuity Mars Helicopter (between left and center rover wheels) were launched in July.
NASA



Addressing noise challenges in the mobility market

BY JULIAN WINKLER, VLADIMIR GOLUBEV AND REDA MANKBADI

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

▲ **Analysis of ground** noise measurements collected while flying the all-electric SureFly vehicle will give researchers information on noise from the rotors, propellers, electric motors and exhaust for hybrid-electric systems for advanced air mobility vehicles.
NASA

The development of urban air mobility concepts has led to increased research in the aeroacoustics community to address the noise challenges in this emerging market. In October, the NASA and FAA-led **Urban Air Mobility Noise Working Group** published a white paper, **"Urban Air Mobility Noise: Current Practice, Gaps, and Recommendations,"** as a NASA Technical Publication. The paper provides noise guidance to mobility stakeholders in the areas of predictive tools and technologies, ground and flight testing, human response and metrics, and regulation and policy.

Examples of UAM-focused acoustic analysis technologies include **UCD-QuietFly**, a new broadband noise prediction tool for UAM aircraft developed using a state-of-the-art empirical wall pressure spectrum model by **University of California, Davis**, in partnership with **Hyundai Motor Co.** and distributed to several universities and companies developing electric vertical takeoff and landing, or eVTOL, vehicles. UCD-QuietFly is designed to **accurately and efficiently predict multirotor trailing-edge noise**, which is dominant at high frequencies.

Separately, a team of researchers at **Embry-Riddle Aeronautical University** in Florida in January performed hybrid high-fidelity simulations of the flow and acoustic field around a propeller like those on consumer drones and quadcopters. This simulation approach provides a framework for studying multirotor interactions with the capability to **accurately predict both tonal and broadband noise components**.

New York-based Moog Inc. and NASA's Glenn Research Center in Ohio conducted **field testing of UAM noise for the SureFly eVTOL** at the Lunken Municipal Airport in Cincinnati. Researchers completed data analysis from these acoustic tests in February. The results will help to characterize **sound sources from advanced air mobility vehicles**, NASA's term for the new class of electric vehicles that would introduce regular aviation services to regions with few if any such services. The class includes cargo and UAM designs as well as their precursors. Tests are planned for hover and flyover acoustic measurements.

Developments in **experimental capabilities to characterize and identify noise sources during flight and in rig tests** have led to more sophisticated approaches. **ATA Engineering Inc.**, headquartered in San Diego, and the **University of California, Irvine**, have extended the continuous-scan acoustic measurement paradigm to problems involving propulsion airframe aeroacoustics for rig testing. Linearly traversing microphone array measurements conducted in January at UCI on a small-scale ducted fan were used for source characterization and prediction of complex interference patterns generated from scattering past a rigid plate, using the boundary element method.

In August, a collaboration between researchers at **NASA's Langley Research Center** in Virginia and Boeing culminated in an innovative acoustic flight test conducted in Montana using an Etihad Airways Boeing 787-10 aircraft as part of the **Boeing eco-Demonstrator program**. The test **collected data from approximately 1,200 microphones on the ground and on the aircraft for special flight conditions** and maneuvers, and the data will advance noise design tools, propulsion airframe aeroacoustic technologies for future low-noise aircraft and novel methods for low-noise operations.

In April, under congressional direction, FAA posted a **Notice of Proposed Rulemaking regarding landing and takeoff noise standards for new supersonic airplanes**. A new noise standard is needed to provide regulatory certainty for manufacturers of new supersonic airplanes under development. NASA assisted FAA in developing the standards by providing performance and noise predictions of notional supersonic aircraft.

In June, researchers at Embry-Riddle simulated rocket launch supersonic noise reduction via water injection from the launch pad by extending large-eddy simulations to multiphase flows. They **identified two important mechanisms for noise suppression**: increased turbulent mixing imposed by high-density water and momentum transfer between the wall boundary layer and the water injection flow. ★

Contributors: *Samuel Afari, Jeffrey Berton, Ian Clark, Dennis Huff, Seongkyu Lee, Stephen Rizzi, Sam Salehian and Parthiv Shah*

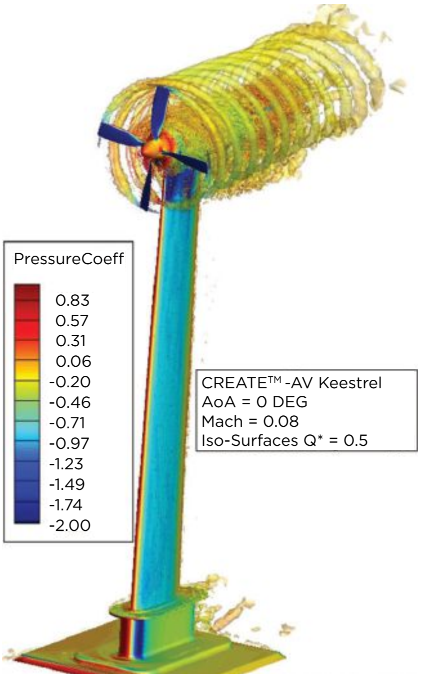
Micro-perforations reduce drag; demonstrating machine learning for vortex identification

BY KEITH BERGERON AND NATHAN HARIHARAN

The **Applied Aerodynamics Technical Committee** emphasizes the development, application and evaluation of concepts and methods using theories, wind tunnel experiments and flight tests.

A novel method for **reducing skin-friction drag in a turbulent boundary layer** was developed at the University of Adelaide in Australia in January and February. Maziar Arjomandi, associate professor at the university and a member of the flow control group, found that such friction and associated turbulence production can be reduced by applying an array of microperforations on a surface with a backing cavity. The micro-perforations experiments, with variations in the geometric parameter settings for the perforations and backing cavity, produced reductions in turbulence intensity on the order of 13%. The results, funded by the Australian Research Council and the Sir Ross and Sir Keith Smith Fund, also show that **microperforations on a wall are capable of suppressing the coherent structures**, thereby passively controlling the turbulent boundary layer. Results from wind tunnel experiments employing an array of microperforations at the center of the plate indicate the optimum size of a perforated hole to be equal to nearly 10 viscous length scales.

In February and March, researchers at the U.S. Air Force Academy's Aeronautics Research Center conducted propeller testing at the academy's Aeronautics Laboratory in Colorado. The research focused on **quiet and efficient propeller designs for electric vertical takeoff and landing vehicles** and small unmanned aircraft systems. The test results have led to improved airfoils and tip configurations that reduce the power required for operation and the noise generated. Such benefits in decreased power and noise have been achieved by reducing the propeller tip vortex, using smoke visualization to confirm the new designs. Custom design software now enables users to prescribe a lift distribution from the hub to the tip of the propeller, unloading the tip to eliminate the tip vortex. A key finding of this effort: The Prandtl bell-shaped curve distribution, originally developed for aircraft wings, shows promise when applied to a rotating propeller.



▼ **Red represents** the highest pressure and green the lowest in this simulation of an electrically-driven C-130 propeller generated by the HPCMP CREATE software.

Lockheed Martin and U.S. Air Force

Efforts to leverage machine learning techniques to enhance applied aerodynamic analyses continued this year, with the applied aerodynamics community generating large amounts of experimental and computational 3D field data. In March, a neural network-based, automated flow field physics-identification method was developed by researchers working under the Computational Research and Engineering Acquisition Tools and Environment portfolio of the U.S. Defense Department's High Performance Computing Modernization Program, or HPCMP CREATE. In July, this neural network method was used to **demonstrate the automated identification of tip-vortices in the flow field of a hovering rotor**. Machine learning is making further contributions in the areas of aerodynamic reduced-order prediction, physics recognition and quality assessment with much potential for future applications.

Earlier in the year, researchers from Boeing and HPCMP CREATE demonstrated the benefits of the application of **direct volume rendering techniques to visualize physics of complex 3D flow fields**. Direct volume rendering techniques have been in existence for several decades but have predominantly been used in the medical imaging and gaming industries. For aerospace applications, direct volume visualization provides an enhanced view of the details of 3D aerodynamic flow field data, detailing both spatial breadth and technical depth. 3D volume rendering based visualization is particularly advantageous to understand fine-scale vortex evolution and breakdown in the wake of a hovering helicopter.

The agreement of simulation results with an open powered test database have **accelerated the design of distributed propulsion systems proposed for all-electric aircraft configurations**. Multiple research teams presented their computational fluid dynamics findings during two Aerodynamics and Performance of Integrated Propellers Special Sessions of the virtual AIAA Aviation Forum in June. Experiments conducted in 2019 on a **scaled model of the NASA X-57** by Helden Aerospace, Empirical Systems Aerospace and NASA in the Lockheed Martin Low-Speed Wind Tunnel in Georgia provided the validation data. Although highly dependent on specific modeling techniques, the high-fidelity CFD with fully blade resolved methods and higher-order schemes gave the most accurate predictions when compared to the wind tunnel tests. ★

Contributors: *Jennifer Abras, Maziar Arjomandi, Keith Bergeron, Mehdi Ghoreyshi, Nathan Hariharan, Tom McLaughlin, Juergen Rauleder and Charles Wisniewski*

Steady progress for space in a year of uncertainty

BY BRIAN C. GUNTER

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

Despite the challenges brought about by the covid-19 pandemic, the astrodynamics community achieved a number of milestones in 2020. This started with the first full year of the **U.S. Space Force**, which was formally established in December 2019. The first mission for the U.S. Space Force was in March and saw the **sixth Advanced Extremely High Frequency communications satellite** reach its geosynchronous orbit. The launch marked the 83rd of an Atlas V rocket, the 138th launch for United Launch Alliance. The rocket also deployed the **TDO-2** rideshare small satellite built by Georgia Tech.

Progress continued toward completing what is already the largest satellite constellation as SpaceX launched its 13th and 14th batches of **Starlink** broadband satellites, bringing the total number to 895 as of October out of a planned constellation of 12,000. The same rockets that launched the Starlink satellites in June and August also carried satellites for Planet, the San Francisco company that operates the second most satellites, now at approximately 150. Specifically, the Falcon 9s launched a total of six SkySat imaging satellites for Planet to complete the 21-satellite SkySat constellation, and those joined Planet's 130 or so Dove imagers.

The year also saw renewed attention on Mars exploration, with multiple missions launched to the red planet in a two-week time frame. The first launch came on July 20, when a Japanese H-IIA launch vehicle boosted the **Hope probe** toward Mars for the United Arab Emirates, commencing its first deep-space mission. Hope will study the Martian climate and atmosphere. Then, on July 23, a Chinese Long March 5 rocket launched an orbiter and rover to begin **Tianwen-1**, which is China's first independent Mars exploration mission. A week later, on July 30, an Atlas V lifted off to begin NASA's **Mars Perseverance** mission, which is scheduled to land the rover on the planet in February 2021.

Early 2020 was also marked by the visit of two natural, but unusual satellites. **Comet Borisov**, or 2I/Borisov, was discovered in late 2019 by amateur astronomer Gennady Borisov and traveled through the solar system much of 2020, undergoing a change in trajectory due to the sun's gravitational pull. The comet is believed to be the second confirmed interstellar object ever detected, with the first being the asteroid **Oumuamua** (1I/2017) in 2017. Meanwhile, in March, NASA's **Near Earth Object Wide-field Infrared Survey Explorer** spotted a comet that scientists named **NEOWISE** (C/2020 F3) after the comet- and asteroid-hunting mission. NEOWISE was the brightest comet visible from the Northern Hemisphere since comet Hale-Bopp in 1997. Its highly elliptic orbit put its closest approach to the sun within Mercury's orbit and its farthest distance well beyond that of Pluto and the Kuiper belt, with an estimated orbital period of 6,700 years.

▼ **A view of Comet** NEOWISE when it was visible in the predawn sky in early July 2020.
NASA

NASA's **OSIRIS-REx** mission reached a milestone in October when it completed its first touch-and-go, or TAG, sample collection from the asteroid Bennu. Following two approach maneuver rehearsals in April and August, the satellite came close enough to the asteroid's surface to deploy its robotic sampling arm to gather up to 2 kilograms of asteroid material and will begin the return journey to Earth in early 2021. The mission has relied on landmark-based optical navigation methods to conduct the various approach maneuvers and to maintain the frozen orbit that allows the spacecraft to stay within a kilometer of the surface between touchdown events. ★

Focusing on safety with aircraft icing tests, radiation risk management and wake turbulence studies

BY MILES T. BENGTSON

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

In the field of aircraft icing, researchers at NASA's Glenn Research Center in Ohio completed a major test campaign in the Icing Research Tunnel in February. This work builds on a previous collaboration with FAA and ONERA, the French national aerospace research center. The test article was a 6-foot span, full-scale wing section based on NASA's Common Research Model, an industry-standard airliner model. Researchers performed computational fluid dynamics and icing simulations to determine the expected performance in the tunnel. Their results showed good agreement with the simulations, thus demonstrating the effectiveness of the computational tools and experiments to predict and understand aircraft icing.

A wing section undergoes testing in the Icing Research Tunnel at NASA's Glenn Research Center in Ohio in February as part of a study to predict aircraft icing.

Andy Broeren/NASA

Space Environment Technologies of Los Angeles advanced the **Automated Radiation Measurements for Aerospace Safety program** in early 2020. ARMAS provides real-time dose monitoring to manage radiation risks for commercial aviation and space flights. An ARMAS sensor flew on a Blue Origin New Shepard suborbital test flight in December 2019, and the program was deemed operationally ready in January. ARMAS sensors have already flown on 750 commercial flights and are scheduled to fly on additional suborbital missions. While in flight, dose data are retrieved in real time, downlinked to the ground and assimilated into a model of the global radiation environment. The program's ultimate objective is to reduce crew and passenger radiation exposure by providing information to operators so they can manage and mitigate radiation risk.

In June, researchers at DLR, the German Aerospace Center, completed analysis on the use of **experimental plates to mitigate wake turbulence risks at commercial airports**. Medium-sized aircraft currently must maintain a separation of approximately 8 kilometers from larger leading aircraft because wake turbulence from the larger aircraft can destabilize the smaller aircraft. During a six-month experimental campaign conducted in 2019, DLR researchers installed so-called plate lines under the final approach path at Vienna International Airport and studied wake vortex behavior for 9,500 landings. Results show that the plate lines cause wake vortices to dissipate significantly thus reducing encounter risks. This may also allow aircraft separations to be decreased in the future.

In January, researchers at the University of Colorado Boulder achieved operation of a novel electron gun that enables **improved laboratory simulation of the space environment**. Energetic electrons in space change the material properties of spacecraft exterior surfaces, and electron irradiation laboratory tests are often used to characterize this degradation. However, conventional electrons guns emit electrons at only a single energy, whereas the orbital environment contains electrons across a broad spectrum of energies. The new broad-spectrum electron gun enables spacecraft materials and components to be tested in an orbital-representative environment.

The U.S. Air Force Research Laboratory's **Very Low Frequency Propagation Mapper satellite** was deployed in low-Earth orbit in February. The satellite is part of a two-spacecraft mission, along with the Demonstration and Science Experiments satellite, which a SpaceX Falcon Heavy rocket launched into medium-Earth orbit in 2019. In addition to studying Earth's natural radiation belts, the mission investigates the use of VLF waves to remediate harmful electrons out of artificial radiation belts. Experiments in the 1950s and '60s showed that detonating a nuclear warhead in space produces an intense radiation belt that could render low-Earth orbit unusable for years. DSX emits VLF waves into the natural radiation belts; the mapper satellite then measures the waves in low-Earth orbit, along with changes in energetic electron fluxes. This tandem experiment is a critical step toward developing technologies to protect our orbital assets from any future nuclear detonations in space. ★

Contributors: *W. Kent Tobiska, Dale Ferguson, Andy Broeren and Frank Holzäpfel*

A Dynetics-built X-61A Gremlin flew over Utah under a DARPA-sponsored program to test the feasibility of launching and recovering cruise-missile-sized drones from conventionally piloted aircraft.
DARPA

X-61A Gremlin flights, Commercial Crew and Mars missions mark eventful year

BY CHRISTOPHER KARLGAARD AND SOUMYO DUTTA

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

The FAA in November lifted the grounding order on the Boeing 737 MAX aircraft so airlines can begin making the changes to software and pilot training required to clear the planes to resume commercial service. The jets were grounded worldwide in March 2019 following the second fatal crash in a span of four months. Boeing resumed production of 737 MAX aircraft in May and in June conducted recertification flight tests after design changes. The FAA in November lifted the grounding order so airlines could begin the changes to software and pilot training required to clear the planes to resume commercial service.

As of November, DARPA was working to resume flights over the Utah desert with one of the four remaining **Dynetics-built X-61A Gremlin Air Vehicles**, the objective for this round being to grasp and hoist a Gremlin onto a C-130, followed by two Gremlins on a subsequent flight. In July, a Gremlin vehicle flew in formation with a C-130, approaching to within 38 meters of the C-130 before parachuting to the ground. The first Gremlin flight, in November 2019, met its test objective of proving the aircraft could be released from the wing of a C-130, but the vehicle crashed at the conclusion of the test when its main parachute did not deploy. DARPA has equipped the demonstration vehicles with parachutes for purposes of the test flights, but operational versions would not require recovery parachutes.

In space transportation, the **uncrewed SpaceX Dragon In-Flight Abort Test** in January verified performance of the **Super Draco abort engines**, clearing the way for the May launch of astronauts Bob Behnken and Doug Hurley to the International Space Station in the **Demo-2** mission. They returned in August. SpaceX utilized an innovative approach to the mission design by relying on ground-based simulations to determine where significant events and phases should start and end. Design engineers carried out these simulations whereas typically the operations staff are a different group. The Demo-2 mission marked final certification of the Dragon design, and cleared the way for the November launch of the Crew-1 operational mission. **Boeing**, the second Commercial Crew provider, worked on **assembling the Starliner crew and service modules** for its next uncrewed launch, after an uncrewed Starliner could not reach the station last December due to an issue with the mission clock. The spacecraft completed 33 revolutions, testing onboard equipment, before landing at White Sands Missile Range in New Mexico.

In April, NASA announced the selection of **Blue Origin, Dynetics** and **SpaceX** to compete to land the first woman and the next man on the moon in the first of **NASA's planned series of Artemis lunar missions**. As of late October, NASA was reviewing the details of the proposals to determine that they meet the **Human Landing System** requirements ahead of the Continuation Review scheduled for December 2020. The review will inform a down selection to compete for the 2024 landing opportunity.

Spacecraft from three nations were launched toward Mars in July: **United Arab Emirates' Hope orbiter; China's Tianwen-1 orbiter and the lander and rover** it will release toward the surface; and **NASA's Perseverance rover with the Ingenuity helicopter**. Hope is the first interplanetary mission from the UAE and the Arab world. The Tianwen-1 mission is the first solo Chinese mission to Mars. Tianwen-1 marks the first attempt to include an orbiter, lander and rover on one mission. NASA's Perseverance rover aims to collect samples for the Mars Sample Return campaign scheduled for the late 2020s. During landing in February, NASA plans to rely on Terrain Relative Navigation technology to avoid hazardous terrain. The Ingenuity helicopter will be deployed from Perseverance after landing, becoming the first powered aircraft on a planetary body. ★

Contributors: *Alicia Dwyer-Cianciolo and Jeremy Shidner*

Novel tools help uncover new insights into complex flows

BY SCOTT DAWSON AND DAVID GONZÁLEZ

The **Fluid Dynamics Technical Committee** focuses on the behaviors of liquids and gases in motion, and how those behaviors can be harnessed in aerospace systems.

Ohio State University and Florida State University in February presented research studying dual jets impinging on a ground plane, providing unique **insights into the physics underlying vertical takeoff and landing aircraft in near-ground hover**. OSU computed large-eddy simulations; FSU performed accompanying experiments. The research has helped elucidate the acoustic feedback mechanism that destabilizes these jets and results in intense acoustic tones. Data-driven and operator-aware decompositions developed at OSU over the past four years are helping to isolate these **acoustic disturbances**, which can be debilitating to ground personnel. The flow generated between the jets is highly asymmetric and disrupts the typical feedback dynamics of isolated jets. Understanding these dynamics helps in the development of new resonant tone prediction models, thus laying the foundation for potential control strategies. The physics-driven modal decomposition method developed in this collaboration has also illuminated fundamental aspects of the physics of hypersonic transition. In particular, it has identified a trapped-monopole structure in the acoustic component of flow over adiabatic walls, which rupture upon wall-cooling, resulting in freestream radiation.

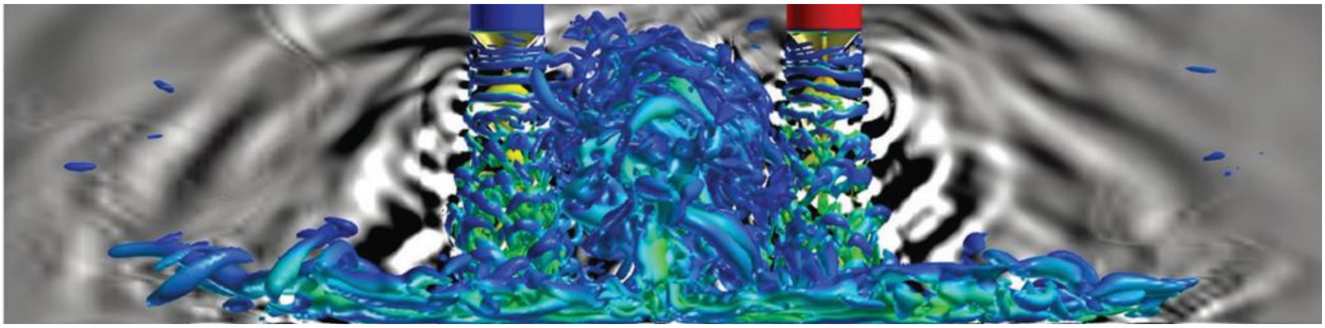
Between January and March, researchers at NASA's Langley Research Center in Virginia conducted Phase 2 of the **Juncture Flow experiment**, which combined novel experimental measurements with computational fluid dynamics simulations to **document the flow physics of a separated wing-body juncture flow**. Researchers acquired high-quality flow field measurements of the velocity field and Reynolds stresses very near the corner using innovative onboard laser Doppler velocimetry and particle image velocimetry instruments positioned inside a fuselage. The experiment expanded the range of data collection to include more measurement locations in the corner region of interest, planar fields and an additional angle of attack. Corresponding CFD efforts were tightly integrated with this experimental campaign and have resulted in an improved quadratic constitutive relation for the turbulence model used for simulating this type of flow.

Experiments at North Carolina State University demonstrated in April that energizing the boundary layer is quite ineffective in controlling the open separation by a fin shock. In contrast to flow-induced closed separation units, these open separated flows are dominated by a separation vortex that exhibits significant complexity in its organization, topology and geometry. Instead, the experiments demonstrated a near annihilation of the separated flow by direct interactions between the separation vortex and the vortex-laden boundary layer generated by a single sub-boundary layer vortex generator. The fact that North Carolina State accomplished significant mitigation of the separation scale with a small-footprint device is alluring for transforming these investigations to practical geometries. **Mitigating and delaying flow separation** is critical to expanding the operational envelope of high-speed platforms.

At the AIAA SciTech Forum in Orlando, Florida, in January, researchers from the Air Force Research Laboratory presented the results of simulations they completed in December 2019 that demonstrated that **control of transition over a flat plate is achievable via the use of local dynamic surface modification**. They based their direct numerical simulations off an experimental arrangement employing control with piezoelectrically driven actuators to stabilize Tollmien-Schlichting instabilities, which are triggered by separate upstream actuation. The simulations demonstrated that a closed-loop control law could achieve similar results to empirically determined optimal control parameters. ★

Contributors: *Nash'at Ahmad, Datta Gaitonde, Venkat Narayanaswamy, Donald Rizzetta, Unnikrishnan Sasidharan-Nair and Spencer Stahl*

▼ **A snapshot of a** large-eddy simulation of supersonic impinging jets shows the fountain flow (upwash) that travels back toward the nozzles (blue and red cylinders at top) in between the two streams after hitting the ground. The black and white contours represent the acoustic activity the jets' interaction induces.
Ohio State University



Facility improvements and novel testing techniques showcase criticality of ground testing

BY ROBERT C. GRIFFITHS

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

▲ **A NASA engineer** inspects the long static pipe installed in the 11-by-11-foot Transonic Wind Tunnel during tunnel calibration at NASA's Ames Research Center in California.
NASA

The ground testing community overcame significant project delays and challenges due to the pandemic to achieve important milestones. The U.S. Air Force's Arnold Engineering Development Complex maintained critical testing at its headquarters in central Tennessee while several of AEDC's geographically separated units also made significant strides. The National Full-Scale Aerodynamics Complex in California demonstrated capabilities on an **acoustic survey rail featuring a traversing microphone array** in the 40-by-80-foot wind tunnel in early February. This effort preceded a U.S. Army and Sikorsky study of the aeroacoustic characteristics of a scaled pusher-propeller configuration in the wake of both a 17% scale UH-60 Black Hawk fuselage and a NACA0015 wing. The staff of the AEDC Hypervelocity Wind Tunnel 9 in Maryland bolstered its array of high-Mach test capabilities by **adding a Mach 18 nozzle** in July. The facility can now supply accurate flow environments at Mach 7, 8, 10, 14 and 18.

The NASA Ames **11-by-11-foot Transonic Wind Tunnel** underwent a calibration in the first quarter. The effort compared data on a 55-foot long static pipe spanning the entire length of the nozzle and test section to a 15-foot short static pipe, followed by benchmark data on the 11-foot's check-standard model from Mach 0.2 to 1.4 at pressures from 0.33 to 2.2 atmospheres. This supported the **Unitary Plan Wind Tunnel Characterization Effort** at NASA's Ames Research Center in California. Meanwhile, Ames' Arc Jet Complex continued thermal protection, vehicle structures, aerothermodynamics and hypersonic entry testing with NASA and contractors, supporting both the Orion and Mars Perseverance rover materials development efforts.

The **National Transonic Facility** at NASA's Langley Research Center in Virginia in March continued **cryogenic testing on a Space Launch System rocket model**. Test temperatures were as low as minus 155 degrees Celsius (minus 250 Fahrenheit), speeds up to Mach 0.95, unit Reynolds number up to 82 million per foot and dynamic pressures up to 3,500 pounds per square foot. The solid rocket booster attach brackets in the wind tunnel were made by Direct Metal Laser Sintering with Inconel-718. Since these were structural components, NTF required additional post-fabrication coupon testing and X-ray-computed tomography scans of the structural attachments for the booster's solid fuel before testing. NASA Glenn Research Center's Space Environments Complex at Plum Brook Station, Ohio, hosted a variety of programs supporting development of **NASA's Artemis lunar crew spacecraft**. Thermo-vacuum and electromagnetic interference and compatibility testing at pressures of 10^{-6} torr and temperatures down to minus 155 Celsius began in late 2019 and ran continuously for two months into 2020. The spacecraft returned to Kennedy Space Center in Florida in preparation for its mission to the moon.

AeroTEC, headquartered in Seattle, completed ground and flight integration testing on the **AeroTEC/MagniX eCaravan Flying Test Bed**, which the company says is the largest all-electric commercial aircraft. The aircraft combined a new 750-horsepower Magni500 electric motor with a new energy storage system on a well-proven Cessna 208B Grand Caravan airframe. Testing was performed at the AeroTEC Flight Test Center in Moses Lake, Washington, with first flight in May.

The first quarter of the year saw significant international accomplishments. JAXA, the Japan Aerospace Exploration Agency, demonstrated its new **Magnetic Suspension and Balance System** on a delta wing model in its 60-by-60-centimeter low-speed wind tunnel at Chofu. The system seamlessly levitates models magnetically to high angles of attack for 6 degrees of freedom force and moment measurements, while adding oscillatory capabilities for dynamic stability derivative measurements — all without model support interference. A partnership among Boeing, the European Transonic Wind Tunnel, Deharde GmbH in Germany and NASA Langley's NTF marked completion on the first phase of a multiyear validation effort for **Remote Control Actuation capability on cryogenic wind tunnel models** using a 4.5% scale Boeing 787 semi-span model. This method, using shape-memory-alloy technology, can reduce testing times up to 90% at flight Reynolds number. ★

Contributors: *Emily Brown, F. Tad Calkins, Victor Canacci, David Chan, Pat Goulding, George Moraru, Shinji Nagai and Eric Paciano*

Drones, space probes and rovers take on ambitious navigation duties

BY UDAY J. SHANKAR, KEVIN P. BOLLINO AND BEHÇET AÇIKMEŞE

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

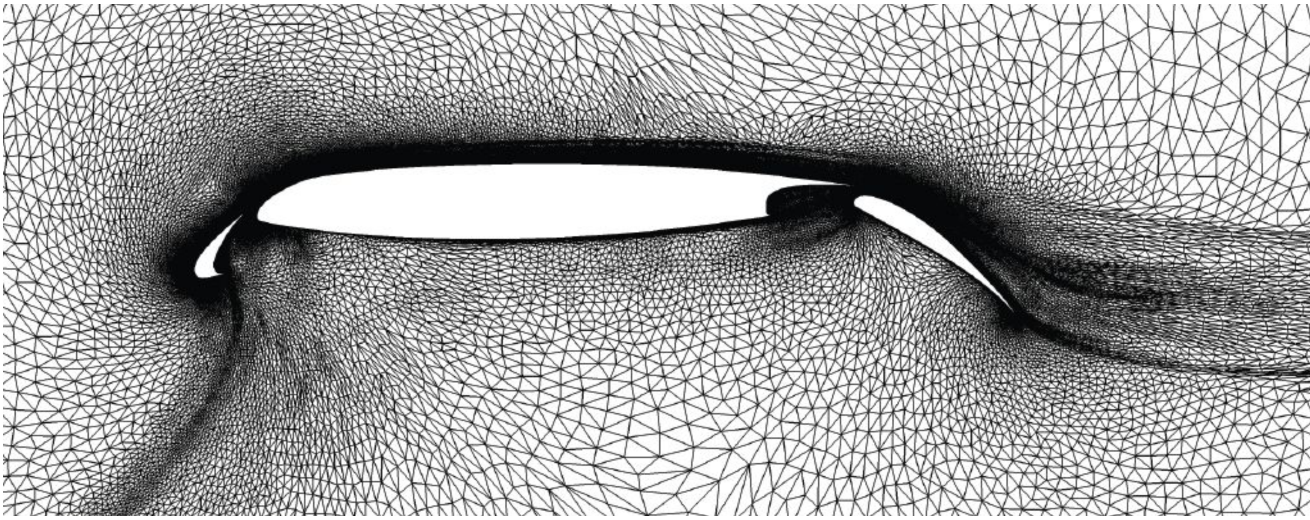
As the covid-19 pandemic spiked household package deliveries, companies such as Amazon, Walmart, Flytrex, Zipline and Flirtey leveraged advances in autonomous unmanned aerial vehicle technology to push for means of faster, alternate delivery service. The Unmanned Aircraft System Integrated Pilot Program laid the foundation in 2019 with Wing Aviation's drone demo delivering food and pharmaceuticals and UPS Flight Forward's drone demo delivering medical supplies. This year, other drone delivery startups quickly followed suit with enhanced performance and improved safety.

Drone maker **Flirtey** of Nevada received a patent in July for its **concept for autonomously deploying a parachute when a drone experiences a problem and then steering the drone to a safe landing zone**. In August, **Amazon's Prime Air** drone program received FAA approval to begin operations with **a goal of delivering 5-pound (2.3-kilogram) packages to customers' doorsteps in 30 minutes or less** and beyond the operator's line of sight from a range of about 15 miles (24 kilometers). This certification signals FAA's confidence in drone delivery operations and safety, enabled by decades of advances in guidance, navigation and controls. In September, **Walmart** initiated a pilot program with Israeli startup **Flytrex** and California-based **Zipline** to start testing its drone delivery program. Some of the technology employs cloud-based smart control systems with humans-in-the-loop to ensure safe operations.

In February, **Northrop Grumman's Mission-Extension Vehicle-1** docked with and took control of **Intelsat-901**, a 19-year-old satellite. According to the company, this was the first commercial spacecraft to dock with an uncooperative target. MEV-1 controlled the attitude and orbit of **Intelsat-901**, establishing a new satellite revitalization paradigm by **telerobotically operating an aging satellite versus refueling it**. MEV-1 subsequently moved **Intelsat-901** from the geosynchronous "graveyard" orbit to its new operational home. In April, **Intelsat-901** restarted its operations for an expected five more years. The mission provides a study in spacecraft guidance, navigation and control: rendezvous and proximity operations, which involve intricate attitude and position control; docking with an uncooperative and uncontrolled satellite; and controlling both satellites to tight pointing tolerances. In August, an Ariane-5 launched MEV-2 with its first mission to resuscitate Intelsat-1002 in 2021. In March, **DARPA** selected **Northrop Grumman** to be its commercial partner for its **Robotic Servicing of Geosynchronous Satellites program**.

In July, an unprecedented three Mars missions commenced. The **Hope orbiter** was launched for the **United Arab Emirates** atop a Japanese H-IIa launch vehicle. Hope will orbit Mars at altitudes of 20,000 to 45,000 kilometers and make observations with two spectrometers and a camera. The mission's primary aim is to inspire schoolchildren and spur UAE's science and technology industries. **China** launched **Tianwen-1**, a triumvirate of an orbiter, a lander and a rover destined for Mars. According to the mission chief scientist, this marks the first time any mission has attempted all three at once. Building on the success of its three-pronged lunar orbiter-lander-rover, Chang'E launched in 2018, Tianwen (which translates to "Questions to Heaven") will explore Mars both at the surface and from altitude. The orbiter will conduct scientific observations and act as a relay for the lander and rover. At the end of July, the U.S. launched the **Mars rover Perseverance** in a quest for signs of ancient microbial life. The rover also carries an experimental miniature helicopter, Ingenuity. A joint NASA-European Space Agency mission is being planned to return samples collected by Perseverance back to Earth in 2031. ★

▼ **Amazon received FAA** certification to deliver packages with drones, including beyond line of sight.
Amazon



Shortened processes, software updates advance meshing, visualization

BY ROMAIN AUBRY AND DAVID MCDANIEL

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

▲ **This solution-adapted** mesh for the High Lift Common Research Model airfoil was created using the Boeing GGNS flow solver and the EPIC grid adaptation toolsets.
Boeing

The meshing and visualization community in January learned the details of a **breakthrough method developed by Carl Ollivier-Gooch**, a professor at the University of British Columbia, when he demonstrated to AIAA SciTech participants **a technique for developing extreme scale meshes in hours rather than weeks.**

Also this year, **Intelligent Light** of New Jersey pushed high-order element post-processing forward with projects for the U.S. Department of Defense High Performance Computing Modernization (HPMCP) Computational Research and Engineering Acquisition Tools and Environments (CREATE) effort and the U.S. Department of Energy's Center for Efficient Exascale Discretizations. Specifically, in 2020 Intelligent Light continued working on the next iterations of the **FieldView CREATE** standardized visualization tool for the Defense Department, after selling rights to FieldView to **Vela Software** of Toronto in 2019. Vela formed a company, FieldView CFD Inc., to develop and market FieldView, while Intelligent Light continues working on the FieldView CREATE product for the Defense Department.

In February, an exploratory committee conducted a survey to decide **the future of the International Meshing Roundtable**, a conference dedicated to the field of mesh and grid generation. Sandia National Laboratories announced in October 2019 at the 28th International Meshing Roundtable that it would step back from organizing and operating IMR. The **Society for Industrial and Applied Mathematics** will host future conferences.

In January, development teams supporting the Defense Department's CREATE effort released new product versions in the areas of meshing and computational environments. The CREATE Foundational Technologies Team released **Capstone Version 11**, which includes multithreading in meshing and sizing proxy construction and makes available boundary layers with constant growth close to the geometry. In addition, this version supports mesh adaptation for both computed-aided design and discrete models. The adaptation capability has been developed in collaboration with the CREATE Air Vehicles (AV) team. In a June paper, researchers from Boeing, the Massachusetts Institute of Technology, NASA and Inria, the French national research institute for digital science and technology, compared adaptive mesh solutions on a 2D cross section of the High Lift Common Research Model. By driving the adaptive meshes to a similar level of mesh convergence, the researchers obtained consistent results between several different adaptive mesh processes. Results helped to identify areas for improvement and to provide mesh generation guidance for future workshops.

On the computational environments front, the **CREATE AV team** released **Versions 11.0 and 11.1 of the fixed-wing simulation product Kestrel** as well as Version 11.0 of the rotary-wing simulation product Helios. After introducing support for thermal non-equilibrium flow solutions and coupled aeroheating problems in the Version 10 cycle, the Kestrel development team made a substantial change to the traditional workflow in Version 11.0 to provide better flexibility in coupling solvers in a multiphysics simulation. This change in paradigm enables relevant analyses of simulations with long time scales, such as the aeroheating of a hypersonic vehicle over a trajectory spanning many minutes. ★

Ramping up work on simulations for advanced air mobility

BY PETER M. T. ZAAL

The **Modeling and Simulation Technical Committee** focuses on simulation of atmospheric and spaceflight conditions to train crews and support design and development of aerospace systems.

The **coronavirus pandemic** significantly impacted demand for, and the operation of, commercial passenger aircraft this year. To assist aviation planners amid this uncertainty, **MITRE Corp. developed two forecast models**. These models draw on diverse feature data and harness the power of machine learning techniques to provide data-driven scenarios with lead times from one week to one month. The two forecasts are being used in tandem, with the first predicting the **risk for covid-19 infections** (and the cascading disruptions) at airports and air traffic facilities and the second predicting **hourly and daily air traffic demand**. These forecast models were shared with FAA and flight operators in June and July to identify key information and performance needs for a range of applications under consideration.

The pandemic also significantly impacted the execution of **human-in-the-loop simulations** in facilities around the world; however, preparations for these simulations continued. NASA announced an **Advanced Air Mobility National Campaign** to promote public confidence and accelerate the introduction of vertical takeoff and landing vehicle designs in urban, suburban, rural and regional environments. As part of the campaign, and to support research that contributes to the introduction of AAM, several facilities across NASA prepared for simulations this year. These simulations will promote vehicle technologies, development of handling-quality and ride-quality standards, and the introduction of AAM vehicles into the national airspace system. In January, researchers gathered at **Future Flight Central**, a simulated air traffic control tower at **NASA's Ames Research Cente**r in California, and demonstrated **how AAM vehicles would land and depart from a vertiport on the terminal A parking structure of Dallas/Fort Worth International Airport**.

Given the proliferation of AAM electric vertical takeoff and landing designs, several teams including **Systems Technology**, **Adaptive Aerospace** and NASA Ames are supporting FAA in developing means of **compliance testing methods for Part 23 small aircraft certification** requirements. While the processes and requirements needed to certify these disparate vehicles for airspace operations are still emerging, the teams are creating methods inspired by the mission-oriented approach to defining handling qualities mission task elements that originated in the U.S. Army's military rotorcraft design standard, ADS-33E-PRF. Also, flight controls and quadrotor models were integrated and flown in February at Ames' Vertical Motion Simulator. The emerging handling-qualities-task elements will be evaluated in the simulator using a variety of aircraft configurations that may include a quadrotor, lift-plus-cruise, tilt-rotor or tilt-wing.

In the space domain, preparations began at Ames under **NASA's Artemis program** for the development, testing and certification of the Human Landing System on the Vertical Motion Simulator and to help train astronauts for landing on the moon by 2024 in one of the landing systems to be developed by NASA's commercial partners. In April, NASA selected three companies to begin work on the **Human Landing System** program. Two of these companies are in discussions with Ames to simulate their lunar lander designs at the Vertical Motion Simulator. ★

Contributors:
Christine Taylor and David Klyde

▼ **Human factors** researchers make a simulated urban air mobility flight over San Francisco in the Aerospace Cognitive Engineering Lab Rapid Automation Test Environment, or ACELeRATE, simulator at NASA's Ames Research Center in California. Researchers spend time in the reconfigurable ACELeRATE to assess how pilots and automation can best work together.
NASA

Demonstrating new plasma and laser-based technologies for multiple applications

BY SALLY BANE AND JOSEPH W. ZIMMERMAN

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

The year was an outstanding one for research and applications development related to plasma and lasers, with notable highlights related to novel technologies in a variety of fields from high-speed combustion to plasma sterilization.

University of Florida researchers working with **SurfPlasma Inc.** of Gainesville made **advances in applications for dielectric barrier discharge, DBD, plasmas**. In January, the team introduced a novel fan-shaped plasma reactor for mixing enhancement of plasma reactive species. To demonstrate effectiveness on aerospace surfaces such as assembly cleanroom facilities or spacecraft components, the team exposed various pathogens to flows from plasma devices within a closed chamber. They demonstrated a five to eight logarithmic reduction in several pathogens, including MRSA, pseudomonas aeruginosa and other bacteria, fungi and spores within minutes. The researchers also **invented a compact portable plasma reactor** and demonstrated it for food preservation and water purification. They reported that **it inactivated surrogate human coronaviruses representative of SARS-CoV2**, the virus that causes covid-19, in air and on porous, contoured surfaces.

In September, the same researchers reported encouraging results from **rotor-blade tip vortex experiments using arrays of serpentine and fan shaped DBD actuators embedded in a Hughes Helicopters HH02 airfoil**. The actuators produced counter-rotating vortices in the boundary layer, demonstrating up to 62% reduction in tip vortex strength for freestream Reynolds numbers of 200,000 to 500,000. These results predict as high as 14.5 decibel reduction in overall sound pressure level due to blade-vortex interaction, thus making these actuators appealing for NASA's Advanced Air Mobility project that includes urban air mobility research in which rotorcraft noise reduction will be a key for public acceptance.

In January, the High Enthalpy Flow Diagnostics Group at the **Institute of Space Systems** in Stuttgart, Germany, reported on **measurements of molecular oxygen using laser-based polarization spectroscopy**, which the authors say is the first demonstration of molecular oxygen detection using this technique. Researchers demonstrated the technique using a high-power microwave plasma torch. Coherent laser diagnostics such as this are crucial for understanding energy distribution in plasma flows used for simulation of atmospheric entry conditions.

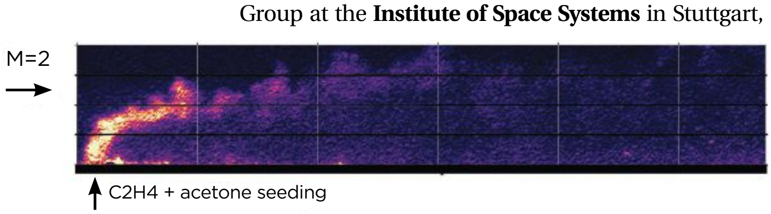
In April, researchers from **Texas A&M University** in collaboration with **Colorado State University** and **Princeton University** in New Jersey reported on **continued development of a dual-pulse laser ignition concept** relevant for improved ignition in internal combustion engines and supersonic combustors. The concept is based on the combination of ultraviolet and near-infrared laser pulses. By tailoring both the energy deposition and heating, this technique allows triggering optical breakdown, minimizes energy requirements and decreases the minimum ignition energy. The research suggests that dual-pulse laser generated plasma could be an efficient tool for controlling dynamics of the ignition kernel, shortening the ignition delay time and providing additional mixing enhancement in high-speed flows.

In June, **University of Notre Dame researchers further developed their plasma injection modules technology for plasma-assisted supersonic combustion**. Researchers applied the acetone planar laser-induced fluorescence technique in the university's Supersonic Blowdown Rig-50 and demonstrated significant enhancement of fuel/air mixing in the Mach 2 flow through application of longitudinal filamentary plasmas collocated with the fuel jet.

In July, researchers at **Purdue University** in Indiana reported on a **new spectroscopic thermometry technique** that applies a probing nanosecond plasma pulse to determine rotational and vibrational temperatures from ultraviolet emissions of nitrogen molecules. This technique applies well-known optical emission spectroscopy techniques of nitrogen but uses a plasma generated at a tungsten electrode gap as a temperature probe. Researchers anticipate that the technique can be applied in modern combustion systems for fast temperature measurements.

In late May, the **U.S. National Academies of Sciences, Engineering, and Medicine** delivered the **2020 Decadal Plasma Assessment**, which reviewed the last decade of achievements in plasma research and development and offered suggestions to federal agencies, policymakers and academics for future research and workforce development related to plasma science and engineering.★

Contributors: *Sergey Leonov, Stefan Loehle, Subrata Roy, Alexey Shashurin and Albina Tropina*



▼ **Researchers at** Notre Dame University further developed their plasma injection modules, or PIMs, technology for improved fuel-air mixing in supersonic combustion. They used acetone planar laser-induced fluorescence to characterize the mixing between the supersonic air stream and injected ethene fuel and demonstrated improvement in mixing with the introduction of PIMs near the fuel injection site.
Notre Dame University

Plasma measurement and hypersonic flight testing among developments

BY AARON BRANDIS, JONATHAN BURT AND CHARLES BERSBACH

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

In August, GE Aviation delivered its custom **F414-GE-100** engine for the **X-59 Quiet Supersonic Technology, or QueSST,** low-boom supersonic demonstrator aircraft to NASA's Armstrong Flight Research Center in California. Developed through a collaborative effort between Lockheed Martin and NASA, the aircraft will test technologies for sonic boom reduction, which would be applicable to supersonic over-land flight by commercial aircraft. Following a critical design review in 2019, development and analysis of the X-59's thermal management systems continued through 2020. The design includes an aft deck of the fuselage under the engine nozzle to help reduce sonic boom noise from the nozzle plume. This aft deck configuration presents challenges in thermal loads on the structure due to extended operation of the afterburner over that structure. Over the past year, Lockheed Martin and NASA independently assessed the thermal loads with high-fidelity computational tools with comparable results. This analysis provided information to ensure the design of the aft deck will be robust to the various operating environment rigors of high-altitude supersonic flight.

▲ **These colors show the** predicted temperature contours for aft-deck surfaces on NASA's X-59 QueSST, short for Quiet SuperSonic Technology low-boom supersonic demonstrator aircraft. The aft-deck surfaces are subject to high thermal loads from the afterburning engine, particularly near the downstream edge of the aft deck.
Lockheed Martin/Kimberly Martin/NASA

On March 19, the U.S. Department of Defense completed a test of a **hypersonic glide body** at the Pacific Missile Range Facility in Hawaii. During the test flight, the Missile Defense Agency monitored and gathered tracking data from the flight experiment that will inform its ongoing development of defenses against hypersonic weapons. This event is a milestone toward the department's goal of fielding hypersonic war-fighting capabilities in the early to mid-2020s. The common hypersonic glide body will be made up of the weapon's warhead, guidance system, cabling and thermal protection shield. Additionally, in September, DARPA and the U.S. Air Force announced completion of captive carry tests of two variants of the **Hypersonic Air-breathing Weapon Concept** and said they are ready to proceed to free flight testing. Army Lt. Gen. Neil Thurgood, who oversees the Army's rapid development of hypersonics, directed energy and space capabilities, said in August during a virtual briefing as part of the Space and Missile Defense Symposium that the Defense Department plans several more flight tests in 2021.

In March, researchers of the **High Enthalpy Flow Diagnostics Group, or HEFDiG,** at the **University of Stuttgart** in Germany utilized light field deconvolution, a technique developed for microscope applications, to provide **true 3D measurements in high-enthalpy plasma flows**. The method is based on using a plenoptic camera, which can capture additional directional information on the light rays emitted by the plasma and allows researchers to effectively look inside or through the plasma. One of the experiments imaged fluorescent liquid being dropped in a small water pool. The results from this experiment illustrate how the light field deconvolution technique can image fluid flows without any entrained discrete particles, as other methods require. The measurements demonstrated at HEFDiG show that time-accurate, fully 3D-resolved plasma measurements can be made, enabling the analysis of complex interactions, instabilities or uniformity with only one signal exposure from one camera. Having such data would **advance the use of high-enthalpy arcjet-driven plasma facilities to improve thermophysics models** without having to make assumptions about the state and uniformity of the flow. ★

Contributors: *Jay Brandon, Martin Eberhart and Stefan Loehle*

Landing safely on Earth, then the moon and Mars

BY OLEG YAKIMENKO

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

▲ **The SpaceX Crew** Dragon capsule Endeavour splashes down in the Gulf of Mexico in August carrying two U.S. astronauts from the International Space Station. NASA's Bob Behnken and Doug Hurley were launched in Endeavour two months earlier.

NASA

Almost nine years after the final space shuttle launch in 2011, **NASA's Commercial Crew** program launched astronauts from the United States, in May with the Demo-2 mission and in November for the Crew-1 mission, both aboard SpaceX Crew Dragon capsules. Demo-2 concluded in August when, after 64 days in orbit, the Dragon Endeavor spacecraft with two astronauts aboard floated to Earth. This was the first time in almost 45 years that astronauts splashed down under parachutes and the first time in the Gulf of Mexico.

Throughout the year, NASA's Artemis program made strides toward landing the first woman and next man on the moon in 2024 with the processing of the **Orion vehicles** for **Artemis-1** and **Artemis-2**. In April, NASA began final integration and inspection of the 11 parachutes of the Artemis-1 Orion spacecraft, bound for its 25-plus-day first flight to lunar orbit in 2021. The agency completed Artemis-2 parachute manufacturing, packing and acceptance in August, setting the stage for Orion's first crewed mission to send humans beyond low-Earth orbit for the first time since Apollo 17 in 1972.

As part of NASA's **Mars 2020** mission, the 1,050-kilogram **Perseverance rover** and new technology demonstration 2-kilogram **Ingenuity Mars helicopter** were launched from Cape Canaveral Air Force Station in Florida in July. The rover is scheduled to land on the red planet at Jezero Crater. Several new technologies will operate during entry, descent and landing, including **Range Trigger and Terrain-Relative Navigation**, while Perseverance descends under the 21.5-meter-nominal-diameter **Disk-Gap-Band parachute**.

In June, the U.S. Army initiated the process to develop the **Next Generation Static Line personnel parachute** for multidomain operations. The Army Combat Capabilities Development Command Soldier Center is leading the technical development and spent the end of the year identifying the capabilities of commercially available parachutes in the U.S. and allied nations. These data, along with user input, will be used to conduct a detailed analysis and determine a potential path in 2021.

CCDC SC, as the technical lead for the **Autonomous Aerial Insertion and Resupply into Dense, Urban, Complex Terrain Joint Capability Technology Demonstration**, or **AAIRDUCT**, worked to develop a way to deploy 2- to 20-kilogram payloads from a Joint Precision Airdrop System, which uses GPS and steerable parachutes. The center conducted tests at Yuma Proving Ground in Arizona in September and October in preparation for an Office of the Secretary of Defense-sponsored operational demonstration.

The Army is also looking at innovative technologies to operate in the highly contested air portion of multidomain operations. One avenue of study this year was a novel, high-offset cargo delivery mechanism under the **Squad Operations Advanced Resupply**, or SOAR, program. CCDC SC completed early testing in July at Dugway Proving Ground in Utah by dropping an expendable cargo transport prototype for resupply loads out of a commercial aircraft. The test demonstrated the prototype being dropped from the host aircraft via drogue parachute, the wing unfolding from a stowed to a deployed position, a turbojet engine starting up onboard the prototype, a powered and then gliding flight, and the prototype touching down under a used personnel parachute. A goal of additional development is to increase the distance cargo can be deployed from the target to over 800 kilometers, more than 50 times the current standoff distance. ★

Contributors: *Jared Daum, Ricardo Machin and Scott Martin*

Covid-19 pandemic hits air transportation hard

BY DAVID THIPPHAVONG AND JOSEPH POST

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

The International Air Transport Association projected in April that three months of severe travel restrictions due to the covid-19 pandemic could result in a loss of 25 million jobs related directly or indirectly to aviation.

In June, IATA projected **unprecedented near-term economic impacts on airlines**, with **revenue losses of $419 billion** and a net loss of $84 billion for 2020. By comparison, global airline industry profits were $27 billion in 2018 and $26 billion in 2019. Through July, passenger traffic had declined by about 60%, and air cargo had declined by about 14% compared with 2019. Following the collapse of air transportation demand in March, airlines canceled or postponed delivery of new aircraft. IATA reported in August that the number of new aircraft deliveries for 2020 plunged by almost 60%. Alexandre de Juniac, IATA director general, predicted in September that global passenger traffic would not return to pre-pandemic levels until late 2023 or early 2024.

Unrelated to the pandemic, in November the FAA and other regulators took steps toward permitting the Boeing 737 MAX aircraft to fly again. Approximately 385 in-service aircraft remained idle, with another 450 undelivered aircraft in storage at Boeing. In November, FAA released its airworthiness directive for the aircraft, which addressed the control laws of the Maneuvering Characteristics Augmentation System, or **MCAS**, and the associated flight deck display system, implicated in two deadly crashes. Safety regulators also identified an additional design flaw involving noncompliant horizontal stabilizer trim wiring that must be addressed. FAA determined that a short circuit of this wiring could potentially lead to uncommanded stabilizer movement.

▼ **KLM parked aircraft on** the runway at its home base of Amsterdam Schiphol Airport when flights were canceled due to the coronavirus pandemic.

The covid-19 pandemic had a profound and detrimental impact on **air traffic management modernization** initiatives in the United States, as FAA prioritized protecting the workforce from infection to sustain facility operations. The agency halted further implementation of its en route digital air-to-ground communications system, **DataComm**, following the pandemic lockdown in March, although three facilities (Kansas City, Indianapolis and Washington) were brought online in 2019. FAA also indefinitely **postponed deployment of its Terminal Flight Data Manager program** in March. The program will replace antiquated paper flight strips with modern touchscreens at 89 airport control towers, with surface metering functionality at 27 of these. The two programs are important pieces of the NextGen modernization initiative and are key to achieving the anticipated efficiency benefits of trajectory-based operations.

Beyond traditional ATM, significant progress was made toward the safe and secure integration of small unmanned aircraft systems into the national airspace system. In addition to releasing Version 2.0 of the **UAS Traffic Management Concept of Operations** in March, FAA collaborated with NASA and industry toward establishing a key technology: Remote ID, the ability of UAS in flight to provide identification and location information that can be received by other parties, particularly FAA, law enforcement and federal security agencies. In May, FAA announced the selection of eight companies to help develop technology requirements for Remote ID: Airbus, AirMap, Amazon, Intel, OneSky, Skyward, T-Mobile and Wing.

In addition to UAS, the FAA started work on **integrating advanced air mobility vehicles**, such as two- to six-passenger electric vertical takeoff and landing aircraft, into the national airspace system. In June, FAA released Version 1.0 of the **UAM ConOps**, which incorporates ideas from NASA and the nascent advanced air mobility industry. The document describes the envisioned operational environment for UAM flights into, out of and within urban areas. The UAM ConOps will be updated to incorporate research findings and ongoing discussions with industry. ★

Steady progress in aircraft design despite covid-19 disruptions

BY MICHAEL LOGAN AND MICHAEL DRAKE

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

▲ **The Delft University** of Technology tests its subscale novel Flying V aircraft.
Joep van Oppen/TU Delft

It was a tumultuous year in aircraft design due to the impacts of covid-19. The year began normally enough with **first flight of Boeing's 777X** in January. The aircraft is the largest commercial twin engine transport and is powered by **GE Aviation's GE9X** engine. Its composite 71-meter-span wing utilizes a novel folding wingtip for easier airport operations.

The pandemic forced considerable replanning of numerous test and development programs. Boeing slowed its 777X testing, Embraer did likewise with its **E175E2**, and Mitsubishi restructured its **SpaceJet Regional Jet** family. General aviation developments continued, including the first flight of **Gulfstream's flagship G700** in February in Georgia. Cessna conducted its first flight of the **Cessna 408 SkyCourier** twin turboprop in May. Powered by Pratt & Whitney Canada PT6A-65SC engines, the SkyCourier targets a 200-knot cruise and range up to 900 nautical miles. It will be offered in both passenger and freighter versions. In July, the **Stratos 716X** kit aircraft made its debut flight in Redmond, Oregon. The six-seat, single-engine light jet is powered by a Pratt & Whitney JT15D-5 engine.

In the military and defense sector, Dynetics had its first free flight test in January of the DARPA-funded **X-61A Gremlins** experimental unmanned air vehicle. The UAV can achieve airborne launch and recovery, and by August it demonstrated a free flight of two hours, rendezvousing with a C-130 Hercules aircraft and concluding with a parachute recovery. In Italy, the **Falco Xplorer** medium-altitude, long-endurance drone from Leonardo flew for the first time in mid-January. Midyear, Taiwan's **Aerospace Industrial Development Corp. T-5 Brave Eagle** advanced jet trainer had its first flight. Designed to replicate the F-CK-1 Indigenous Defense Fighter, the T-5 has 80% new parts and is oriented specifically for training. The U.S. Navy delivered the first **Bell Boeing CMV-22 Osprey** tilt-rotor to an operational squadron in mid-June. In September, Boeing powered up the engine of its **Airpower Teaming System unmanned loyal wingman aircraft** in preparation for a first flight. Possibly the biggest surprise of the year was the U.S. Air Force announcement in September that it had designed and flown a **secret fighter jet** in only a year, but it released few details.

The tremendous enthusiasm around electric-powered vehicles continued into 2020. Momentum slowed as many major players (such as Airbus, Rolls Royce and Boeing) replanned to new financial realities. Steady developments continued, though, including China's **EHang**, which conducted the first U.S. flight in North Carolina of its autonomous air taxi, the two-seat **EHang 216**. In May, the **magniX All-electric Cessna 208B** first flew at Moses Lake in Washington. Billed as the "largest all-electric commercial aircraft," the modified C208B uses a 750-horsepower electric motor and was developed by magniX and AeroTEC, both based in Washington state. Slovenian company **Pipistrel** blazed new territory when its two-seat **Velis Electro** trainer received the first European Union Aviation Safety Agency's light sports aircraft certification in June.

Research and development vehicles also advanced. A subscale **Flying V aircraft**, a joint endeavor between Delft University of Technology and KLM Royal Dutch Airlines, was flown midyear. Weighing 22 kilograms with a 3-meter wingspan, the vehicle flew from an airbase in Germany. At scale, the large, long-range commercial transport concept targets a 20% reduction in fuel consumption when compared with today's aircraft. California-based Swift Engineering flew its solar-powered, long-endurance UAV in July from Spaceport America in New Mexico. In Cranfield, England, ZeroAvia flew the first hydrogen fuel cell-powered flight of its modified Piper M350 test aircraft. ★

Aircraft operations experience steep decline during pandemic

BY TOM REYNOLDS

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

This year saw unprecedented impacts to aircraft operations from the covid-19 pandemic. **Global airline operations fell by 70% in March** compared with 2019. Operations slowly started to return: by early November, U.S. flights were down 40% and passengers down 60% compared to the previous year. Airlines responded to the pandemic and lower demand by grounding fleets and introducing new operating procedures, including frequently deep cleaning cabins, keeping middle seats empty and requiring masks. These protocols were designed to mitigate virus transmission risk and regain consumer confidence in air travel. However, industry forecasts suggest airline operations may not recover to 2019 levels for several years.

Air traffic control regulators were still busy. In January, **FAA's Automatic Dependent Surveillance-Broadcast Out mandate** became reality. In March, the not-for-profit corporation in charge of Canada's civil air navigation system, **NAV CANADA**, and the **United Kingdom's National Air Traffic Services** completed the first year of space-based ADS-B operations, with observed oceanic benefits of reduced workload, improved position accuracy and earlier warning of aircraft deviations from planned routes.

Midyear, FAA and the European Union Aviation Safety Agency completed Boeing 737 MAX test flights to evaluate changes to the flight control system after crashes in 2018 and 2019. In November, FAA published an airworthiness directive, clearing airlines and Boeing to begin preparations for reentry to service, which include updating software and pilot training procedures. Also midyear, FAA introduced its **National Airspace System 2035 vision**. It describes ways to accommodate new entrants, as well as traffic management services in the same volume of airspace where trajectory information is shared as an enterprise service with systemwide safety assured by continuous data exchange and **artificial-intelligence-based automated monitoring**.

NASA looked toward the transformation of the national airspace system, including the introduction of new vehicle types and operational paradigms. In the X-plane business again, NASA's **X-59 Quiet Supersonic Technology** aircraft has moved from the drawing board to assembly at Lockheed Martin in preparation for a series of test flights over three years to explore whether the low-boom flight demonstrator works as expected. The ultimate test will be flyovers of several U.S. cities to measure public reaction to the hushed sonic thumps.

FAA and NASA released initial concepts this year for **how urban air mobility, or UAM, vehicles will integrate into the airspace**. FAA's concept of operations targets nearer-term, low density/complexity operations using published corridors supported by traffic management from PSUs, short for providers of services for UAM. NASA's concept of operations targets medium-term, medium-density and medium-complexity operations in larger regions of airspace supported by PSU networks. This year, NASA worked with numerous participants simulating UAM operations to verify interoperability requirements during nominal and contingency conditions. From the industry side, companies with existing UAM projects continued their vehicle developments, while new players such as startups **Archer Aviation**, based in California, and **Autoflight**, a Chinese company, entered the already crowded field.

Commercial space operations continued to make headlines, highlighted by the first launch of astronauts by a private company with the May launch of the SpaceX Demo-2 test flight and the November Crew-1 operational mission, both aboard Crew Dragon capsules. Meanwhile, Blue Origin, Virgin Galactic and other commercial space companies edged closer to regular operations. ★

Contributors: *Gabriele Enea, Antony Evans and John Koelling*

▼ **Technicians at** Lockheed Martin's Skunk Works factory examine the cockpit section of NASA's X-59 Quiet SuperSonic Technology research airplane. The view is toward the rear of the aircraft. The yellow metal is the wing's internal structural ribs. Lockheed Martin

Progress in long-duration flight, navigation and space systems support

BY PAUL VOSS

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

Raven Aerostar balloons logged approximately **12,500 flight days in the stratosphere** supporting scientific, commercial and engineering development missions. In early August, the South Dakota-based company completed a **duration-demonstration flight that lasted 59 days**. After launching from **Raven Aerostar**'s flight operations facility near Sioux Falls, the balloon's altitude was set by an automated navigation system that uses a combination of weather data and the motion of the balloon at various altitudes. The balloon was kept within 100 nautical miles of its intended target point for 30% of the flight. A second balloon with improvements to the automated navigation system was launched on Aug. 19, and the mission was still progressing as of Nov. 1. The system was directed to target areas in South Dakota, the Texas Panhandle and northern Florida and to remain within 100 nautical miles of its various targets for 100% of the time while in station-seeking mode. Raven Aerostar also demonstrated tactical launch balloons, with payloads up to 23 kilograms, that can be operated by a two-person crew with a minimal logistics footprint.

In January and again in June, Near Space Corp. conducted **heavy-lift balloon drop tests** in support of recovery parachute qualification for Boeing's Starliner Commercial Crew development program. NSC completed this multiflight heavy-lift campaign with a final drop of 10 tons for Boeing in September.

NASA sponsored a set of space mission studies in 2020 to serve as inputs to **a new decadal survey that will set priorities for the agency's planetary science missions**. One of those studies was for **a Venus flagship mission** that would send an aerobot (robotic balloon), lander and orbiter to Earth's closest neighbor. The proposed Venus aerobot is based on variable-altitude balloon technology derived from terrestrial vehicles such as **Google's Loon**, Arizona-based **World View's Stratollite** and the author's controlled meteorological balloons. Early prototyping work on this Venus aerobot technology is underway at NASA's Jet Propulsion Laboratory in California and its partners NSC and Thin Red Line Aerospace of Canada.

In April, NASA's **Planetary Science and Technology through Analog Research** program awarded a team of JPL researchers and their partners funding to conduct a campaign over the state of Oklahoma to **monitor earthquake activity with infrasound sensors carried on solar-heated hot-air balloons**. This work builds on JPL's instrumentation and data-analysis techniques for seismic-event detection from balloons, paving the way for an aerobot to search for seismic activity on Venus.

NASA's Antarctic balloon program began the year with a 33-day, two-circuit, circumpolar flight of **Washington University's Super-Trans-Iron Galactic Element Recorder** instrument as well as a near-150-day flight of a small super pressure balloon test flight of **Dartmouth College's Balloon Array for Radiation-belt Relativistic Electron Losses**, formerly the Radiation Belt Storm Probes mission, to study Earth's radiation belts. In response to the covid-19 pandemic, flight campaigns were suspended in March, and the NASA Balloon Program adjusted by focusing on development of the sensor and instrumentation suite for its **Super Pressure Balloon**. Balloon manufacturing and some operational support elements restarted in July. Advances were also made in over-the-horizon and line-of-sight telemetry systems used on balloon flights. Useable science data rates through the low-cost Tracking and Data Relay Satellite System transceiver increased from 92 kilobits per second to 960 kbps, and line-of-sight rates increased from 1 megabits per second to 12 Mbps.

In February, **CNES**, the French space agency, completed a series of technical and scientific validation flights for the **Stratéole 2 long-duration balloon** campaign. CNES released eight pressurized balloons in late 2019 from the Seychelles Islands; the balloons flew well into 2020. The longest flight was 107 days with an average of 85 flight days per balloon. ★

▶ **A Near Space Corp.** balloon is prepared for a heavy-lift drop test to help with the qualification of recovery parachutes for Boeing's Starliner Commercial Crew development program.
Near Space Corp.

Contributors: *Russ Dewey, Debora Fairbrother, Jeffrey Hall, Mike Smith and André Vargas*

Flight test players persevere through challenges

BY KARL GARMAN AND ANDY FREEBORN

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

▲ **A Boeing-FAA crew** tests a 737 MAX aircraft in July, despite the covid-19 pandemic.
FAA

Flight testing activity generally slowed in 2020. The covid-19 pandemic forced many aerospace workers to work from home, and economic factors affected the demand for aerospace products and services.

In May, **SpaceX** and NASA launched a **Crew Dragon** capsule in its first crewed orbital flight test, the Demo-2 mission. The flight also was the first time that humans launched atop a Falcon 9 rocket. Crew Dragon became the first commercial crewed spacecraft to dock with the International Space Station, before returning to Earth in August, and paved the way for the November launch of four astronauts for the Crew-1 mission. With the May launch, Crew Dragon became the first new crewed American-produced orbital spacecraft since the space shuttle's first flight in 1981.

Throughout 2020, Boeing prepared for a second uncrewed flight test of its **CST-100 Starliner** spacecraft. NASA accepted a Boeing recommendation to fly a second uncrewed test flight after software issues prevented the first flight's rendezvous and docking with the ISS in December 2019.

In April, the **Virgin Orbit** satellite launching aircraft completed its final flight test prior to conducting a space launch test. The captive carry system pairs a modified Boeing 747 carrier with a two-stage **LauncherOne rocket**. In May's first launch demonstration, the LauncherOne separated cleanly from the carrier plane, but the flight was terminated before the payload reached space because a propellant line broke.

In January, Boeing completed the **first test flight of its new 777X aircraft**. Notable features include a longer composite wing and folding wingtips. The company anticipates the variant will increase fuel efficiency and decrease operating costs compared with earlier 777 models. Boeing and FAA testers also completed **737 MAX recertification flight tests** in July, and Canadian regulators started their tests in August. The flights provided data for the FAA's November airworthiness directive describing the changes required for resuming MAX services.

In April, Airbus reported achieving the **first fully automatic air refueling contact using a boom system** on its A330 Multi Role Tanker Transport platform with a Portuguese Air Force F-16 receiver aircraft. The test campaign focused on improving the system capabilities in preparation for a follow-on certification phase expected in 2021.

In July, Dynetics completed the **second test flight of the X-61A** vehicle as part of **DARPA's Gremlins** program in Utah. The program is designed to deploy drones from military aircraft through a towed docking system while out of an adversary's range, followed by airborne retrieval for refurbishment and reuse of the drones.

Rotary wing flight test programs posted achievements in 2020. In January, **Bell-Textron's V-280 Valor** tilt-rotor aircraft had a test flight operating in a highly autonomous mode. In October, a **Sikorsky-Boeing** team reported expanding the **SB-1 Defiant**'s performance envelope to a speed of 211 knots.

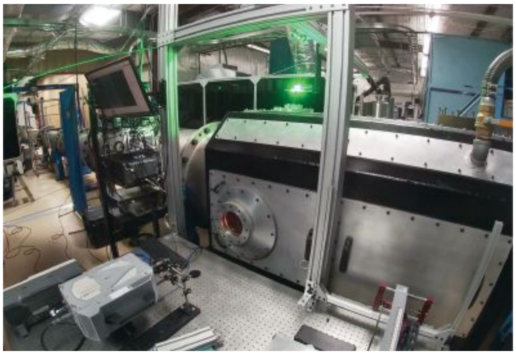
Academic institutions contributed toward flight test-related research and teaching. Throughout 2020, University of Kansas researchers worked on artificial intelligence control systems. The new AI-based methods adapt to dissimilar platforms and scenarios with the goal of developing control systems that "learn" to fly different aircraft, much like a human pilot. Programs like this continue the trend of using drones as low-cost flight test platforms. ★

Contributors: *Derek Spear, Starr Ginn, Shawn Keshmiri and Andrew Knoedler*

Flight tests and commitment to research mark hypersonics progress

BY LIZ STEIN AND GREG JOHNSTON

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



The Hypervelocity Expansion Tunnel, or HXT, at Texas A&M University provides flight-matched conditions up to Mach 15.
Texas A&M University

The covid-19 pandemic did not slow the pace of progress in hypersonics, with 2020 encompassing advancements in modeling and simulation, designs, ground test facilities and flight tests.

But first, in big news for students: the U.S. Department of Defense, through the Office of the Undersecretary of Defense for Research and Engineering Joint Hypersonics Transition Office, in October **awarded Texas A&M University's Engineering Experiment Station $20 million per year over five years** to establish and manage the **University Consortium for Applied Hypersonics**. JHTO director Gillian Bussey said, "This effort focuses not only on developing technologies but also on funding applied research at universities and linking researchers in academia, government and industry."

Advancing the state-of-the-art in simulation, researchers at the U.S. Department of Energy's Sandia National Laboratories in June demonstrated the **performance portability of their Sandia Parallel Aerodynamics and Re-entry Code, or SPARC**. Highlighting the **advantages of next-generation heterogenous computer architecture**s, a hypersonic simulation of a realistic re-entry trajectory ran up to 16 times faster on the DOE's graphics processing unit-based Sierra supercomputer than on a central processing unit-based high-performance computing cluster.

Leveraging Cart3D's adaptive mesh refinement capability, the **Pterodactyl project** at NASA's Ames Research Center in California in June and July **developed multiple concepts for non-propulsive control systems to achieve precision targeting of a deployable entry vehicle**.

Enabling future designs, the **German Aerospace Center's Key Technologies for High Speed Return Flights of Launcher Stages, or STORT**, program passed its preliminary design review in April. The flight experiment will demonstrate active and passive thermal management concepts and ceramic matrixed composite structures and perform measurements of shock wave boundary layer interactions.

In the commercial high-speed point-to-point domain, NASA's **Hypersonic Technology Projec**t in January defined challenge areas to advance hypersonic flight for dual-use applications. In August, the U.S. Air Force awarded venture-backed startup **Hermeus**, based in Georgia, a **contract for the conceptual design of a hypersonic personnel transport** based on modifications to Hermeus' existing Mach 5 passenger aircraft design.

This year saw university experimental facilities with low operational cost but high capability come online. **Texas A&M University** installed a **large-scale Hypervelocity Expansion Tunnel** that became fully operational in February. The tunnel provides flight-matched conditions up to Mach 15 and has a large complement of advanced laser-based diagnostics offered through the adjacent Aerospace Laboratory for Lasers, Electromagnetics and Optics. In October, the **University of Texas at Arlington** demonstrated the first femtosecond (millionth of a billionth of a second) two-photon absorption laser-induced fluorescence and femtosecond laser electronic excitation tagging diagnostic measurements at its arc-jet tunnel facility.

In the most tangible measure of progress for hypersonics, there were numerous flight tests during the year. In January, China released footage of a **DF-26 missile launch** during a military drill and said that it had speeds capable of up to Mach 18 and a range up to 6,000 kilometers. In March, **JAXA, the Japan Aerospace Exploration Agency**, **tested a supersonic combustion ramjet in its hypersonic wind tunnel** at the Kakuda Research Center in northern Japan. Also in March, the **U.S. Defense Department completed a second test of its common hypersonic glide body**, putting additional stresses on the system and validating the design, which is ready for transition to Army and Navy weapon system development. In September, the **Indian Ministry of Defense Research and Development Organization** said it flight tested a domestic **hypersonic technology demonstrator vehicle** for the first time. Also in September, **China launched a reusable experimental spacecraft** after multiple tests to ensure control during hypersonic re-entry. ★

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"Gravity drive" is latest experiment in carbon-free propulsion for airships

BY ALAN FARNHAM

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

Rare it is when a new form of propulsion swims into aviation's ken. Yet in January, Andrew Rae, a professor at Scotland's University of the Highlands and Islands, announced in Unmanned Systems Technology magazine that he and a team of colleagues had test-flown **a prototype drone airship propelled by nothing more than gravity**. By so doing, Rae took a recondite concept previously associated with interstellar space travel ("gravity drive") and applied it to a small robotic blimp.

Rae's novel system — one of **several experiments underway around the world for propelling airships by means other than fossil fuels** (e.g., fuel cells, photovoltaic electricity or gaseous hydrogen) — achieves forward motion by making an airship rise and fall: An onboard compressor, powered by solar cells and at night by a battery, pumps air into a bladder inside the blimp's envelope. Increase the pressure, and the air inside the bladder grows heavier, causing the craft to sink. Reduce the pressure, and the blimp, now lighter, ascends. Controllable pitch, the craft's aerodynamic shape and a pair of winglets mounted athwart the hull translate these porpoise-like rises and falls into forward thrust. Such craft, says Rae, in theory could remain aloft indefinitely — and at low cost. Rae and his team also investigated the feasibility of building a larger, follow-on vehicle capable of carrying a 100-kilogram payload to an operating altitude of 20,000 meters.

▼ **Hybrid Air Vehicles** of England moved closer to its goal of equipping its Airlander 10 airship with hybrid-electric propulsion by 2025. The company also unveiled a production version, depicted here, which would differ from the prototype by having a bow thruster, an enlarged payload bay and an envelope with lower drag, among other new features.

Hybrid Air Vehicles Ltd.

As for other experiments, **Britain's Hybrid Air Vehicles Ltd.** moved closer in 2020 to its goal of equipping its **Airlander 10 with hybrid-electric propulsion by 2025**. In January, HAV announced that hybrid-electric propulsion would give Airlander a 90% reduction in carbon emissions compared to a conventional craft of comparable capacity (90 passengers). HAV also unveiled details of a **production-version Airlander**, which would differ from the prototype by having such new features as a bow thruster, an enlarged payload bay and an envelope with lower drag.

In February, opposition politicians in Quebec questioned the wisdom of the province's having invested $30 million in French airship-maker **Flying Whales**, whose heavy-lift airship would be powered by hybrid-electric engines; one representative asked if the decision perhaps had been made by someone "inhaling helium."

Goodyear, in the latest iteration of its 100-year relationship with Germany's **Zeppelin** company, in May introduced a conventionally powered Zeppelin-made advertising airship for Europe — Goodyear's first in 12 years.

Helium demand, reduced by covid-19's depressing effect on the world economy, came closer into balance with supply, resulting in a stabilization of gas prices. Helium market expert Phil Kornbluth predicted in March that new gas supply from Algeria, Qatar and New Mexico will counterbalance revived post-virus demand.

August marked the 125th anniversary of a flight that should have been impossible but was witnessed by thousands: A reporter for the New York World ascended from the Brooklyn Navy Yard in a one-man, **pedal-powered dirigible** designed by Carl Myers of upstate New York. After demonstrating to a cheering crowd that he could navigate both with and against the wind, he waved goodbye and pedaled the length of Manhattan Island, landing eventually in Yonkers.

On a more somber note, Oct. 5 marked the 90th anniversary of the crash and immolation of R101, the ultimate expression of Britain's imperial airship ambitions of the 1930s. A six-month, multimedia exhibit in the U.K. at Cardington, R101's former base, will commemorate this tragic tale of "flight and fantasy, exploration, greed and folly." ★

V/STOL experiences expand across multiple programs

BY ERASMO PIÑERO JR.

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

▲ **A British F-35B** on the deck of HMS Queen Elizabeth in United Kingdom waters in January, the first time fighter jets had operated from a British carrier in home waters in a decade.
British Royal Navy

Lockheed Martin began the year with a **$35 billion contract** for short takeoff and vertical landing, conventional takeoff and landing and carrier variants of the **F-35** aircraft. As of early November, Lockheed Martin had delivered more than 585 F-35s, which are operational on 26 bases around the world.

According to **Lockheed Martin** news releases, the F-35B short takeoff and landing capabilities attracted international customers based on initial users' experiences, including the F-35B's ability to take off from the deck of an amphibious warship or from austere, expeditionary locations. The U.S. Marine Corps — the first military service to declare initial operational capability of the aircraft in 2015 — was the first U.S. military branch to employ an F-35 in combat during operations over Afghanistan in September 2018.

The United Kingdom also achieved F-35B program milestones in 2020. In January, the Royal Air Force's 617 Dambusters Squadron participated in the multinational combat exercise Red Flag at Nellis Air Force Base in Nevada. In January, the first operational **U.K. F-35Bs** arrived aboard the **HMS Queen Elizabeth**, the lead ship of the Royal Navy's new Queen Elizabeth aircraft carrier class, to begin carrier qualification flights. A second carrier qualification period occurred in June, during which British F-35B pilots set a record for the number of sorties flown from the Queen Elizabeth.

The **U.S. Army Future Vertical Lift** initiatives continued with flight testing this year. Joint Multi-Role Technology Demonstrator demonstrators, including **Sikorsky's SB>1 Defiant** compound helicopter and **Bell's V-280 Valor** tilt-rotor, have been accumulating flight time since 2018. The first demonstrator to fly was the Bell tilt-rotor design in December 2017; Sikorsky's SB>1 has been flying since March 2019, exceeding 200 knots in October. In March, the Army announced that Sikorsky and Bell received contracts to each build a prototype of its future attack reconnaissance aircraft. Sikorsky will use its coaxial rotor **S-97 Raider** compound helicopter demonstrator as the basis for its offering. Bell will use a semi-compound configuration based on the drive train of the commercial **Bell 525 helicopter**.

Large electric vertical takeoff and landing passenger and cargo aircraft — typically autonomous vehicles for private, military or commercial applications — continued to advance, with more than 300 eVTOL concepts being studied by midyear. The number of designs appearing every year keeps the public engaged on this exciting new form of transportation, which takes advantage of distributed electric propulsion VSTOL technology. One such multi-engine eVTOL vehicle, the **Airbus A³ Vahana**, concluded its flight test program in November 2019. The flight test team, which started its test operations in 2016 and conducted more than 130 flights, will pass on lessons learned to Airbus's follow-on test vehicle, **CityAirbus**.

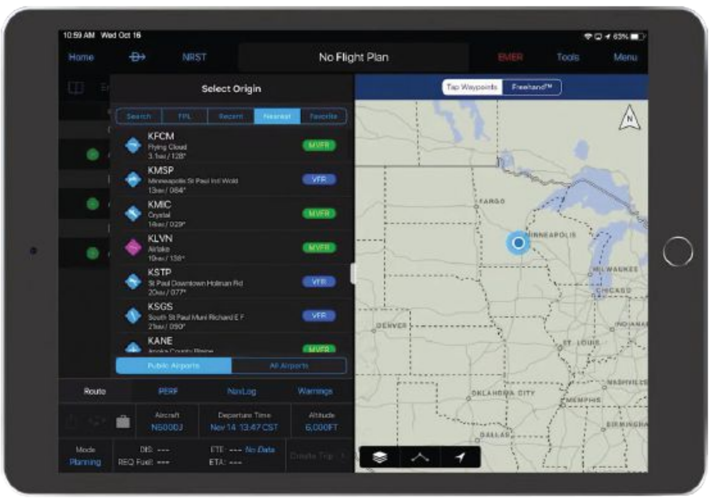
NASA's pilotless **Mars Ingenuity helicopter**, a VSTOL vehicle, began its trip to the red planet in July. Ingenuity will explore the Jezero Crater, its intended landing zone on Mars. It will be a momentous event for the VSTOL industry and the culmination of 224 years of vertical flight progress, which begun with the vertical flight ideas of Sir George Cayley in 1796. ★

Contributors: *Michael Hirschberg, Richard Mange and Paul Park*

Digital breaches heighten awareness of cybersecurity needs

BY SAM ADHIKARI

The **Aerospace Cybersecurity Working Group** provides awareness, education and standards development to help protect aerospace's digital infrastructure.



▲ **Garmin's** aviation services were among its products affected by a ransomware attack.
Garmin

Governments and cybersecurity research organizations unmasked several alleged cyber espionage groups targeting the aerospace sector in 2020, including Iran-based hackers, who the U.S. Department of Justice indicted in September.

In July, **ransomware reportedly hit Garmin**, and the subsequent outage caused problems in Garmin's aviation services, including flight planning and mapping. The attempt heightened awareness on ransomware cyberattacks on aviation communication and software.

In the interest of data privacy, national security and defense, President Donald Trump in May extended a **ban on telecom infrastructure from Chinese companies Huawei and ZTE** for another year. Multiple outlets reported in March that the White House was planning to roll out a ban on drones from China-based manufacturer DJI, but such an order was never issued.

In October, Sens. Rob Portman, R-Ohio, and Gary Peters, D-Mich., introduced the **Risk-Informed Spending for Cybersecurity Act** to require cyber-risk-based budgeting "in response to a 2019 report revealing most agencies lack comprehensive cyber risk frameworks."

The U.S. Department of Transportation Office of Inspector General in September published its report, "FAA and Its Partner Agencies Have Begun Work on the Aviation Cyber Initiative and Are Implementing Priorities," which recommends that FAA in consultation with its ACI partners identify the resources needed to meet the current schedule for achieving ACI's remaining priorities, determine how to allocate the resources and revise the schedule as necessary.

Also in September, the U.S. Department of Defense published a notification of plans to issue an interim rule to amend the Defense Federal Acquisition Regulation Supplement to implement the Cybersecurity Maturity Model Certification framework and associated assessment methodology to **assess contractor implementation of cybersecurity requirements and enhance the protection of unclassified information within the Defense Department supply chain**. CMMC certification will be a five-year rollout and is not applicable for recently awarded contracts. CMMC has five levels starting at Level 1, which focuses on performing basic cyber hygiene practices, and going to Level 5, which showcases advanced cybersecurity processes and demonstrated ability to optimize cybersecurity capabilities. CMMC's initial focus will be acquisitions in the areas of missile defense and nuclear security.

In March, the **Cyberspace Solarium Commission** released its report outlining **a U.S. cyber infrastructure to protect government operations, industry and Americans from cyberattack**. Actions include the sharing of national intelligence information with industry to perform precise threat analysis and development of discrete protections.

In September, the **U.S. National Institute of Standards and Technology** published Special Publication 800-53, Revision 5, which introduces capabilities and functionality to **protect personal-private information in government and within sectors of critical infrastructure**. Previous versions of this baseline have not included protection of privacy as critical to the development and operation of systems. The revision aligns the Risk Management Framework, which is critical to development of Defense Department systems, with the Cybersecurity Framework, a primary base for development of cyber resilience in the critical infrastructure from a 2016 presidential executive order.

In February, **Lockheed Martin** released the **Cyber Resiliency Level measurement tool** as a means to establish a system's current cyber resiliency risk and to allow customer discussion of a future state of cyber resiliency risk for the system under evaluation. In August, Lockheed Martin declared full operating capability of the first cyber range, specifically focused on cyber testing of avionics systems. The National Cyber Range is a DARPA project to build internet-based infrastructure that can be used to carry out cyberwar games. The project serves as a test range where the military can create antivirus and other cyber defense technologies to guard against cyberterrorism and cyberattacks from hackers. ★

Contributors: *Dawn M. Beyer, Stephen Blanchette, Gabriel Elkin, Preston D. Frazier, Margee Herring, Jeremy Jacobsohn, Steve Lee, Jimmie McEver, Bryce Leonard Meyer, Gerald L. Ourada and Virginia Stouffer*

Promise and uncertainty in the satellite communications industry

BY PETER GARLAND

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

The satellite communications "crises in direction" continued this year. The availability of innovative low-cost launchers, the development of digital and photonic payloads, and the well-funded private enterprise potential to provide low-Earth orbit constellation-based global services were promising. At the same time, the traditional service industry waited for direction, and manufacturers struggled to survive to reap the benefits of a promised tomorrow that never seems to arrive.

Continued communications satellite overcapacity, falling market prices, ongoing advances and additions to planned nongeosynchronous orbit megaconstellations, and persistent market uncertainties caused operators to limit geostationary orbit satellite orders again this year. Covid-19's impact did not help, and OneWeb's sudden bankruptcy in March, less than a week after launching 34 satellites, bolstered dire "I told you so" predictions regarding unrealistic LEO constellation promises.

Meanwhile, **SpaceX increased to 895 in-orbit Starlink satellites** as of October and announced the **imminent start of broadband service**. The British government purchased a controlling **OneWeb** share in July, apparently an alternative to its previously announced Global Navigation constellation. Other constellation announcements, including the LEO expansion of **SES' O3b medium-Earth orbit constellation** in May, looked feasible, but Canada-based **Telesat** continued postponing the selection of a manufacturer for its LEO venture.

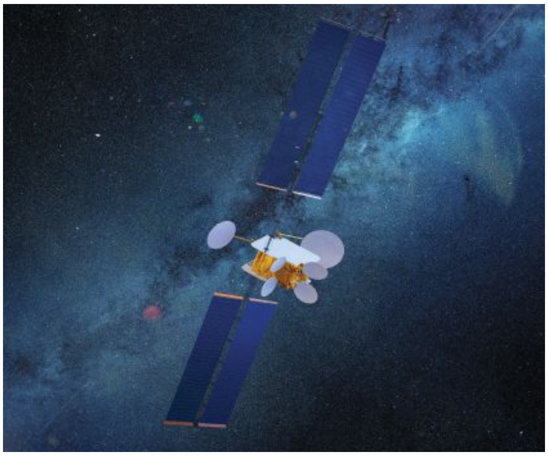
Intelsat and SES, both based in Luxembourg, ordered a total of 13 C-band satellites from Colorado-based Maxar Technologies, Northrop Grumman, Boeing and Thales Alenia Space this year, paid for by the terrestrial 5G industry through the Federal Communications Commission. Those and seven other orders of geosynchronous Earth orbit satellites as of October were a shot in the arm for the industry. In terms of GSO technologies, in June, **Australia-based Optus** selected **Airbus' OneSat** digital platform, which provides flexible and repeatable designs that overcome geographic distribution of users and specific orbit and coverage constraints. This was Airbus' second sale of OneSat following the award of three satellites by United Kingdom-based Inmarsat in 2019. The increased streaming digital video presence and the disappearance of satellite dishes in suburbs due to fiber-optic internet to homes and wireless access expansion indicated a general **contraction of the direct broadcast industry**.

This year saw the introduction of reliable laser intersatellite links, developments in phased array antenna technologies, early developments in photonic payloads and ongoing development in digital onboard processing — although the latter was still hampered by flexibility limits, long development cycles and uncertainties in driving application requirements. In ground technology, the holy grail for LEO constellations continued to be elusive; no company had yet to demonstrate low-cost fully electronic user terminals.

The terrestrial wireless industry introduction of **5G broadband wireless services**, seen by some as an opportunity and others as a threat, highlighted a perennial disappointment in the industry: better integration of satellite solutions within the global terrestrial network. Satellites have much to bring by expanding access to 5G services. Despite the proliferation in content by companies such as Facebook and Google, cost of access still dominates availability of broadband services. Satellite and terrestrial service operators producing a common network expansion road map, where each technology is accommodated on merit, will solve many of these problems.

One bright spot, as the program for the 38th International Communications Satellite Systems Conference — which was delayed until late next year — highlighted, was interest in **expanding space exploration communications**. The trends of internationalization, privatization and standardization, and the resulting concept of extending the social media world and internet to the moon and beyond, excited and galvanized the industry. **NASA's Artemis** and the **European Space Agency's proposed Moonlight programs** endorsed these trends this year. The resulting business volume will not replace the commercial sector but will provide continuity of expertise and innovation within the industry. ★

Contributors: *Thomas Butash and Chris Hoeber*



▶ **Airbus Defense and** Space won a contract to build a OneSat telecommunications satellite for Australia-based Optus.
Airbus

New architectures, agile development and next-gen rad-hardening lead work in computing

BY RICK KWAN

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

▲ **Flight hardware for a** U.S. Air Force B-21 stealth bomber ran software produced by agile development practices in a Defense Department enterprisewide secure software development environment. The process allows software to be deployed in containers, in effect, apps on a smart mobile airborne platform.
Northrop Grumman

Scientific and engineering supercomputing took a giant leap in performance this year due to innovation in computing architecture. The agile software development pipeline stretched its way from enterprise computing to flight-ready hardware. Computing in the radiation environment of space is on the brink of a performance boost.

As for supercomputers, **the fastest in the world**, as measured by High Performance Linpack, is now **Fugaku**, according to Top500.org. Fugaku, named after Mount Fuji, was made by **Fujitsu** of Tokyo and is installed at Japan's **RIKEN Center for Computational Science**. The TOP500 list, released in June, placed it at 415.5 petaflops (million billion floating point operations per second), about 2.8 times faster than its closest competitor, **Summit at Oak Ridge National Laboratory** (148.6 petaflops) in Tennessee. The major difference between them is architecture. Summit epitomizes a hybrid cluster of traditional multicore central processing units and highly parallel graphics processing units. For Summit, these were nodes of IBM Power9 CPU and Nvidia Volta GPU chips connected by Nvidia NVLink within a node and Mellanox EDR InfiniBand between nodes.

By contrast, Fugaku is built with Fujitsu's 48-core A64FX CPU chips based on the ARMv8.2-A architecture, but exploiting its Scalable Vector Extension. Published in 2016, SVE adds instructions that handle 32 vector registers, which are between 128 and 2048 bits wide. In the case of A64FX, the vector registers are 512 bits. The registers can hold eight double-precision or 64 single-byte elements in parallel. In addition to pushing CPU-based parallelism, SVE is pushing the compiler technology necessary to achieve it. Begun in 2014, Fugaku is expected to start public service in 2021.

Many computers on the TOP500 list are now part of the **Covid-19 High Performance Computing Consortium**. They support 80 research projects in bioinformatics, epidemiology and molecular modeling.

Turning to agile development, software containers and aircraft, in a drive to deliver war-fighting capabilities in a timely fashion, the **U.S. Air Force** has embarked on broad adoption of agile software development practices and infrastructure. It has deployed a variety of Defense Department enterprisewide **DevSecOps** (software development, security, software operations) services. Developers utilize secure source code repositories, build digitally signed software container images, and run them on **Kubernetes**, a platform for running a cluster of containers. In May, Will Roper, the assistant secretary of the Air Force for acquisition, technology and logistics, congratulated developers for getting a Kubernetes cluster to run on "flight-ready hardware" of a **B-21 stealth bomber**. The B-21 isn't slated to fly until December 2021 at the earliest. But the Air Force ran a Kubernetes cluster on a Lockheed Martin F-16 during flight in late 2019.

In the area of **radiation-hardened computing**, **Perseverance**, the new NASA rover launched toward Mars in July, has the same chassis design as its predecessor Curiosity. That includes the **BAE Systems RAD750**, a radiation-hardened cousin of the 32-bit single-core IBM/Motorola PowerPC 750. It has been a mainstay for roughly 15 years of rovers, landers and orbiters at the moon, Mars and beyond, with clock speeds of 110 to 200 megahertz, reaching a processing rate of 266 million instructions per second. Its successor, the **RAD5545**, saw its first shipments in July to Lockheed Martin in the form of a rad-hard software-defined radio. The RAD5545 is a 64-bit quad-core design based on the PowerPC e5500. It is capable of 5.6 Dhrystone giga (billion) instructions per second, or 3.7 giga floating-point operations per second.

Boeing continued prototype development of the rad-hard **High Performance Spaceflight Computing processor** based on the ARM Cortex-A53, a quad-core 64-bit design that has been used in several smartphones and single-board computers, such as the Raspberry Pi 3. Prototypes of this processor are scheduled for delivery in 2021.

The increases in performance for spacecraft computers should translate into greater spacecraft autonomy deeper into the solar system, as well as real-time capabilities such as software defined radio. ★

Radio data communication makes headway

BY FRED WIELAND, NIKOLAOS FISTAS AND THOMAS DAUTERMANN

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

▲ **Primary flight** display and navigation display of an A320 during the GPS Landing System approach into Thessaloniki Airport in Greece utilizing the GLASS system. The station identifier "S34A" indicates it is the first Satellite-Based Augmentation System approach to Runway 34.
DLR

DLR, the German Aerospace Center, implemented and flight tested its **GPS Landing System Approaches Based on Satellite-Based Augmentation System, or GLASS**, in Salzburg, Austria, and Thessaloniki, Greece, in February with its A320 Advanced Technology Research Aircraft. DLR had tested GLASS in Braunschweig, Germany, for the first time in May 2019 using a Lufthansa Airbus 319, when DLR also used the system to perform an automatic landing. At many small airports, the regional SBAS is the only service available for approach in low-visibility conditions. However, air transports are more commonly equipped for GLS, which employs the Ground-Based Augmentation System. To enable GLS-equipped aircraft to fly approaches using SBAS, DLR developed GLASS. It uses a ground-based SBAS-capable receiver to determine the differential GPS corrections, which are uplinked to the GLS-equipped transport with the glidepath procedure using the same VHF datalink as GBAS. It is a cost-effective way to enable satellite-based approaches with vertical guidance within the SBAS service area for aircraft equipped for GLS. Since the system combines SBAS and GLS, most components are already certified, and recertification is not required.

In August, **Mosaic ATM** and teammate **Honeywell** completed an **Unmanned Aircraft System Command and Control Link Management System, or C2LMS**, validation laboratory. The laboratory implements three communication link types: terrestrial cellular, C-band line of sight and L-band satellite communication. The L-band service is provided by the Inmarsat Ground AERO Gateway; the C-band LOS links use two radios; and the terrestrial cellular links use a Rohde and Schwartz Cellular Wideband Radio Communication Tester. Mosaic and Honeywell used the lab at the end of the year to design and develop validation test cases and to support software for the C2LMS, which is part of the performance standards that RTCA Special Committee 228 is developing for UAS command and control. The C2LMS specification contains 23 interworking requirements and 17 security requirements, all of which the Mosaic/Honeywell team must validate.

In Europe, new regulations took effect in February requiring air navigation service providers to offer Controller Pilot Data Link Communication services and airspace users to be capable of using such services for operations at least 28,500 feet above sea level.

The **Datalink Support Group** met in January, May and September to advance the datalink implementation in Europe. The European Organization for the Safety of Air Navigation, the European Aviation Safety Agency and the Single European Sky Air Traffic Management Research Deployment Manager established the group in September 2019. Datalink is recognized worldwide as the key enabler for new methods of air traffic management that increase traffic density and improve operational efficiency, as well as support scalability. In Europe, datalink technology is paving the way for the implementation of the Single European Sky ATM Research program solutions in which datalink integrates ground-based ATM systems with the avionics to enable 4D trajectory management and other advanced concepts. The standard datalink technology in service is the VHF Digital Link Mode 2, but the use of this technology has been hindered by technical and operational deficiencies that prevent the datalink's full benefit from being realized. ★

Contributor: *Mark Darnell*

Human-machine teaming is key to the future of aerospace

BY JOHN-PAUL CLARKE

The **Human-Machine Teaming Technical Committee** fosters the development of methodologies and technologies that enable safe, trusted and effective integration of humans and complex machines in aerospace and related domains.

There is little debate that the future of warfare will include greater integration of humans and machines, so it should come as no surprise that many of the accomplishments in human-machine teaming this year occurred in the military domain.

In January, the **Kratos XQ-58A Valkyrie test drone** completed its fourth test flight only four months after suffering damage in a crash in October 2019. The Valkyrie is a testbed for the **U.S. Air Force Research Laboratory's Skyborg "loyal wingman" technology** that the Air Force envisions will enable **formations of autonomous, low-cost and relatively expendable drones** that would accompany and collaborate with F-15EX and F-35 fighter jets in the same way as crewed aircraft.

In July, Boeing Australia conducted a series of flight tests involving three uncrewed aircraft that took off, achieved and departed from their required formations and landed autonomously. The flight tests were an important step toward the development of **Boeing's Airpower Teaming System**, an uncrewed loyal wingman aircraft in development in Australia.

In August, the DARPA Competency-Aware Machine Learning project received **BAE Systems' MindfuL software program** designed to **increase transparency in machine learning and artificial intelligence systems** by auditing them to provide insights about how these systems reached their decisions, and thereby enable autonomous systems to assess their own competency and strategy and express both in a form understandable to humans.

There were also significant events in the civil domain — especially with reduced crew operations and single pilot operations.

In July, **Airbus** concluded its **Autonomous Taxi, Take-Off and Landing project** to explore how autonomous technologies could help pilots focus less on aircraft operations and more on strategic decision-making and mission management. Over two years, Airbus conducted 500 test flights, culminating in a series of six test flights in which A350-1000 aircraft taxied, took off and landed autonomously using fully automatic vision-based onboard image recognition technology.

In August, Airbus subsidiary **Acubed** followed up on the work in the Autonomous Taxi, Take-Off and Landing project by starting flights in California to collect data and advance autonomous technology that will make the next clean-sheet narrow-body aircraft capable of single-pilot operation. Also in August, **Xwing**, a San Francisco-area autonomous systems startup, conducted **numerous fully autonomous passenger flights in a Cessna 208B Grand Caravan**.

Events outside aerospace also indicated a future with greater interaction between humans and machines. In July, researchers with the U.S. Army Combat Capabilities Development Command's Army Research Laboratory, in collaboration with researchers from the University of Southern California, announced that they had developed the **Joint Understanding and Dialogue Interface capability**, which enables bidirectional conversational interactions between soldiers and autonomous systems, thereby **allowing soldiers to verbally interact with machines**.

Given all the activity, human-machine teaming is poised to become a key area of research and development in aerospace, especially considering the increasing capabilities of machines as illustrated in August during DARPA's third and final **AlphaDogfight Trials**, an AI air combat competition that pitted AI against humans. ★

▼ **The Kratos XQ-58A** Valkyrie test drone flew its fourth test flight in January.
Air Force

Progress in autonomy: space robotics, satellite systems, air traffic control

BY NATASHA A. NEOGI

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

Several advances in intelligent aerospace systems were made this year.

The **Integrated System for Adaptive Autonomous Caretaking** teams at **NASA's Ames Research Center** in California and **Johnson Space Center** in Texas collaborated in June to demonstrate an integrated data approach for anomaly detection and isolation. Using a simulation of **Astrobee** in the **International Space Station**, this work combines vehicle system telemetry, static spatial information and functional relationships for vehicle hardware, and robot data, obtained by Astrobee's mapping and inspection software, to detect and isolate the root causes of anomalous data. This technology is funded by the Space Technology Mission Directorate's **Game Changing Development** Program and will inform the Vehicle Systems Manager software design, which will autonomously manage NASA's planned lunar Gateway outpost.

Also this year, the NASA-funded **Jet Propulsion Laboratory** in California conducted autonomy experiments in orbit with the **ASTERIA cubesat**, short for Arcsecond Space Telescope Enabling Research in Astrophysics. While contact was lost with ASTERIA in December 2019 after several in-flight autonomy experiments, JPL used a flat-sat ground-based replica of the ASTERIA spacecraft to continue testing and demonstrating autonomy capabilities throughout the year. The work culminated in an integration of three autonomy capabilities: 1) The Multi-mission Executive, or MEXEC, which demonstrated the use of tasknets for commanding and onboard execution that allows specification at a "task" level instead of using time-based sequences. MEXEC executed nominal science observations onboard, and is demonstrating replanning around anomalies on a ground testbed. 2) Optical navigation algorithms performed onboard orbit determination in low-Earth orbit without GPS, demonstrating an independent means of spacecraft orbit determination using only passive imaging of other bodies. 3) MONSID, a model-based approach to detect and identify hardware malfunctions, is being tested on the testbed to demonstrate in-situ hardware health assessment needed for advancing autonomy beyond monitor-response mechanisms.

▶ **Drones were flown in** Reno, Nevada, as part of NASA's **Unmanned Aircraft System Traffic Management** project. Researchers shared data this year that was collected during hundreds of flights.
NASA

In the field of air traffic control, NASA's **Unmanned Aircraft System Traffic Management** project completed its last and most complex flight demonstration and in June reported the results to the aviation community. Nearly 400 flights of small uncrewed air systems were conducted in the downtown areas of Reno, Nevada, and Corpus Christi, Texas, in 2019 with the UTM system managing scenarios of high-density drone traffic. The testing involved 35 industry partners that provided the drones, ground test equipment and service supplier systems for traffic management. Data on the performance of the UTM system and the effects of flying in the urban canyons with communication and GPS navigation challenges were reported in several publications at AIAA's virtual Aviation Forum.

The **Vehicle Systems and Control Laboratory** at Texas A&M University flight tested a vision-based system for detection and tracking of small uncrewed air systems. The technology could prove useful for the counter-UAS missions. The system combines the advantages of the long-wave infrared and visible spectrum sensors using machine-learning for vision-based detection through previously difficult environments such as when the vehicles are flying above and below a treeline, in the presence of birds and sun glare. The main algorithm is built upon the **YOLOv3 object detector retrained to detect small aircraft** on synchronized and blended Red-Green-Blue and long wave infrared video frames.

Eight competitors raced to develop artificial intelligence algorithms for **DARPA's Alpha Dogfight Trials**. These algorithms, which are capable of performing **simulated within-visual-range air combat**, were tested at the Alpha Dogfight Trials Virtual Final Event in August. These eight teams competed against various AI algorithms developed by **Johns Hopkins Applied Physics Laboratory** and then against every other competitor in a round-robin tournament. Of the eight competitors, Heron Systems, Lockheed Martin, Boeing's Aurora Flight Sciences and Physics AI were finalists in a heated competition. Winner Heron Systems went on to beat an experienced human fighter pilot in the final matchup. ★

Contributors: *Lorraine Fesq, Ron Johnson, Jonathan Rogers, Kelsey Swanson and John Valasek*

Improving physiological monitoring sensor systems for pilots

BY NICHOLAS J. NAPOLI, ANGELA HARRIVEL AND ALI RAZ

The **Sensor Systems and Information Fusion Technical Committee** advances technology for sensing phenomena, fusion of data across sensors or networks, and autonomous collaboration between information systems.

The mission requirements, operational environment and technological capabilities of aerospace systems are on an upward trajectory of increasing complexity. This requires a paradigm shift in engineering to account for human and technical components working together as a system of systems. Such a shift will better address physiological concerns around crew members and may usher in an era of synergistic balance between human abilities and system capabilities. The immediate concerns of continuous physiological events that are occurring in flights across F-15, F-16, F-18, F-22, F-35 and other training platforms show that these events are multi-factorial and complex. This year, aerospace research and development programs have looked to sensor systems to fuse real-time data to help **bridge the gap between human physiological requirements and aircraft systems**. The development of these physiological monitoring systems is at the forefront of advanced life support systems in the cockpit, cognitive monitoring for objective workload assessment, the enabling of performance adaptions and improved human-machine interaction.

NASA's Engineering and Safety Center and NASA's **Armstrong Flight Research Center** in California continued their **Pilot Breathing Assessment program** in which sensor systems measure numerous physiological breathing parameters for continuous in-flight measurements. In August, NASA released a video, "Improving Flight One Breath at a Time," that describes progress on **linking of breathing dynamics to high-altitude flights, aerobatic flights and any other fighter flight maneuver**. Such advanced life-support system frameworks contribute to the explanation of physiological episodes in flight, including hypoxia and hypocapnia, and lead to **improvements in oxygen delivery systems**, while increasing our understanding of how breathing impacts human performance.

In January, the **U.S. Air Force Research Laboratory's Air Systems Directorate** at Wright-Patterson Air Force Base in Ohio received solicitations for **advanced pilot health monitoring systems** for integrated cockpit sensing. The solicitation built on the inaugural Physiological Episodes Mitigation Technology Summit and Industry Day that Air Systems hosted in December 2019. The summit was part of the effort to demonstrate existing sensor technologies integrated with a government-provided open-architecture software application program

▶ A NASA pilot wears a U.S. Air Force harness, helmet and oxygen mask for evaluation during the Pilot Breathing Assessment program at NASA's Armstrong Flight Research Center in California.
NASA

interface and the Air Force's **Cognitive Operations Gear Pack** software. This is in order to store, process and retransmit signals from multiple pilot vital signs sensor systems. The sensor system and information fusion goal is to develop a system of sensors to monitor variables such as air quality, cognition, pilot vitals and breathing as inputs into systems providing feedback to the human for corrective actions.

Also in January, **Naval Air Systems Command expressed interest in physiological sensors for pilot monitoring** and released a solicitation for physiological monitoring fabrics and biosensing garments for aerospace applications. This suggests that the Navy, in addition to NASA and the Air Force, has recognized the need to explore novel sensor systems for synergistic design of human and aerospace systems and is looking for integrative sensor designs that would be built into the flight suits and are comfortable, flexible and reusable.

These new sensor technologies lay only the foundation toward advanced human-machine teaming technologies, adaptive workload information for pilot-mounted display system augmentation and workload management systems to handle the complex environments of future aerospace systems. The advances in sensor systems that began this year, when paired with information fusion technologies in the future, will enable new capabilities in human and aerospace system synergy. Their development is expected to continue in the upcoming years and promise to have an impact across multidomain battlefield scenarios and human space exploration. ★

An augmented reality aircraft (right) flies beside a real aircraft in this view showing what pilots would see on their helmet visors during a training flight. With AR, pilots can run through scenarios that cannot be safely performed with two real aircraft.
Red 6

Year brings greater dependency on software

BY CHRIS THAMES

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

The aerospace community this year continued to become more dependent on software to solve problems, whether that be turning to Zoom and Teams to carry on operations during the pandemic or developing software for aircraft and spacecraft. Because of the interconnectivity of systems around the world, software development and test activities largely continued despite the pandemic, though with cybersecurity becoming more important than ever.

In air transportation, FAA approved in August a plan for mitigating the software issues underlying the crash of two **Boeing 737 MAX** aircraft, including a software patch to resolve concerns with the **Maneuvering Characteristics Augmentation System or MCAS**. Flights to recertify the system were started in June, and FAA in November issued an airworthiness directive laying out steps airlines and Boeing must take to prepare the planes for reentry to service. The impacts stemming from this software problem are likely to be felt even after the MAX returns to service.

In June, eight teams competed for cash prizes in the U.S. Air Force Hack-a-Sat space security challenge at Defcon. After the success of the 2019 challenge to hack systems identical to those aboard an F-15 fighter aircraft, teams of "ethical" hackers were invited to identify potential vulnerabilities by attempting to hack a satellite. A U.S. team called PFS won by gaining network control of the simulated ground station, reestablishing communication with a tumbling satellite and being the only team to repair the satellite's attitude control system. Cybersecurity has been a concern within the aerospace community for years, and those concerns have only continued to grow as bad actors have increasingly tried to gain access to critical systems.

The Air Force has also been looking to **virtual reality** and to **augmented reality** options for enhancing **pilot training**. In February, one company, **Red 6** of California, demonstrated an AR system that simulates aircraft during training flights by displaying AR vehicles on the visor of a trainee pilot's modified helmet. This capability would allow trainers to create scenarios that would not be possible with real aircraft due to the potential safety risks.

In June, engineers from Jacobs Engineering Group, PTC software company and NASA described how they turned to **artificial intelligence** to assist in the design of life support components for NASA's forthcoming lunar surface spacesuit, the **Extravehicular Mobility Unit**, or **xEMU**. Utilizing AI in the design process allows for the analysis of a significantly larger number of options in a fraction of the time that could be accomplished by humans.

In May, **SpaceX** launched a largely automated **Crew Dragon** capsule to the International Space Station with astronauts Bob Behnken and Doug Hurley aboard, marking the first human mission to ISS under NASA's Commercial Crew program and clearing the way for the November launch of four astronauts for the Crew-1 mission. Both SpaceX and Boeing were aiming to launch crew members to the ISS this year, but software errors were discovered during the **Boeing Starliner** orbital flight test in late 2019, resulting in a delay for the Starliner's first flight with a crew. Formal qualification testing of the updated software began in August, with a plan for an uncrewed flight test in 2021. ★

Contributor: *Stephen Blanchette*

Launching missions to Mars and the asteroids beyond

BY GIANG LAM

The **Aerospace Power Systems Technical Committee** focuses on the analysis, design, test or application of electric power systems or elements of electric power systems for aerospace use.

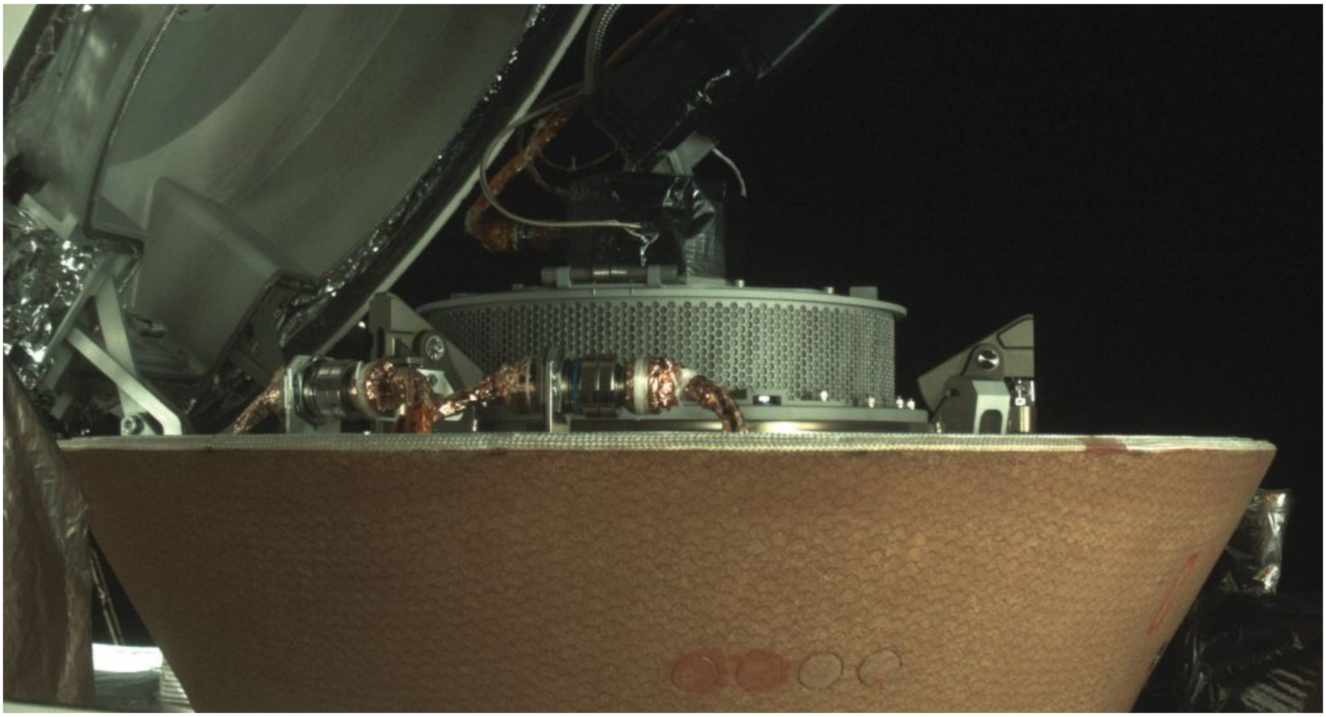
NASA's **Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer, or OSIRIS-REx**, spacecraft collected samples from the surface of the asteroid Bennu in October. The spacecraft, which launched in 2016, maneuvered to approach the asteroid, touched down on Bennu with its **Touch-and-Go Sample Acquisition Mechanism** instrument to gather surface samples and sealed the samples collected into its **Sample Return Capsule**. The mission required a minimum of 60 grams (2.1 ounces) of surface samples. TAGSAM collected well over that amount. It was so much that the seal over the instruments could not close as designed, and some of the sample escaped. However, scientists got the capsule to close earlier than scheduled, securing the samples. OSIRIS-REx will begin its return to Earth next year and drop off of its samples in 2023.

For the first time, three missions started the seven-month journey to Mars within the same year. NASA's nuclear-powered **Mars 2020 Perseverance rover** and its passenger, the solar-powered helicopter **Ingenuity**; the **United Arab Emirate's Hope orbiter**; and **China's Tianwen-1** orbiter, rover and lander all were launched to Mars in July. Perseverance is a twin of the 2016's Mars Curiosity rover in operation on the planet since 2012. The Hope mission will be the first from an Arab country to enter orbit around another planet. Tianwen-1 will be China's first mission to Mars.

The **Psyche mission**, of which Colorado-based **Maxar Technologies** is the primary contractor, completed critical design review in July, in preparation of manufacturing flight hardware and instruments for Phase C. The mission aims for a closer examination of a unique metal asteroid, **16 Psyche**, which appears to be the exposed nickel-iron core of an early planet comparable to Earth's core. The Psyche spacecraft will be powered by solar electric propulsion as it heads to the metal asteroid located at approximately 2.4 astronomical units, between Mars and Jupiter.

In September, two identical small satellites that are part of the **Janus mission** passed their Key Decision Point C to begin project implementation. The twin spacecraft will be tasked with returning **the first high-resolution images of the binary asteroids 1996 FG3 and 1991 VH**. Each spacecraft will be solar powered at approximately 100 watts, propelled by electric thruster, and weigh about 36 kilograms (80 pounds) each. The Janus mission is part of NASA's Small Innovative Missions for Planetary Exploration program to study binary asteroids beyond Mars orbit.

Lockheed Martin's Lucy spacecraft passed its Key Decision Point in August, allowing the company to proceed with assembling and testing the spacecraft and its instruments in preparation for launch to the **Trojan asteroids leading and trailing in orbit with Jupiter**. Lucy will be powered by two 7-meter-diameter solar arrays providing approximately 22,000 W of power in Earth's orbit and approximately 400 W at 5.7 AU. ★



▼ **The Sample Return** Capsule on NASA's OSIRIS-REx spacecraft holds materials collected from the surface of the asteroid Bennu.

NASA/University of Arizona/Lockheed Martin

Electric propulsion research accelerates toward the future

BY JAMES SZABO

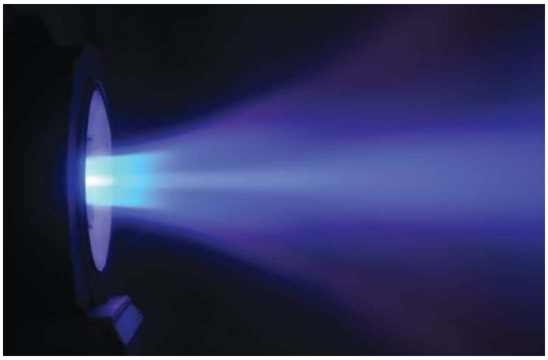
The **Electric Propulsion Technical Committee** works to advance research, development and application of electric propulsion for satellites and spacecraft.

By mid-2020, 900 operational spacecraft were maneuvering with electric propulsion, which accelerates propellants to much higher velocities than possible via chemical reaction. In February, **Northrop Grumman's Mission Extension Vehicle-1** reached geosynchronous orbit propelled by 3-kilowatt Aerojet Rocketdyne XR-5 Hall effect thrusters, allowing it to dock with the Intelsat 901 communications satellite and move it to a new orbital slot where it began a five-year mission extension, all firsts for commercial spacecraft. **MEV-2** was launched in August. In March, the U.S. Air Force's sixth **Advanced Extremely High Frequency communications satellite**, made by Lockheed Martin, reached geosynchronous orbit where it is propelled by XR-5s for orbital acquisition, station keeping and maneuvering. Japan's Hayabusa2 spacecraft headed back to Earth from asteroid Ryugu for a Dec. 6 arrival, propelled by four microwave discharge gridded ion engines, which provided 1,275 kilometers per second of velocity change through September.

Back on Earth, many new electric propulsion systems were being developed.

In January, **Busek Co. Inc.** of Massachusetts delivered its third all-iodine-fueled **BIT-3 radiofrequency gridded ion engine system**. BIT-3 will fly on multiple spacecraft in deep space and low-Earth orbit. In February, Aerojet Rocketdyne and ZIN Technologies finished testing a **NEXT-C flight ion thruster and power processing unit** at NASA's Glenn Research Center in Ohio. The Johns Hopkins University Applied Physics Laboratory in Maryland received delivery of the hardware for NASA's **Double Asteroid Redirection Test** mission.

Also in January, Busek began delivering its **BHT-350 Hall thrusters** for satellite constellations. In February, Busek's BHT-600 Hall thruster completed a 7198-h xenon duration test at Glenn, demonstrating 1.0 meganewton-seconds of total impulse. Also in February, **Safran Aircraft Engines** in France finished qualifying the **PPS-5000 Hall thruster** for 7 meganewton-second missions. Through August, the qualification thruster had accumulated 10.8 meganewton-seconds of total impulse in 11,607 hours. Safran also continued developing its low-power PPS X00 Hall thruster. Through September, **Apollo Fusion** of California won contracts for its **ACE and ACE MAX Hall thruster** systems. Through August, endurance testing for its two krypton fueled systems reached 1,000 hours.



◀ **The Institute for** Space Systems' 100-kilowatt SX3 thruster operates on argon in a high-voltage mode using a LaB6 hollow cathode.
University of Stuttgart

NASA's Jet Propulsion Laboratory in California and various contractors continued preparations for the **Psyche mission**. In May, critical design reviews were held for the spacecraft and propulsion system, which is based on **Fakel SPT-140 Hall thrusters** from Russia. JPL also began wear testing the subkilowatt Hall thruster at the heart of its **Astraeus Propulsion System for small spacecraft**. In August, CU-Aerospace of Illinois delivered a prototype xenon flow controller for **Astraeus**, and a prototype power processing unit was also fabricated.

Work continued on NASA's Power and Propulsion Element, which will act as the lunar **Gateway's service module**. The Maxar-built vehicle will be propelled by Aerojet Rocketdyne's Advanced Electric Propulsion System and Busek's BHT-6000 Hall thrusters. In March, Aerojet Rocketdyne completed a flight-like AEPS power processing unit, and VACCO of California completed a flight-like xenon flow controller.

Low-power electrospray propulsion development continued at a brisk pace, targeting small spacecraft. **Accion Systems Inc.** of Massachusetts developed its **Tiled Ionic Liquid Electrospray thruster chip** technology, testing 35 devices through September. In May, Busek's BET-300-P electrospray thruster passed environmental testing and demonstrated total impulse. Meanwhile, the Plasma and Space Propulsion Laboratory at the University of California in Los Angeles in collaboration with Busek, JPL and the Air Force Research Lab characterized electrospray capillary emission, identifying mechanisms reducing lifetime and performance at some conditions.

Research at the Institute for Space Systems in Stuttgart, Germany, was robust. Early in the year, the institute demonstrated an **Inertial Electrostatic Confinement Thruster** with an electromagnetic nozzle. In March, it tested a radio frequency helicon plasma thruster as part of the **European Union's Project Discoverer**. The institute tested its SX3 applied field magnetoplasmadynamic thruster with a LaB6 cathode. In midyear, it completed endurance and integrated testing of the miniature 5-joule Petrus pulsed plasm thruster. Additional Petrus experiments took place at the European Space Agency's European Space Research and Technology Center in the Netherlands. Petrus flight hardware was delivered to the University of Rome for the Greencube cubesat. ★

Electrified aircraft flight tests moving at full throttle

BY GOKCIN CINAR AND PHIL ANSELL

The **Electrified Aircraft Technical Committee** supports the integration of electrified aircraft systems through the design, evaluation and application of key technologies, including components for propulsion, actuation, safety, airworthiness and thermal management.

The year saw several exciting developments and flights of electrified aircraft systems. In May, the **first test flight of a fully electric Cessna 208B Grand Caravan**, which the company said is the world's largest all-electric aircraft, took place at the AeroTEC Moses Lake Flight Test Center in Washington. The aircraft was powered by magniX's 560-kilowatt propulsion system. MagniX, an electric motor manufacturer based in Washington state, powered the world's first fully electric commercial aircraft operated by Canada-based Harbour Air Seaplanes last December.

In June, Slovenian company **Pipistrel's Velis Electro** became the first European Union Aviation Safety Agency type-certified electric aircraft for day visual flight rules operations. The two-seat trainer has an endurance of up to 50 minutes (plus visual flight rules reserve) and is powered by DO-311A-compliant lithium propulsion batteries.

In September, California-based Ampaire flew its latest prototype, **Electric EEL, a hybrid-electric modification of a six-seat Cessna 337**. In October, the EEL flew 549 kilometers across California, the longest flight for an electrified aircraft, according to the company. The hybrid electric aircraft has a tractor propeller driven by a nose-mounted electric motor in addition to a pusher propeller powered by a conventional combustion engine in the rear.

▼ **Ampaire's Electric** EEL hybrid electric aircraft demonstrator flew 549 kilometers.
Ampaire

Also in September, California-based **ZeroAvia flew the first hydrogen fuel-cell-powered commercial-grade aircraft**. The company conducted a series of test flights using a modified Piper M six-seater aircraft outfitted with a fully electric battery and fuel-cell power system and a motor-driven propeller system.

The French startup company **VoltAero's Cassio 1 demonstrator**, equipped with the company's patented series/parallel hybrid-electric power module, made its first flight in October. The power module installed in the aft fuselage-mounted pusher position combines three 60-kilowatt electric motors with a conventional internal combustion engine.

Throughout the year, Airbus performed flight testing of its full-scale electric vertical takeoff and landing demonstrator, **CityAirbus**. The four-seat multicopter is remotely piloted for autonomous flight. It employs four coaxial ducted propeller units and eight 100-kilowatt electric motors powered by 110-kW-hour batteries.

The NASA-funded **University Leadership Initiative Electric Propulsion — Challenges and Opportunities project** being carried out by Ohio State University, Georgia Tech, University of Wisconsin-Madison, University of Maryland and North Carolina Agricultural and Technical State University completed its third year of research and hardware development. This year, the team started tests on the 200 kW electric machine in preparation for the testing of the 1-megawatt power electronics, motor and electric drive at NASA's Electric Aircraft Testbed facility in Ohio.

Another NASA ULI program completed its first year of research through the **Center for High-Efficiency Electrical Technologies for Aircraft**, a team comprised of members from 10 institutions across academia, industry and government. The group's research focuses largely on developing power, propulsion and aircraft systems technologies for fully electric commercial transport-class aircraft using hydrogen fuel-cell power and battery energy storage systems. The team reached several milestones this year, including the **initial design of a 2.5 MW fully superconducting electric machine and power system**, lightweight liquid hydrogen storage tank designs, a hydrogen aircraft configuration with distributed electric propulsion system, and accompanying modeling and optimization tools. ★

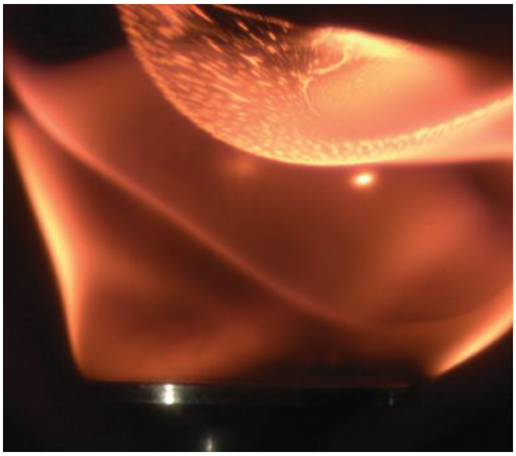
Levitating droplets, 3D-printed gun propellants, electromagnetic munitions and a game-changing solid-fuel ramjet

BY JOHN F. ZEVENBERGEN

The **Energetic Components and Systems Technical Committee** provides a forum for the dissemination of information about propellant and explosive-based systems for applications ranging from aircraft to space vehicles.

The next generation of air-breathing propulsion systems will require novel high-energy fuels, such as by adding high-energy density materials like aluminum to enhance fuel performance. In January, researchers at the University of Hawaii and Texas Tech University **doped droplets with nano-aluminum particles and studied their combustion**. The levitator device effectively simulates microgravity for purposes of analysis, meaning that experiments normally conducted at the International Space Station can be carried out much easier and faster in the terrestrial laboratory. Initiation and enhancement of combustion was a consequence of forming highly reactive atomic oxygen and aluminum monoxide radicals in the reaction of aluminum atoms with molecular oxygen in the gas phase. These radicals initiated the degradation of jet fuel JP-10 via atomic hydrogen abstraction forming hydroxyl radicals such as hydroxide and aluminum hydroxide in reactions. Ongoing research is examining the chemistry of other solid nanofuel additives to catalyze hydrocarbon combustion and improve propulsion.

Additively manufactured gun propellants may allow new geometries to be considered and decrease the amount of solvent used in the manufacturing process. In July, researchers from the Purdue Energetics Research Center in Indiana **additively manufactured gun propellants using vibration-assisted 3D printing** in a project funded by the U.S. Strategic Environmental Research and Development Program with the Army Research Laboratory and the Naval Postgraduate School as collaborators. A variety of 3D-printable gun propellant pastes were characterized, from single-base and double-base to low-vulnerability ammunitions. The team then tested double-base propellant strands in a nitrogen environment at pressures up to 13.8 megapascals (2,000 PSI), in which the strands exhibited a steady burning behavior. Higher pressure tests are planned. The team used vibration-assisted 3D printing because of its ability to extrude highly viscous pastes. This allowed the researchers to use minimal solvent without modifying referenced gun propellant formulations, a feat that they could not achieve using other direct-write additive manufacturing techniques.



This jet fuel droplet was ultrasonically levitated by researchers at the University of Hawaii so they could analyze the effects of enriching the fuel with nano-aluminum particles.
Texas Tech University

In May, Raytheon Missiles and Defense and the Netherlands Organization for Applied Scientific Research, TNO, **unveiled a ramjet-powered 155-millimeter artillery round**, which will push the boundaries of range to over 100 kilometers. At the core of the design will be a compact and highly efficient solid-fuel ramjet, a type of air-breathing propulsion system designed for supersonic flight speeds, using a solid fuel to provide the necessary energy. TNO has a long history in solid-fuel ramjet technology, and in 2004 performed the world's first successful demonstration of a 35-mm spin-stabilized air defense projectile with an integrated solid-fuel ramjet motor. The **Raytheon-TNO team** will leverage this experience when designing the new round and also leverage TNO's new ramjet test facility, which is capable of simulating a wide range of operational conditions, permitting evaluation without having to fire the round from a gun. The first test series in this facility were completed in July.

In March, the **European Defense Agency** awarded a service contract to the **Fraunhofer Gesellschaft** in Germany, represented by its Institutes for Technological Trend Analysis INT and High-Speed Dynamics, Ernst-Mach-Institute EMI, for **a study on high-power electromagnetic munitions**. The study is expected to assess the key technology gaps and scientific challenges associated with developing such future munitions. A second outcome will be recommendations to capability developers about the opportunity high-power electromagnetic munitions could bring to future warfare, through scenarios and the assessment of their operational performances. As a third output, the study results will help planners to better understand improvements needed to ensure that future military equipment and systems with electronics onboard remain robust in the face of high-power electromagnetic threats. The final report will be delivered 18 months after the start of the project. ★

Contributors: *Michelle Pantoya, Hans Martin Pastuszka, Steve Son and Wolter Wieling*

Aircraft engine community improves standing for operations after recovery

BY MICHAEL G. LIST

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

▲ **The second Boeing** 777x aircraft, powered by two GE9X engines, began test flights.
Boeing

The aircraft engine community saw a strong start to the year, with focus on improving manufacturing, sustainability, efficacy of operations and responsiveness to airframers and airliners.

GE Aviation and **Boeing** celebrated the **first flight of the 777X** at Paine Field in Everett, Washington, in January. Two GE9X engines powered the widebody aircraft. GE Aviation developed the GE9X engine, which includes 300 3D-printed engine parts in seven components, including fuel nozzles, heat exchangers and low-pressure turbine blades. A second 777X airplane began flight testing in April, and in September, GE Aviation received airworthiness certification from FAA for the GE9X after nearly 5,000 hours of testing.

In February, **Pratt & Whitney** announced that the **first aftermarket 3D-printed part, a fuel system component, would replace conventionally manufactured parts**. The joint effort with Component Aerospace Singapore and Singapore-based ST Engineering represented a new application of additive technology for commercial engine maintenance, repair and overhaul, or MRO, operations that will reduce the overall logistics footprint.

In February, **Rolls-Royce began manufacturing UltraFan composite fan blades** at its Bristol, England, location for a new demonstrator engine with a diameter of 3.556 meters. UltraFan is part of a geared turbofan engine for high bypass ratio and is reportedly the largest fan diameter in development. The engine is being designed to deliver a 25% fuel and emissions reduction over Rolls-Royce's first-generation Trent engines.

The fall in demand for air travel due to the covid-19 pandemic accelerated in March. Throughout the industry, companies worldwide announced lockdowns, reductions in employees, furloughs and facility closures as they tightened and refocused. Despite the negative business impacts, the engine manufacturers renewed focus on support and MRO of existing fleets.

Pratt & Whitney exploited excess capacity at its MRO partners to conduct **upgrades across the Geared Turbofan fleet**. The **PW1100G**, which powers the **Airbus A320neo**, underwent a material change in the third stage of the low-pressure turbine and replacement of the main gearbox to increase durability. In August, Pratt & Whitney announced completion of the turbine and gearbox upgrades for IndiGo of India.

In July, Rolls-Royce announced that no **Boeing 787** aircraft remained grounded for durability problems, positioning the fleet for improved operations as demand increases. Rolls-Royce redesigned intermediate pressure compressor blades and high-pressure turbine blades and replaced intermediate turbine blades for the Trent 1000 TEN engine. In addition to the upgrade efforts, Rolls-Royce piloted improved training and inspection capabilities via Librestream, a digital visualization platform that allows airline technicians to conduct inspections in conjunction with remote experts.

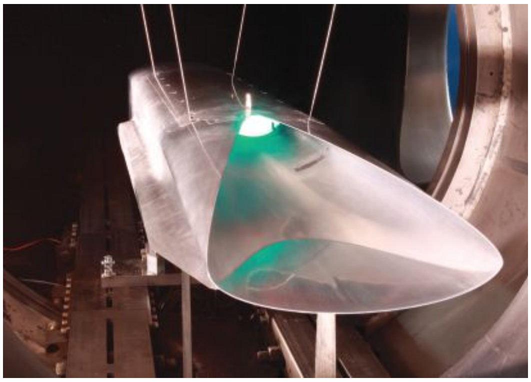
Honeywell Aerospace, based in Arizona, obtained FAA certification in August for a **3D-printed, flight-critical No. 4/5 bearing housing on the ATF3-6 turbofan engine**. The engine, designed in the 1960s, powers the **Dassault Falcon 20G** aircraft for the French Navy. Printing the bearing housing reduces lead-time from two years to two weeks for about a dozen aircraft in operation.

The industry also continued support of advanced aircraft demonstrations for next-generation aviation. In August, **NASA's Armstrong Flight Research Center** in California took delivery of an afterburning **GE Aviation F414-GE-100 engine** to power the Mach 1.42 **X-59 Quiet Supersonic Technology X-plane**. GE Aviation redesigned the F414 engine operation and controls as well as externals to meet X-59 needs. Lockheed Martin's Skunk Works in California began the X-59 assembly this year. Once complete, the company will test the aircraft and collect data on quiet supersonic flight to inform regulators as new rules for over-land supersonic flight are considered. ★

Canada, China, Europe and U.S. cite progress in hypersonic propulsion

BY KHALED A. SALLAM

The **High-Speed Air-Breathing Propulsion Technical Committee** works to advance the science and technology of systems that enable supersonic and hypersonic air vehicle propulsion.



Engineers from the German Aerospace Center in Gottingen this year tested the Small Scale Flight Experiment, a sub-scale air-breathing hypersonic engine, at the High-Enthalpy Shock Tunnel in Germany, with funding from the European Commission-financed Stratofly Project. DLR

The Stratofly Project, after two and a half years of research funded by the European Union, accelerated experiments on the pollutant emission quantification of hydrogen-fueled scramjet engines for civilian Mach 8 flight. The project aims to **assess the potential of hypersonic civilian aircraft to reach Technology Readiness Level 6** on the 9-point internationally recognized readiness scale by 2035, meaning the technology would be tested in a relevant environment. Keys are to prove the technological, societal and economic aspects, specifically: thermal and structural integrity, subsystems design and integration including smart energy management, environmental aspects of combined propulsion cycles impacting climate change, noise emissions and social acceptance, and economic viability accounting for safety and human factors.

In July, the European Commission representatives announced the funding of the **More&Less project**, short for Multidisciplinary Optimization and Regulations for Low-boom and Environmentally Sustainable Supersonic aviation. The project was proposed by major partners of the Stratofly project and leading U.S.-based high-speed aviation companies with the aim of **developing supersonic aircraft concepts with low noise and climate impact** through intensive research in the fields of experimental and numerical studies of aerodynamics, jet-noise, sonic-boom, propulsion and pollutant emissions as well as environmental impact and eventually integrating all outcomes into the multidisciplinary holistic framework.

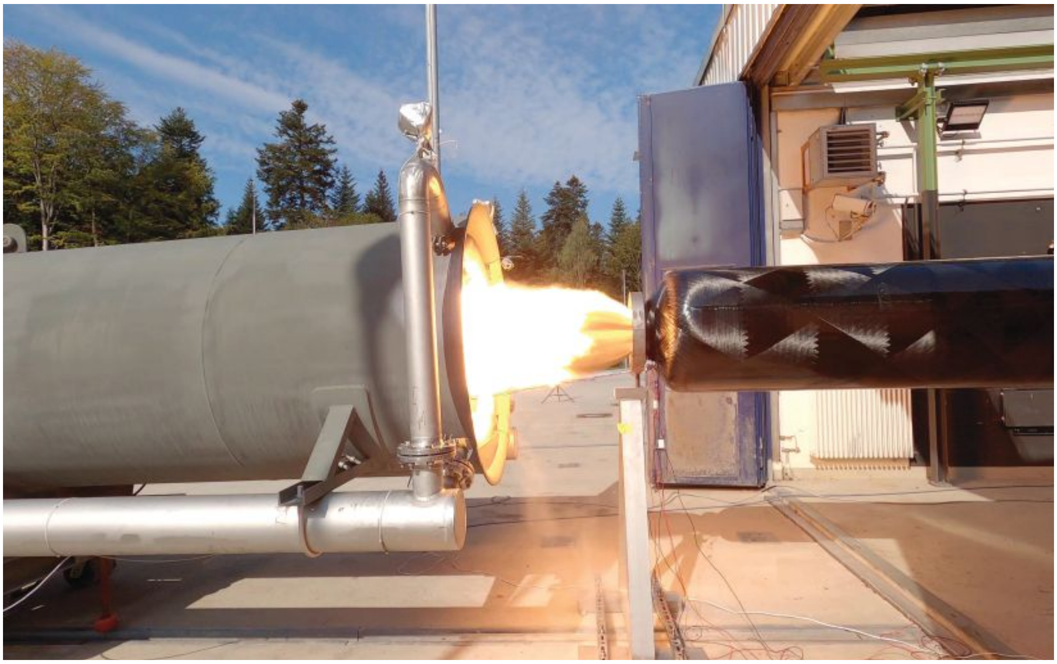
In January, **Space Engine Systems** of Edmonton, Canada, signed a memorandum of understanding with **Spaceport Cornwall** in the United Kingdom ahead of integrated testing onboard a **modified conventional two-seat fighter body comprising two air-breathing engines and one rocket engine**. Plans call for reaching an altitude of 98,000 feet (30 kilometers) in air-breathing mode before transitioning to an off-the-shelf rocket engine to reach low-Earth orbit. Space Engine Systems ground tested its complete DASS GN1 engine (Mach 4.2-5): heat exchangers, compressor, combustor, turbine, multi-fuel afterburner injection, ramjet and mixed nanoparticle-LNG and LH2/Jet A fuels at a simulated altitude of approximately 30 km. Titanium and magnesium alloys facilitated high-temperature heat exchangers.

DLR Lampoldshausen in Germany focused on investigating **new composite materials for the flame holders of scramjet combustors**. From January to late March, several material combinations were tested at typical boundary conditions of a Mach 5.5 to Mach 6 flight. Some material samples were tested to destruction on purpose. The experiments were conducted to investigate the applicability of transpiration cooling systems in scramjets and the phenomena resulting out of the interaction between a wedge-flame holder and coolant secondary flow. When the **covid-19 pandemic** hit in the middle of March, the efforts were shifted to upgrading the facility in a mix of home office and at-site tasks. The break was used to **upgrade the air vitiator test bench's data acquisitioning systems** and to upgrade the existing optical measurement equipment by improving the in-house Background Oriented Schlieren code and by adding new components to the setup.

China reported that it developed **a new scramjet**, which was demonstrated in ground tests to run continuously for 600 seconds. This is expected to **increase the range of the DongFeng (DF)-17 boost-glide hypersonic weapon** from 2,000 km to 10,000 km. This long-duration operation is attributed to advances in fuels and active engine cooling technologies.

In September, DARPA and the U.S. Air Force announced completion of captive carry tests of two variants of the HAWC, short for **Hypersonic Air-Breathing Weapon Concept advanced air vehicle**. The joint effort seeks to develop an effective and affordable air-launched hypersonic cruise missile. The upcoming flight tests will focus on hydrocarbon scramjet-powered propulsion and thermal management techniques to enable prolonged hypersonic cruise. The flight data collected is intended to increase the confidence in air-breathing hypersonic systems. Lockheed Martin's HAWC demonstrator is powered by an Aerojet Rocketdyne scramjet engine while Raytheon's demonstrator is powered by a Northrop Grumman scramjet combustor. ★

Contributors: *Jesse Kadosh, Kevin Kremeyer, Bayindir Saracoglu and Friedolin Strauss*



Encouraging tests of hybrids hold hope of safer, reliable access to space

BY TIMOTHY MARQUARDT AND JOSEPH MAJDALANI

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

▲ **The first firing of** HyImpulse's 75-kilonewton thrust, paraffin/liquid oxygen hybrid rocket motor was performed in September at the German Aerospace Center's test site in Lampoldshausen, Germany.
Mario Kobald

In the realm of academic research, several groups tackled fundamental problems in hybrid rocket combustion this year. Between January and March, the Propulsion Research Lab at **Utah State University** developed a **new oxidizer for hybrid rockets**. This oxidizer, called Nytrox, is blended by percolating oxygen under pressure into nitrous oxide until the solution reaches saturation. The addition of molecular oxygen mitigates the risk of inadvertent thermal or catalytic decomposition and leads to a system that is safer and more compact than existing alternatives.

In April, researchers at the Technion-Israel Institute of Technology shared the results of their investigation into the use of **expandable graphite to enhance fuel regression rates**. This type of intercalated graphite forms long, thin strings that protrude from the fuel surface and facilitate the heat transfer to the solid grain; this process gives rise to a two- to threefold increase in the burn rate of polymeric fuels without compromising any of their mechanical properties. Moreover, adding 5% expandable graphite to paraffin waxes was shown to produce up to 50% regression rate enhancement.

Researchers at Stanford University used experience with laser ignition systems to study the **two-dimensional propagation of flame sheets above fuel slabs**. Their measurements, published in August, show that flames spread evenly in all directions from the point of ignition despite the presence of oxidizer crossflow in hybrid chambers.

In February, Sierra Nevada Corp. tested a **novel hybrid rocket engine** under the **DARPA Operational Fires program** that demonstrated high-energy density and the capability for deep throttling and smooth shutdown on command. Along similar lines, **bluShift Aerospace** of Maine had a busy year proving its **new modular, carbon-neutral engine** in the wake of nearly 100 hot-fire tests. A final series of static test firings in August paved the way for the forthcoming launch of its **Stardust 1.0 rocket**.

In Europe, Nammo of Norway improved its flight-proven 30-kilonewton engine by redesigning the catalyst assembly, which converts hydrogen peroxide into a hot steam and oxygen mixture that fuels combustion. Further, the German startup **HyImpulse Technologies** developed a 75 kN Paraffin-LOX hybrid motor, called **HyPLOX75**, and completed the first hot-fire tests in September at the German Aerospace Center in Lampoldshausen. With this milestone, HyImpulse moves one step closer to the 2022 first launch of its small launch vehicle, which will use 12 Turbopump-fed HyPLOX75 engines in the first and second stages.

Across the Pacific, **Gilmour Space Technologies** of Australia completed a 110-second, mission-duration test firing of the company's **new single-port hybrid motor** in mid-July. The Taiwanese **TiSPACE** completed the flight model hot-fire qualification for its four-engine second-stage propulsion system, while a group at the Advanced Rocket Research Center of the National Chiao Tung University in Taiwan **demonstrated stable hovering flight of a hybrid rocket platform** in early September. ★

Contributors: *Yen-Sen Chen, Marty Chiaverini, Sascha Deri, Alon Gany, Mario Kobald, Veronika Korneyeva, Tony Whitmore and Jong-Shinn Wu*

Studies yield hopeful results for saving fuel, meeting performance goals

BY JONATHAN S. LITT

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

Between February and April, North Carolina-based Blue Force Technologies conducted a **parametric study exploring shape characteristics appropriate for meeting common inlet design requirements**. This study focused on inlets using serpentine (i.e., offset) diffuser shaping for low radar cross-section. Cost, complexity, size and radar cross-section are important constraints when designing relatively compact air intake systems with total pressure recovery and distortion characteristics suitable for existing commercial turbofan engines. Secondary flow features often migrate and coalesce within serpentine diffusers and are difficult to attenuate once they are established. The resulting flow defects persist to the engine face, impacting engine performance and operability. The methodical survey provided information about the secondary flow features within the diffuser and the design parameters that have the most influence on them, including diffuser length, centerline offset, aspect ratio distribution and area distribution. The study resulted in a database useful for the design of fixed-geometry, short-length, low-cost inlet systems capable of meeting a broader range of performance and operability requirements.

Clean Sky 2, the European program that promotes the development and testing of hybrid electric propulsion technology for 2035-era short- to medium-range airliners, announced multiple achievements by its research partners in the first half of the year.

In January, a research team from ONERA, the French national aerospace research center, announced results from a multidisciplinary design and performance analysis of a hybrid electric distributed propulsion concept known as **DRAGON, or Distributed fans Research Aircraft with electric Generators by ONERA**. DRAGON is an A320-like electrically powered aircraft concept using distributed fans along the wingspan on the pressure side in the rearward position. DRAGON is being used to mature transonic distributed electric propulsion. Results indicate 7% fuel burn reduction for a 2,750-nautical-mile (5,093-kilometer) design mission relative to a conventional configuration.

Also in January, NLR, the **Netherlands Aerospace Center**, announced results from an **energy optimization study of a parallel hybrid electric propulsion system architecture** retrofitted to a 150-passenger short-range Airbus A320neo, or new engine option, reference aircraft. Using a parametric system model and tool chain for HEP performance analysis and system optimization, NLR estimated reductions in fuel and total energy consumption of up to 7% and 5%, respectively, for short-range missions.

In June, DLR, the **German Aerospace Center**, shared results from two key studies. The first study involved an **overall assessment of a hybrid electric A320 aircraft design concept**. The assessment covered three variants, all powered by turbofan engines and electric motors, which aid the off-design engine operation in taxi and descent; the motors utilize electric power generated by solid-oxide fuel cells and a booster battery. The propulsion system architecture was designed to reduce fuel burn for off-design idle engine conditions, which accounts for about 10% of the total fuel consumption of the global A320 aircraft fleet. Off-design performance optimization resulted in estimated fuel savings of 4% to 9%. The second study involved **an energy efficiency comparison between a partially turboelectric, boundary layer ingesting short-range aircraft concept and a conventional turbofan-engine-powered aircraft**. The partially turboelectric concept utilizes a rear fuselage-mounted BLI inlet/fan driven by an electrical motor powered by two wing-mounted turbofan engines. DLR optimized the thrust fraction of the rear BLI fan for two powertrain technology levels (standard and advanced). Researchers observed block-fuel savings smaller than 2%. ★

Contributors: *Tim Conners, Morgan Funderburk and Dyna Benchergui*

▶ **ONERA, the French** national aerospace research center, is leading three projects: the six-seat Ampere-distributed electric demonstrator aircraft project (top); the NextGen ONERA Versatile Aircraft boundary-layer ingesting project to integrate ultra-high bypass geared turbofan engines into 180-passenger medium-range aircraft (middle); and the DRAGON hybrid-electric aircraft project that could deliver reduced fuel consumption (bottom).
ONERA

Milestones reached in development, testing and flight of new liquid propulsion systems

BY BRANDIE L. RHODES

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

History was made in May when SpaceX launched NASA astronauts Bob Behnken and Doug Hurley to the International Space Station in a **Crew Dragon capsule on a Falcon 9 rocket** and safely returned them to Earth. It marked the first crewed mission from U.S. soil since space shuttle Atlantis in 2011, and data from the flight cleared the way for the November launch of the Crew-1 mission. This year, SpaceX also flew one of its Falcon 9 first-stage rocket boosters for the sixth time — a milestone in rocket reusability. Falcon 9's first stage uses nine liquid oxygen-RP-1 Merlin engines with its second stage powered by one Merlin Vacuum engine.

In August, **Starship**, SpaceX's reusable transportation spacecraft designed to eventually carry crew and cargo to Earth orbit, the moon, Mars and beyond, demonstrated a test hop to a height of 150 meters. On this flight test, Starship was powered by a single Raptor engine — a reusable liquid oxygen-methane full-flow staged-combustion rocket engine.

NASA also made progress with its **Artemis** program to put humans back on the moon. The **Space Launch System** deep-space rocket began a series of tests in January at **NASA's John C. Stennis Space Center** in Mississippi. The tests are scheduled to culminate in an eight-minute hot-fire test of the core stage's four **Aerojet Rocketdyne RS-25 engines** generating a combined 1.6 million pounds of thrust. Also this year, NASA awarded commercial contracts for the **development of three lunar lander designs and two elements of the lunar Gateway**. The Power and Propulsion Element for Gateway will incorporate a refuellable bipropellant reaction control system.

The new **U.S. Space Force** awarded the **National Security Space Launch Phase 2 contracts** to **United Launch Alliance** and **SpaceX** in August. ULA's **Vulcan Centaur rocket** evolved from the Atlas V and Delta IV vehicles. Its first stage has two natural gas-fueled **Blue Origin BE-4 engines**, while two **Aerojet Rocketdyne RL-10 engines** power the second stage. The RL-10 has considerable heritage, with the 500th flight of the engine occurring in March with the launch of the **Advanced Extremely High Frequency-6 satellite** on an **Atlas V** rocket.

In August, NASA's **Green Propellant Infusion Mission** demonstrated a new green propulsion system developed by Aerojet Rocketdyne. The system operates

▶ **A SpaceX Falcon** 9 rocket carrying a Crew Dragon capsule lifts off from Kennedy Space Center on the Demo-2 mission. The Falcon 9's first stage is powered by nine liquid oxygen-RP-1 Merlin engines.
SpaceX

on a low-toxicity, high-performance propellant developed by the **U.S. Air Force Research Laboratory**.

In Europe, **ArianeGroup hot-fire tested an additively manufactured combustion chamber** at the German Aerospace Center, DLR's facility in Lampoldshausen in May. The 130-kilonewton-class hardware features a low-cost copper alloy, a cold-gas sprayed jacket and a 3D-printed, single piece injector head. The expander cycle integrated technology demonstrator was developed as part of the European Space Agency's Future Launchers Preparatory Program and is designed to power next-generation upper stage engines. In support of Prometheus, the European liquid oxygen-methane precursor engine program, subsystem components were tested and delivered for engine integration this year.

In March, **JAXA, the Japan Aerospace Exploration Agency**, conducted **hot-fire testing of the liquid oxygen-liquid hydrogen experimental reusable vehicle RV-X** at the Noshiro test complex. Japan's new H3 launch system underwent a first-stage development firing test, referred to as a battleship firing test. The H3 first stage will have two or three liquid oxygen-liquid hydrogen LE-9 engines. Captive fire tests of the H3 second stage, powered by an LE-5B-3 engine, were conducted from July to September at the Mitsubishi Heavy Industries Tashiro test complex in preparation for the first H3 launch. ★

Contributors: *Kevin Lohner, Scott Miller, Koichi Okita, Dieter Preclik and Chris Radke*

Advances seen in nuclear propulsion for human missions to Mars

BY BRYAN PALASZEWSKI

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

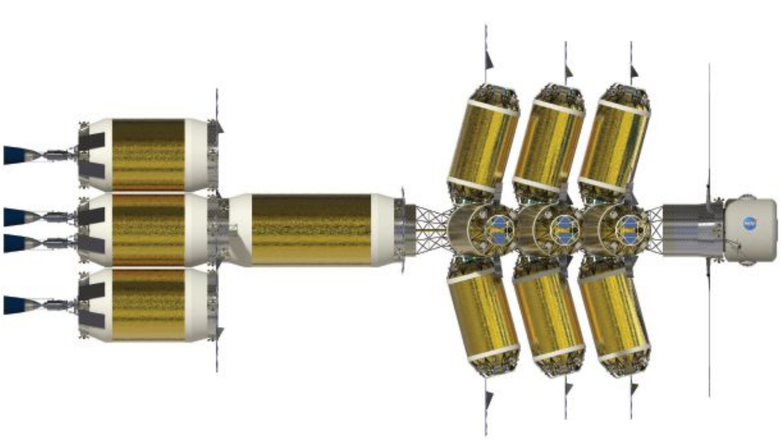
Significant progress toward deciding the **best propulsion method for a crewed mission to Mars** occurred this year when researchers from Aerojet Rocketdyne unveiled **options for Mars opposition class (very high energy) missions** that would utilize low enriched uranium fuel in nuclear thermal propulsion engines.

Aerojet Rocketdyne has been working with NASA and industry partners since 2016 to "increase the feasibility" of such LEU designs, the authors note in the paper "Mars Opposition Missions Using Nuclear Thermal Propulsion" presented at the virtual AIAA Propulsion and Energy Forum.

NTP work has often focused on highly enriched uranium fuels for Mars conjunction class (or lower energy delta-velocity) missions to provide flight times of 900 days, 600 of them in Mars orbit. An opposition-class mission would have a duration of less than two years but demand two to three times the delta-V.

For such LEU missions, researchers investigated main engine specific impulse, or Isp, the appropriate number of engines and the Earth orbital location of the Mars transfer vehicle. By using drop tanks, a form of rocket staging, the performance of the overall vehicle significantly improved. Essentially, empty propellant tankage would be dropped off as the hydrogen propellants are expended. Both Space Launch System and commercial launch vehicles were included in the team's efforts.

▼ **Hydrogen fuel stored** in 12 drop tanks on the right side of this assembly would be accelerated through the nuclear thermal engines on the left side, safely propelling a crew toward Mars in their Deep Space Habitat labeled with the NASA logo.
NASA



Several NTP designs showed significant LEU benefits for both cargo and crewed Mars missions. To get the vast amount of required hydrogen propellant into space, commercial vehicles and NASA Space Launch System rockets would be launched to deliver up to 12 drop tanks of hydrogen fuel to the awaiting crew or cargo spacecraft. The hydrogen fuel would be passed through the nuclear reactors, one per engine. Once a drop tank is emptied, it would be discarded at a predetermined staging location. Many assembly locations and architectures showed promising assembly options for human Mars missions.

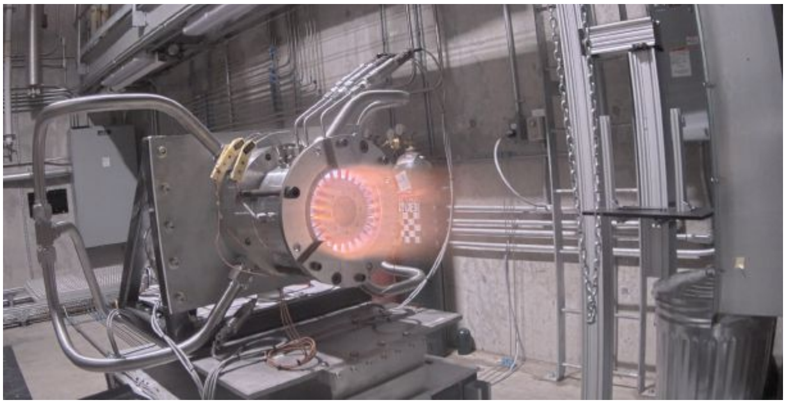
Also at the August AIAA event, Greg Sullivan, the former deputy manager of the **U.S. Space Nuclear Thermal Propulsion program** (originally called **Timberwind**), briefed attendees about the program's achievements in the 1980s and '90s. In the most important test of the SNTP engine technology, engineers pumped hydrogen fuel into a reactor filled with sand-sized zirconium-carbide coated fuel particles. They achieved a temperature of 3,000 K, meaning the Particle-Bed Reactor could have yielded double the specific impulse, or fuel efficiency, of a chemical rocket engine and also more thrust. The program was transferred from the Strategic Defense Initiative Organization to the Air Force and terminated before a full engine was built. If the engine had operated, it would have run for two minutes, meaning it could not be directly applicable to a Mars mission requiring hours of operation.

Turning to other technologies, utilizing lasers to deliver energy over vast distances has the potential to realize rapid transit missions within the solar system, interstellar precursor missions and true interstellar missions to other solar systems. In August, McGill University in Montreal proposed the use of **directed light energy onto a low areal density reflective foil, or lightsail**. The reflected beam would be capable of accelerating spacecraft to speeds on the order of a quarter of the speed of light. To achieve such great velocities in the near-field of the laser array necessitates great accelerations and thus large dynamic loads being applied to the lightsail. In the case of an ideally smooth sail, the impinging light would undergo normal specular reflection, thereby ensuring the sail's shape and directional stability, but no material is ever perfectly flat on all scales. Because of the inevitable occurrence of nonuniform loading generated by surface irregularities, it remains uncertain whether a lightsail would retain its shape and not collapse or wrinkle when experiencing the large photon pressures that would be involved in laser-driven interstellar flight. Lightweight onboard support structures are an option to assure the lightsail's success. ★

Taking off from Earth to space with pressure gain combustion research

BY BAYINDIR H. SARACOGLU AND AJAY K. AGRAWAL

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



▲ **This hydrogen-**powered rotating detonation combustor was coupled with an axial turbine vane row and tested this year at PETAL, the Purdue Experimental Turbine Aerothermal Lab, in Indiana.
Purdue University

Research into pressure gain combustion, PGC, continued to focus this year on power generation, propulsion and rocket applications. **NASA awarded three new contracts for research on rotating detonation rocket engines**, a Phase 1 Small Business Technology Transfer award for RDRE diagnostics and supported three Space Technology Research Fellowships.

In June, the **European Commission funded the INSPIRE program**, short for inspiring pressure gain combustion integration, research and education. Participants from five European countries and the United States will recruit 15 doctoral students to conduct research on PGC engines. The European Space Agency awarded a contract to a consortium led by the von Karman Institute in Belgium to **numerically and experimentally investigate pulse detonation technology for spacecraft thrusters** and significantly increase the lifetime of the spacecraft attitude control systems through its competitive express procurement process. The research started in July.

INSpace LLC and Purdue University of Indiana, with funding from the U.S. Air Force Research Laboratory, **developed and tested a new high-pressure 5 Klbf-class (5,000 pounds of force) RDRE combustor** employing direct liquid oxygen injection.

Aerojet Rocketdyne developed air-breathing rotating detonation engine analytical tools and hot-fire components under government and internal sponsorship to demonstrate operability across a broad range of flight conditions with advanced fuels.

In July, the **University of Alabama** perfected particle image velocimetry at 100 kilohertz to measure the highly periodic, subsonic-supersonic flow field at the RDE exit to identify localized flow segments that tend to diminish the trust performance. Concurrently, UCLA researchers pioneered high-speed, megahertz, optical diagnostics for in-situ pressure, temperature and species measurements in annular RDRE flows using tunable midwave infrared lasers, enabling quantitative in-situ diagnostics to look beyond wave-speed and thrust.

Researchers at the **Naval Postgraduate School** in California, characterized combustor inlet-nozzle area ratio effects and the importance of chamber gap width on delivered pressure gain. In early 2020, **California State Polytechnic University Pomona** designed and tested two deflagrative pressure gain combustion systems in collaboration with the **U.S. Air Force Institute of Technology**. Since February, two **Purdue University student teams** have been collaborating with the **U.S. Department of Energy** to integrate a supersonic axial turbine with RDE and optimized diffusers. Having PGC chambers coupled with turbomachinery can significantly augment the performance of gas turbine engines. Such research activities pave the way to future engines architectures based on PGC.

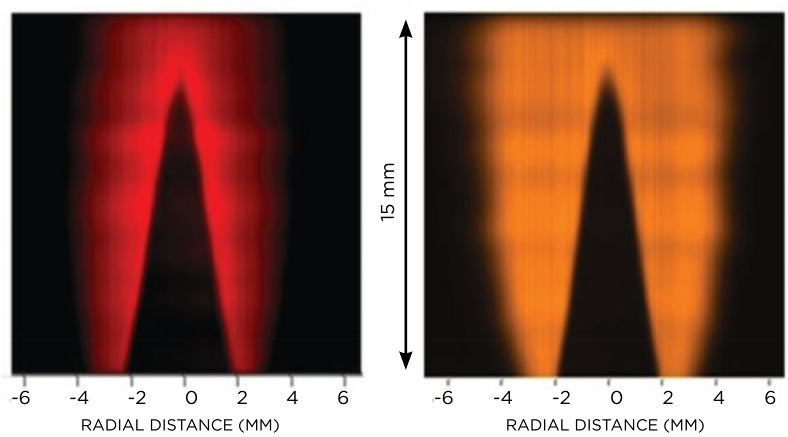
In January, scientists at the **Semenov Federal Research Center** in Russia **developed a detonation afterburner, installed it on a TJ100S-125 jet engine and ground tested it**. The results showed a 30% reduction of specific fuel consumption in comparison to conventional afterburners. A pulse detonation hydro-ramjet was also developed at the center to create periodic water jets to propel sea vessels. Direct benefits of PGC on the propulsion systems and subsystems may widen its application on aerial and naval vehicles in the future. In Japan, **Nagoya University** and its partners including **JAXA, the Japan Aerospace Exploration Agency**, fabricated the flight model of the detonation engine system for the sounding-rocket S-520-31 spaceflight test scheduled for 2021.

Also during 2020, researchers at NASA's Glenn Research Center in Ohio investigated **resonant pulse combustion** and RDE systems for application to gas turbine engines and RDREs using numerical simulation. The **U.S. Naval Research Laboratory** focused on the wave dynamics of hollow and flow-through RDEs; first by replacing the center body of a baseline RDE with either a head-end wall or flowing an inert gas through the center, and then taking a more representative RDE for propulsion and attaching a convergent-divergent and an aerospike nozzle to the combustion chamber. Throughout the year, the laboratory worked with the **University of North Carolina at Charlotte on detonation wave instabilities within an RDE**, and with the University of Alabama on radial RDE's to improve thrust performance for rocket applications. ★

Insights made about imaging radicals, predicting soot yields and detonations

BY TIMOTHY OMBRELLO AND CLARESTA DENNIS

The **Propellants and Combustion Technical Committee** works to advance the knowledge and effective use of propellants and combustion systems for military, civil and commercial aerospace systems.



▲ **These images of** hydrogen atoms (left) and hydroxyl radicals (right) in Bunsen flames were produced at Texas A&M University by laser light excitation and subsequent fluorescence. The images reveal spatial details about chemical transitions that occur during combustion.
Waruna Kulatilaka/Texas A&M

Researchers at the **Optical Diagnostics and Imaging Laboratory at Texas A&M University** this year **demonstrated a femtosecond (fs), laser-based scheme for imaging multiple chemical species using a single laser source**. By using 308-nanometer, 100-fs broadband laser pulses, the researchers recorded laser-induced fluorescence images of atomic hydrogen and the hydroxyl radical simultaneously in flames. Proceedings of the Combustion Institute published the details of that work in September. Similarly, in a Combustion and Flame article, which appeared in April, the same group demonstrated simultaneous imaging of carbon monoxide and hydroxyl radical using fs laser pulses of 283 nm. High signal-to-noise imaging measurements were also obtained using a custom-designed and fabricated robust, tunable laser system that is approximately six times more efficient compared to commercial optical parametric amplifier systems for generating fs pulses of 283 nm. Simultaneous spatially and temporally resolved imaging of these chemical species in flames provides significant insights into the chemical and transport processes involved in flames, leading to improved chemical kinetic mechanisms and an understanding of pollutant formation pathways.

In February, researchers at the **University of Central Florida** published the results of a comprehensive campaign that **evaluated the sooting tendencies of select biofuels** in the Proceedings of the National Academy of Sciences. The experiments, performed under engine-relevant conditions, found which fuels had reduced sooting tendencies and helped identify chemical mechanism improvements needed for better predictive capabilities. The study was motivated by a continual desire to better understand renewable alternative fuel emissions in comparison to conventional petroleum fuels. To meet this challenge, the UCF team measured and characterized the sooting tendencies of biofuels using shock tube and laser absorption schemes as part of the ongoing **Co-Optimization of Fuels and Engines, or Co-Optima, initiative** from the U.S. Department of Energy. While biofuels are promising renewable alternatives to fossil fuels that could lower net greenhouse gas emissions, their combustion properties are not as well-characterized because they represent a wide range of chemical structures, which induce different emission behavior. Five high-performance biofuels (cyclopentanone, ethanol, methyl acetate, methyl furan and alpha-diisobutylene) selected by the Co-Optima program were included in the initial study, and throughout the year, the group continued its measurement strategy to investigate heavier fuels such as esters and farnesane.

In an interesting connection to astrophysical phenomena, researchers from the University of Connecticut, UCF and the U.S. Naval Research Laboratory this year performed experiments in a carefully controlled turbulent hydrogen-fueled chemical flame environment and numerical simulations of thermonuclear explosions **to prove a theory that if the turbulence intensity is sufficiently high, deflagration-to-detonation transition can occur in an unconfined space**. The team explored the Chapman-Jouguet deflagration criteria and flame compressibility dynamics of these fast turbulent flames following the initial development of a theory of turbulence-induced DDT that was highlighted in a November 2019 Science article. Developing and validating such a theory has been an experimental and numerical challenge because of boundary influences and the range of temporal and spatial scales involved. The evolution of a flame (deflagration) to a detonation is strongly influenced by the boundaries of the system, such as the walls in a confined volume, causing reflections of pressure and expansion waves produced by heat release. ★

Contributors: *Kareem Ahmed, Farhan Arafin, Samuel Barak, Jessica Chambers, Vadim Gamezo, Ayush Jain, Waruna Kulatilaka, Andrew Laich, Sneha Neupane, Erik Ninnemann, Alexei Poludnenko, Ramees Rahman, Brian Taylor, Anthony Terracciano, Subith Vasu and Yejun Wang*

Booster, tactical flight tests abound while variety of science missions are launched

BY CLYDE E. CARR JR. AND JOSEPH MAJDALANI

The **Solid Rockets Technical Committee** studies techniques applied to the design, testing and modeling of rocket motors based on solid propellant grains.

NASA and Northrop Grumman conducted the **Flight Support Booster-1 test for the Space Launch System** rocket in September. The test provided 75% of the initial thrust for the Artemis missions. In June, Northrop Grumman delivered the first set of booster segments to NASA. Earlier in the year, Aerojet Rocketdyne delivered the jettison motor, abort motor and inert attitude control motor. The deliveries and tests were in preparation for the launch of Artemis I in 2021.

In February, Northrop Grumman completed the qualification of the 8×31 kilonewton valve attitude control motor for the **Artemis II launch**. Moreover, four Atlas V vehicles with Aerojet Rocketdyne boosters and Northrop Grumman separation motors launched the **Solar Orbiter satellite, Advanced Extremely High Frequency-6 satellite**, **X-37B spaceplane**, **FalconSat-8 satellite** and **Mars Perseverance** payloads into orbit. In July, a Northrop Grumman Minotaur IV lifted a **National Reconnaissance Office spacecraft** from NASA's Wallops Island Flight Facility in Virginia with three decommissioned LGM-118 Peacekeeper missiles and an Orion 38 fourth-stage motor.

From February to August, three large booster tests were carried out on **Northrop Grumman's OmegaA second stage** and **GEM-63XL**, a 63-inch-diameter (160 centimeter) Graphite Epoxy Motor, as well as a 53-inch-diameter (134 centimeter) demonstration motor by Aerojet Rocketdyne. While the OmegaA test validated the targeted ballistics, thermal and steering performance, the smaller motor's demo helped to verify the affordability and performance of future U.S. Air Force strategic missiles. As for the strap-on GEM-63XL, which United Launch Alliance intends to use on its Vulcan Centaur, the tests confirmed the projected ballistics.

▼ **The GEM-63XL, which** is intended for use as one of several strap-on boosters on United Launch Alliance's Vulcan Centaur, was statically fired at Northrop Grumman's test facility in Utah.
NASA

The U.S. Navy fired two unarmed life-extension **Trident II (D5LE) three-stage missiles** from the USS Maine (SSBN-741) over the Pacific Ocean in February. Lockheed Martin manufactured the D5LE missiles, and the tests brought the total number of Trident launches to 178.

Raytheon and the U.S. Navy flight tested a **dual-pulse SM-2 missile** from the White Sands Missile Range in New Mexico in February. The test was part of a return to production campaign, which has exceeded 2,700 flights. Also at White Sands, Lockheed Martin tested its **Precision Strike Munitions surface-to-surface missile** in March and April before further testing an **upgraded Patriot PAC-3 MSE**; the latter was shown to be highly effective at intercepting and destroying a ballistic missile target.

Several qualification tests for the **Europropulsion P120C** and **Avio Zefiro** 40 motors — with the third one on the P120C completed in October — will enable the integration of these motors into the upcoming first flights of the Ariane 6 and Vega-C vehicles scheduled for the second half of 2021. In September, the Vega returned to flight after an unexpected launch failure in July 2019. The team identified and corrected second-stage flaws in Zefiro 23, which enabled the rapid return to flight of Europe's new **Small Spacecraft Mission Service satellite dispenser**. Furthermore, the European Space Agency concluded in August its review of the **Experimental Modelling of Alumina Particulate project**, which the German Aerospace Center led with Swedish and Italian support. In June, the French submarine Le Téméraire launched an **unarmed M51 ballistic missile** from the Caribbean to the North Atlantic Ocean. The M51 consists of a three-stage solid rocket motor designed by the Ariane Group.

The Japanese **HII-B vehicle with four SRB-3A strap-on motors** made its last flight from the Tanegashima Space Center in May, delivering supplies to the International Space Station. Additionally, China launched two Kuaizhou three-stage all-solid vehicles and one Long March-11 four-stage vehicle in the first half of 2020. ★

Contributors: *Filippo Maggio and Agostino Neri*

Energy systems focus on environmentally friendly aviation

BY FARZAD MASHAYEK, KEIICHI OKAI AND TAKUYA MIZUNO

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

AeroTEC and MagniX of Washington state flew a modified Cessna Grand Caravan 208B for 30 minutes in May on the all-electric aircraft's first flight. The companies say the **eCaravan**, which can carry nine passengers, is the **largest all-electric commerical aircraft**. The plane was powered by a 750-horsepower (560 kilowatt) magni500 propulsion system from MagniX.

"As the world's largest all-electric commercial aircraft, this is a significant milestone in disrupting the transportation industry," said MagniX CEO Roei Ganzarski.

In further flight tests in 2020, the eCaravan climbed and cruised at 8,000 feet. The flight range remains one of the elusive milestones for electric planes since the battery energy density is much lower than liquid fuel energy density. To combat this barrier, new aircraft must be designed around the concept of battery-powered propulsion. Israeli firm Eviation designed one of these new planes. Eviation Alice is powered by the MagniX electric motor and is capable of carrying nine passengers.

"This path is slower and more expensive but eliminates any range limitations or anxiety," Ganzarski said.

There are in fact, by some estimates, 200 aircraft designs that rely on electric power; some are purely electric, such as eCaravan, and some are hybrid. In addition to low energy density of the commonly used lithium-ion batteries, there are other obstacles for electric planes to penetrate a competitive market next to their liquid fuel-powered counterparts. The weight of the battery remains the same throughout the flight, whereas fuel weight diminishes after being consumed for combustion. Nonetheless, the promise of lowering emissions will be a major impetus for pursuing electric aircraft as the future of aviation.

Another promising technology for lowering emissions is biofuels for powering gas turbine engines. In May, Japan-based IHI Corp. obtained a new international standard (ASTM D7566 Annex 7 HC-HEFA SPK) for a **biojet fuel production process based on microalgae** found naturally in fresh water. IHI has carried out research and development on technologies to achieve mass outdoor/open-pond cultivation.

Also in biojet fuel production, in June, Japan-based Mitsubishi Power and partners Toyo Engineering Corp., JERA and JAXA, the Japan Aerospace Exploration Agency, started test operations for its **fuel production from woody biomass through gasification and Fischer-Tropsch synthesis** for aviation. The team continued verification operation of the test plant by analyzing the production fuel compatibility to ASTM standard (D7566 Annex 1).

In August and October, neat biojet fuels produced in the above-mentioned two projects were individually confirmed to meet their respective ASTM standards. The two research and development ventures focusing on the production of bio-derived aviation fuels using woody biomass and microalgae were started in Japan in 2017 as the commissioned project by the New Energy and Industrial Technology Development Organization. Japan's Ministry of Economy, Trade and Industry and the Ministry of Land, Infrastructure, Transport and Tourism in 2015 had originally discussed and formed the concept and plans of the processes needed to realize flights using biojet fuel to commemorate the Tokyo 2020 Olympic and Paralympic Games. The games were postponed due to the covid-19 pandemic.

Biojet fuel is recognized as a new form of energy that will contribute to reducing CO_2 emissions and configuring some of the key elements of sustainable aviation fuel. Through these projects, the project team has accumulated technology and skills for broader commercialization of biojet fuel. ★

▼ **MagniX and AeroTEC** flew an all-electric version of a Cessna Grand Caravan 208B in its inaugural flight over Washington state in May. The eCaravan is "the largest all-electric commercial aircraft," the companies say.
MagniX

Progress for human life support in Earth orbit and in Mars atmosphere

BY JONATHAN G. METTS

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

A **SpaceX Crew Dragon** capsule became the first commercial spacecraft to fly humans in orbit, delivering NASA astronauts Bob Behnken and Doug Hurley to the International Space Station in May on the Demo-2 mission that paved the way for the Crew-1 mission launch in November. The Demo-2 astronauts and capsule returned to Earth in August, splashing down in the Gulf of Mexico. SpaceX engineers described the upgraded capsule's **environmental control and life support system** in the 2020 proceedings of the International Conference on Environmental Systems. Dragon combines lithium hydroxide sheets, activated charcoal, HEPA filtration, an ammonia-scrubbing resin and humidity-sipping Nafion membranes for **air revitalization**. Umbilical connections supply air cooling and perform leak checks on the astronauts' suits. During the capsule's return through the atmosphere, **storage tanks of breathable nitrox gas** cooled the cabin air via open-loop purge. The cabin also has a refrigerant-based air conditioner for before launch and after splashdown. The technology was demonstrated in January in a ground test with suited test subjects ahead of the Demo-2 mission, which set up the November launch of four astronauts for the Crew-1 operational mission.

NASA conducted **Spacecraft Fire Safety Experiment IV** in May on a predisposal Northrop Grumman Cygnus spacecraft. The microgravity fire investigation tested large-scale combustion at low total cabin pressures and elevated oxygen concentrations. Researchers included a "smoke eater" and carbon dioxide scrubber for **Saffire-IV** to demonstrate **cleanup of toxic combustion gases**. As published in Fire Safety Journal in May, previous Saffire research involved an enclosed furnace burning common materials to compare fire detection technologies. Investigators at the Desert Research Institute in Nevada and the University of Nevada, Reno, found multiple key technologies were sensitive to microgravity fire detection, including low-cost metal oxide sensors and a smoke-sniffing particle counter.

In September, University of Connecticut researchers published results in the Proceedings of the National Academy of Sciences of their experiment looking at **the effects of extended spaceflight on muscle growth**. The signaling proteins myostatin and activin A regulate muscle growth. Suppressing these proteins, either genetically or pharmaceutically, protected mice from muscle and bone loss during extended spaceflight on the ISS. Untreated mice experienced typical muscle and bone loss during microgravity but recovered within two weeks upon postflight treatment with a signal protein inhibitor. A similar therapy could potentially help humans maintain a baseline physique during extended microgravity flights.

NASA launched its **Perseverance rover** in July as part of its Mars 2020 mission. Perseverance carries a novel technology demonstrator for life support and rocket propellant production. The **Mars Oxygen In-Situ Resource Utilization Experiment, or MOXIE**, is an oxygen-generation experiment utilizing Martian air, which is 96% carbon dioxide. The intake flow is filtered, compressed to about 1 bar, and then heated to 800 degrees Celsius for the solid oxygen electrolysis reactor, where a cathode electrochemically splits some of the carbon dioxide into oxygen and carbon monoxide. If successful, the small-scale experiment, about the size of a car battery, will separate oxygen gas from other reaction products. MOXIE will analyze the purity and production rate of the oxygen before cooling and venting it back into the Martian atmosphere. NASA wants to understand how well this technology performs on Mars to determine how it could be used to support human exploration of that planet. ★

▼ **NASA astronauts** Bob Behnken, left, and Doug Hurley prepared to exit the SpaceX Crew Dragon Endeavour capsule onboard the SpaceX recovery ship shortly after splashing down in the Gulf of Mexico.
NASA

Microgravity research aids long-duration human space missions

BY SUNIL CHINTALAPATI

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

In May, NASA conducted **Saffire-IV, the fourth Spacecraft Fire Safety Demonstration**, inside a **Northrop Grumman Cygnus cargo spacecraft** on its return trip from the International Space Station. On Earth, flames tend to extinguish in a low oxygen environment, but previous flame experiments in space showed that when oxygen levels are decreased the flame front weakens and then breaks into flamelets that resemble hemispherical caps that move randomly toward the lower levels of incoming oxygen. From a crew safety perspective for long-term missions, it is crucial to understand how fire behaves in microgravity and how different materials used for either spacecraft or habitat construction contribute to flame propagation.

Designed by researchers at **NASA's Glenn Research Center** in Ohio and built by Cleveland-based **Zin Technologies Inc.**, Saffire is a 3-feet-by-5-feet self-contained module that contains several sensors. Researchers used four cameras to view the size and spread of the flame within the module. They conducted a series of experiments with longer and stronger flames using Solid Inflammatory Boundary at Low Speed fabric, a composite of 75% cotton and 25% fiberglass. Saffire IV experiments included a scrubber to remove carbon dioxide and a prototype for a smoke eater to remove particulates. The validated and tested hardware technologies from Saffire experiments will be incorporated into the **Orion spacecraft**.

Samples of the **Space Biofilms investigation** returned to Earth in April with SpaceX's 20th commercial resupply services mission to the ISS. Space Biofilms flew to the ISS in November 2019. The research focused on the growth of bacteria, fungi and protists on wet surfaces; a combination of these microbial organisms is referred to as biofilms. In the confined areas of a spacecraft, biofilm formation could cause equipment to malfunction and pose a health risk for the crew. Scientists and researchers from NASA and **DLR, the German Aerospace Center, the University of Colorado in Boulder, MIT, Saarland University in Germany, the University of the Valley of Guatemala** and Colorado-based **BioServe Space Technologies** designed an experiment to characterize the formation and growth of biofilms on materials and environmental conditions in microgravity. Scientists at CU Boulder performed RNA sequencing to characterize associated gene expression of the biofilms. Results from this investigation may lead to improved methods and materials for controlling biofilms on long-duration space missions.

Reusing and conserving material resources will be an important capability for long-duration space missions. In January, crew members on the ISS installed **Made in Space's Recycler tech demo**. The crew can recycle polymer materials into reusable filaments in the recycler. The reusable filament is spooled into a feedstock canister, which is much like canisters that the Florida-based Made in Space's 3D printer uses. The crew can then **3D-print** new items.

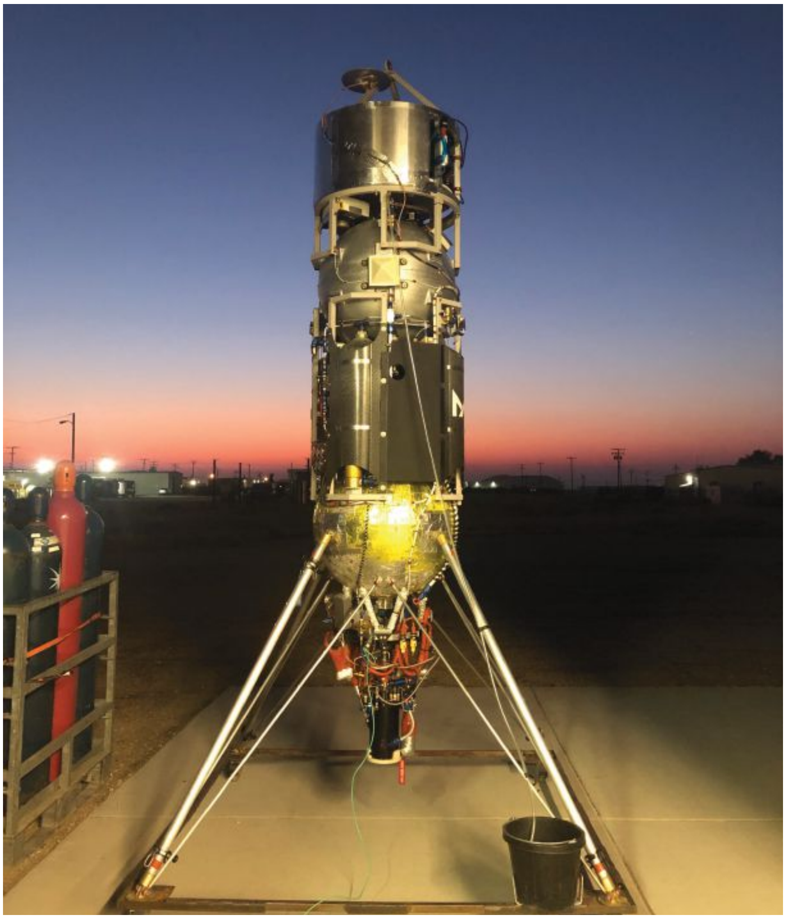
In news that bodes well for the future of microgravity research, an August memo released jointly by the White House Office of Management and Budget and the Office of Science and Technology Policy stated, "Microgravity research in biological and physical science on new platforms in low-Earth orbit is important to enabling longer duration human missions in space and may have practical benefits to life on Earth." The statement confirms a growing emphasis and the critical need to have commercial platforms such as the ISS to further microgravity research to aid in the development of long-duration human missions and enable humans to reach the moon and Mars. ★

▼ **Researchers burned a** cloth sample, a composite of 75% cotton and 25% fiberglass, during the Saffire IV fire safety experiment onboard a Cygnus cargo spacecraft after it left the International Space Station. As shown here, the flame spreads after ignition; the bright specks are glowing char on the cloth.
NASA

Suborbital flight testing paves way for long-term goals

BY NICOLE QUENELLE AND JOHN KELLY

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



▲ **Psionic Technologies'** navigation doppler lidar payload is mounted on Masten's Xodiac vehicle for a flight test. The flight helped to validate the technology's navigation algorithms and processing capabilities in advance of a future closed-loop flight test.
NASA

NASA selected several technologies from the **Flight Opportunities** program this year for upcoming lunar missions — a significant achievement that highlights the culmination of the program's iterative flight testing to advance NASA goals. This year also saw significant flight testing of many promising innovations through the program's Tech Flights awards in which researchers receive NASA funding to purchase a suborbital flight from a commercial provider to test their technology in a relevant environment.

In January, NASA selected a **navigation doppler lidar, or NDL, technology** from its Langley Research Center in Virginia as part of the agency's Commercial Lunar Payload Services, or CLPS, contracts. Tested on Flight Opportunities-facilitated flights with California-based Masten Space Systems in 2017, the innovation provides precise velocity and range sensing during descent and landing for tightly controlled navigation and touchdown on the moon. The technology will fly there on two CLPS flights for testing in advance of potential use on a crewed lunar mission.

In June, NASA announced the selection of Pennsylvania's Astrobotic to deliver the agency's **Volatiles Investigating Polar Exploration Rover**, or VIPER, to the moon's South Pole in late 2023. Astrobotic will deliver the rover on the company's Griffin lander using lidar-based hazard detection technology matured through Flight Opportunities. The **water-seeking mobile VIPER robot** will help pave the way for crewed missions to the lunar surface beginning in 2024, advancing toward NASA's goal of long-term human presence on the moon.

Commercial flight providers Masten Space Systems and Blue Origin completed flights in 2020 with funding and facilitation from Flight Opportunities.

In September, NASA licensee Psionic Technologies, based in Virginia, flew its commercial version of NDL technology on **Masten's Xodiac vertical takeoff and vertical landing vehicle** in Mojave, California. Xodiac functions much like a lander, providing testing to validate Psionic's navigation algorithms and data processing and enabling the company to make any modifications before advancing to a future closed-loop flight test. Maturation provided by the flight also supports production of flight-ready NDL units that companies could use on contract under NASA's Human Landing System program.

In October, Blue Origin's New Shepard rocket launched to space carrying nine Flight Opportunities-supported innovations, including **technologies for sustainable food production in space, cryogenic fluid management and regolith collection**. Flying on the New Shepard propulsion module were technologies fundamental to NASA's **Safe and Precise Landing–Integrated Capabilities Evolution technology suite**, including precision landing sensor systems, algorithms and a new computer. Exposing the payloads to more than two minutes of microgravity, the New Shepard flight provided data to tell researchers how their technologies respond to the reduced gravity environment.

"These suborbital flights enable researchers to quickly and iteratively test technologies with the opportunity to make adjustments between flights," said Christopher Baker, program executive for Flight Opportunities at NASA Headquarters in Washington. "The ultimate goal is to change the pace of technology development and drastically shorten the time it takes to bring an idea from the lab to orbit or to the moon." ★

The vast difference in boat traffic around Venice, Italy, before and after the country locked down to deal with the covid-19 pandemic is seen in images released by Planet Inc.
Planet Inc.

Small satellites becoming new normal

BY BRYAN ROGLER, MICHAEL SWARTWOUT AND SCOTT PALO

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

Government agencies and private industry are making large investments in small satellite technologies when cost and schedule might have previously prohibited them.

In April and June, **DARPA's Blackjack program** awarded its first contracts to satellite bus and payload providers to create a global high-speed network in low-Earth orbit for the U.S. Department of Defense. The award confirmed the DoD's interest in continuing to push small satellite technologies and philosophy into the traditional aerospace complex.

The U.S. Navy and the National Geospatial-Intelligence Agency tapped **Capella Space** of California for **synthetic aperture imagery** in May and June. The company offers Earth imaging data through clouds and at night. Capella Space launched its first operational satellite on a Rocket Lab booster in August as part of a planned constellation of 36.

In January and June, the **National Reconnaissance Office launched additional classified satellites** via small launch vehicles from **Rocket Lab's Electron rocket**, indicating adoption of small satellite technology in the secret sections of the government.

Despite the impact of covid-19, the small satellite industry continued operating while also providing a unique historical snapshot. In May, Earth-imaging company **Planet Inc. published image sets showing before and after lockdowns views** around the world at commonly busy locations. Satellite imagery companies then analyzed the images to calculate how the flow of economic resources, such as oil and steel, were altered; other analyses included measuring the changes in pollution levels due to the slowdown.

The 3-unit HARP cubesat, named for its Hyper-Angular Rainbow Polarimeter instrument, was deployed in February from the International Space Station. The **HARP instrument** is a precursor to a larger version planned for NASA's Plankton, Aerosol, Cloud ocean Ecosystem, or PACE, satellite, which will be 400 times the size of the 3U cubesat. The project is a joint effort between Utah State University's Space Dynamics Laboratory and the University of Maryland, Baltimore County. Also in February, the Compact Infrared Radiometer in Space instrument, described as a calibration lab, was deployed on a separate cubesat. The HARP instrument measures the "size distribution of cloud droplets, which can provide information on the properties of ice and water clouds" to aid in learning how aerosols affect climate modeling. HARP is a preview of a path for small satellite technology to verify prototypes of planned larger systems quickly and cheaply. In June, NOAA confirmed a plan to use commercial companies' radio occultation observations in official global weather forecasting to supplement aging satellite systems, highlighting that small satellites are not only stepping stones but also capable end solutions.

New rules from the Federal Communications Commission went into effect in August that could reduce licensing costs for small satellites by an order of magnitude, which should increase their commercial popularity.

Small satellites continued to provide a means for academic study across the world. **Guatemala's first satellite, Quetzal-1**, deployed in April; a team of students and other partners built it at the University of the Valley of Guatemala. The **National University of Singapore** displayed a quantum computing experiment with its **SpooQy-1** satellite a year after its first deployment in 2019, potentially paving the way for cost-effective gains in privacy and cybersecurity. ★

Lunar and Mars projects open space architecture opportunities

BY BARBARA IMHOF, THEODORE W. HALL AND MARIA JOÃO DURÃO

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

A new generation of space architects seized opportunities to design habitable flight hardware for lunar exploration and development. Participants in a variety of collaborations included Axiom Space, Blue Origin, the Center for Design and Space Architecture, Dynetics, the European Space Agency, LIQUIFER Space Systems, NASA, Northrop Grumman and Thales Alenia Space.

In January, NASA reached an agreement with Axiom Space to add a module to the International Space Station that will evolve into an independent commercial space station when the ISS is retired. In June, Axiom contracted with **Thales Alenia Space** to design and build its **habitation module** and a **micrometeoroid shield** for its connecting node.

NASA announced awards in April to three teams to develop **Human Landing System preliminary designs**: the Blue Origin-led National Team, Dynetics and SpaceX.

In May, following an ESA authorization to develop and build the **International Habitat Module for the lunar Deep Space Gateway**, Thales Alenia Space hired **LIQUIFER Space Systems** to design **crew systems and interior configurations** in collaboration with systems engineers.

The **Center for Design and Space Architecture** at NASA's Johnson Space Center in Texas contracted in June to provide overall internal architecture evaluations for the **Dynetics Human Landing System**. Also in June, NASA awarded a contract to **Northrop Grumman** to develop the **Habitation and Logistics Outpost module for Gateway**. In August, Northrop Grumman began collaboration with CDSA to grade its HALO design.

NASA initiated in June the **Lunar Loo Challenge** for design of a new toilet to operate in both microgravity and lunar gravity. The requirements include limits on mass, volume, power consumption and noise level. This follows on earlier work by CDSA architect Zachary Taylor and published in September in Acta Astronautica on the Universal Waste Management System that also considers the optimum squatting posture and a smoother surface that is easier to sanitize.

Space architecture has not only become an integral part of space mission technical design but has also entered public consciousness as an exciting new field of work and career choice. This was demonstrated by the popular **"Moving to Mars" exhibit** at the Design Museum in London, which closed in February. During its six-month run, 80,000 people visited the show in person, and over 60 million people accessed online and print coverage. The exhibit featured immersive environments and numerous objects, including contributions from NASA, ESA and SpaceX. The London-based architecture firm Hassell contributed a full-scale concept of a Mars habitat. There were also a range of scale models, a video and technical drawings that explore how scientists and engineers might bring a human perspective to life on Mars. The Swedish National Museum of Science and Technology in Stockholm announced in April that the exhibit would open there in December.

In July, NASA announced that the winner of its Exploring Hell competition for the design of a Venus surface rover was Youssef Ghali, an architect and product designer in Cairo. There were 572 entries from 82 countries, comprising a mix of teams and individuals. ★

Contributor: *Zachary Taylor*

◀ **During its six-**month run, 80,000 people visited the "Moving to Mars" exhibit, which included this Mars habitat at the Design Museum in London. An additioinal 60 million people viewed online and print coverage.

Naaro

Launch of Perseverance rover caps 2020 in space robotics

BY ERIK KOMENDERA, JIAN-FENG SHI AND GARDELL GEFKE

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

The Mars 2020 mission launched from Cape Canaveral in Florida in July with the **Perseverance rover** and the **Ingenuity helicopter** headed to Mars to land in the Jezero Crater. Perseverance is based on the Curiosity rover but with several upgrades, adding about 50% more payload. It also can collect and cache samples for a future return mission. Ingenuity is a flight demonstrator that will be the first attempt at controlled flight on another planet. At 1.8 kilograms and with carbon fiber blades that spin at 2,400 rotations per minute, Ingenuity is designed to operate in an atmosphere that is less than 1% as dense as Earth's atmosphere.

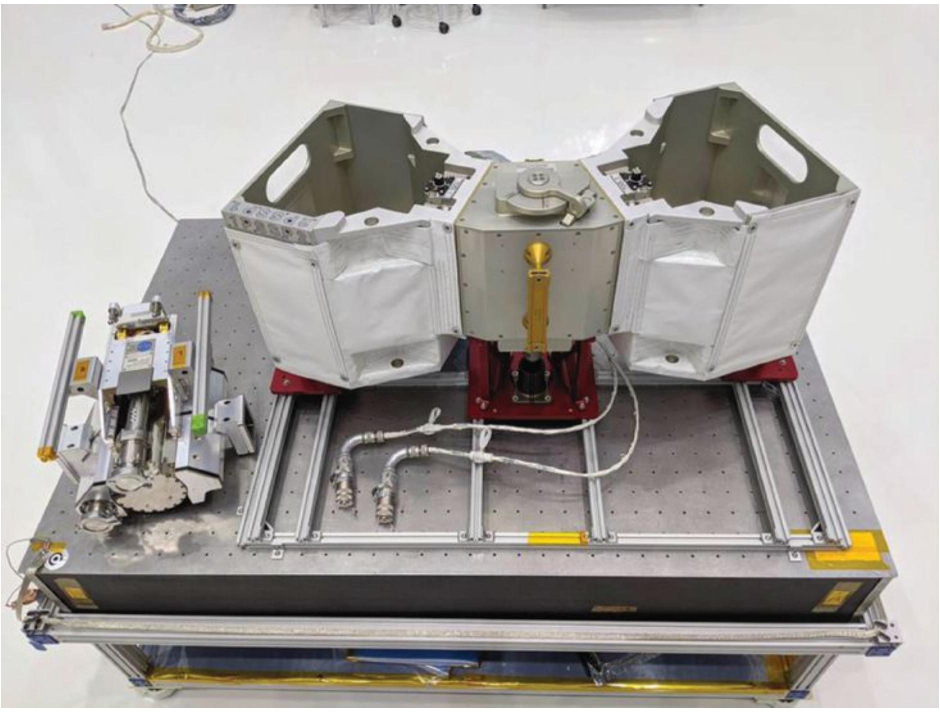
Astronauts installed the **Robotic Tool Stowage storage unit** on the **International Space Station** during a spacewalk in July. NASA's **Exploration and In-Space Services, or NExIS**, delivered RiTS to the ISS in December 2019. Two **Robotic External Leak Locator** tools are in the RiTS, which provides the RELLs with thermal and physical protection and allows them to be readily deployed by the Special Purpose Dexterous Manipulator. RELLs are used to detect the location of external ammonia leaks and to rapidly confirm a repair, thereby eliminating the need for spacewalks to carry out the same tasks. The RELL and RiTS capabilities could be useful for exploration missions and future human habitats, including the Gateway.

In January, **Maxar** finalized a $142 million contract with NASA to perform an in-space assembly demonstration using the **Space Infrastructure Dexterous Robot, or SPIDER**. The lightweight robotic will be integrated with the spacecraft bus that Maxar is building for NASA's **On-Orbit Assembly and Manufacturing-1, or OSAM-1**, formerly Restore-L, which will refuel a satellite in low-Earth orbit. In April, engineers installed the fuel tank for OSAM-1 in Maxar's California factory. NASA also contracted with Maxar in February for Maxar's Sample Acquisition, Morphology Filtering and Probing of Lunar Regolith robot arm. **SAMPLR** will acquire samples on the moon and determine the geotechnical properties of lunar regolith.

Canadian company MacDonald, Dettwiler and Associates Corp. announced in May that it received a contract worth $145 million ($190 million Canadian) to **support robotic operations on the ISS** from 2020 to 2024. MDA will provide logistics and sustaining engineering services to the Canadian Space Agency and its international partners for the ISS program. In June, the Canadian minister of Innovation, Science and Industry announced that Canada intends to contract with MDA to build Canadarm3. The **Canadarm3** will be the next-generation smart robotic arm, a small dexterous arm and a set of specialized tools. Using advanced machine vision, cutting-edge software and advances in artificial intelligence, this highly autonomous system will be able to perform tasks without human intervention.

In March, the Dextre and Canadarm2 robotic systems on the ISS extracted the **Bartolomeo platform** from a SpaceX Cargo Dragon spacecraft and installed it on the ISS's Columbus module. Bartolomeo is a new platform for small commercial payloads that significantly expands the station's capability to host commercial experiments. Dextre was used in the emergency removal and replacement of a failed power module for one of the ISS solar arrays. The module failed on July 1 and was replaced within six days, restoring the station's full power capabilities. ★

Contributor: *Laurie Chappell*



▼ **Astronauts installed** the Robotic Tool Stowage storage unit outside the International Space Station in July.
NASA

Preparations for space settlements continued, despite a challenging year

BY BRYCE L. MEYER

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

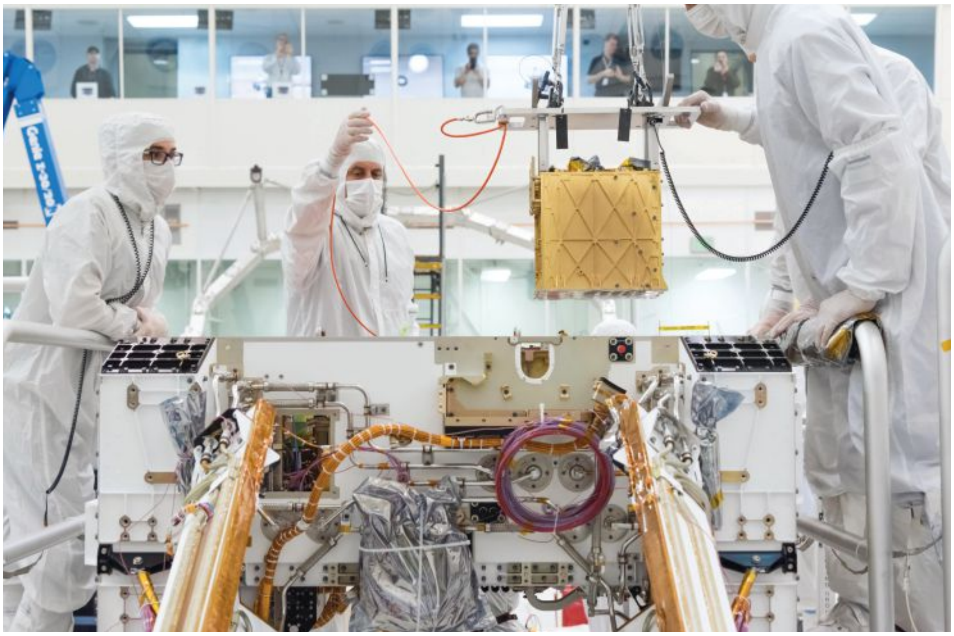
NASA sent the **Mars Oxygen In-Situ Resource Utilization Experiment, or MOXIE**, to Mars aboard the Perseverance rover in July. MOXIE will attempt to harvest oxygen from the Mars atmosphere, supporting future settlements until plants in settlers' gardens can recycle the air they use. The oxygen also could be used as propellant for spacecraft or Martian aircraft. Though MOXIE is the mass and size of a car battery, it can produce 10 grams of oxygen per hour when running, or about 1.1% of a human's breathing requirement.

SpaceX sent two NASA astronauts to the International Space Station in a **Crew Dragon** spacecraft in May on the Demo-2 mission, beginning the commercial ability to sell seats to orbit and clearing the way for the Crew-1 mission that was launched in November. Demo-2 boosted hopes for an **orbital economic ecosystem** that could enable **space hotels** such as those planned by **Axiom**, **Bigelow** and others. Early hotels in plans would be more like base camps in space, where tourists would have simple sleeping sacks and a few compartments for privacy. These first steps could lead to setting up a **space economy** in which such designs become lodging for space factory builders and operators. The Axiom and Bigelow designs require meals to be shipped from Earth with visitors, which is possible because of Crew Dragon's multiton cargo capacity. Chefs on Earth would make the food, which staff would warm up and serve in orbit. Eventually, hotels would include small gardens for some fresh food and that could recycle the air and water.

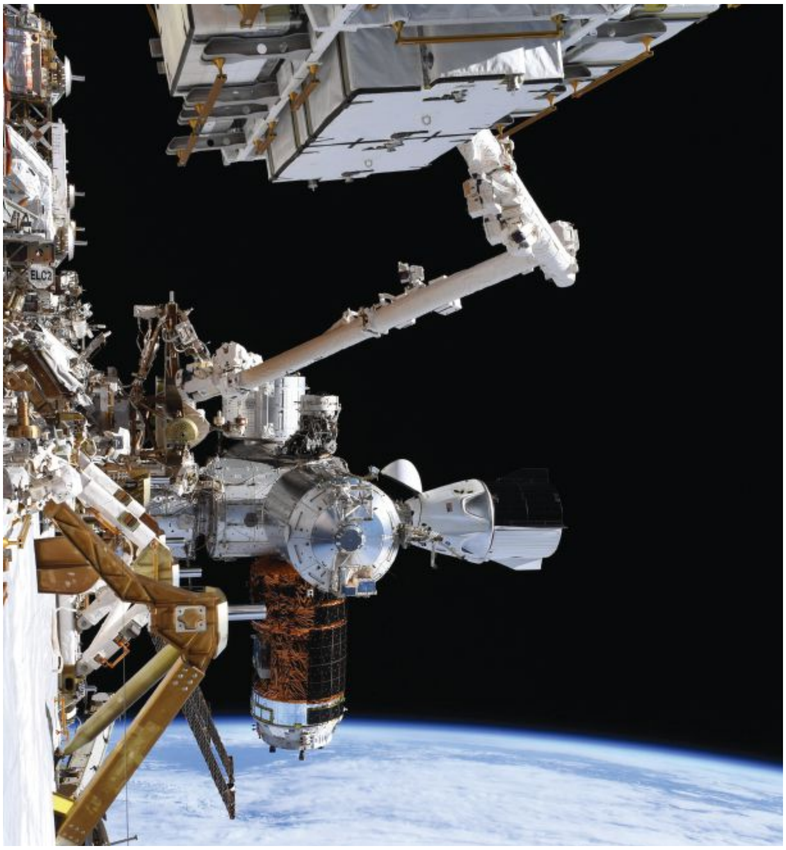
In April, NASA announced several technology investments, including three **lunar landers** from private companies: **Blue Origin's Integrated Lander Vehicle, Dynetics' Human Landing System and SpaceX's Starship**. These landers would put humans on the moon, and all three designs are made for long-term use to act as outposts and support the construction and support of permanent bases.

In September, NASA announced **pricing for delivery of lunar regolith**. The pricing of dirt sounds innocuous, but such efforts set funding profiles that allow capital investment in companies by allowing revenue projection. In particular, NASA will pay for the regolith transferred to NASA, which means a miner would have to collect the mass on the moon and bring it intact to a NASA location to get paid. Such funding promotes the development of spacecraft that can land and operate on the moon but also grab material, launch it from the moon, reenter Earth's atmosphere and land. The mining role would likely feature at least some autonomy due to the seconds of communications latency to control robots on the moon from Earth. The **mining robots** would have to survive the lunar environment long enough to make the mission profitable. Further, the delivery of the vehicle and return of the dirt would have to be cost-efficient, encouraging reusable or low-cost disposable craft. This element of a space-based economic web could lead to long-term settlement of the moon.

▼ **The Mars Oxygen** In-Situ Resource Utilization Experiment, or MOXIE, is installed on the Perseverance rover. MOXIE will attempt to harvest oxygen from the Mars atmosphere.
NASA



Space X's **Starship prototypes** completed several hop tests, which could lead to the 2024 Starship variants such as the lunar lander. The economy of scale offered by the giant Starship vehicle if SpaceX is successful would make it easier for more people to go to space, including to the moon and maybe Mars, in a far more cost effective way. The large ship would allow **larger construction projects in orbit** and larger supply lifts to settlements in orbit and beyond. These early hop tests show the "fail early and often" best engineering practice that reduces risk early in development, before design changes become more costly. ★



Commercial human spaceflight leads year of firsts

BY ONALLI GUNASEKARA, HANG WOON LEE AND KOKI HO

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

▲ **SpaceX's Crew Dragon** Endeavour spacecraft (center right) was docked with the International Space Station during the Demo-2 mission.
NASA/Twitter

SpaceX became the first private company to take humans into orbit with the **Crew Dragon Demo-2** mission in May. The capsule carrying NASA astronauts Bob Behnken and Doug Hurley was launched on a Falcon 9 rocket from the Kennedy Space Center in Florida to the International Space Station. The mission ended the demonstration of SpaceX's crew transportation system and started a new era of human spaceflight in which commercial rockets can transport humans to low-Earth orbit from U.S. soil. In August, the capsule returned to Earth after additional habitability tests, setting up November's launch of the Crew-1 mission.

In work beyond Earth's orbit, NASA selected SpaceX in March as the **first U.S. commercial provider for the Gateway Logistics Services contract** to deliver cargo, experiments and supplies for NASA's Lunar Orbital Platform-Gateway. In September, NASA released its plan to land the first woman and next man on the moon by 2024 as part of the Artemis program. Gateway, a significant component of Artemis, will be a strategic staging point for deep-space exploration.

U.S. companies **Blue Origin, Alabama-based Dynetics and SpaceX** are also contributing to Artemis. In April, NASA awarded the companies contracts valued at $967 million to develop human-rated lunar landers. In May, Pennsylvania-based **Astrobotic** — another U.S. company contributing under the CLPS initiative — was awarded $199.5 million to deliver NASA's new **Volatiles Investigating Polar Exploration Rover**, or VIPER, which could be the first U.S. rover on the moon since the Apollo 17 lander in 1972. VIPER is part of the first wave of ground truth missions intended to determine if the water resources on the moon are sufficient and capable of being mined economically. In July, NASA and the Japanese government affirmed international collaboration for the lunar Gateway by signing the Joint Exploration Declaration of Intent, reflecting future cooperation and partnership in space exploration between the two countries.

More historic firsts included the **U.S. Space Force's first space launch** in March, delivering an Advanced Extremely High Frequency-6 communications satellite to orbit onboard a United Launch Alliance Atlas V rocket from Cape Canaveral Air Force Station in Florida. The Space Force became an official military branch in December 2019.

After a 328-day mission aboard ISS, NASA astronaut **Christina Koch** set the record for the **longest single spaceflight by a woman**. Koch completed 5,248 orbits, equivalent to roughly 291 trips to the moon and back, and she participated in experiments that will provide insights to the effects of long-duration spaceflight on a woman.

In academia, the Space Systems Optimization Group at Georgia Tech in May published a paper detailing its **novel semi-analytical model for robotic on-orbit servicing**. The work — supported in part by DARPA — responds to the growing demand for robotic on-orbit servicing for future sustainable space exploration. Also, the Massachusetts Institute of Technology developed a new framework for optimal planning of space mission campaigns for asteroid deflection under epistemic uncertainty for Earth-crossing asteroids that are highly ranked on the Palermo scale. This work — supported in part by NASA, Draper and the Samsung Foundation of Culture — brings in a new way to take advantage of the space logistics and mission design research to ensure the safety of Earth. ★

Contributors: *Robert Shishko and Olivier de Weck*

Commercial Crew successes lead the way in a pivotal year

BY JESUS A. OROZCO AND CHRISTOPHER R. SIMPSON

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

A NASA launch ushered in the era of commercial spaceflight, the **U.S. Space Force** launched its first payload and three governments launched Mars missions while the covid-19 pandemic paralyzed the world for most of the year.

The Space Force completed the military's next-generation communications constellation with its March launch of the **Advanced Extremely High Frequency-6 satellite**. It was the first launch for the space warfare service branch, which was founded in December 2019. The Space Force also welcomed its first 86 members into its ranks — all graduates of the U.S. Air Force Academy. In August, the service released its first doctrine, which describes the Space Force's five core competencies as space security, combat power projection, space mobility and logistics, information mobility and space domain awareness.

In April, NASA disclosed the three U.S. companies that will **develop the Artemis program's human moon landers** planned to land astronauts on the moon beginning in 2024. The three companies are **Blue Origin, Dynetics and SpaceX**. All three will have NASA teams embedded in their projects as part of the 10-month base period disclosed in the Next Space Technologies for Exploration Partnerships Appendix H Broad Agency Announcement.

In May, **NASA and SpaceX launched U.S. astronauts in a Crew Dragon capsule** on a Falcon 9 rocket from Kennedy Space Center in Florida. Astronauts Doug Hurley and Bob Behnken arrived at the International Space Station 19 hours later on the **Demo-2** mission. The Crew Dragon remained docked to the ISS for 63 days before bringing the astronauts back to Earth; the capsule splashed down in the Gulf of Mexico. Neil Mallik, network director of the Human Space Flight Communication and Tracking Network at NASA's Goddard Space Flight Center in Maryland, said that NASA evolved to support "commercial human spaceflight missions while maintaining a focus on safety … [considering] contingency operations and launch escape scenarios [which] drove unique implementations of the space network, specifically, the ability to provide a rapid repointing of [a tracking and data relay satellite] in the event of off-nominal performance from the Falcon 9."

Jon Rodriguez, the Flight Dynamics Facility mission lead for Demo-2 and part of the HSF CTN at Goddard, said that he hoped the "SpaceX DM-2 launch provided a small respite to those who were able to watch" during the "dark and uncertain time" of the covid-19 pandemic. The Demo-2 mission's success also allowed for SpaceX and NASA to launch the Crew-1 mission on Nov. 15.

Looking toward Mars, the United Arab Emirates Space Agency designed and developed the **Hope orbiter** for the **Emirates Mars Mission** that launched in July to study daily and seasonal weather cycles on Mars. It was the first mission to Mars by an Arab country. Also in July, China launched the **Tianwen-1** mission, which consists of an orbiter, a lander and a rover. NASA launched the Perseverance rover and Ingenuity helicopter in July; they are expected to reach Mars in February 2021. ★

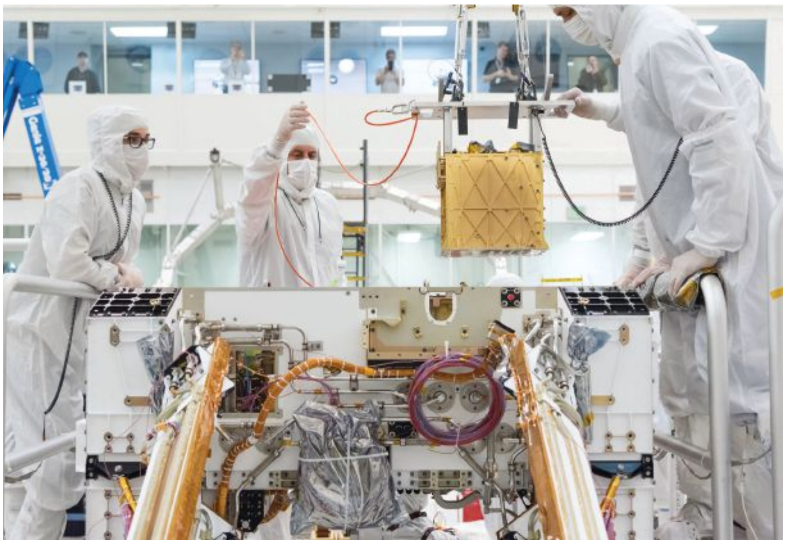
Contributors: *Neil Mallik and Jon Rodriguez*

▼ **The SpaceX Crew** Dragon capsule with NASA astronauts Bob Behnken and Doug Hurley onboard was retrieved shortly after the Dragon splashed down in the Gulf of Mexico. The Demo-2 mission was followed in November by the first operational Commercial Crew launch and docking with the station, a mission dubbed Crew-1. NASA

First in-situ resource utilization payload heads to Mars

BY LAURENT SIBILLE AND FORREST MEYEN

The **Space Resources Technical Committee** advocates affordable, sustainable human space exploration using nonterrestrial natural resources to supply propulsion, power, life-support consumables and manufacturing materials.



▲ **NASA technicians at** the Jet Propulsion Laboratory install the Mars Oxygen In-Situ Resource Utilization Experiment, or MOXIE, aboard the Perseverance rover.
NASA

The **Mars Oxygen In-Situ Resource Utilization Experiment**, or **MOXIE**, the first ISRU project to be launched to another planet, began its journey to Mars aboard the Perseverance rover in July. MOXIE will demonstrate solid oxide electrolysis processing of the thin carbon dioxide atmosphere to produce 6-10 grams of oxygen each hourlong opportunity over the course of the Martian year.

In September, three years after delivering the MOXIE flight hardware, a team from Utah-based OxEon Energy and NASA's Jet Propulsion Laboratory in California **tested a 10-cell solid oxide electrolysis stack, scaled to five-times MOXIE capacity at Mars pressure**. This test is part of a scale up to 2-3 kilograms per hour of the rate of oxidizer production needed to fuel rockets to return astronauts to Earth after a Mars mission. In October, OxEon delivered to JPL a system integrating carbon dioxide-steam solid oxide co-electrolysis with a methanation reactor for production of oxygen and methane propellants at Mars pressure.

The use of material resources in space became a more visible part of major space agencies' mission planning and execution this year. In April, NASA selected three design teams led by **Blue Origin, Dynetics** and **SpaceX** to design **human lunar landing systems**, which all feature in-space oxygen refueling. The recognition of risks posed by landing large, high-thrust spacecraft on unprepared lunar soil prompted research on **ISRU-based solutions for landing and launch pads**. In March, California-based Masten Space Systems tested sintered Hawaiian basalt tiles made by the Pacific International Space Center for Exploration Systems for two seconds under an oxygen/methane rocket engine exhaust. In October, NASA's Swamp Works and Masten completed a test design review for upcoming longer-duration, higher-thrust tests of a subscale pad. Texas-based Exploration Architecture Corp. and the University of Texas at San Antonio employed a unique melting and 3D-printing process to achieve a solidified brick of basalt fines for potential landing and launch pads.

Many groups continued development on lunar ISRU payloads. **Honeybee Robotics** and NASA completed in August a critical design review for the **1-meter TRIDENT, or The Regolith and Ice Drill for Exploration of New Terrains,** to equip NASA's **Volatiles Investigating Polar Exploration Rover, or VIPER**, for the exploration of icy polar lunar regolith. Early in the year, Space Applications Services-led consortia completed Phase A of the European Space Agency's Lunar **ISRU Demonstration Mission** to extract 100 grams of water or equivalent oxygen from lunar regolith using hydrogen reduction, carbothermal reduction and Fray-Farthing-Chen Cambridge processes. In February, NASA's Space Technology Mission Directorate formed the **Lunar Surface Innovation Consortium** administered by Johns Hopkins Applied Physics Laboratory to focus collaborative efforts among government, academia, nonprofit organizations and U.S. industry on solving challenges presented by the lunar environment for NASA's Artemis program. ISRU is one of the alliance's six focus areas. In June, the Space Technology Mission Directorate also selected several lunar ISRU technology maturation projects for oxygen production from water ice extraction and oxides reduction. In September, NASA teams unveiled the **Lunar Water ISRU Measurement Study**, which defines a measurement plan to identify and characterize a lunar water reserve for ISRU purposes to provide guidance on scale and requirements for the broad space resources community. In addition, a newly formed NASA Simulant Advisory Committee sent out a survey in September to identify lunar simulant needs for development and testing of lunar ISRU and surface systems.

In August, the Luxembourg Space Agency in cooperation with ESA and the **Luxembourg Institute of Science and Technology created the European Space Resources Innovation Center**. The founders aim for it to become an internationally recognized center of expertise for scientific, technical, business and economic aspects related to the use of space resources for human exploration and the in-space economy. ★

Contributors: *Koorosh Araghi, Kyla Edison, Michael Hecht, Mathias Link, Diane Linne, Diego Urbina, Sam Ximenes and Kris Zacny*

Space systems have busy year: human spaceflight, Mars missions and on-orbit servicing

BY ZACHARY KREVOR

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

One of the most significant accomplishments of the year was the **launch and safe return of NASA astronauts Bob Behnken and Doug Hurley** aboard a SpaceX Crew Dragon capsule. This Demo-2 mission, flown under NASA's Commercial Crew program, represented the first time a private company delivered astronauts to the International Space Station and cleared the way for November's Crew-1 launch. The May launch delivered the astronauts to the ISS after a 19-hour flight. They returned aboard the Crew Dragon in August, splashing down into the Gulf of Mexico, where a SpaceX vessel retrieved them and the capsule. The astronauts returned an American flag that was left on the ISS during the final space shuttle mission in 2011.

Northrop Grumman's **Mission Extension Vehicle** docked in February with Intelsat IS-901, assumed control and began station-keeping maneuvers, **extending the life of Intelsat IS-901** for up to five years. This was the first time a spacecraft extended the life of a commercial satellite after docking with it in orbit, according to Northrop Grumman and Intelsat. Another MEV launched in August and was to dock with Intelsat IS-1002 early in 2021.

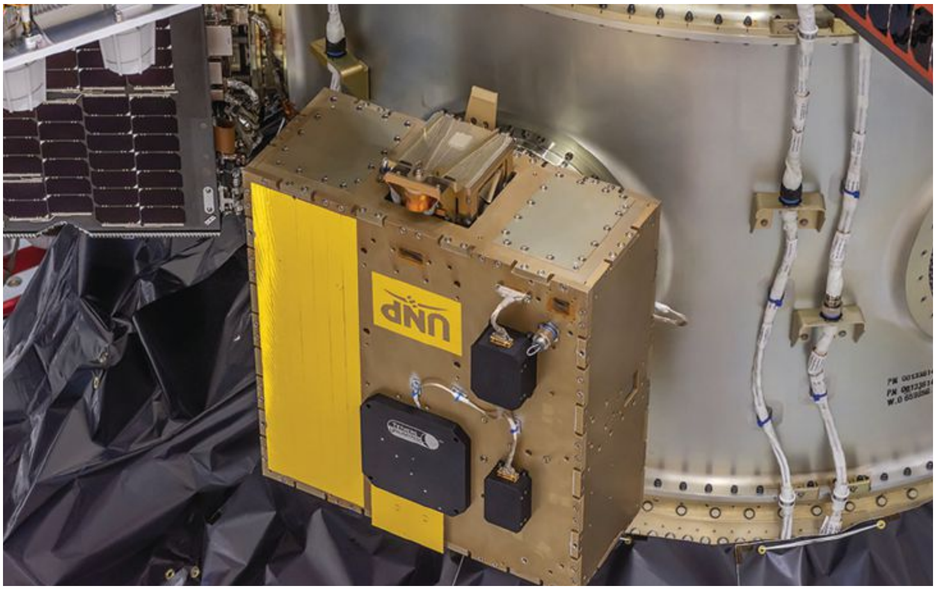
The international space systems community conducted **three Mars missions** this year. NASA began its Mars 2020 mission in July with the launch of the **Perseverance rover and the Ingenuity helicopter**. The rover's mission is to seek evidence of ancient life and collect samples for a future Mars mission. Perseverance is about the size of an automobile and comparable in size to the Curiosity rover. Ingenuity weighs approximately 2 kilograms and is a technology demonstrator.

The United Arab Emirates launched the **Emirates Mars Mission orbiter**, nicknamed Al Amal or Hope, in July on an H-2A rocket from the Tanegashima Space Center in southern Japan; it is to reach Martian orbit in February 2021. The primary mission is to observe Mars weather and evaluate how Mars' weather contributes to atmosphere loss. China launched the **Tianwen-1** spacecraft on a Long March-5 heavy-lift launch vehicle in July; it is scheduled to reach Martian orbit in February 2021. The spacecraft, including an orbiter, a lander and a rover, is to loiter in Mars orbit and release the lander and rover in April 2021. The primary objectives for this mission are to conduct a survey of the planet from orbit and on the ground.

The U.S. Space Force launched the **X-37B spaceplane** in May on an Atlas V rocket, the first launch for the X-37B since 2017. Boeing's Phantom Works division built the X-37B, which first launched in April 2010. Two X-37B vehicles have been built, with the previous OTV-5 mission staying on orbit for 780 days. The X-37 has launched on two launch vehicles: United Launch Alliance's Atlas V and SpaceX's Falcon 9. ★

***Contributors:** John Carsten and Patrick Chai*

▼ **The Mars** Perseverance rover and Ingenuity Mars Helicopter (between left and center rover wheels) are scheduled to land on Mars in February 2021.
NASA



Tethers demonstrate propellantless propulsion in low-Earth orbit

BY SVEN G. BILÉN

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

▲ **Observations this year** show that Georgia Tech's Prox-1 satellite, shown attached to its launch vehicle in 2019, is de-orbiting at least 24 times faster than before deployment of its Terminator Tape tether for an end-of-life demonstration.
SpaceX

The **Tether Electrodynamic Propulsion CubeSat Experiment**, or TEPCE, a U.S. Naval Research Laboratory-built mission to investigate electrodynamic-tether propulsion, reentered the atmosphere in February. After launch and deployment in late 2019, the spacecraft divided into two 1.5-unit cubesats connected by a 1-kilometer-long conducting tether. When current flowed through the tether, it pushed against the Earth's magnetic field to generate drag thrust, demonstrating propellant propulsion.

Washington-based Tethers Unlimited Inc. announced in January that it had demonstrated on-orbit operation of its **Terminator Tape** on Prox-1, a 71-kilogram cubesat built by **Georgia Tech** with funding from the U.S. Air Force Research Laboratory's **University Nanosatellite Program**. Launched into low-Earth orbit in June 2019 with tether deployed in September 2019, **Prox-1** is deorbiting more than 24 times faster than before deploying the tether, according to observations from the U.S. Space Surveillance Network. The operations demonstrate that electrodynamic tethers are viable systems for end-of-life satellite disposal from low-Earth orbit. Several other satellites have been outfitted with Terminator Tape modules, including NPSat-1 built by the Naval Postgraduate School.

York University's **Deorbiting Spacecraft using Electrodynamic Tethers, or DESCENT**, was integrated into Texas-based NanoRacks' flight hardware in August for transportation to NASA's Wallops Flight Facility in Virginia. DESCENT consists of two 1U cubesats that will separate, deploying a 100-meter bare electrodynamic tether, to determine its effectiveness as a deorbiting device.

In March, the European Commission-funded **Electrodynamic Tether Technology for Passive Consumable-less Deorbit Kit**, or **E.T.PACK**, project passed its first-year review. The project is led by University Carlos III of Madrid with partners from University of Padua, Dresden University of Technology, Fraunhofer Institute for Ceramic Technologies and Systems, Sener Aeroespacial and Advanced Thermal Devices. The project's researchers are constructing prototype deorbit hardware for a future flight demonstration. Consisting of two separate modules, the deployment mechanism module and electron emitter module, these will be connected by a 500-meter-long tape tether made of segments with different functionalities. With a 12U-cubesat overall volume, the hardware is aimed at demonstrating **accelerated propellantless deorbiting from low-Earth orbit** with a bare-tape tether anode and different types of cathodes, including a low-work-function tether. The prototype system will be scalable to deorbiting satellites up to 1,000-kilograms mass and 1,200-kilometer altitude by using a longer tape tether. Other E.T.PACK milestones include the June testing of the hollow cathode at low mass flow rates; the July completion of the design of the deployer mechanism; and the September manufacturing of the first samples of low-work-function tether, completion of the second generation of the mission analysis software (BETsMA v2.0) and design of the full deorbit hardware.

In September, the University of Michigan's 3U cubesat **Miniature Tether Electrodynamics Experiment-1, or MiTEE-1**, completed the last of its required tests and software verifications before delivery. MiTEE-1 is part of NASA's **Educational Launch of Nanosatellites** program. For this mission, MiTEE-1 will not use a tether but instead will deploy a rigid 1-m boom to measure the electrodynamics of electron current collection to a pico-/femto-scale satellite endbody (satellite mass up to 200 grams) in the Earth's ionosphere using a 200-volt variable-bias power supply. The cubesat also uses an electron beam filament source to emit electrons into the ionosphere that is characterized by a miniature Langmuir-probe instrument. ★

Crewed launch returns to Kennedy Space Center

BY DALE ARNEY

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

U.S. astronauts were launched from NASA's Kennedy Space Center in Florida for the first time since 2011. For the Demo-2 mission, Bob Behnken and Doug Hurley flew to the International Space Station aboard a **SpaceX Crew Dragon** capsule atop a Falcon 9 rocket in May, clearing the way for November's Crew-1 launch. Boeing prepared for an uncrewed test flight of its Starliner capsule after the initial December 2019 uncrewed flight on a United Launch Alliance Atlas V rocket was shortened due to a software error. In February, a Northrop Grumman Antares rocket delivered a Cygnus cargo vehicle to the ISS. SpaceX launched its 19th successful Cargo Dragon resupply mission to the ISS in March.

In August, NASA completed the fourth of eight **Green Run tests for its Space Launch System** at NASA's Stennis Space Center in Mississippi. The test verified the main propulsion system components were operable and leak-free. Northrop Grumman fired a full-scale version of SLS's solid boosters in September, and in July, Aerojet Rocketdyne completed all of the propulsion hardware for the first crewed flight of the SLS.

▼ **The core stage for a** Space Launch System rocket was transported from NASA's Michoud Assembly Facility in Louisiana to its Stennis Space Center in Mississippi.
NASA

SpaceX launched its **100th mission** in August, and in April its Falcon 9 rocket became the most flown active rocket with its 84th launch. An August launch of a Falcon 9 flew a booster core for a record sixth time; a Falcon 9 payload fairing was reused for the first time in November 2019. SpaceX performed 150-meter test flights in August and September of its Starship prototype at its south Texas facility.

ULA in July launched NASA's Perseverance rover to Mars on an Atlas V rocket. Blue Origin delivered a pathfinder **BE-4 engine**, and Northrop Grumman completed the first qualification test for a strap-on booster. Both are being developed for ULA's next-generation rocket, Vulcan Centaur.

Virgin Galactic's VSS Unity spaceplane conducted two unpowered glide flights, one in May and one in June. After a failed attempt in July, California-based Rocket Lab's Electron satellite launch vehicle returned to flight in August. That flight also included the first flight of Rocket Lab's new Photon spacecraft bus. Also this year, Rocket Lab received a launch operator license from FAA allowing launches from NASA's Wallops Flight Facility in Virginia starting in late 2020.

In May, the **Long March-5B**, China's heavy-lift rocket intended to support a space station in low-Earth orbit, delivered an uncrewed version of its next-generation spacecraft. In March, China's first launch of the **Long March-7A**, upgraded to include nontoxic propellants and modular systems, failed to reach geosynchronous transfer orbit.

In September, **Europe's Vega rocket returned to flight** to deliver 53 satellites for 21 customers. In July, the United Arab Emirates launched a probe to Mars aboard Japan's H-2A rocket, and China launched its Tianwen-1 mission to Mars aboard the Long March-5. Russia launched the 27th, 28th and 29th Gonets-M satellites in September on a Soyuz rocket. It had launched the 24th, 25th and 26th satellites in December 2019 on a Russian Rokot rocket. It was final launch of a Rokot; the first one debuted in 1990.

In July, Israel launched its **Shavit-2 smallsat rocket** for the first time since 2016. Japan launched the final H-2 Transfer Vehicle to the ISS in March. In April, Mitsubishi Heavy Industries in Japan test fired its LE-9 engines for 240 seconds in preparation for its next-generation H3 rocket. ★

Industry, U.S. military work on hypersonics and advanced integrated design processes

BY JAMES D. WALKER AND NICHOLAS J. MUESCHKE

The **Weapon System Effectiveness Technical Committee** advances the science and technology of predicting, measuring, evaluating and improving the lethality of weapon systems.

The U.S. Department of Defense launched a **common hypersonic glide body** in March from the Pacific Missile Range Facility, Barking Sands, in Hawaii. During flight test-2, the C-HGB flew to a designated impact point. The test further prepared for the acquisition of the C-HGB for use in two programs, the Army's Long Range Hypersonic Weapon and the Navy's Conventional Prompt Strike. The C-HGB was transitioning this year from lab-based production to a Dynetics-led team. (Dynetics was subsequently purchased by Leidos.)

In February, the **U.S. Air Force canceled its air-launched Hypersonic Conventional Strike Weapon** program, which used the C-HGB. The Air Force said that the cancellation was not due to poor performance but that there was a need to narrow the options of hypersonics weapons. The service said it is focusing on a smaller hypersonics boost-glide munition, the **Air-launched Rapid Response Weapon**, built by Lockheed Martin. In June and August, the Air Force completed ARRW captive-carry tests, in which it was carried by a B-52 Stratofortress; an F-15 Eagle also could potentially carry it.

▲ **A B-52 Stratofortress** carries an AGM-183A Air-launched Rapid Response Weapon under its wing during a captive-carry test.

U.S. Air Force

In September, DARPA and the Air Force announced that two variants of the **Hypersonic Air-breathing Weapon Concept**, a scramjet missile with hypersonic speed, completed captive-carry tests. Raytheon Technologies and Lockheed Martin developed the air vehicle configurations as part of the program, which intends to build and demonstrate technologies to advance the development of an air-launched hypersonic cruise missile.

In October, DARPA kicked off the **Symbiotic Design for Cyber Physical Systems** program. It introduces **artificial intelligence** into design tools to help speed the design process. The vision of the program is to expand and accelerate exploration of design spaces by combining the best of human intuitive associations across design domains and machine recognition of statistical patterns in data and exploration of large search spaces looking for optimal solutions. The program aims to transform the human-focused model-based design flows used today to a symbiotic process of collaborative discovery by humans and continuously learning AI-based co-designers. Specific design challenges include a range of aircraft, from small uncrewed aerial vehicles to urban air taxi class vehicles; UAV digital designs will be fabricated as part of the program for demonstration purposes.

Will Roper, the Air Force's assistant secretary for acquisition, technology and logistics, said in an interview in September that the Air Force has fabricated and flown, in secret, a **prototype next-generation aircraft** as part of the **Next Generation Air Dominance** program.

"We've already built and flown a full-scale flight demonstrator in the real world, and we broke records in doing it," he said. "We are ready to go and build the next-generation aircraft in a way that has never happened before."

Roper said that a year after completing an analysis of alternatives, the Air Force tested a virtual version of its next fighter and then used cutting-edge advanced manufacturing techniques to construct a full-scale prototype and fly it with mission systems onboard. The integration of systems in the design phase is central to modern weapon system effectiveness. ★

Aerospace traffic management faces new challenges

BY FRANK L. FRISBIE

The **Aerospace Traffic Management Integration Committee** monitors, evaluates and seeks to influence the direction of ATM technologies with a focus on efficiency, public safety and national security.

U.S. federal regulation as of Jan. 1 required aircraft to operate **Automatic Dependent Surveillance-Broadcast Out** equipment in most controlled airspace, but not all aircraft owners met the deadline. Aircraft operators are still steadily upgrading their aircraft to meet the mandate. By midyear, **about half of the 190,000 general aviation aircraft were equipped**; installations continued at approximately 3,000 per month.

The U.S. Federal Communications Commission reversed a 2011 decision in April and approved plans by Virginia-based **Ligado Networks** to establish a terrestrial broadband network in **frequencies adjacent to the widely used GPS frequency band**. FAA, the Department of Transportation, the Department of Defense and many in the GPS user community have challenged the approval over the years because GPS signal levels are relatively low at the receiver site, because aircraft rely on GPS for onboard navigation and because air traffic control surveillance depends on the ADS-B relay of the onboard position to ground controllers. In October, an 80-member industry coalition, including AOPA, urged Congress to halt deployment over concerns about GPS interference.

In March, **FAA shut down and evacuated the air traffic control tower** at Chicago's Midway International Airport after **three staff members tested positive for covid-19**, a situation identified as "ATC zero." Later that week, a similar situation shut down the tower at McCarran International Airport in Las Vegas, and most impactful to the national airspace, the New York Air Route Traffic Control Center shut down in March. FAA quickly addressed these events and, in close collaboration with the union representing employees, implemented nationwide plans to mitigate the loss of controller and maintenance personnel so that operations could be quickly restored. Among the mitigation strategies was keeping a noninfected reserve crew on standby and ready to move in quickly if the duty staff had to be relieved. Coincidentally, significantly lower air traffic due to the pandemic allowed for reduced staffing and flexible controller deployment, facilitating the implementation of the mitigation strategies.

Interest in uncrewed air systems pushed forward this year private-sector development of propulsion, capacity, autonomy and airframes while NASA and FAA led efforts to deal with airspace management to accommodate operations and integration into the broader national airspace under the **UAS Traffic Management program**. Closely coupled with the UAS efforts is the development of **urban air mobility** concepts embodied in the **UAM Concept of Operations v1.0** that FAA circulated in June. FAA seeks to accommodate intra-urban corridors operating simultaneously with fixed wing, helicopter and UAS traffic. The agency cited the growth in road traffic congestion and vehicle development as reasons for the UAM operations concept. Companies such as California-based Joby Aviation, Vermont-based Beta Technologies and California-based Wisk Aero are well along in developing small aircraft meant for four to six passengers. Also contributing to the excitement is the U.S. Air Force **Agility Prime** program to replace the **V-22 Osprey** tilt-rotor aircraft with a combat-ready flying car. The Air Force started the program in April to tap into commercial flying car innovation by sharing government resources with industry in exchange for knowledge transfer and collaboration with participating aerial mobility companies.

In recognition of the increasing need for space traffic management, a National Academy of Public Administration study released in August concluded that the U.S. Commerce Department's Office of Space Commerce was best suited to take on civil space traffic management work, ranking ahead of NASA, FAA and the Defense Department. ★

Contributor: *Charles Keegan*

▼ **Lift Aircraft showed** off its Hexa rotorcraft to U.S. Air Force leaders as part of the Air Force's Agility Prime program to promote the development of electric vertical takeoff and landing vehicles.
U.S. Air Force

Progress toward the 2030 vision of CFD

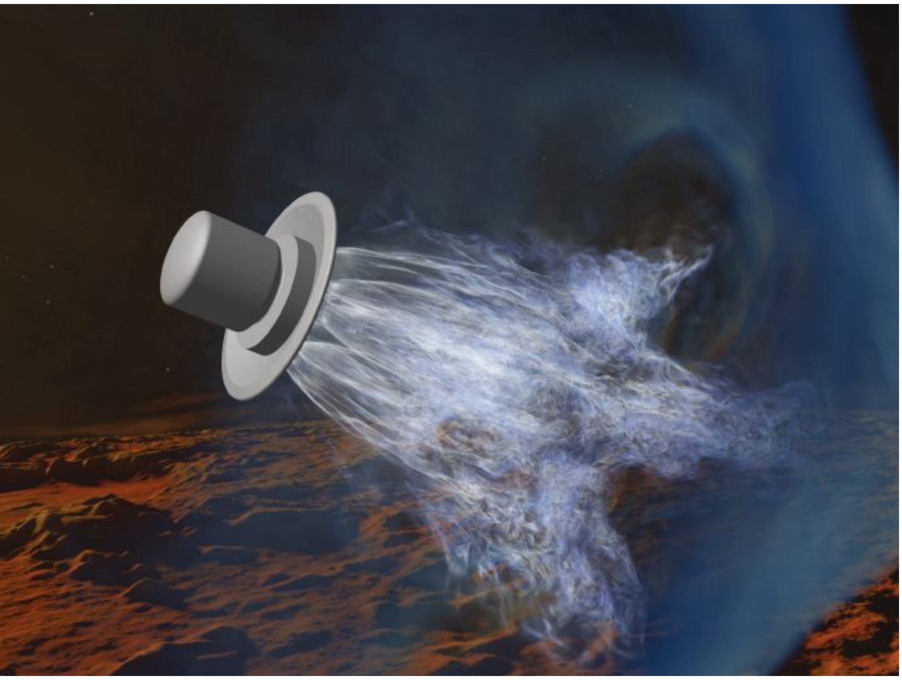
BY REYNALDO J. GOMEZ III AND ANDREW W. CARY

The **CFD Vision 2030 Integration Committee** advocates for, inspires and enables community activities recommended by the vision study for revolutionary advances in the state-of-the-art of computational technologies needed for analysis, design and certification of future aerospace systems.

NASA, industry and academic researchers met three of the four key 2020 goals articulated in NASA's Vision 2030 computational fluid dynamics technology improvement plan released in 2014, according to the "2020 Review of CFD2030 Roadmap" produced by the Integration Committee.

Over the past year, multiple government, industry and university tools used adaptive meshes to simulate the flow over a commercial transport aircraft in a high-lift takeoff and landing configuration. These results meet a 2020 road map algorithm goal of **a technology demonstration of grid convergence for a complete configuration**. More research and development are needed to achieve the demonstration of convergence for unsteady flows on complex geometries.

In a related development, researchers at NASA's Langley Research Center in Virginia used the FUN3D flow solver and an improved grid refinement approach to show mesh adaptation results that reduced human interaction time compared to fixed-mesh approaches. Automated mesh generation and adaptation of viscous problems **eliminates one of the most time-consuming manual aspects of the CFD process**.



▼ **A Mars crew lander** concept fires its rocket motor to slow down in this image of retro-propulsion simulation created by NVIDIA and NASA. The data is from a FUN3D simulation run on the Summit supercomputer at the Oak Ridge Leadership Computing Facility in Tennessee. Two scalar fields, density and vorticity magnitude are rendered to highlight the leading shock and rocket motor plume structures.

Patrick Moran/NASA; Marc Nienhaus and Rajko Yasui-Schoeffel/NVIDIA

Also at Langley, researchers implemented the Hierarchical Adaptive Nonlinear Iteration Method, or HANIM, in the USM3D flow solver and FUN3D, and demonstrated improved solver time to solution on several NASA projects. Specifically, **the Transonic Truss Braced Wing project used USM3D HANIM to reduce the time** to produce accurate solutions from seven to eight hours to 15 to 20 minutes on the Pleiades supercomputer at the NASA Advanced Supercomputing Division. The FUN3D HANIM version of the code was also used to support the Global Center for Medical Innovation task force efforts to improve N95 mask design in the global response to the COVID-19 pandemic.

Even with these speed improvements, flow solver run times are too long to conduct multidisciplinary design optimization in a timely manner. Researchers from MIT and the University of Texas at Austin addressed this problem through new methods that leverage Monte Carlo variance reduction techniques and machine learning along with effective reuse of information from past optimization iterations. In September, researchers writing in the journal Reliability Engineering & System Safety documented **a method for computationally efficient, reliable design of a single element model rocket combustor** by reusing existing information for Monte Carlo variance reduction via IRIS-RBDO (Information Reuse for Importance Sampling in Reliability-Based Design Optimization). These new techniques are enabling computationally efficient implementations of robust optimization to ensure safe, efficient designs.

Also this year, NASA and computing pioneer NVIDIA met a key 2020 technology demonstration goal by **performing on-demand visualization and analysis of a multibillion-point unsteady CFD simulation**, according to the "2020 Review of CFD2030 Roadmap." NASA researchers continued to refine their predictions of **Mars Crew Lander entry flowfields** using the massively parallel GPU accelerated version of FUN3D. This effort builds on the 2019 technical achievements in HPC and visualization that were shown at the November 2019 Supercomputing Conference. The researchers used the Summit GPU-accelerated supercomputer at Oak Ridge National Lab in Tennessee to perform these large unsteady simulations, meeting another key CFD 2030 high-performance computing goal. The NVIDIA real-time visualization of 150 terabytes of unsteady simulation data used four dedicated NVIDIA DGX-2 systems with 16 NVIDIA Tesla V100 GPUs and 16 Solid State Drives on each DGX system, while using NVIDIA's GPUDirect to move the data directly to GPU memory. ★

Full-scale SLS booster test, OSIRIS-REx nail-biter are among exploration successes

BY LEENA SINGH, SURENDRA P. SHARMA AND CHRISTOPHER MOORE

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

NASA put its **Space Launch System** through its first full-scale booster test in September at Northrop Grumman's Utah site. Engineers and researchers will use data collected from the **Flight Support Booster-1** test to verify the rocket motor's performance capability, propellant efficiencies, build processes and potential new materials comprising the booster. Since full-scale booster tests are rare, NASA ascribes multiple test objectives to each with the goal that any changes to the boosters will still allow them to meet performance and design needs at launch. The SLS rocket, Orion spacecraft, lunar Gateway and Human Landing System are the backbone of NASA's deep-space exploration program, Artemis, aiming to put humans back on the moon by 2024 and then on to Mars. The SLS boosters are the largest, most powerful boosters built that can deliver the exploration spacecraft, Orion, astronauts and supplies to the moon from Earth in a single launch.

▲ **A two-minute hot-fire test was the first solid rocket booster test for NASA's Space Launch System. NASA and Northrop Grumman, the SLS booster lead contractor, will analyze the results to choose potential new materials and processes for missions after Artemis III.**
NASA/Northrop Grumman

OSIRIS-REx, short for NASA's Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer, briefly touched asteroid Bennu and collected regolith samples from its surface in October. Two days later, the mission team received images of the sample collector head that showed some of the particles collected were leaking from the sample collector. The team worked round-the-clock for two days to stow and seal the the Sample Return Capsule for its return.

NASA's **Parker Solar Probe** performed its **fifth perihelion pass of the sun** in June followed in July by its third flyby of Venus at 830 kilometers. Parker has been using Venus for gravity-assisted flybys to slingshot into lower and lower solar passes. The **Venus flyby** was tracked by Earth observatories that, together with Parker's telemetry, provided information about how Venus interacts with solar winds and insight into its effects felt on Earth. Parker will continue to make progressively closer passes to the sun. Data collected from the probe's four instrument suites through November 2019 were publicly released in April.

The joint European-Japanese large-scale Mercury-mapping mission on the twin **BepiColombo** spacecraft that was launched in October 2018 performed an Earth gravity-assisted pass in April at 12,000 kilometers to check its suite of scientific instruments. It was the first of its nine scheduled planetary-assisted passes, with the next two scheduled around Venus. Among BepiColombo's instrument suite tested in this flyby were cameras, a precision magnetometer and the highly sensitive **Italian Spring Accelerometer**, which measures acceleratons imparted to the spacecraft by solar radiation. BepiColombo's objectives include mapping Mercury's magnetosphere. Apart from Earth, Mercury is the only other terrestrial planet with a magnetic field, and this mission may provide more insight into Earth's magnetosphere.

The **Japan Aerospace Exploration Agency** researchers working on the **Hayabusa-2** reentry capsule spent much of 2020 analyzing the telemetered data collected from the capsule on its six-year mission to the asteroid Ryugu. JAXA also managed logistics that will allow the capsule to land in Australia's Woomera area and researchers to collect the capsule. ★

Transformational flight prototyping strong in 2020

BY KENNETH H. GOODRICH AND MICHAEL D. PATTERSON

The **Transformational Flight Integration Committee** serves as a focal point for a community of practice engaged in technical, business and societal issues associated with transformational approaches to on-demand air mobility enabled by the convergence of advanced technologies.

The advanced air mobility community experienced a range of advancements along with a few setbacks during the year. At the Consumer Electronics Show in January, the **Hyundai Motor Group** unveiled a program to develop **urban air mobility aircraft** integrated with autonomous, purpose-built vehicles and transportation hubs.

In February, the National Academies of Sciences, Engineering, and Medicine released a report titled **"Advancing Aerial Mobility: A National Blueprint."** It strongly endorsed AAM as a new frontier in aeronautics and mobility and highlighted the importance of public acceptance of AAM, particularly in the areas of safety, noise and privacy. In late February, the **GoFly competition** hosted its Final Fly Off event at Moffett Airfield near San Francisco. Due to high winds, none of the final four teams attempted to complete the flight challenge task, and the $1 million grand prize is still available. Tokyo-based teTra Aviation received the $100,000 Disruptor Award for innovation.

NASA announced partnership agreements in March with 17 companies supporting developmental testing for the **AAM National Campaign**, scheduled for summer 2022. The companies include 11 airspace simulation partners and five vehicle information exchange partners. Also in March, NASA kicked off the **AAM ecosystem working groups**, a public forum to discuss AAM development.

In April, the U.S. Air Force hosted Launch Week for its **Agility Prime** initiative. Agility Prime is a nontraditional program to accelerate the commercial market for AAM vehicles through use of innovative procurement methods. **Joby Aviation** and **Beta Technologies** have advanced to Phase III of the Initial Capabilities Opening. Completion of Phase III enables companies to receive Air Force support for prototype aircraft development and testing and the Air Force to act as a launch customer for production aircraft.

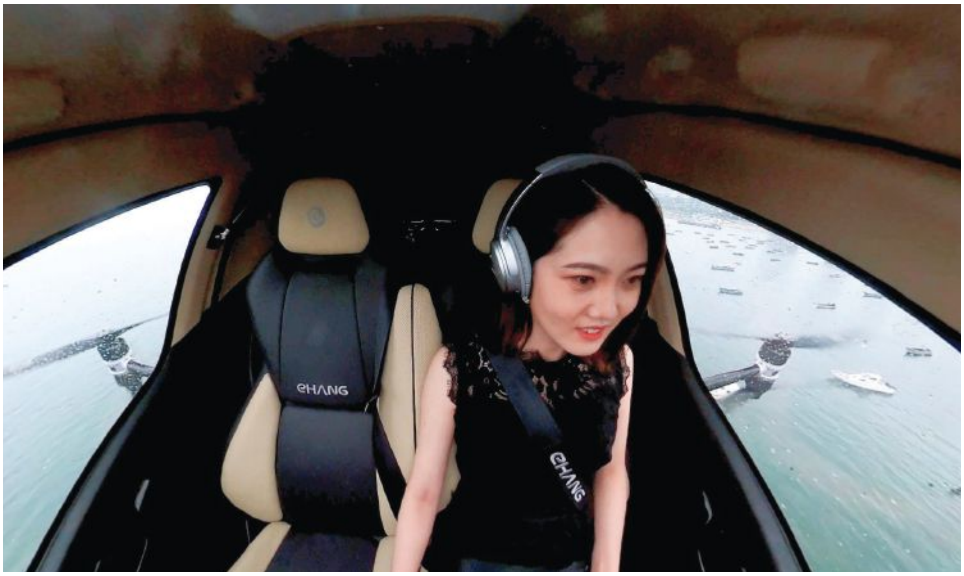
The **European Union Aviation Safety Agency** in June granted a light-sport aircraft type certificate to **Pipistrel's Velis Electro**, making it the first fully electric aircraft to be type certified, a milestone three years in the making. In September, Pipistrel unveiled a new hybrid-electric, uncrewed, vertical takeoff and landing cargo aircraft, the Nuuva V300, to carry up to 460 kilograms of cargo. The company is prioritizing the development of this new aircraft over its passenger electric vertical takeoff and landing aircraft and expects initial operation of the V300 to begin in approximately 2023.

In June, **FAA's NextGen Office** released a concept of operations for **urban air mobility**. Targeted at early passenger operations, the concept of operations proposes operations in corridors between UAM aerodrome pairs. These corridors would be managed through a combination of community-based rules and third-party services, with the goal of introducing high-density UAM routes with limited impact on traditional air traffic control.

In July, **eHang** showcased remotely piloted, passenger UAM operations with four demonstration flights conducted from Yantai, China.

The year was also not without setbacks that indicate some of the difficulties in enabling transformational flight. In January, electric regional aircraft developer **Eviation** lost a prototype aircraft to a battery fire on the ground in Arizona. Similarly, in February, German-based eVTOL aircraft developer **Lilium** lost one of its prototypes to a ground battery fire near Munich. However, both companies have continued their development.

Overall, progress in transformational flight has remained strong in 2020, and the ecosystem is pushing to begin multiple novel forms of operations in the 2023-2024 time frame. ★



▼ **EHang conducted four** passenger-carrying, sightseeing flights with a remotely piloted aircraft in China.

eHang

Astronauts again launch from U.S. soil

BY KEVIN BURNS

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

▲ **The crew onboard the** International Space Station welcomes Bob Behnken and Doug Hurley (not visible) in May after their arrival in a SpaceX Crew Dragon capsule.
NASA

Historians will likely remember 2020 for the coronavirus pandemic and its worldwide effects, including hits to the aerospace industry. But as NASA astronaut Chris Cassidy told CNN in May from the International Space Station, "There's hope in being united. When I look down at the planet, it's just a big beautiful spaceship that has 7 billion astronauts on it."

In August, the **U.S. Space Force** published its first doctrine, titled "Spacepower." The United States established the Space Force in December 2019. It is the first new U.S. military branch since the establishment of the Air Force in 1947.

After nine years of relying on Russia to launch U.S. astronauts to ISS, a new era began in U.S. space exploration as Endeavour, the **SpaceX Crew Dragon** capsule, was launched on the Demo-2 mission from Kennedy Space Center in Florida in May; it delivered **astronauts Bob Behnken and Doug Hurley** to the station the next day. The astronauts praised the experience, saying that docking Endeavour was so smooth that they didn't even feel it. In June from the ISS, Hurley said, "The suits were custom designed and fitted to us, so they were very comfortable and much easier to get in and out of in zero G." Demo-2 cleared the way for the Crew-1 mission, which was launched in November with four astronauts onboard.

This year saw many **centennial celebrations** commemorating 1920 events, including the founding of Canadian, Venezuelan, Ecuadorian and South African air forces; the founding of Argentine and Peruvian naval aviation forces; the founding of Stinson Aircraft Co., de Havilland Aircraft Co. and Davis-Douglas Co.; the founding of Australian airline **Qantas**; the first autogyro; the first flight in Hawaii; the **first flight across the Sahara Desert**; the **first east/west crossing of Australia**; the creation of the first U.S. Coast Guard air station; the establishment of the U.S. Army Air Service; and the **U.S. Postal Service's first transcontinental airmail flight**. Also, 1920 saw Germany's Imperial German Air Service and England's Women's Royal Air Force disbanded. And 100 years ago, Frank Hawks took 23-year-old **Amelia Earhart on her first flight**.

World War II ended 75 years ago. It had a tremendous impact on aerospace, including the U.S. Navy's first recorded use of jet-assisted takeoff; the beginning of operations for Mexican airline Aerovias Braniff; the founding of Transportes Aéreos Portugueses (the future TAP Portugal); the **founding of the International Air Transport Association**; the creation of Avro Canada as a part of the Hawker Siddeley Group; and Essair Airways becoming the first airline to operate as a "feeder" or "local service" airline.

Sixty years ago, the Army Ballistic Missile Agency of the Redstone Arsenal in Alabama formally became a part of NASA and was renamed the **George C. Marshall Space Flight Center**. This year was the **50th anniversary of the flight of Apollo 13**, one of the near disasters of the Apollo program, and the 45th anniversary of the Apollo-Soyuz Test Project, the first international human spaceflight, which opened the way for international space cooperation as well as future joint missions such as the ISS. Also, it was the 30th anniversary of the launch of the Hubble Space Telescope from the space shuttle after more than a decade of research and development. ★

A year of turmoil and success in aerospace

BY AMIR S. GOHARDANI

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

This year saw a series of notable challenges for the aerospace industry. The covid-19 pandemic led to slower demand in commercial aviation with fewer travelers and a need for fewer workers. With customers deferring new aircraft deliveries, less maintenance work was also required, leading to lower demand for spare parts. Many aircraft manufacturers saw short-term concerns, including cash flow and liquidity. Contrary, on the defense side, the pandemic effects were not as severe due to resources allocated prior to the disease outbreak and the ongoing mission of supporting critical national defense objectives. Despite the uncertainty, there were many success stories.

In May, **NASA astronauts Doug Hurley and Bob Behnken** arrived at the International Space Station aboard SpaceX's Crew Dragon capsule as part of the Demo-2 test flight mission. The spacecraft launched from NASA's Kennedy Space Center in Florida. The mission marked the first time NASA astronauts reached and entered the ISS from a commercial spacecraft. Demo-2 was SpaceX's final test flight to validate the spacecraft, launch vehicle, spacesuits and other components of its crew transportation system, clearing the way for November's Crew-1 launch.

In October, **Blue Origin** launched its single-stage **New Shepard** suborbital rocket to the edge of space. A hydrogen-fueled BE-3 engine powers the rocket. The experimental flight was part of NASA's Artemis program to put humans on the moon and then later on to Mars. Blue Origin tested its precision lunar landing technology. The flight was New Shepard's 13th since 2015 and the seventh of Blue Origin's latest reusable New Shepard booster.

In August, **Amazon** received FAA's **Part 135 certification**, giving the company federal approval to operate its fleet of **drones for package delivery**. Wing Aviation and UPS Inc. received approval in 2019 and conducted limited deliveries in 2020. Part 135 certification allows an organization's small drones to carry the property of another for compensation beyond visual line of sight.

NASA's Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer, or **OSIRIS-REx**, briefly touched asteroid Bennu in October, collecting a sample from the surface. Preliminary images of the sample collector head indicated it to be full of asteroid particles, even though some of the particles seemed to be escaping through the collector's lid. With a mission objective of collecting a sample of at least 60 grams (2.12 ounces) from a carbonaceous near-Earth asteroid and returning it to Earth for a detailed analysis, Bennu proved to be ideal. Scientists chose Bennu because of the asteroid's proximity to Earth, its chemical composition and its size, among other criteria. ★

▼ **NASA astronauts** Bob Behnken, left, and Doug Hurley aboard SpaceX's Crew Dragon.
NASA

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Other Important Numbers: Aerospace America / Karen Small, ext. 7569 • AIAA Bulletin / Christine Williams, ext. 7575 • AIAA Foundation / Alex D'Imperio, ext. 7536 • Book Sales / 800.682.AIAA or 703.661.1595, Dept. 415 • Communications / Rebecca Gray, 804.397.5270 • Continuing Education / Jason Cole, ext. 7596 • Corporate Programs / Nancy Hilliard, ext. 7509 • Editorial, Books and Journals / Heather Brennan, ext. 7568 • Exhibits and Sponsorship / Paul doCarmo , ext. 7576 • Honors and Awards / Patricia Carr, ext. 7523 • Integration and Outreach Committees / Nancy Hilliard, ext. 7509 • Journal Subscriptions, Member / 800.639.AIAA • Journal Subscriptions, Institutional / Online Archive Subscriptions / Michele Dominiak, ext. 7531 • K–12 Programs / Sha'Niece Simmons, ext. 7590 • Media Relations / Rebecca Gray, 804.397.5270 • Engage Online Community / Luci Blodgett, ext. 7537 • Public Policy / Steve Sidorek, ext. 7541 • Section Activities / Lindsay Mitchell, ext. 7502 • Standards, Domestic / Hilary Woehrle, ext. 7546 • Standards, International / Nick Tongson, ext. 7515 • Technical Committees / Angie Lander, ext. 7577 • University and Young Professional Programs / Michael Lagana, ext. 7503

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

Calendar

FEATURED EVENT

11–15 & 19–21 JANUARY 2021

Online Event

The world's largest event for aerospace research and development has expanded into eight days of programming over a two-week time frame. The new format offers a convenient, condensed daily schedule. The 2021 forum will explore the functional role and importance of diversity in advancing the aerospace industry.

aiaa.org/scitech/registration

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2021			
9–10 Jan	5th AIAA Propulsion Aerodynamics Workshop (PAW05)	ONLINE (http://learning.aiaa.org)	
11-15 & 19-21 Jan	AIAA SciTech Forum	VIRTUAL EVENT	8 Jun 20
21–22 Jan	1st AIAA CFD Transition Modeling Prediction Workshop	ONLINE (http://learning.aiaa.org)	
26–27 Jan	1st AIAA Stability and Control Prediction Workshop	ONLINE (http://learning.aiaa.org)	
28 Jan–4 Feb*	43rd Scientific Assembly of the Committee on Space Research and Associated Events	Sydney, Australia —HYBRID EVENT (cospar2020.org)	14 Feb 20
31 Jan–4 Feb*	31st AAS/AIAA Space Flight Mechanics Meeting	VIRTUAL EVENT (http://space-flight.org)	
26 Feb–16 Apr	Design of Experiments: Improved Experimental Methods in Aerospace Testing Course	ONLINE (http://learning.aiaa.org)	
4 Mar–22 Apr	Fundamentals of Classical Astrodynamics and Applications Course	ONLINE (http://learning.aiaa.org)	
6–13 Mar*	2021 IEEE Aerospace Conference	VIRTUAL EVENT (www.aeroconf.org)	
15–19 Mar	AIAA Congressional Visits Day	VIRTUAL EVENT	
18 Mar–8 Apr	Hypersonics: Test and Evaluation Course	ONLINE (http://learning.aiaa.org)	
26–27 Mar	AIAA Region III Student Conference	Ann Arbor, MI	5 Feb 21
26–27 Mar	AIAA Region IV Student Conference	Stillwater, OK	1 Feb 21
2–3 Apr	AIAA Region V Student Conference	Iowa City, IA	21 Feb 21

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

3–4 Apr	AIAA Region VI Student Conference	Long Beach, CA (VIRTUAL)	6 Feb 21
6 Apr–13 May	Design of Space Launch Vehicles Course	ONLINE (http://learning.aiaa.org)	
8–9 Apr	AIAA Region II Student Conference	Tuscaloosa, AL	23 Feb 21
9–10 Apr	AIAA Region I Student Conference	New Brunswick, NJ	19 Feb 21
9, 16, 23 Apr	Understanding Space: An Introduction to Astronautics and Space Systems Engineering Course	ONLINE, 3 full days (http://learning.aiaa.org)	
12–14 Apr*	55th 3AF Conference on Applied Aerodynamics (AERO2020+1)	Poitiers, France (http://3af-aerodynamics2020.com)	
15–18 Apr	AIAA Design/Build/Fly Competition	Tucson, AZ	
20–22 Apr	AIAA DEFENSE Forum	Laurel, MD	17 Sep 20
20–22 Apr*	Integrated Communication, Navigation, and Surveillance (ICNS) Conference	VIRTUAL EVENT (https://i-cns.org)	
5–7 May*	6th CEAS Conference on Guidance Navigation and Control (2021 EuroGNC)	Berlin, Germany (https://eurognc2021.dglr.de)	
7, 14, 21 May	Foundations of Model-Based Systems Engineering (MBSE) Course	ONLINE, 3 half days (http://learning.aiaa.org)	
31 May–2 Jun*	28th Saint Petersburg International Conference on Integrated Navigation Systems	Saint Petersburg, Russia (elektropribor.spb.ru/en)	
5–6 Jun	3rd AIAA Geometry and Mesh Generation Workshop (GMGW-3)	Washington, DC	
5–6 Jun	4th AIAA CFD High Lift Prediction Workshop (HLPW-4)	Washington, DC	
5–6 Jun	1st AIAA Ice Prediction Workshop	Washington, DC	
6 Jun	2nd AIAA Workshop for Multifidelity Modeling in Support of Design & Uncertainty Quantification	Washington, DC	
7–11 Jun	AIAA AVIATION Forum	Washington, DC	10 Nov 20
22–25 Jun*	ICNPAA 2021: Mathematical Problems in Engineering, Aerospace and Sciences	Prague, Czech Republic (icnpaa.com)	
9–11 Aug	AIAA Propulsion and Energy Forum	Denver, CO	11 Feb 21
17 Aug	AIAA Fellows Dinner	Washington, DC	
18 Aug	AIAA Aerospace Spotlight Awards Gala	Washiington, DC	
6–10 Sep*	32nd Congress of the International Council of the Aeronautical Sciences	Shanghai, China (icas.org)	15 Jul 19
13–15 Sep*	3rd IAA Conference on Space Situational Awareness (ICSSA)	Madrid, Spain (http://reg.conferences.dce.ufl.edu/ICSSA)	15 Jun 21
25–29 Oct*	72nd International Astronautical Congress	Dubai, UAE	
15–17 Nov	ASCEND Powered by AIAA	Las Vegas, NV	

● AIAA Continuing Education offerings

**Meetings cosponsored by AIAA. Cosponsorship forms can be found at aiaa.org/events-learning/exhibit-sponsorship/co-sponsorship-opportunities.*

MAKING AN IMPACT

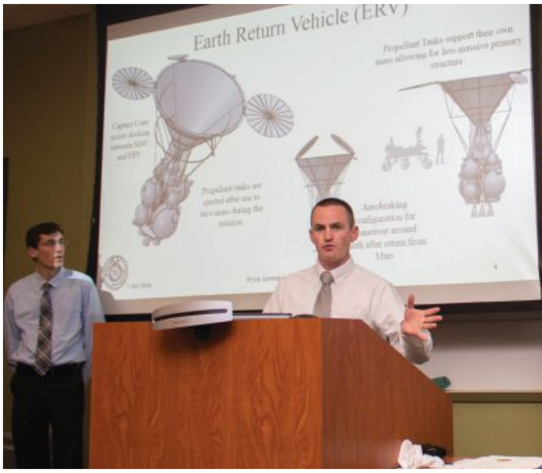
2020 AIAA Foundation Wrap-Up

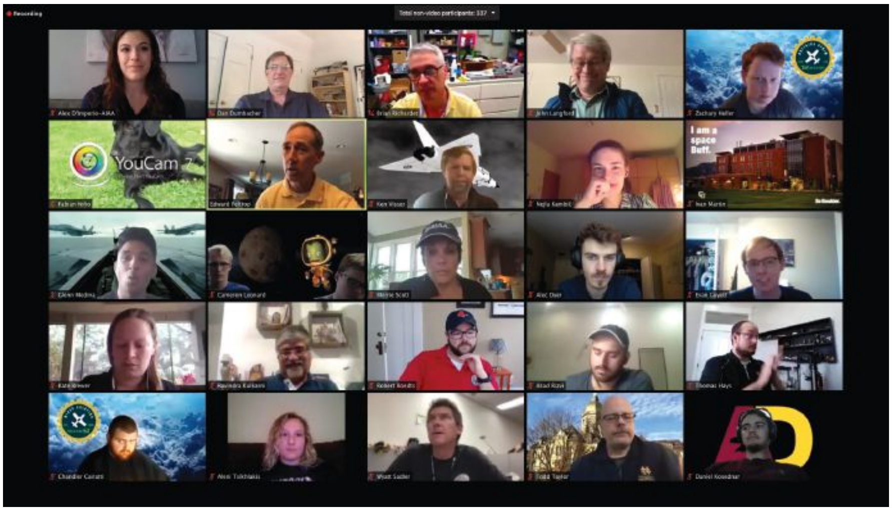
It has been an interesting year with most in-person events canceled in 2020. AIAA, like many other organizations, quickly adapted to a virtual environment. The Foundation's mission to inspire the next generation of aerospace professionals became even more important.

Here are a few ways the Foundation focused its efforts to assist students and educators:

- Participated in Science is Cool VIrtual Unconference to promote free educator resources available through the Foundation.
- Partnered with Higher Orbits to bring space and STEM/STEAM to the homes of students across the country during these challenging times through the Higher Orbits Space at Home initiative.
- Honored 30 Diversity Scholars at the inaugural virtual ASCEND event
- Distributed 41 classroom grants affecting 26,261 students
- Presented 3 K–12 Educator Achievement Awards
- Presented 22 undergraduate scholarships and graduate awards to deserving students to further their education

In 2021, the Foundation will celebrate its 25th anniversary. With your continued assistance, we are looking forward to making an even bigger impact next year!





For more information about the AIAA Foundation, visit **aiaa.org/ Foundation**. Please reach out to Foundation Director Alex D'Imperio at AlexandraD@aiaa.org about the Foundation's goal of impacting one million students and becoming involved or donating to the AIAA Foundation.

AEROSPACE RESEARCH CENTRAL

New Book Releases

Design of Rockets and Space Launch Vehicles

by Don Edberg and Willie Costa

A timely and comprehensive exposé of important concepts and applications that provides enhanced understanding and exposure to practical aspects of design, engineering, manufacturing, and testing. Although it is primarily intended for readers with at least a third-year level knowledge of aerospace engineering, mathematics, and physics, because it contains many applications and step-by-step illustrated examples along with photographs or line drawings of actual hardware, it will also be of interest to practicing engineers, technical managers, and others who are interested in how rockets work in either the big picture sense, or in areas other than one's specialty. This book will answer many questions as to "why things are done this way."

Active Spanwise Lift Control: A Distributed Parameter Approach

by Joaquim Neto Dias and James E. Hubbard Jr.

This book presents a novel approach to tackle the gust alleviation problem. The authors directly address the spanwise behavior of aerodynamic loads. Because the gust loads are mainly caused by disturbances in the spanwise lift, the aim is at controlling the shape of the lift distribution profile along the span. Therefore, this distributed approach allows control of the loads at all points of the wing structure. Moreover, using modal decomposition concepts, the control surfaces can be designed to maximize controllability of the most relevant aerodynamic modes, which naturally results in lower actuator rate requirements. This methodology described in the book is used to synthesize regulators, to suppress gust disturbances in lift distribution, and trackers, to dynamically follow any desired reference lift profile. A special observer structure decouples the gust input from the state estimation process and provides estimates for the gust amplitude along time, thus rendering the gust measurements ahead of the aircraft unnecessary.

Journal News

Special Section in *AIAA Journal*

Look for the special section on the "Recent Progress on Rotating Detonation and its Application," which will be included in the December issue (Guest Editors: Bing Wang, Tsinghua University, People's Republic of China, and Jian-Ping Wang, Peking University, People's Republic of China).

Special Issue on "Machine Learning in Aerospace"

The *Journal of Aerospace Information Systems* intends to publish a special issue on Machine Learning in Aerospace. This collection will include high-quality articles describing emerging methods and results of applying machine learning to aerospace-related fields ranging from run-time perception and decision systems to single and multi-vehicle control. While most developments reported will tailor emerging ML approaches to domain-specific applications, there are also meaningful issues to address, when handling large-scale aerospace systems, that require fundamental advancement in ML methodologies. This special issue aims at being a medium to have a wide scope of recent efforts in such problems.

Guidelines can be found in the full Call for Papers on the JAIS page in Aerospace Research Central: **arc.aiaa.org/sda/1141/JAIS_Special_Issue_CFP_MachineLearninginAerospace.pdf**.

Submission Deadline: 15 January 2021.
Anticipated Publication Date: August 2021.

Special Issue on Systems Engineering's Top Space Challenges

The *Journal of Aerospace Information Systems* intends to publish a special issue on Systems Engineering's Top Space Challenges. This issue will tackle four pressing, space-related Systems Engineering challenges that demand cross-disciplinary solutions.

Systems Engineering Space Challenges

1. Should mass still be a driver for most space missions?
2. Are existing required design margins in handbooks and standards adequate for modern space systems?
3. Should a systems engineering glossary/definitions/ontology be enforced to support the development of a space system?
4. Do space engineers need to learn Model-Based Systems Engineering to successfully adopt Digital Engineering?

Authors need not respond directly to one of the Systems Engineering challenges if the manuscript relates to the challenges or is in the spirit of solving complex Systems Engineering problems.

Submission Deadline: 1 March 2021
Anticipated Publication Date: December 2021
More info: arc.aiaa.org/sda/1141/JAISSpecialIssueCallforPapers-SEChallenges.pdf

AIAA has published over 300 books and almost 200,000 technical articles. AIAA's current publications include eight technical journals, three book series, national and international standards documents, a growing number of eBooks and other electronic products, and a full-service, interactive website. For the most authoritative technical publications, go to ARC (arc.aiaa.org).

Celebrate the Class of 2021 AIAA Associate Fellows!

THURSDAY, 21 JANUARY 2021, 1600 HRS ET

Join us as we recognize our Class of 2021 AIAA Associate Fellows at the AIAA Associate Fellows Induction Ceremony, held during the virtual 2021 AIAA SciTech Forum. The new Associate Fellows will be honored for their accomplishments in engineering or scientific work, outstanding merit, and contributions to the art, science, or technology of aeronautics or astronautics. To register, please visit **aiaa.org/SciTech/program/recognition**. For more information about the Class of 2021, please visit **aiaa.org/Associate Fellows2021**.

Inaugural YP Technical Excellence Lecture

The AIAA Hampton Roads Section (HRS) Young Professionals Committee has organized a new series of Technical Excellence Lectures to highlight the significant technical contributions of AIAA HRS Young Professionals. Their inaugural lecture was held on 7 October in a virtual lunch & learn format featuring the work of the 2020 Laurence Bement Young Professionals Paper Competition Winner, ***Amanda Chou***.

Dr. Chou is a research engineer in the Flow Physics & Control Branch at NASA Langley Research Center. Her research has primarily focused on using experiments to help develop tools in the physical modeling of high-speed laminar-turbulent transition. Dr. Chou received her B.S. in Aerospace Engineering from Virginia Tech and her M.S. and Ph.D. in Aeronautics and Astronautics from Purdue University.

Dr. Chou presented her research on the topic of "Transition Due to Patterns of Roughness on a Supersonic Flat Plate," followed by a Q&A session. Approximately 50 people attended the webinar, and the presentation was well received.

Upcoming AIAA Virtual Career Fair

Be more than just another resume, receive dedicated time with employers looking to hire at the AIAA Virtual Career Fairs. Speak directly with recruiters through private one-on-one online chats.

Student Virtual Career Fair
15 December, 1200–1500 hrs ET USA
aiaa.org/studentcareerfair

Employers: Showcase your company, opportunities, and benefits to qualified candidates in one-on-one chats via text, audio, and video. Corporate members receive discounted pricing.

Nominate Your Peers and Colleagues!

NOW ACCEPTING AWARDS AND LECTURESHIPS NOMINATIONS

PREMIER AWARD
- Daniel Guggenheim Medal

TECHNICAL EXCELLENCE AWARDS
- Aerospace Power Systems Award
- Air Breathing Propulsion Award
- Energy Systems Award
- Haley Space Flight Award
- Hypersonic Systems and Technologies Award
- Propellants & Combustion Award
- Space Automation & Robotics Award
- Space Operations & Support Award
- Space Systems Award
- von Braun Award for Excellence in Space Program Management
- Wyld Propulsion Award

LECTURESHIPS
- Dryden Lecture in Research
- Durand Lecture for Public Service

Please submit the four-page nomination form and endorsement letters to **awards@aiaa.org** by **1 February 2021**

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

AIAA
SHAPING THE FUTURE OF AEROSPACE

Obituaries

AIAA Fellow Statler Died in June

Dr. Irving Statler died on 25 June. He was 96.

In 1945, Statler graduated from the University of Michigan with a B.S. in Aeronautical Engineering and in Engineering Mathematics. He then served in the military spending time as an engineering aide in the Compressibility Unit at the Aerodynamics Branch, Aircraft Laboratory, Wright-Patterson AFB.

In 1946, Dr. Statler joined the Cornell Aeronautical Laboratory (CAL) where, over 24 years, he held positions in the Flight Research Department, as head of the Applied Mechanics Department, and as principal scientist of the Aero-sciences Division. He took a leave of absence from 1953 to 1955 to attend the California Institute of Technology (Cal Tech) from which he was awarded a Ph.D. in Aerospace Engineering and Mathematics in 1956. His dissertation was on development of three-dimensional, compressible, subsonic, unsteady-wing theory and examining importance of unsteady aerodynamic effects to prediction of dynamic stability characteristics of aircraft. While at Cal Tech, Dr. Statler was a senior research engineer in the Research Analysis Section of the Jet Propulsion Laboratory.

In 1970, Dr. Statler left CAL to become the director, Aeromechanics Laboratory, U.S. Army Aviation Systems Command's Research and Technology Laboratories. For 15 years he led rotorcraft research in aerodynamics and flight controls under a unique Army-NASA partnership at NASA Ames Research Center. This collaboration resulted in the tiltrotor technology that led to the revolutionary V-22 Osprey VTOL aircraft and he was also instrumental in initiating multiple international R&D agreements with leading aerospace laboratories around the world.

In 1985 Dr. Statler left the Army to accept the appointment as director, Advi-

AIAA Fellow and Past ARS President Sutton Died in October

George P. Sutton, former chief scientist of DARPA and Executive Director of Rocketdyne, whose seminal book on rocket propulsion guided rocket scientists across 9 editions and multiple generations, died on 15 October. He was 100 years old.

Sutton received a B.S. degree in mechanical engineering at the California Institute of Technology, followed by an M.S. degree and postgraduate work. In 1943, he joined the Aerojet Corporation where he initially worked directly with the renowned Aeronautics Professor Theodore von Kármán in analyzing the effects of hot air boundary layers or the heating of liquid rocket propellants in the tanks of flying large diameter vehicles, and he developed high pressure, high frequency rocket propulsion pressure pick-up for measuring combustion vibration and propellant oscillations. Sutton was in charge of making a U.S. copy of the German A-4 rocket engine used in the German V2 missile. He also designed, built, and tested a new 75,000 lb. thrust chamber, the largest U.S. rocket engine at the time.

When Aerojet became Rocketdyne, Sutton's work continued in various position with responsibilities to develop and test different rocket engines until 1972. He became the executive director of Engineering and assistant to the president.

Sutton's achievements crossed industry, government, and academia. In government, Sutton worked as the chief scientist of the DARPA and as DARPA deputy director. There he started the development of several large liquid propellant rocket engines for eventual applications in long range ballistic missiles. He served on the Scientific Advisory Board of the U.S. Air Force for 11 years and was awarded the Air Force's Silver Civilian Medal for his contributions.

He also worked for about 10 years at the Lawrence Livermore National Laboratory as an associate program leader on the Machine Tool Task Force (5 Volumes of Advanced Precision Technology of Machine Tools) and as an assistant division leader in Manufacturing Technology, as well assuming responsibility for various rocket propulsion projects.

In academics, Sutton accepted an appointment as the Hunsaker Professor of Aeronautical Engineering at MIT in 1958–1959. He was also a member of the mechanical engineering faculty of the California Institute of Technology for four years and taught several analytical courses and student laboratory lessons and served as a guest lecturer at several universities as well as at company and government laboratories.

Sutton was an AIAA Fellow and past president of the American Rocket Society (ARS), one of the predecessor societies that merged to create AIAA. Sutton joined the ARS in 1947 and served as its president in 1959. He was elected as a Fellow in 1960. He also was a founder of the Southern California Section. He received the Pendray Aerospace Literature Award from ARS in 1951 and again in 2002 from AIAA for his outstanding contributions to aeronautical and astronautical literature. *Rocket Propulsion Elements* is his most renowned work – no other aerospace books have evolved and been updated with as many editions. In 2006, he published *History of Liquid Propellant Rocket Engines* with AIAA. This text tells the story of how technological advances were made, who made them happen, and the different kinds of vehicles that have been propelled by liquid propellant rocket engines. He was a prolific author, publishing dozens of technical articles in AIAA publications and other professional journals and magazines.

sory Group for Aerospace R&D (AGARD) to the NATO Military Committee in Paris. After his three-year assignment with AGARD ended in 1988, he embarked on a new career in Human Factors research. He joined NASA Ames Research Center as a principal engineer, Aerospace Human Factors Research Division. He became head of the Office of Space Human Factors and from 1992 to 1994, he served as chief of the Human Factors Research Division.

Dr. Statler was project manager of a series of projects to develop automated methodologies for analyzing diverse data sources to enable safety analysts in the air transportation industry to obtain reliable information on events or trends in daily operations that could compromise the safety of the system. His group developed and led a large innovative project called Aviation Performance Measuring System (APMS) to monitor commercial aircraft continuously in nearly real time. APMS evolved into an even larger project called Aviation System Monitoring and Modeling (ASMM) under NASA's Aviation Safety Program. The technology developed under the ASMM project for extracting and merging information from very large dispersed data sources, Dr. Statler's group demonstrated the concept of a Distributed National FOQA Archive (DNFA) with data from 10 airlines. The DNFA was handed off to the FAA.

Dr. Statler retired in 2008 after 20 years with NASA, but volunteered as an Ames Associate until 2014, when he was 90 years old.

Over the course of his career Dr. Statler was honored with many awards including the Ministry of Defense of France La Médaille de l'Aéronautique (1986), the NATO Military Committee Chairman's Medal (1988), the NASA Outstanding Leadership Medal (2006), and the FAA's Excellence in Aviation Research Award (2009). He was recognized with AIAA's International Cooperation Award in 1992 for "two decades of sustained, notable contributions to the initiation and management of highly-productive collaborative, multi-national aeronautics research programs and scientific exchanges involving the United States, France, Germany, Israel, Italy, Japan, the Netherlands, and the NATO/AGARD community."

During his career, Dr. Statler was a member of the American Helicopter Society and a Fellow of AIAA, the Royal Aeronautical Society, AAAS, and the German Aerospace Society. Dr. Statler authored or co-authored over 70 publications and presentations on slender-body aerodynamics, nonstationary aerodynamics, dynamic stability and control, nonlinear control theory, hydrofoil theory, ground-based and in-flight simulation, rotary-wing aerodynamics, pilot human factors, man-machine interaction, data-base mining, anomaly detection, and aviation safety. In 2020, he published a new book, *Human Consciousness: The Evolution of Our Sensor of Society*.

AIAA Associate Fellow Krug Died In July

Edwin H. Krug died 9 July at age 96.

Taught how to fly by his uncle as a teenager, he became interested in an aeronautical career. Between 1944 and 1946 he served in the U.S. Navy on the USS Chloris, and then in the Washington DC Bureau of Aeronautics.

Krug earned a BSAE degree from Virginia Polytechnic Institute and an MSAE from MIT before accepting a position with General Dynamics (Convair) as the aerodynamicist in change of automatic flight control systems for airplanes and missiles, specifically the B58 (Hustler) and MX2224, a pilotless plane. Lear, Inc., which later became Lear Siegler, lured Krug to Michigan in 1954, where he continued to work as an aeronautical engineer until he retired.

Krug, a 70+-year member of AIAA, served on the Science Advisory Board for the State of Michigan and also served as the Executive Program Director of Space Shuttle ADI.

AIAA Senior Member Snedeker Died in August

Richard "Dick" S. Snedeker died on 16 August. He was 93 years old.

Snedeker served in the U. S. Navy from 1945 to 1946. He graduated with a bachelor's degree in aeronautical engineering from Princeton University in 1951 and received a master's in 1961.

Initially employed by Princeton University Press as a technical illustrator and editor, Snedeker moved on to work at Aeronautical Research Associates of Princeton (ARAP), where he spent his 40-year career working in the field of experimental fluid dynamics. He published nearly 100 papers and received five U.S. patents. He retired from ARAP in 1997. He was a member of AIAA for over 70 years.

AIAA Associate Fellow Greene Died in October

Bob Greene, a self-taught computer and aerospace engineer who was a driving force in the AIAA Atlanta Section, died on 8 October. He was 69 years old.

After earning a bachelor's degree in business administration and management from Mississippi State in 1978, Greene developed a passion for space travel and designing a rocket propulsion system that would help people safely reach Mars. He presented a paper entitled "Getting Around the Solar System Quickly: A Design Study for a High Speed, Highly Reusable Nuclear Fission Rocket Engine for Use on Deep Space Missions" at the 53rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference in July 2017. He started the Aeronaut Corporation, an aviation, marine, and aerospace company that specialized in fluid power system designs, out of his house.

Greene was extremely involved with AIAA for more than 20 years at the regional and section levels. He was the program chair for the AIAA Atlanta Section, as well as its Congressional Visits Day state team captain. Greene worked to promote STEM programs through AIAA, and under his leadership, the Atlanta Section earned a third-place finish in the large section category for Public Policy in the annual AIAA Section Awards in 2019.

Greene was recognized with the 2018 AIAA Sustained Service Award for his involvement with AIAA. He was enthusiastic about the possibilities of the space industry and tourism, and recently had been working on a paper about tandem autonomous robots for exploring lava tubes on the moon and Mars.

JAHNIVERSE

CONTINUED FROM PAGE 96

Moreover, any object traveling along a space-time geodesic has its own inertial frame. An astronaut in Earth orbit is a pseudo-inertial observer because most of their trajectory is determined by the curvature of space-time, and the remainder of the trajectory is mainly defined by nongravitational accelerations such as solar radiation pressure and atmospheric drag. This understanding of the inertial frame was Einstein's epiphany. He concluded that inertial mass and gravitational mass were equivalent so that someone in free fall would not be able to sense any absolute acceleration. On the other hand, someone propelled in a rocket in free space at a rate of 9.8 meters per second squared would feel like they are on Earth's surface.

So, real forces are only those that would cause a deviation of an object's path from its space-time geodesic. Interestingly, this is exactly what is measured by inertial measurement units with accelerometers. There are applications you can load onto your cellphone to read out its acceleration as measured by its internal accelerometer. In the classes I teach, I always ask my students if accelerometers measure gravity, and the answer should be "no." Place your cellphone on a table and it should read 1 g. It's not measuring gravity but rather the normal force preventing it from falling, or following its space-time geodesic. In a purely free-fall environment, your phone's accelerometer would register zero, for no acceleration. Given all of this back and forth and apparent differences in theories kinetic and kinematic, here is where Newton and Einstein meet: Newton's principle of determinacy. It states that if we know an object's initial position and velocity, we can predict where it will be for all time. This principle holds true for objects moving along their space-time geodesics and hence is where Newton can thank Einstein for showing where this principle is valid.

To be sure, Newtonian dynamics are used every day by millions of us, astrodynamicists included. However, as a former spacecraft navigator at NASA's Jet Propulsion Laboratory, I can tell you that you'll never be successful at sending probes across the solar system without correcting Newtonian dynamics for Einstein's relativistic effects. Personally, I don't like mixing theories to make things work, so I enjoy understanding the observed and predicted motion of stuff in space considering space-time to be what influences that motion kinematically, and then focus my effort on understanding real kinetics. Maybe the real reason for the large imprecision in G is that it is based on measuring space-time geodesics, and the shape of space-time is always changing, thus G is in constant change. ★

LOOKING BACK

COMPILED BY FRANK H. WINTER and ROBERT VAN DER LINDEN

1920

1 **Dec. 3** A coastal patrol service begins from Mitchel Field in New York to Langley Field in Virginia with two Dayton-Wright DH-4 light bombers. They transmit wireless reports on shipping accidents. **Aircraft Year Book, 1920**, p. 258.

Dec. 12 Powered by two Salmson Z.9 230-horsepower water-cooled radial engines, a Bleriot-Spad 33 airliner completes its first flight. It starts service between Paris and London in 1921 and, after several improvements, becomes the Spad 126. The Spad 33 can carry four passengers in the cabin while the pilot flies from an open cockpit. David Baker, **Flight and Flying: A Chronology**, p. 136.

1945

Dec. 3 A de Havilland Vampire 1 becomes the world's first pure jet aircraft to operate from an aircraft carrier when the third prototype completes an arrested landing on the British Royal Navy's HMS Ocean. The fighter is modified for deck landings. Subsequently, the Royal Navy orders naval Sea Vampires for the Fleet Air Arm. A.J. Jackson, **De Havilland Aircraft Since 1909**, p. 430.

Dec. 3 The first U.S. Army Air Forces' jet fighter unit, the 412th Fighter Group, receives its first Lockheed P-80A aircraft at March Field in California. E.M. Emme. ed., **Aeronautics and Astronautics, 1915-60**, p. 52.

Dec. 8 The Bell Model 47 helicopter prototype, one of the first modern helicopters with a two-bladed main rotor and stabilizing bar, makes its first flight. It is the first helicopter to receive an airworthiness certificate from the Civil Aeronautics Administration. C.M. Voss, **Brief History of The First Use of Helicopters in Agriculture**, pp. 2-3, 10.

Dec. 9 The first experimental onboard TV transmissions are broadcast from an aircraft. The transmissions, called Stratovision, are conducted at Middle River, Maryland, by Westinghouse Electric and Glenn L. Martin Co. using an airplane flying in the stratosphere. E.M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 52.

2 **Dec. 14** The Army Air Forces awards a contract to Bell Aircraft for the development of two swept-wing, rocket-powered supersonic flight research aircraft later known as the Bell X-2. (The photo shows the X-2 in 1954 as it drops away from its Boeing B-50 carrier plane.) E.M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 52.

Dec. 22 The Beechcraft Model 35 Bonanza completes its first flight. With a distinctive butterfly tail section, the Bonanza soon becomes a popular single-engine general aviation aircraft. Still in production in various forms, more than 17,000 "V" tail and conventional tail Bonanzas have been built. Alain J. Pelletier, **Beech Aircraft and Their Predecessors**, pp. 130-134.

1970

Dec. 1 Ruth Law Oliver dies at age 85. The early aviator and exhibition flyer set a speed record in 1916 by flying a Curtiss biplane 1,094 kilometers from Chicago to Binghamton, New York, in six hours, seven minutes. She had been the owner of Ruth Law's Flying Circus and became known as the first woman to loop-the-loop and fly at night. **Washington Post**, Dec. 4, 1970, p. B18.

Dec. 5 The first positive identification of amino acids of extraterrestrial origin is reported in the science journal Nature by a NASA team headed by Cyril Ponnamperuma. The researchers say they found an abundance of amino acids in a meteorite that fell near Murchison, Australia, in 1969. It is probably the first conclusive proof of extraterrestrial chemical evolution of chemical processes that precede the origin of life. This is therefore strong evidence of the possible existence of life elsewhere in the universe. **Nature**, Dec. 5, 1970, pp. 923-926; **New York Times**, Dec. 8, 1970.

3 **Dec. 6** Retired Gen. Thomas S. Power, former commander of the U.S. Strategic Air Command, dies at 65. He received flight training at Kelly Field (later, Kelly Air Force Base), Texas, where he was commissioned a second lieutenant in 1929. During World War II, he held a succession of bomber unit commands, culminating in deputy chief of staff for operations of the U.S. strategic bombing forces in the Pacific. In July 1957, he received his fourth star and assumed the command of SAC, retiring in 1964. **Aviation Week**, Dec. 14, 1970, p. 20.

Dec. 9 Soviet Gen. Artem Mikoyan dies in Moscow at age 65. Mikoyan, with Mikhail Gurevich, headed the design bureau that produced the MiG series of Russian fighter aircraft. **Aviation Week**, Dec. 14, 1970, p. 25; **New York Time**s, Dec. 10, 1970, p. 1.

4 **Dec. 10-11** The Soviet Union's robotic Lunokhod 1 completes a total of nine hours of exploration missions, traveling 10 kilometers over the lunar surface, including in and out of a crater, and transmits TV pictures of the lunar landscape and data on the moon's soil properties. **Space Business Daily**, Dec. 14-15, 1970.

Dec. 12 CNES, France's national space agency, launches its Peole (Preliminaire Eole) experimental meteorological satellite on a Diamant-B booster from Kourou, French Guiana. The primary objective is to flight-qualify the gravity gradient stabilization system and tracking localizer to be used in its planned EOLE weather balloon satellite to be launched the following year. **Aviation Week**, Dec. 21, 1970, p. 21.

Dec. 15 The Soviet Union's Venera 7 (Venus 7) reaches the planet Venus and becomes the first spacecraft to land on another planet. During its 35-minute descent by parachute, it transmits data on the planet's largely carbon dioxide atmosphere. It sends back data for 23 minutes and records temperatures up to 580 Celsius plus enormous atmospheric pressures. Overall, Venera 7 confirms the earlier findings of Venera 4 that Venus is inhospitable to life. **Aviation Week**, Dec. 21, 1970, p. 22.

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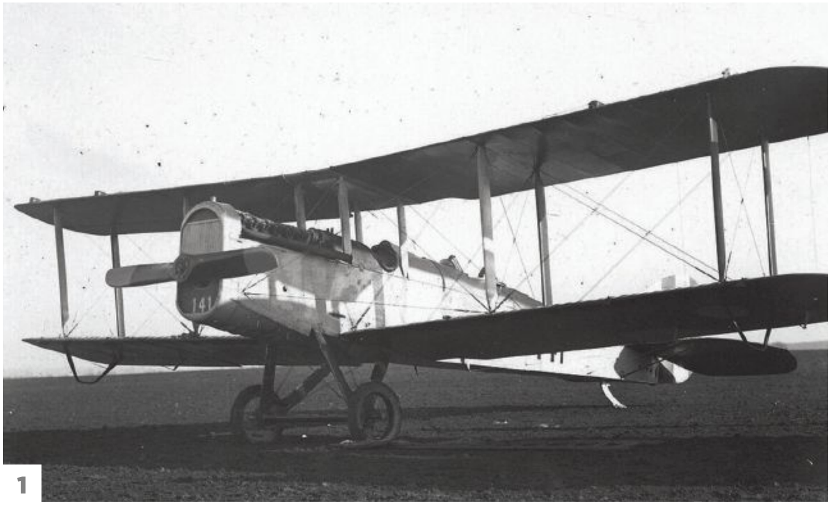
5 **Dec. 2** The Solar and Heliospheric Observatory is launched. The satellite is a joint project between NASA and the European Space Agency and is intended to explore the sun's interior, its atmosphere and the solar wind. NASA, **Astronautics and Aeronautics, 1991-1995**, p. 667.

6 **Dec. 7** The Galileo probe becomes the first spacecraft to orbit an outer planet. Launched by the Atlantis space shuttle in August 1990, Galileo reaches Jupiter after receiving gravitational assist flybys of Venus and Earth. Once in orbit the spacecraft releases a probe to explore the atmosphere of Jupiter. **Solarsystem.nasa.gov**



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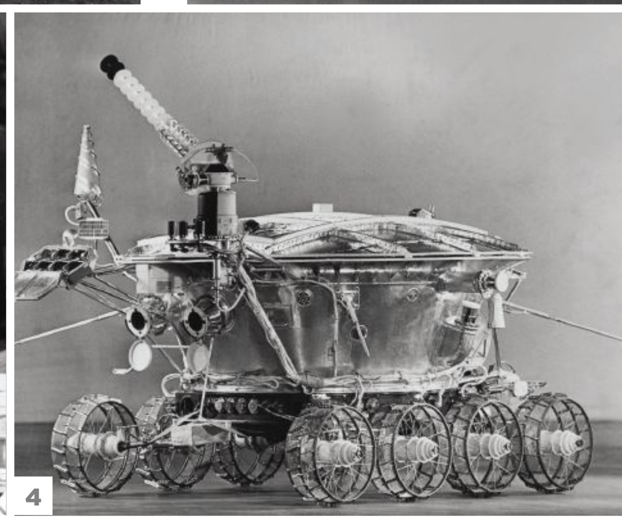

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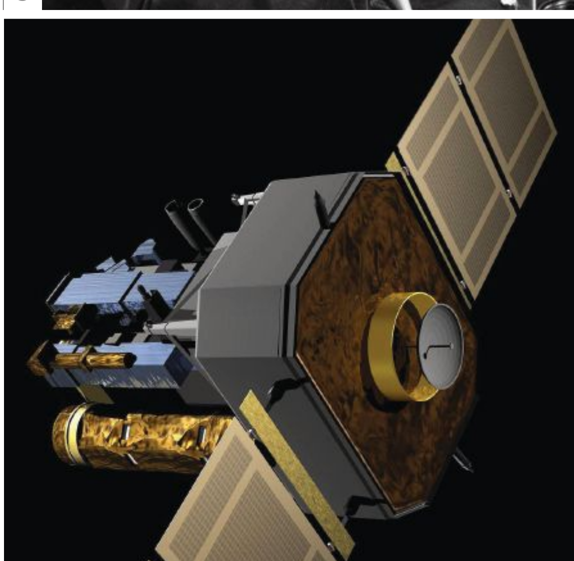

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Gravity according to Einstein and Newton

BY MORIBA JAH

Sir Isaac Newton, circa 1686, came to believe that the same principle that makes objects fall toward Earth, such as an apple from a tree, governs the movements of objects in the sky, such as the moon, in an idea now called the Universal Law of Gravitation that became a key element of his 1687 masterpiece, "Principia," or in English "Mathematical Principles of Natural Philosophy." This gravitation law describes the attractive forces between two masses as proportional to their mathematical product and inversely proportional to the distance between them squared. The proportionality constant in this relationship is known as G and should not be confused with g, as in a unit of Earth's gravity. G can be inductively inferred through experimentation and observational data. But while physicists treat G as a constant, in reality G has a variability of about 1 in 10,000 for reasons that remain unknown. By contrast, other physical constants show variabilities on the order of 1 part per million or billion, and even zero variability such as the speed of light in a vacuum and Planck's constant, which captures the movement of atomic particles and waves. The claim from physicists is that G is difficult to measure precisely because gravity is such a weak force as opposed to others. In my line of work as an astrodynamicist, it tends to be the dominant apparent effect governing the motion of objects in space, and we know that the gravitational potential is dynamic. For instance, Earth's total mass distribution is not constant.

As for the acceleration due to gravity, what Newton inferred as an invisible centripetal force, Einstein more appropriately inferred as the curvature of a 4-dimensional manifold that he called space-time, which indicates the path a particle, an object or even a photon would take depending on its position and velocity with respect to space-time. The path taken in space-time by anything, just due to its position and velocity with respect to it is called a geodesic, the shortest path between any two points. Newtonian dynamics are kinetic in that they ascribe a force as a cause of the observed motion, generally modeled in Euclidean space, which is isomorphic, meaning equal-shaped with time being an absolute quantity. Conversely, for Einstein, what is known as gravity is not a force but evidence that we exist in a pseudo-Riemannian, or nonisomorphic, space whose shape comes from the presence of masses with time being a relative quantity. Einstein's Theory of General Relativity is a kinematic theory in that it provides a geometric explanation of gravitational motion. Therefore, all real forces are nongravitational.

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