National Aeronautics and Space Administration

Armstrong Flight Research Center

Research, Technology & Engineering 2019

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NASA

From the Director:
Research and Engineering Directorate

It is an honor to endorse the 2019 NASA's Armstrong Flight Research Center *Research, Technology, and Engineering Report*. The talented researchers, engineers, and scientists at Armstrong continue to create innovative solutions to address some of the most pressing challenges facing the aerospace community, particularly as new technologies are expanding the field of flight transportation.

Armstrong prides itself on its ability to develop new techniques, technologies, and test methodologies that address critical aerospace challenges. Researchers are currently undertaking cutting-edge projects that will advance our ability to achieve critical aerospace goals, such as quiet supersonic flight, electric aircraft, and integration of unmanned vehicles into the National Airspace System. In addition, teams are addressing some of the unique aspects associated with space access as well as other diverse challenges across mission directorates.

As we continue our efforts to support NASA's aerospace research and development missions, we strive to ensure that the public is aware of the advancements we have achieved. This report is a compilation of the wide range of work being conducted at Armstrong, along with contact information for the associated technologists responsible for each effort. We encourage you to reach out to these investigators for more information or to discuss collaboration ideas.

Bradley C. Flick

Director for Research and Engineering

From the
Center Chief Technologist

I am pleased to present highlights of the tremendous body of research and engineering work performed at NASA's Armstrong Flight Research Center. Our innovators possess the skills and ingenuity to not only accomplish Armstrong's flight research and test missions but also support NASA missions across the entire agency. In addition, they are constantly pushing the envelope of new technologies and capabilities that are contributing to the expansion of what is possible in the field of aerospace and flight transportation.

Armstrong's project teams tackle the nation's most complex flight research projects. They develop novel solutions that advance emerging technologies from the concept stage and on to experimental formulation and final testing. Among the myriad projects taking place across the center, researchers are developing and refining technologies for electric propulsion vehicles, a low-boom flight demonstrator, ultra-efficient aircraft, air launch systems, and experimental X-planes. The center's unique location and airborne research laboratories, combined with the distinctive capabilities of its personnel, enable testing and validation of a wide variety of new research concepts.

This document highlights key results and benefits from research efforts that have been undertaken by Armstrong researchers. The projects span focus areas including electric propulsion, vehicle efficiency, supersonics, space and hypersonics, autonomous systems, flight and ground experimental test technologies, and much more. The appendix includes contact information for the principal investigator (PI) of each project, and we encourage you to engage with these researchers.

I am proud to be a part of the amazing team here at Armstrong and am pleased to share these details of our work with you. We welcome opportunities for partnership and collaboration, so please contact us to learn more about these cutting-edge innovations and how they might align with your needs.

David Voracek
Center Chief Technologist

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NASA to Test New Propulsion Technology

With 14 electric motors turning propellers and integrated into a uniquely designed wing, NASA will use the X-57—its first all-electric experimental aircraft and the first crewed X-plane in decades—to demonstrate that electric propulsion can make planes quieter, more efficient, and more environmentally friendly.

Distributed electric propulsion technology is based on the premise that closely integrating the propulsion system with the airframe and distributing multiple motors across the wing will increase efficiency, lower operating costs, and increase safety.

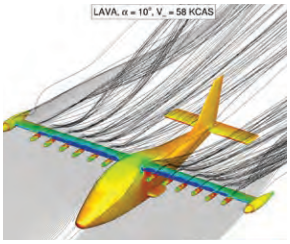
The first of three X-57 aircraft configurations arrived at Armstrong in October 2019 for testing and preparation for initial flight tests. Dubbed Modification II (Mod II), this configuration will undergo ground tests, followed by taxi tests, and then flight tests.

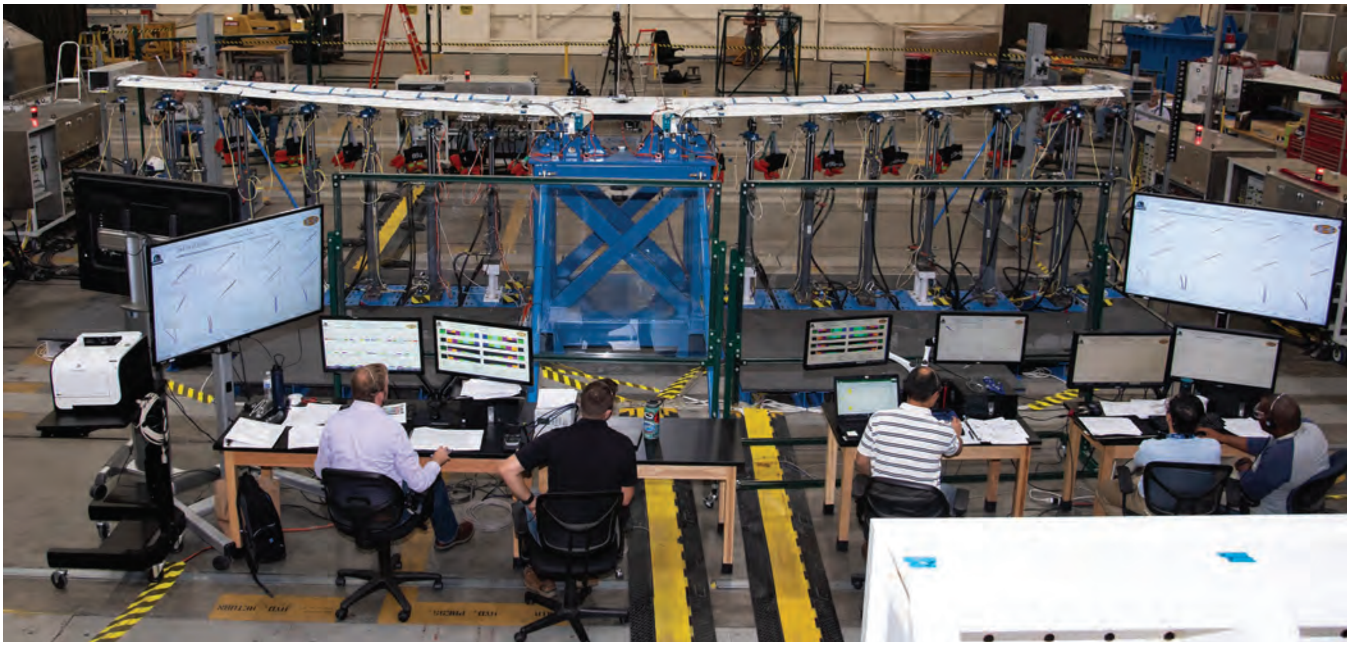
A goal of the X-57 project is to help develop certification standards for emerging electric aircraft markets, including urban air mobility vehicles, which also rely on complex distributed electric propulsion systems. NASA will share the aircraft's electric propulsion–focused design and airworthiness process with regulators and industry, which will advance certification approaches for aircraft utilizing distributed electric propulsion.

Following are highlights of recent accomplishments and a look at what lies ahead in several key areas.

Aero Database Development

Researchers at Armstrong and NASA's Ames and Langley Research Centers have run more than 2,500 computational fluid dynamics (CFD) cases using a variety of CFD codes to support the development of an X-57 aerodynamic database. The database models the aerodynamics of the baseline X-57 vehicle and also includes aerodynamic increments from the cruise propulsors on the wing tips and the 12 high-lift propulsors distributed along the wing's leading edge. Propulsors are modeled in CFD using actuator disks with thrust and power values derived from XROTOR models of the cruise and high-lift propellers. An uncertainty model for the aerodynamics of the vehicle was derived, in part, from the variation between the different CFD codes and was incorporated into the database. The aerodynamic database was implemented at NASA Langley, and Armstrong piloted simulations for controls analysis and airworthiness evaluations.





The distributed electric aircraft wing that will fly in the final configuration of the X-57 flight tests completed its testing in the Flight Loads Laboratory.

with X-57 Maxwell Experimental Aircraft

The electric motors for X-57's Mod II vehicle and their propellers were powered up and spun together in an integrated spin test.

Systems Integration and Test Planning

The X-57 aircraft is undergoing a series of tests before the Mod II flights occur. Weight and balance tests, ground vibration tests, and post-shipment functional checkout activities will occur first. Hardware and software upgrades will be implemented to improve propulsor efficiencies, followed by a series of system-level verification tests. Off-nominal cases will be checked to ensure there are no unexpected system behaviors. Then instrumentation data will be transmitted from the vehicle to the control room during hangar radiation tests as well as combined system tests to check for electromagnetic interference and compatibility issues. For dynamic testing, a low-speed taxi test will identify any loose wiring connections at the interfaces. At the completion of these build-up tests, the X-57 aircraft will be ready for flight.

Wing Loads Testing

Following the Mod II phase, Modifications III and IV will feature a high-aspect ratio wing, compared to the wider, standard wing from the Mod II phase. The Mod III/IV wing was tested at Armstrong's Flight Loads Laboratory to calibrate installed strain gauges for real-time loads monitoring and to verify that the wing met design specifications. The new wing will permit the repositioning of the electric cruise motors to the wingtips, which could significantly boost aircraft efficiency. The Mod IV configuration will include 12 smaller high-lift motors in addition to the two larger cruise motors on each end of the wing to produce distributed electric propulsion.

Collaborators: NASA's Langley Research Center, Glenn Research Center, Ames Research Center, and Johnson Space Center; Empirical Systems Aerospace; Joby Aviation; Xperimental; Scaled Composites; Utah-based Electric Power Systems; TMC Technologies; and Tecnam

Benefits

- **Enables cleaner flight:** Electric propulsion provides a 5- to 10-factor reduction in greenhouse gas emissions with current forms of electricity generation and essentially zero emissions with renewable-based electricity.
- **Reduces lead emissions:** Electric propulsion provides a technology path for small aircraft to eliminate the use of 100 low-lead (100LL) avgas, which is the greatest contributor to current lead emissions.
- **Improves efficiency for commuter aircraft:** This research could lead to the development of an electric propulsion–powered commuter aircraft that is more efficient than today's models.
- **Reduces total cost of ownership for small aircraft:** This project will demonstrate high-performance electric motors, controllers, and power delivery systems that are more reliable and easier to maintain than traditional hydrocarbon-based systems. These technologies will eventually allow aircraft to be built with reduced maintenance costs and improved reliability in flight.

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Supersonics Technologies

Supersonic flight overland is currently severely restricted because sonic booms created by shock waves disturb people on the ground and can damage property. Innovators at Armstrong are working to solve this problem through a variety of innovative techniques that measure, characterize, and mitigate sonic booms. NASA's goal for sonic boom research is to find ways to control and lessen shock wave noise so that federal regulators will allow supersonic flight overland.

The development of a new experimental plane called the X-59 QueSST—which stands for Quiet Supersonic Technology—is advancing as part of the Low-Boom Flight Demonstration mission. When the new X-plane arrives from Lockheed Martin Aeronautics Company's Skunk Works® plant, Armstrong researchers will qualify and flight test it. QueSST will be used to help gauge how people respond to the lower intensity "thump" rather than the disruptive sonic boom in different areas of the United States. Determining a tolerable level of noise for supersonic flight is key to suggesting that the Federal Aviation Administration (FAA) amend its current rules for supersonic aircraft. Success could lead to opening a new market for next-generation aircraft.

Shock-Sensing Probe to Study Sonic Booms

A new shock-sensing probe in development at Armstrong is expected to provide researchers with key information about sonic booms. The Armstrong probe is mounted on the nose of an F-15B aircraft that flies through the shock waves of another supersonic aircraft. In addition to measuring the static pressure change through the shock waves, the probe measures the change in Mach number and flow angularity. Researchers are comparing these measurements to computational fluid dynamics (CFD) models to verify those predictions. If successful, the probe will be used for the Low-Boom Flight Demonstration mission.

Work to date: In 2018 and 2019, the team flew five flights with the shock-sensing probe on the nose of the F-15B aircraft. Three of those flights were to calibrate the probe, and the other two were to measure the shock signature of an F/A-18 aircraft. The team encountered and addressed minor instrumentation issues. Thus far, the comparisons between the flight measurements and CFD models have been favorable.

Looking ahead: The team is redesigning a portion of the probe to aid with assembly and disassembly. This modification is solely to make it easier to maintain the probe and will have no effect on probe measurements. Phase 2 flights are scheduled for late spring to early summer 2020.

Partner: Eagle Aeronautics

Benefits

- **High performance:** Measures flow speed, static pressure, and angularity
- **Improves measurement:** Allows for probing to be conducted at a higher closure rate, due to reduced pneumatic lag

Applications

- Facilitating aircraft design that may ultimately enable overland supersonic flight

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Armstrong Prepares for Arrival of X-59 Quiet Supersonic Aircraft

Illustration of the completed X-59 QueSST landing on a runway (Credit: Lockheed Martin)

The Low-Boom Flight Demonstration mission seeks to enable the possibility of boarding a commercial supersonic airliner and flying across the United States in half the time it takes today. To support this goal, NASA is developing the X-59 Quiet Supersonic Technology (QueSST) airplane, whose unique shape and technology are designed to turn sonic booms associated with faster-than-sound flight into barely perceptible sonic thumps. Armstrong researchers are making significant contributions to this project, particularly in the areas of studying, characterizing, quantifying, and measuring sonic booms as well as work with an external vision system, which is necessary due to the plane's unusual design. These achievements are highlighted in the following pages.

The X-59 will be flown above select U.S. communities to measure and record public response to its noise while flying supersonic. The resulting statistically valid data will be used to consider changing the regulation to be based on an acceptable sound level rather than a prohibition that has been in place since 1973. Construction of the X-59 by Lockheed Martin Aeronautics Company continues, and the project passed its Critical Design Review in October 2019 and another key program management review in December. By the end of 2019, the airplane was taking shape on the factory floor.

Assembly work is concentrated within three major sections of tooling. The forward jig is home to the X-59's fuselage, the center section to the airplane's single-piece wing, and the rear jig is set up for the fabrication of the airplane's tail holding the vertical fin and the horizontal stabilizer—a section also known as the empennage. Final assembly and integration of the airplane's systems is targeted for late 2020.

Initial flight tests at Armstrong in 2021 will ensure the vehicle operates well and will be followed by a series of supersonic flights to validate if it is producing quieter sonic booms as expected. After that, the X-59 will begin its community overflights to gather public response data, with the plan to present that information to the Federal Aviation Administration and others in 2023.

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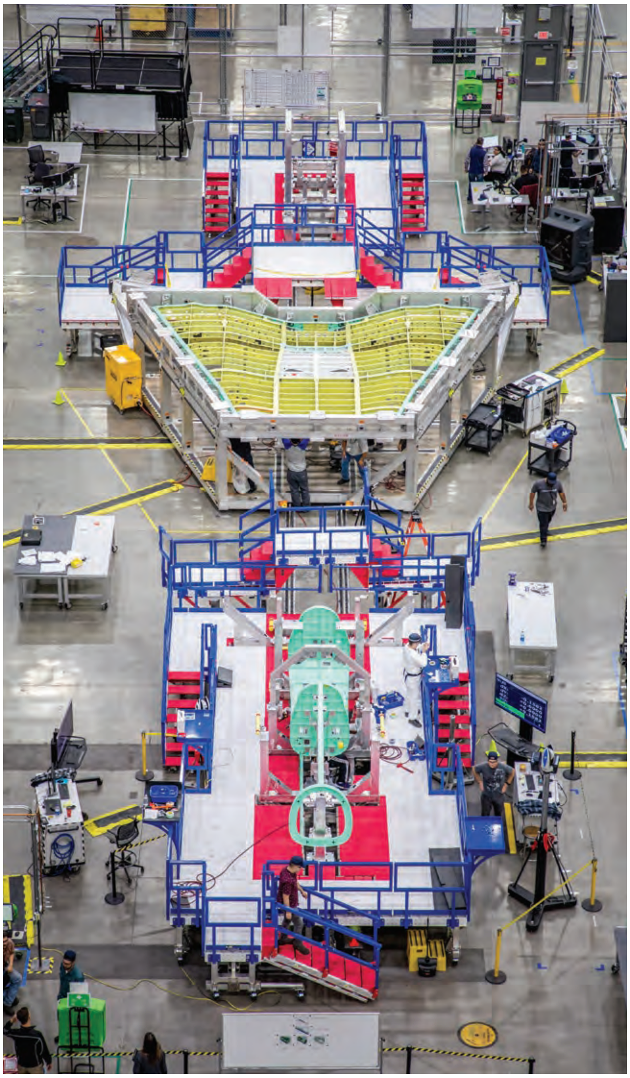
Construction and assembly of the supersonic QueSST research plane at Lockheed Martin Aeronautics Company's Skunk Works® factory (Credit: Lockheed Martin)

Flying Qualities for Low-Boom Vehicles

Armstrong innovators are developing guidelines and evaluating stability and control characteristics for the planned supersonic Low-Boom Flight Demonstration mission. NASA is working to develop aircraft that can fly at supersonic speeds and deliver a soft thump instead of the disruptive boom associated with supersonic flight today. In addition to stability and control evaluations, Armstrong researchers are developing a supersonic autopilot to control aircraft parameters, such as the flight path and changes in Mach speeds to prevent coalescence of shock waves and minimize perceived sonic boom noise levels on the ground.

Work to date: Armstrong researchers have developed a pilot-in-the-loop and batch non-linear simulation based on the initial models. The team has used the simulation to analyze vehicle stability, controllability, and handling qualities and to design trade studies on speed brakes, gear brakes, and approach and landing control system types. Piloted studies to evaluate landing performance during simulated malfunctions of the external vision system (XVS) have also been completed.

Looking ahead: As design iterations continue, the team will refine stability and control characteristics. Next steps also include designing a supersonic autopilot to enable the aircraft to fly desired test trajectories without focusing a sonic boom on the ground. In addition, control room displays to provide real-time stability margins and flight envelope clearance are being developed.

Partners: NASA's Langley Research Center and Lockheed Martin

Benefits

- **Integrated research:** Enables NASA to become more aware of relevant issues due to independent analysis of stability and control characteristics
- **Advanced:** Works to manage sonic boom noise levels through innovative autopilot design

Applications

- Low-Boom Flight Demonstration mission support
- Subsequent commercial supersonic aircraft design

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Simulating Malfunctions of the X-59's External Vision System

As part of their work evaluating stability and control characteristics for the X-59 Quiet Supersonic Technology (QueSST) aircraft, Armstrong researchers are evaluating risks associated with an in-flight malfunction of the external vision system (XVS). The XVS is a camera and display system that will provide a forward-looking view from the X-59 cockpit. Because the X-59 uses an XVS in lieu of a front windshield, the pilot may need to rely on alternative navigational aids—such as the instrument landing system (ILS)—to maintain situational awareness and land the aircraft if the XVS were to display incorrectly or not at all. The XVS uses custom image processing software and camera systems to create an augmented reality view of the X-59 pilot's forward line-of-sight along with graphical flight data overlays.

Work to date: Researchers successfully designed, coordinated, and implemented pilot-in-the-loop (PIL) simulations with a dozen test pilots to assess landing performance in cases without a forward view monitor. The PIL simulations included a synthetic runway overlay to provide additional navigational aid to approach and landing tasks. This additional implementation resulted in significant overall improvements in touchdown and rollout dispersions from all pilots involved.

Results suggest that safe landing of the aircraft is possible with the use of an ILS and synthetic runway overlay. In contrast, ILS-only landings exhibited lower measured performance. Test pilots displayed significant learning curves depending on their experience level with flying remotely piloted aircraft due to similarities involved with learning to pilot aircraft with monitor displays.

Benefits

- **Anticipates novel design challenges:** Enables exploration of potential hazards in a safe and cost-effective manner within a fully simulated environment
- **Reduces risk:** Ensures pilot safety while furthering sonic boom reduction research efforts

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Using Schlieren Techniques to Understand Sonic Booms

Research efforts at Armstrong were the first to use schlieren photography to capture images of shock waves emanating from aircraft in supersonic flight. Flow visualization is one of the fundamental tools of aeronautics research. Background-oriented schlieren techniques use a textured background to visualize air density gradients caused by aerodynamic flow. These images allow researchers to study life-sized aircraft flying through Earth's atmosphere, which provides more informative results than modeling or wind tunnels.

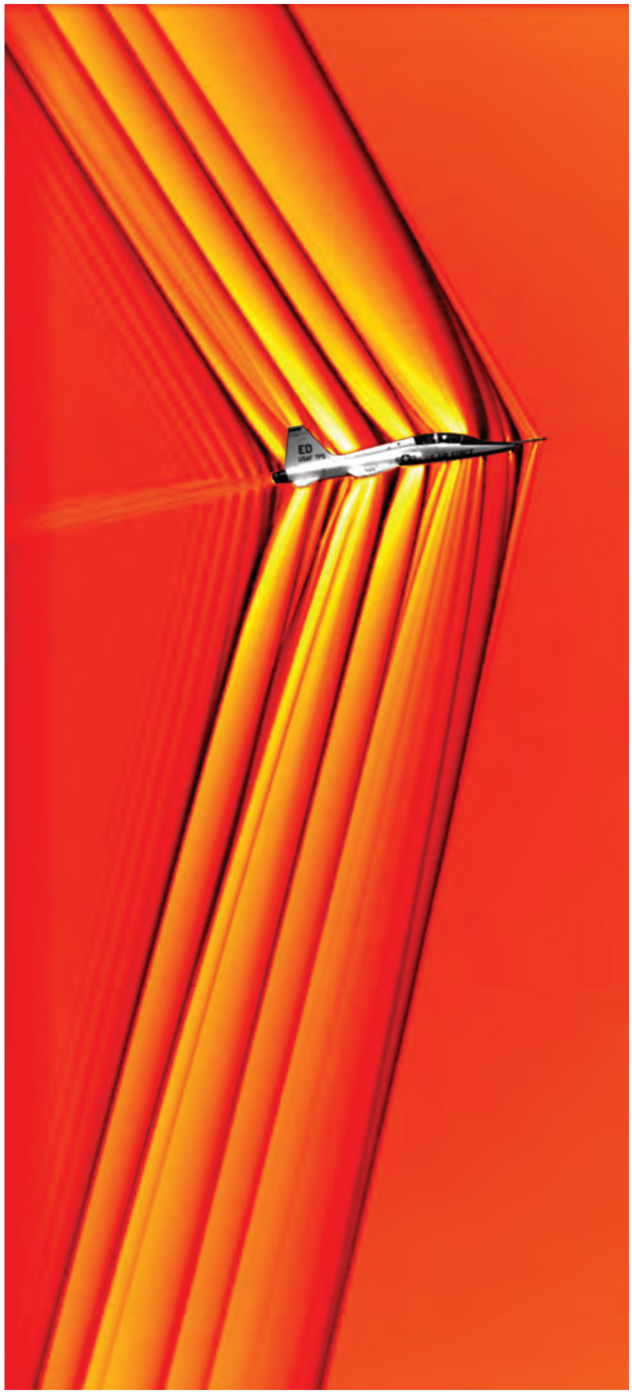
NASA is progressing on its work with the U.S. Navy to develop an airborne pod to image the X-59 Quiet Supersonic Technology (QueSST) aircraft. This pod will provide the opportunity to obtain air-to-air images of the X-59 shock wave structure using both the Sun and the ground as backgrounds. These techniques were pioneered with the Background Oriented Schlieren Using Celestial Objects (BOSCO) and Air-to-Air Background Oriented Schlieren (AirBOS) technologies. The data will be instrumental in validating prediction codes and correlating with ground-based sonic boom acoustic data.

Work to date: Researchers continue to expand schlieren flight test techniques. Research efforts in 2018 and 2019 focused on augmenting the current schlieren capabilities. The AirBOS with Simultaneous Referencing (AirBOS-SR) approach enables multiple frames of close-up images from various angles, including a side-view perspective. The technique also enables images of multiple flight conditions, such as acceleration and aircraft configuration changes.

Sky-Based Background Oriented Schlieren (SkyBOS) is exploring the possibility of using backgrounds from the Sun and other celestial bodies in the night sky, and other low-textured backgrounds (e.g., clouds, near horizon) in the day sky. This would greatly improve the usability and value of schlieren techniques for flight testing.

Looking ahead: In addition to its work with the Navy, the team will also continue to develop SkyBOS capabilities, with plans underway to modify the center's "shock lab" to perform shock studies with various sensors. Future work also includes imaging subsonic aircraft flow fields.

Partners: NASA's Ames Research Center, U.S. Navy (NAVAIR Point Mugu), and the U.S. Air Force Test Pilot School



Benefits

- **Real-world visualization:** Schlieren techniques enable visualization of shock wave geometry in the real atmosphere with real propulsion systems, which cannot be duplicated in wind tunnels or computer simulations.
- **Improved data:** Studying life-sized aircraft flying through Earth's atmosphere provides better results than modeling, helping engineers design better and quieter supersonic airplanes.

Applications

- Studying shock waves for supersonic and subsonic aircraft
- Understanding flow phenomena for wing-tip vortices, engine plumes, wind turbines, and rotorcraft

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Quantifying and Measuring Sonic Booms

Because the Federal Aviation Administration (FAA) has not yet defined a maximum allowable sonic boom loudness, Armstrong innovators are researching ways to identify a loudness level that is acceptable to both the FAA and the public. The Armstrong team and a number of industry, academic, and NASA partners have identified and validated several methods and techniques for capturing and measuring booms and their impacts. Activities range from collecting data above and below sonic booms via a sophisticated array of microphones to gathering information from remote sensors and wireless network–controlled microphones strategically placed within communities.

Work to date: The Armstrong team is continuing to advance NASA's understanding of sonic boom phenomena via boom tests. This includes the Sonic Booms in Atmospheric Turbulence (SonicBAT) project, which is working to develop analytical and numerical models of the effects of atmospheric turbulence on noise levels and then validate the models using research flights. Flights were performed in the hot-dry climate of Edwards Air Force Base in California and the hot-wet climate of NASA's Kennedy Space Center in Florida to study the different effects of the two turbulence climates.

The **Quiet Supersonic Flights 2018 (QSF18)** campaign is defining techniques and instrumentation required to perform sonic boom community-response testing. Researchers are assessing possible recruitment, sampling, and surveying methods for effectively analyzing the impact of sonic booms on communities. The campaign is also developing new instrumentation and analysis tools to correlate sonic boom noise levels with human responses across large communities. QSF18 was NASA's first low sonic boom community-response research effort that was performed using a community unaccustomed to hearing sonic booms. Previous sonic boom noise response efforts have focused on tools and methodology and were performed at small military locations that frequently experience sonic booms. QSF18 used a unique F/A-18A dive maneuver called a "low-boom dive" that simulates what future, quiet commercial supersonic airplanes may sound like. The QSF18 research flights were conducted in Galveston, Texas.

The Armstrong team, along with industry and academic partners, has also identified and validated several methods and techniques for capturing and measuring sonic booms. A notable method is the **Boom Amplitude and Direction Sensor (BADS)**, which employs six pressure transducers widely spaced on the vertices of an octahedron. The **Supersonic Pressure Instrumentation Kit Ensemble (SPIKE)** combines a high-quality microphone recording system and accurate time tagging in a solar-powered and rugged case to withstand the harsh desert environment where most of the tests are performed.

NASA is working to develop new microphone array systems capable of spanning 2,500 meters. The systems would need to be able to remotely manage up to 150 recording devices. These systems will be required for future large-scale community response testing.

The team uses the **Shock-Sensing Probe (SSP)**, an F-15B equipped with a special probe for measuring shock waves near an aircraft. Taking measurements as close as 100 feet below an aircraft, the SSP is capable of capturing shocks that will create sonic booms on the ground. Such measurements will help with designing the body of future quiet supersonic aircraft.

The team also utilizes the **Airborne Acoustic Measurement Platform (AAMP)**, a TG-14 motor glider with a high-quality microphone mounted on its wing, to measure sonic booms up to 12,000 feet above the ground. This test equipment is used to record sonic booms generated above the atmospheric turbulent boundary layer of Earth. Recently the TG-14 has been used to assess the feasibility of leveraging data transmitted from an aircraft to autonomously trigger recording systems on the ground.

Looking ahead: Future sonic boom community-response projects will implement the newly developed strategies and technologies on large communities across the country that are representative of the national demographic. These activities will play a key role in testing the anticipated X-59 Quiet Supersonic Technology (QueSST) aircraft.

Planning is also underway for measuring and characterizing the sonic boom footprint of the QueSST aircraft. Before flying over communities, NASA will need to validate that the sonic boom produced by the X-59 has noise levels on the ground that are comparable to the design target levels. This effort will require the capability to measure the greater than 30-mile sonic boom carpet on the ground, using the AAMP to measure the sonic boom above the ground and using the SSP to measure the shocks just below the aircraft.

Partners: NASA's Langley Research Center and Kennedy Space Center, KBRwyle, Pennsylvania State University, The Boeing Company, Gulfstream Aerospace, Lockheed Martin, Applied Physical Sciences Corp., Volpe National Transportation Systems Center, Eagle Aeronautics, Gaugler Associates, and Fidell Associates

Benefits

- **Advances sonic boom research:** These programs are producing valuable data to help characterize key elements of sonic booms (e.g., evanescent waves, sonic boom propagation effects, impact of flight maneuvers).
- **Informs aircraft design:** Data from these efforts will be critical for informing designs of future supersonic aircraft.
- **Quantifies perceptions:** Data from these programs includes public reaction, which will be critical as the FAA considers allowing overland supersonic flight.

Applications

- Supersonic aircraft design
- Flight planning
- FAA approval of overland supersonic flight

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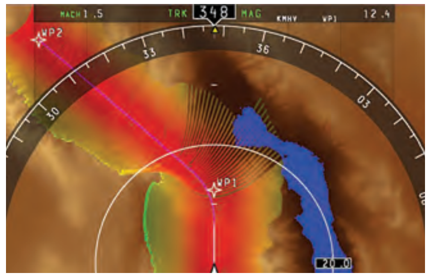
Mitigating Sonic Booms

Armstrong innovators are advancing unique technology that will permit pilots to make in-flight adjustments to control the timing and location of sonic booms. The Cockpit Interactive Sonic Boom Display Avionics (CISBoomDA) is a software system capable of displaying the location and intensity of shock waves caused by supersonic aircraft. The technology calculates an airplane's sonic boom footprint and provides real-time information, allowing pilots to make the necessary flight adjustments to control the impact of sonic booms on the ground. It can be integrated into cockpits and flight control rooms, enabling air traffic controllers to analyze flight plans for approval, monitor aircraft in flight, and review flight data to enforce regulations.



Work to date:
The real-time cockpit system has been demonstrated during supersonic flights on an F/A-18, which compared computations with boom measurements on the ground. A collaboration with Rockwell Collins helped advance the system and implement the capability to utilize a worldwide terrain database to predict where and how a sonic boom will impact the ground as well as at what sound pressure level. Recent updates include the addition of guidance functionality to the display, which incorporates automatic route impact assessment with threshold depictions, Mach/altitude options for resolutions, and combined real-time and precomputed footprint depiction. The system was integrated into NASA's Quiet Super Sonic Technology (QueSST) aircraft.

Looking ahead: Next steps are to define noise standards.

Partner: Rockwell Collins

Benefits

- **Enables overland supersonic travel:** Because pilots can control the location and intensity of sonic booms, the system may allow future-generation supersonic aircraft to fly overland.
- **Provides a tool for the FAA:** Software such as CISBoomDA could provide the Federal Aviation Administration (FAA) with the ability to approve flight plans, monitor flying aircraft, and review flight data to enforce regulations.

Applications

- **In flight:** Enables pilots to avoid producing sonic booms or control their location and intensity
- **On the ground:** Allows the FAA to approve and monitor plans for supersonic flights

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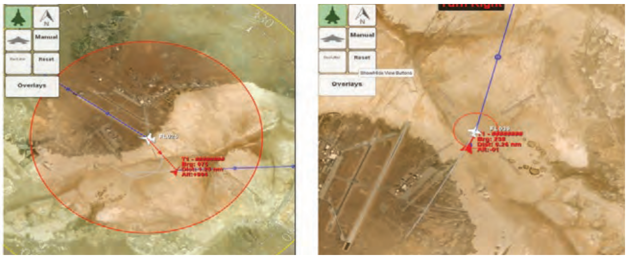

Enhanced Vision Display for Collision Avoidance

Enhanced ADS-B System for Supersonics

Armstrong researchers collaborated on flight tests that could help a new generation of supersonic commercial jets meet a government mandate requiring aircraft to be equipped with Automatic Dependent Surveillance-Broadcast (ADS-B) Out radios that broadcast GPS position and identity. This research effort combined an ADS-B system adapted for supersonic vehicles with an enhanced vision display designed for ADS-B traffic information and alerting to provide increased situational awareness. The goal of this research effort is to develop a robust ADS-B system for commercial supersonic aircraft that could allow safe integration into the National Airspace System. This research is the first to demonstrate that NASA's ADS-B architecture complies with the mandated performance accuracy for supersonic aircraft.

Work to date: In September 2018 at Edwards Air Force Base, NASA conducted three flight tests, reaching speeds of Mach 1.4 and accelerations of 5 *g*. Researchers from NASA and the Federal Aviation Administration (FAA) evaluated the ADS-B tracking from FAA ground stations to verify position accuracy throughout the subsonic and supersonic flights. The flights furthered the development and certification of the technology in four key areas: ADS-B flights at supersonic speeds, enhanced vision display, conflict detection algorithm, and use of artificial intelligence algorithms for accurate flight trajectory predictions.

Looking ahead: The collaborative research team is working to demonstrate a similar system on hypersonic platforms and commercial space vehicles.

Partner: Vigilant Aerospace Systems

Benefits

- **High performance:** Meets the ADS-B Out FAA-mandated accuracy of 304 feet at speeds up to Mach 2.0
- **Improved safety:** Enhances collision avoidance capabilities for supersonic aircraft
- **Accurate and fast:** Broadcasts position 120 miles in all directions every 1 to 10 seconds

Applications

- Supersonic military and commercial aircraft
- Hypersonic aircraft and commercial space vehicles

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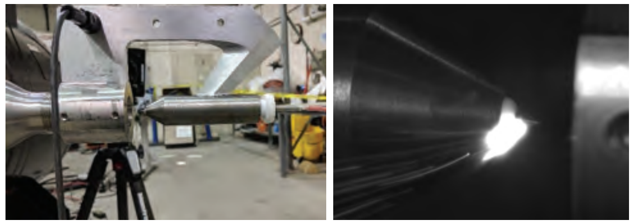

Supersonic Plasma Acoustic Reduction Concept (SPARC)

Plasma-based energy deposition via electric discharge has been shown in small-scale wind tunnel tests to weaken shock waves generated by basic aerodynamic shapes in the near field. Armstrong researchers are working to acquire data farther away from a model to determine whether these positive effects extend to the far field or if the shock waves regain their original strength as they propagate away from the electric discharge. Positive far-field data would indicate this plasma-based electric discharge is a viable method of sonic boom mitigation worthy of further study and full-scale implementation.

Work to date: With Center Innovation Fund resources, the SPARC team built and tested a prototype power supply and cone-cylinder-shape test article and demonstrated the ability to generate an electric discharge at the nose of the model. The researchers also assembled the system necessary for generating the supersonic flow over the model and showed with traditional schlieren techniques that they can generate a clearly defined shock wave at the model nose.

Efforts are now (1) determining the magnetic field requirements for rotating the electric discharge about the axis of symmetry of the model while the model is in supersonic flow and (2) setting up a test to change the angle of incidence of the supersonic flow over the model in order to force an approximately axisymmetric distribution of plasma about the model. Generating an axisymmetric distribution of plasma at the nose of the model is required in order to have a maximum observable impact on the shock wave.

Looking ahead: Next steps are to conduct testing in the 9x7-foot Supersonic Wind Tunnel, part of the Unitary Plan Wind Tunnel complex at NASA's Ames Research Center. Positive results would pave the way to more in-depth research into the practicality of this technology and a flight test to further investigate effects far away from the test article.

Partner: Spencer Kuo, New York University

Benefits

- **Advances research:** Increases database relating to the impact of plasma on shock waves generated by aerodynamic shapes in supersonic flow
- **Informative:** Contributes to the understanding of plasma and supersonic flow interactions

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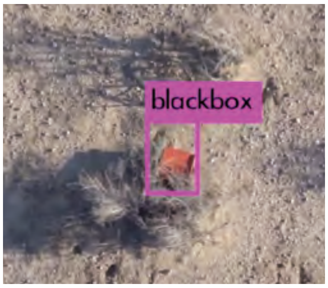
Autonomous Systems

Armstrong is contributing to NASA's Roadmap for Robotics, Tele-Robotics, and Autonomous Systems through research in a wide range of areas, such as artificial intelligence, advanced flight control laws, new testing methods, collision avoidance technologies, and much more.

Armstrong's pioneering research into lifesaving collision avoidance technologies has the potential to be applied beyond aviation and could be adapted for use in any vehicle that has to avoid a collision threat, including aerospace satellites, automobiles, marine vehicles, and more.

Artificial Intelligence for Object Recognition with Small UAS



Drone technology developed at Armstrong aided rescue and recovery efforts in Texas following Hurricane Harvey in 2017. Engineers are now evaluating this technology for use at aircraft crash scenes, which can be dangerous to rescue personnel due to hazardous cargo, flammable and toxic liquids, and adverse terrain. The technology uses artificial intelligence (AI) and an advanced camera system to detect and classify objects during flight and store those objects and their locations in a local Earth geo-browser. The goal is for an AI-enabled unmanned aerial system (UAS) to locate survivors, aircraft debris, and key flight recording instrumentation and then geo-tag all elements of a crash site to create a debris map.

Work to date: NASA conducted a staged mishap exercise in November 2018 at Mojave Air and Space Port to explore the use of an AI-enabled small UAS to locate the aircraft's flight black box instrumentation. Researchers achieved a drone live video feed to Armstrong at 2.5 megabits per second speed and 30 frames per second frequency with a 3-second lag via an LTE mobile Wi-Fi hotspot. In addition to successfully locating the black box, the technology achieved further development in two key areas: UAS vision-based object detection and classification using AI algorithms and live stream using 4G/LTE.

Looking ahead: The collaborative research team is working to demonstrate a similar system on larger UAS platforms.

Partner: Mojave Air & Space Port

Benefits

- **Enhances safety:** Enables drone-based disaster response and real-time detection of aircraft debris, survivors, and flight instrumentation
- **Real-time information:** Provides live stream video to research and rescue organizations

Applications

- Aviation mishap investigations
- Search-and-rescue operations
- Damage assessment
- Surveillance and security

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Improved Ground Collision Avoidance System (iGCAS)

Armstrong's iGCAS can be used for a wide variety of aircraft, including general aviation, helicopters, and unmanned aircraft. The technology has been incorporated into an application for tablets and other handheld/ mobile devices.

Armstrong's iGCAS leverages leading-edge fighter jet safety technology, adapting it to civil aviation use as an advanced warning system. It offers high-fidelity terrain mapping, enhanced vehicle performance modeling, multi-directional avoidance techniques, efficient data-handling methods, and user-friendly warning and cuing systems. The algorithms in Armstrong's technology have also been incorporated into an application for mobile devices that can be used by pilots in the cockpit, enabling significantly safer general aviation. This feature will give pilots access to this lifesaving safety tool regardless of the aircraft type. The system can also be incorporated into electronic flight bags (EFBs) and avionics systems.

The payoff from implementing the system, which was designed to operate on a variety of aircraft (e.g., military jets, unmanned aircraft, general aviation airplanes) with minimal modifications, could be billions of dollars and hundreds of lives and aircraft saved. Furthermore, the technology has the potential to be applied beyond aviation and could be adapted for use in any vehicle that has to avoid collision threats, including satellites, ships, automobiles, scientific research vehicles, and marine charting systems.

Work to date: This improved approach to ground collision avoidance has been demonstrated on small unmanned aircraft, a Cirrus SR22, and an experimental Cozy Mark IV aircraft while running the technology on a mobile device. These tests proved the feasibility of the mobile app–based implementation. The testing also characterized the flight dynamics of the avoidance maneuvers for each platform, evaluated collision-avoidance protection, and analyzed nuisance potential (i.e., the tendency to issue false warnings when the pilot does not consider ground impact to be imminent). In 2019, under the Resilient Autonomy effort, the team integrated the system with a commercially available MGL Avionics unit and began flight tests on Langley's Lancair aircraft. Flight tests will continue into 2020 and the system will be integrated with an air collision avoidance capability.

Looking ahead: Future versions of the technology may employ a phone's wireless capabilities to connect it to an airplane's autopilot system. It could one day exploit a phone's built-in location sensors to make a wireless or USB connection completely unnecessary. The Armstrong team is also working with avionics manufacturers to integrate iGCAS software into their systems.

Partner: NASA's Langley's Research Center

The Auto GCAS team accepted the Collier Trophy on June 13, 2019.

The Auto GCAS technology—which NASA has been expanding to support non-fighter aircraft as iGCAS—was awarded the 2018 Robert J. Collier Trophy by the National Aeronautic Association. The prestigious award is presented annually for the greatest achievement in aeronautics or astronautics in America. A committee of 30 aviation and aerospace professionals selected the team as the recipient for the development, integration, and test of the proven, life-saving technology. The 8-foot-high Collier Trophy arrived from the Smithsonian National Air and Space Museum to honor the team for the historic win.

Benefits

- **High-fidelity terrain mapping:** Armstrong's patented approach to digital terrain encoding enables the use of maps with fidelity that is 2 to 3 orders of magnitude better than existing systems.
- **Flexible platforms:** This tool can be used with a variety of aircraft, including general aviation, helicopters, unmanned aircraft, and fighter jets such as the General Dynamics F-16, with the ability to incorporate the specific maneuvering performance for each aircraft type into the platform.
- **Nuisance-free warnings:** The iGCAS technology ensures that alarms will be triggered only in the event of an impending collision, reducing the risk of false alarms that may cause pilots to ignore the safety system.
- **Multi-directional maneuvers:** Unlike existing systems that recommend only vertical climbs, this innovation can recommend various turns to avoid a collision, making it more appropriate for general aviation and unmanned aircraft.
- **Proven technology:** A follow-on to a system currently flown in F-16 test aircraft will be integrated into the aircraft's next generation for the U.S. Air Force's fleet.

Applications

- General aviation
- Military aircraft
- Drones/Unmanned aircraft
- Helicopters
- Digital autopilots

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Resilient Autonomy

Armstrong researchers are leading an effort to develop a framework for autonomous aircraft that the Federal Aviation Administration (FAA) could leverage to establish certification standards. The goal of the Resilient Autonomy effort is to create a robust methodology for evaluating unmanned and autonomous systems using an approach known as Multi-Monitor Run-Time Assurance (MM-RTA). The approach uses open access expandable variable-autonomy architecture (EVAA) software testbeds to ensure safe operations. The framework coordinates various functionalities with risk-based logic, safely binding untrusted behavior and relieving the requirement to certify all guidance logic possibilities. EVAA is structured to allow the addition and removal of monitors, sensors, and aircraft models with a minimum of validation and verification requirements.

Work to date: In 2019, the Office of the Undersecretary of Defense for Research and Engineering funded Resilient Autonomy to further EVAA development. The goal is to integrate EVAA onto multiple unmanned aircraft as well as general aviation aircraft. Safety features within EVAA are being expanded to include geo-fence, well clear, obstacle spacing, ground and obstacle avoidance, air traffic avoidance, in-flight route re-planning, and emergency forced landing.

Looking ahead: Researchers are finalizing plans for two technology demonstrations designed to test and validate the framework. In summer 2021, the team plans to autonomously fly a drone from Armstrong through the airspace over rural areas to Camp Roberts, a National Guard post in central California. The demonstration will exercise terrain, obstacle, and air collision avoidance capabilities. The FAA could leverage safety documentation developed from the demonstration as a certification pathway.

Additional demonstrations will be conducted between Edwards and China Lake showcasing EVAA's ability to react to emerging situations and either safely conduct a mission or abort a mission and autonomously initiate a return to base. In conjunction with the EVAA development and testing, the team will work with the FAA to develop a certification approach for autonomous aircraft.

Partners: FAA, Department of Defense, Terra Pixel, Amazon Prime Air, Skyward, Scientific Applications & Research Associates (SARA), U.S. Southern Command, U.S. Special Operations Command, and Air Force Research Laboratory

Benefits

- **Revolutionary:** Research will inform standards and best practices that will accelerate the certification of autonomous systems.
- **Reliable:** Approach uses supervisory control as a deterministic trustworthy way to ensure safety.

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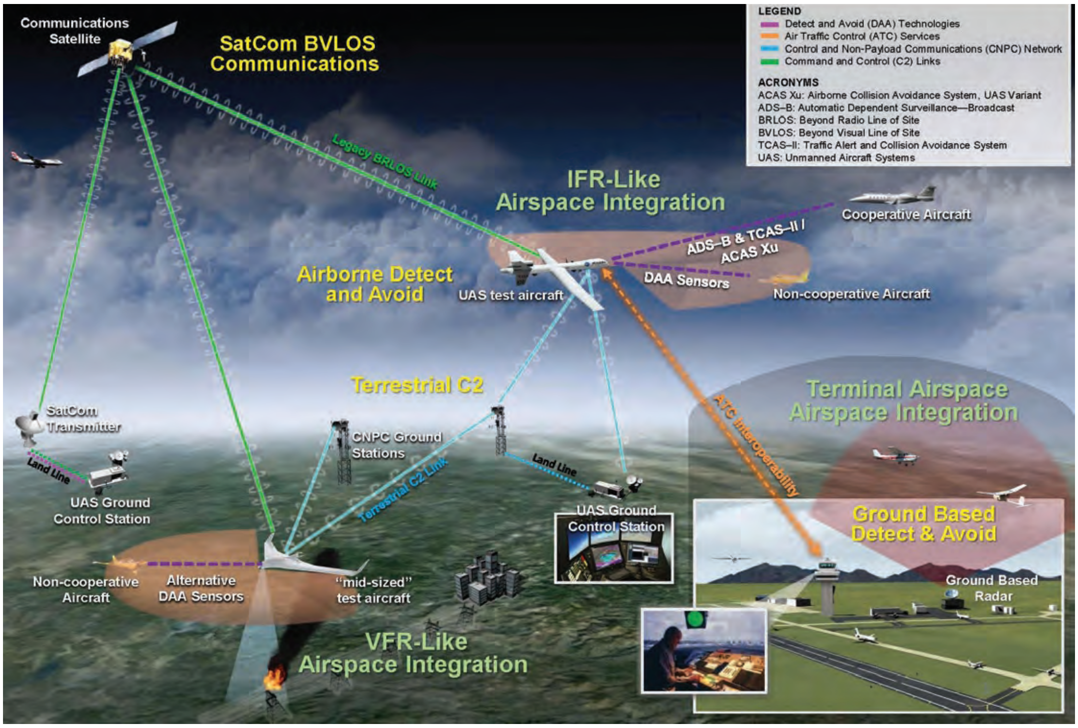
Unmanned Aircraft System (UAS) Integration in the National Airspace System (NAS) Project



The UAS in the NAS project is a multi-center research project that is developing operational concepts and technologies to aid in establishing and evaluating performance standards with industry to make it possible for unmanned aircraft to fly routine operations in U.S. airspace. Unmanned aircraft offer new ways of increasing efficiency, reducing costs, and enhancing safety. As new uses for these vehicles are considered, project partners are working to overcome safety-related and technical barriers to their use, such as a lack of detect-and-avoid (DAA) technologies and robust communications systems.

Providing critical data to such key stakeholders as the Federal Aviation Administration (FAA) and the RTCA Special Committee 228, the project is conducting system-level tests in a relevant environment to address safety and operational challenges. The project falls under the Integrated Aviation Systems Program in NASA's Aeronautics Research Mission Directorate.

The project's research continues to address two technical challenge areas:

- Develop DAA operational concepts and technologies in support of standards to enable a broad range of UAS that have communication, navigation, and surveillance (CNS) capabilities consistent with instrument flight rules (IFR) operations and are required to detect and avoid manned and unmanned air traffic
- Develop satellite and terrestrial-based command and control (C2) operational concepts and technologies in support of standards to enable the broad range of UAS that have CNS capabilities consistent with IFR operations and are required to leverage allocated protected spectrum

Another technical activity, System Integration and Operationalization (SIO), is working toward routine commercial UAS operations in the NAS by integrating DAA and C2 technologies; obtaining approval to operate in the NAS for a flight demonstration in 2020; working toward type certification; and sharing lessons learned with the UAS community.

Work to date:

Armstrong's contribution to the project includes overall project management and integrated test and evaluation functions.

The first phase research portfolio (2011–2016) was successfully completed and addressed larger UAS transitioning through the NAS encountering both cooperative (i.e., equipped with a means of electronic identification, such as a transponder or ADS-B) and non-cooperative traffic. These activities provided critical research and flight test validation that culminated in the release of RTCA Minimum Operational Performance Standards (MOPS), which were then translated into FAA Technical Standard Orders for UAS DAA, airborne radar, and C2 systems.

With the release of the Phase 1 UAS DAA standards, Armstrong successfully presented a safety case and in June 2018 conducted a No-Chase Certificate of Authorization flight demonstration in non-segregated airspace with its Ikhana UAS group. This demonstration showcased an alternate means of compliance with the federal see-and-avoid requirements, employing only onboard DAA capabilities. This activity was recognized with the Aviation Week Network's Laureate Award for Commercial Aviation in the Unmanned Systems category in 2019.

The second phase research portfolio (2017–2020) is addressing expanded operations in the NAS for a broader class of UAS. These activities are refining the UAS DAA MOPS and expanding to include extended operations in the NAS as well as approach/departure operations in the terminal area for both large and mid-size UAS. Armstrong's Phase 2 activities include the design and integration of low size, weight, and power (SWaP) DAA systems onto a mid-size TigerShark XP UAS to enable flight test development of a low SWaP airborne radar and provide validation data for Phase 2 MOPS. These flight test activities wrapped

The Navmar Applied Sciences Corporation TigerShark aircraft flew over Edwards Air Force Base in July 2019 during a series of flight tests to support development of DAA standards for medium-sized UAS.

up with the employment of the live, virtual, and constructive (LVC) distributed environment to immerse multiple U.S. Air Force UAS pilots in an operational scenario flying a mid-size UAS encountering cooperative and non-cooperative traffic.

Looking ahead: In 2020, the effort will incorporate results into a standards document that will inform FAA UAS integration policies and operational procedures, document the work that has been completed, and close out the project. Lessons learned are being applied towards SIO activities to support its milestones.

Collaborators: Federal Aviation Administration; RTCA; General Atomics Aeronautical Systems; Bell; PAE ISR; Navmar Applied Sciences Corporation; Honeywell Aerospace; Collins Aerospace; LinQuest Corporation; Virginia Tech Mid-Atlantic Aviation Partnership; Northeast UAS Airspace Integration Research (NUAIR); MIT Lincoln Laboratory; Air Force Research Lab; and NASA's Ames, Langley, and Glenn Research Centers

Benefits

- This DAA, C2, and vehicle-level research will provide information to the FAA as it develops policies and procedures to integrate UAS into the NAS.
- The research will advance MOPS for UAS and low SWaP airborne radar models.

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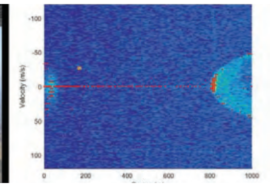

Miniaturized Radar for Small Unmanned Aerial Systems (UAS)

Armstrong innovators are developing a miniature collision avoidance radar sensor for small UAS. Currently, commercial use of small UAS in the National Airspace System (NAS) is constrained by regulatory issues based on multiple safety concerns, some of which this technology addresses. This radar sensor is small, lightweight, and compact so that it can fit easily onto a drone. It is designed to determine the range, speed, and location of multiple hazards in real time and alert the drone to avoid a collision. The sensor operates day or night and in all weather conditions, detecting both cooperative and non-cooperative hazards. It can also transmit data to a ground station where operators can make flight decisions.

Work to date: Researchers completed a miniature prototype along with custom calibration setup and processing and real-time monitoring software. The team also successfully completed four manned aircraft flight tests, during which the radar successfully detected and tracked a Cessna-172. NASA received a patent for the technology in May 2019.

Looking ahead: Next steps are to schedule unpiloted flight tests, refine the sensor design, and integrate it with an autopilot or flight director. To date, two new patent license agreements are in process for this technology, one for commercial and another for military operations.

Partner: Vigilant Aerospace Systems

Benefits

- **Safe:** Enhances detect-and-avoid capabilities for small UAS, increasing safety for other aircraft as well as people and property on the ground
- **Enabling:** Provides critical situational awareness for operation of UAS in the NAS
- **Reliable:** Operates day or night; in rain, fog, and clouds; and more reliably than sensors based on cameras or lasers
- **Lightweight and compact:** Weighs just 32 ounces and measures 4x3x4 inches

Applications

- Package delivery
- Search and rescue
- Surveillance
- Scientific research

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Technologies to Enable Urban Air Mobility

NASA is leading a national effort to develop technologies and analysis methods for small (four to six passengers) electrically powered aircraft—a key component to the emerging concept of Urban Air Mobility (UAM). UAM envisions a safe and efficient air transportation system where electric air taxis and air ambulances operate alongside small-package delivery drones above populated areas.

In traditional aircraft, the propulsion and flight control systems operate independently. Electric vertical takeoff and landing aircraft—known as eVTOL—instead use the same electric motors for both propulsion and flight control. A team of Armstrong researchers is studying how electric motors, batteries, and the merging of propulsion and flight controls could affect the way aircraft are designed, tested, and certified. The goal at Armstrong is to improve the safety and reliability of this new class of air vehicles by developing innovative tools and methods, and by contributing to the evolving standards, guidelines, and best practices for the industry.

Research at Armstrong began in 2019 and is focused on three areas: optimal control allocation, stability of integrated flight control and electric propulsion, and pilot-aircraft interaction models.

Optimal Control Allocation

Aircraft with many control effectors, such as the multiple rotors of an eVTOL air taxi, offer a great deal of flexibility in how the vehicle is controlled. The Armstrong team is developing a novel control allocation method to be tested in the simulation of a NASA-developed six-passenger eVTOL concept aircraft. The control allocation research seeks to simultaneously maintain the aircraft's flight path while accommodating failures, optimizing energy efficiency, and ensuring that powertrain components stay within their temperature limits—all while taking into account external conditions like weather and traffic.

Stability of Integrated Flight Control and Electric Propulsion

The combined voltage, power, weight, and thermal characteristics required for eVTOL aircraft are prompting the development of brand-new classes of electrical components. These components will be nonlinear, highly distributed, and dynamically coupled with the aircraft's flight control system, leading to the need for new system-level stability analysis techniques and robustness standards. The Armstrong team is developing modeling methods for distributed electrical propulsion components and investigating techniques to analyze the stability and robustness of integrated flight control and power systems.

Pilot-Aircraft Interaction Models

Some studies predict that UAM operations could lead to as much as a 50 percent increase in demand for commercially rated pilots, leading to a severe shortage of qualified individuals. Several companies developing eVTOL aircraft have proposed that automation could be used to reduce the training requirements for pilots, and in some cases eliminate the need for a pilot entirely. The Armstrong team is studying the interaction of mathematical models of human pilots and various eVTOL concepts to better understand aircraft handling qualities and UAM pilot training requirements. The team is also developing technologies to aid the pilot and/or autopilot in staying within the aircraft's envelope safety limits.

Benefits

- This research effort is pioneering new concepts in the field of distributed electric propulsion and will provide the community with new tools, methods, and guidelines to help ensure passenger safety and acceptance of a potentially revolutionary advance in human transportation.

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X-56A Multi-Utility Technology Testbed (MUTT)

Armstrong engineers continue to pioneer new research in aircraft design and modeling. Researchers are experimenting with revolutionary flexible wing technologies that can reduce weight, improve aircraft aerodynamic efficiency, and suppress flutter.

The X-56A aircraft is intended to facilitate the development of tools and technologies and acquire data to validate modeling techniques. The results could enable future airliners to use lighter weight, flexible wing designs to conserve fuel.

This work has applicability beyond flight safety and design optimization. Lessons learned with the X-57A aircraft can be applied to other vehicles, such as supersonic transports, large space structures, and unpiloted aircraft.

Multi-Utility Testbed Advances Aeroservoelastic Technologies

Longer and more flexible wings are considered crucial to the design of future long-range, fuel-efficient aircraft. Because these wings are more susceptible to flutter and the stress of atmospheric turbulence, NASA is investigating key advanced control technologies for active flutter suppression and gust load alleviation. The goal of the X-56A MUTT project is to advance aeroservoelastic technology through flight research using a low-cost, modular, remotely piloted experimental aircraft. The aircraft is being tested using flight profiles where flutter occurs in order to demonstrate that onboard instrumentation not only can accurately predict and sense the onset of wing flutter but also can be used by the control system to actively suppress aeroelastic instabilities.

Work to date: In 2018 and 2019, the aircraft's envelope with the flexible wings was expanded. This culminated with flights at speeds beyond flutter, demonstrating the use of active flight controls for the suppression of flutter. To date, a total of 39 flights have been conducted by NASA.

Looking ahead: The team will transition to flight testing a new set of wings developed by Northrop Grumman to continue its research on highly flexible wings.

Partner: Air Force Research Laboratory

Benefits

- **Enables new technology:** Facilitates construction of longer, lighter, more flexible wings for crewed and remotely piloted aircraft
- **Configurable:** Enables a vast array of future research activities for wing sets, tail sections, sensors, and control surfaces

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X-56A Controllers Safely Stabilize Flutter

The X-56A Multi-Utility Technology Testbed (MUTT) research team suppressed body freedom flutter with a modern and a classical controller during flight tests in 2018 and 2019. These two mathematical ways of directing the aircraft were instrumental in enabling the team to advance research on lightweight, flexible aircraft wings. The primary challenge for control of body freedom flutter is to both automatically track vehicle flight control commands and suppress flutter within the pilot's stick frequencies. The two objectives conflict and must be carefully addressed in the control law design. The goal of this research is to develop robust controllers that can safely extend the control envelope for commercial aircraft.

Work to date: The X-56A team completed flight tests demonstrating that the controllers successfully suppressed flutter. The primary purpose of the classical controller was to collect data to enable use of the more complex and advanced control system. The modern controller permitted the aircraft to operate safely at higher speeds, suppressing flutter deeper into the regions where the aircraft is less stable. To prove the effectiveness of the flutter suppression, researchers implemented a sequence of flight maneuvers where the controller was turned off—for less than 2 seconds as the aircraft approached flutter—allowing the flutter mode to grow uncontrolled. When the system reactivated after a set time, the controller stabilized the flutter mode and lessened the oscillations.

Looking ahead: The team is analyzing data and will be presenting and publishing results. Future work will involve replacing the highly flexible wings with stiffer wings for more research.

Benefits

- **Enables more design freedom:** Contributes to the development of robust controllers that will enable designers to consider lighter and/or larger wing profiles
- **Increases safety:** Reduces the likelihood of losing control of aircraft

Applications

- Civilian and military aircraft subject to body freedom flutter in their flight envelope
- Multi-objective control designs in any industry with conflicting tracking and regulation objectives

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X-56A in ground vibration test configuration

Structural Dynamics Ground Testing Enables Model Validation

Structural dynamics ground tests were a key part of preparing the X-56A Multi-Utility Technology Testbed (MUTT) for flight tests. The aircraft is designed for high-risk aeroelastic flight demonstration and research. Therefore, model validation for the X-56A was especially important because the structural model was used to develop a flight control system with active flutter suppression capabilities. The team conducted a series of tests to validate structural models and overcame several challenges to produce valuable information that the team is already applying to structural dynamics testing with a similar vehicle.

Work to date: The team performed three separate sets of tests in Armstrong's Flight Loads Laboratory to validate the X-56A structural models. First, ground vibration testing (GVT) was conducted with both the wing by itself (attached to a strongback) and the complete vehicle at two mass conditions (empty and full fuel). Then the team studied two boundary conditions for the complete vehicle (on landing gear and suspended free-free). The original soft-support test configuration for the GVT used multiple bungees that resulted in unforeseen coupling interactions between the bungees and the vehicle structural modes. The team resolved this issue by adapting the test setup via multiple iterations.

Second, pitch moment of inertia (MOI) tests were conducted using a compound pendulum method and repeated with two different pendulum lengths for independent verification. Third, wing proof loads tests were performed by attaching the wing to a strongback and applying loads. These tests helped verify the wings of X-56A were sufficiently characterized for model validation and strong enough to withstand various flight loads during flight tests.

Looking ahead: The team is applying lessons learned with the X-56A aircraft to a new set of GVTs for the X-56B, which has similar wings.

Benefits

- **Saves resources:** Enables testing of emerging approaches and test techniques in a safe environment
- **Cutting edge:** Advances knowledge in the field of structural dynamics testing

Applications

- Structural dynamics testing

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System Identification for Flexible Aircraft

This research effort focused on designing multi-sine programmed test inputs for use in flexible aircraft system identification situations. In this context, system identification is the process of exciting aircraft and control system dynamics, collecting flight data measurements, and constructing models from the data. For the X-56A Multi-Utility Technology Testbed (MUTT) aircraft, system identification was needed to refine and validate preflight aerodynamic and aeroelastic predictions and to verify robust stability of flight control laws. System identification as applied to the X-56A aircraft entailed modeling the response to as many as 10 separate control surfaces and two engines.

The Armstrong team applied optimization techniques to select excitation frequencies, amplitudes, and phases in order to efficiently generate data with a high signal-to-noise ratio across a wide frequency band while maintaining a margin with respect to operating limitations. While this approach was tailored toward flexible aircraft, it is applicable to any complex system identification problem where manually tailoring the excitation is impractical. In addition to validating preflight predictions and control system design, the approach is useful for computational fluid dynamics simulation to reduce expensive computation time.

Work to date: The X-56A flexible wing flight test campaign was completed and included 27 flights in 2018 and 2 in 2019. Low-order equivalent systems and state-space models were estimated from the flight data, in some cases at flight conditions beyond the flutter boundary.

Looking ahead: The multi-sine programmed test inputs will be applied to the new X-56B configuration data in 2020, reducing required flight test time and reducing costs for future industry partners.

Partner: NASA's Langley Research Center

Benefits

- **Powerful:** Generates high-quality flight data quickly and safely
- **Efficient:** Promotes real-time and onboard data reduction for control room monitoring

Applications

- Fundamental research
- Control system requirements verification

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Integrated Flight Dynamics and Aeroservoelastic Modeling and Control

This research effort is developing flight control systems and mathematical models that integrate both structural and flight dynamics. As modern aircraft become more flexible and these disciplines converge, conflicts arise between independently developed modeling methodologies. Because the structural and flight dynamics of the X-56A Multi-Utility Technology Testbed (MUTT) aircraft are acutely coupled, resulting models are capable of capturing the requirements of both disciplines.

Work to date: The Armstrong team's linear models have been validated in flight tests with the X-56A flexible wings at speeds beyond the open flutter. The models are able to accurately predict the point of instability and were applied to the design and evaluation of the flight control laws used to stabilize the structure. The unsteady aerodynamic and structural data has been integrated with a non-linear piloted simulation. The piloted simulation allows for evaluation of the dynamics and development of pilot techniques in highly non-linear conditions, such as takeoff and landing, enabling the safe operation of the X-56A.

Partner: Air Force Research Laboratory

Benefits

- **More design freedom:** Enables the design of lighter, larger, and more flexible wing profiles
- **Economical:** Increases fuel efficiency
- **Safer flight:** Reduces likelihood of structural damage
- **Innovative:** Advances the state of the art for higher aspect ratio wing and enables future N+3 commercial aircraft concepts (i.e., three generations beyond the current commercial transport fleet)

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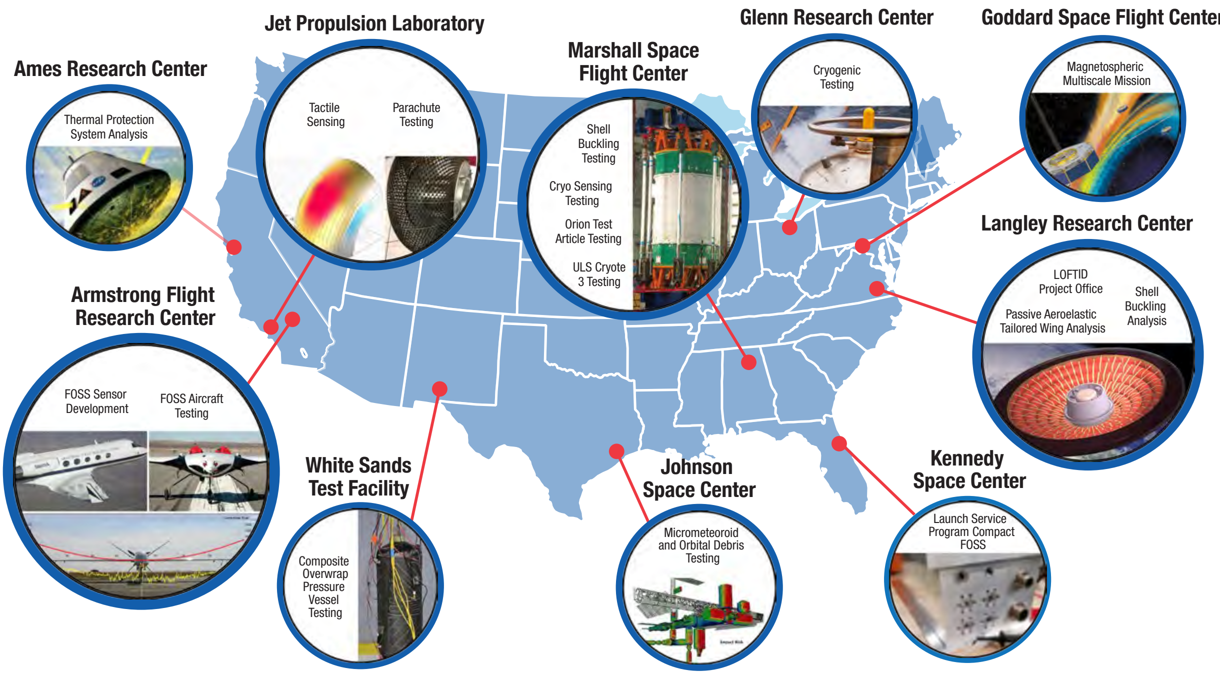
Fiber Optic Sensing System (FOSS)

FOSS Addresses Technical Challenges Across the Agency



What began as a research tool to collect aerodynamic data from research aircraft is now solving technical challenges within the agency and beyond. NASA's patented, award-winning Fiber Optic Sensing System (FOSS) technology combines advanced strain sensors and innovative algorithms into a robust package that accurately and cost-effectively monitors a host of critical parameters in real time. It is being widely used throughout NASA to support research projects as varied as investigating next-generation flexible wings, measuring liquid fuel levels, and monitoring strain on spacecraft.

FOSS uses up to a 40-foot, hair-like optical fiber that provides up to 2,000 data points each. The state-of-the-art system processes information every quarter-inch along the fiber at rates up to 100 times per second to measure strain, shape deformation, temperature, liquid level, and operational loads.

Through the years, the FOSS team has optimized the technology to refine the infrastructure and speed with which the system collects and transmits data, and the technology's easy-to-integrate elements now complement and add color to existing instrumentation.

For example, NASA's unmanned Ikhana aircraft was the first to fly with a FOSS wing shape sensor. In that test, researchers placed FOSS sensors in the same locations as conventional strain gauges but also ran fibers the length of the wing. While the FOSS sensors matched well with the results from the conventional sensors, they also revealed unexpected high stress points at locations between the conventional sensors—data that would have been completed missed if not for FOSS.

FOSS enables researchers to verify finite element models to a high degree of spatial resolution. It also allows researchers to identify unexpected phenomena in cases where a model is not completely accurate or does not contain enough degrees of specificity. FOSS enables both validation and discovery, making the entire research process more effective and efficient.

Industry has taken notice. Commercial rocket providers are using FOSS in their laboratories, and companies in a variety of industries are exploring how FOSS can improve their operations. The FOSS team continues to refine algorithms to support additional applications, with the goal of adding FOSS to the suite of instrumentation on NASA aircraft, as well as other assets across the agency.

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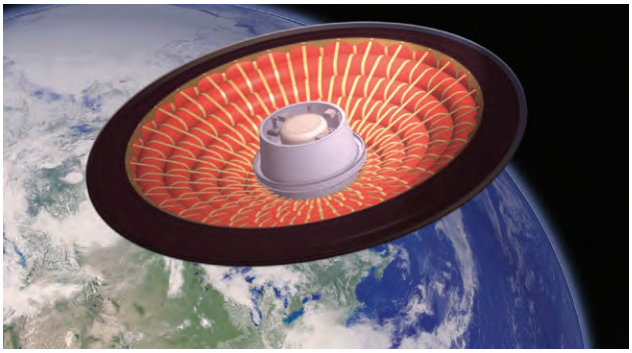

NASA's 'Rocket Box' FOSS to Fly on Launch Vehicles

Armstrong and NASA's Kennedy Space Center researchers have collaborated for years to ruggedize the Fiber Optic Sensing System (FOSS) so it can be used to measure aggressive launch loads on spacecraft. Further collaborations with industry partners have resulted in durable instrumentation, and Armstrong researchers are now readying a new combination of mechanical enclosure and instrumentation for launch within the next year on several rocket launches. The goal is for this "rocket box" to fly on NASA's Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID) and United Launch Alliance's Vulcan rocket, as well as with other commercial launch providers.

Work to date: The FOSS team has assembled five rocket boxes and completed early-stage environmental testing to simulate rocket launch conditions.

Looking ahead: Next steps are to complete electrical testing in preparation for shipment to NASA's Langley Research Center for final environmental testing. The goal is to validate that FOSS can provide critical parameter measures (e.g., strain, load, temperature, shape) in aggressive launch environments.

Partners: NASA's Kennedy Space Center and Langley Research Center and United Launch Alliance

Benefits

- **Advanced:** Provides validated structural design data that could enable future launch systems to be lighter and more structurally efficient
- **Ruggedized:** Allows FOSS to be used effectively in many more practical applications that require a more robust system

Applications

- Rockets
- Reentry vehicles
- Jet engines
- Inflatable wings and airships
- Test aircraft

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Credit: U.S. Navy

MicroFOSS Technology Leverages Low-Cost Components for High-Performance Tasks

Armstrong researchers are reducing the Fiber Optic Sensing System (FOSS) technology's size, power requirement, weight, and cost to effectively extend opportunities for broader fields of application. Applying lessons learned during development of the "rocket box" technology, they have designed a compact package useful for monitoring a host of critical parameters in real time. Dubbed MicroFOSS, this version of the technology is smaller, less expensive, and more robust. It leverages electronics that are commonly available for the smartphone and tablet industry, departing from the expensive military-grade processors and components of previous versions.

Work to date: The team developed multiple laboratory systems and successfully tested them in the field. The technology reduces the channel interrogation system from eight channels to between two and four channels. This design simplification minimizes the risk of potential issues during flight, enabling the robustness required for challenging applications.

Looking ahead: Armstrong is collaborating with the U.S. Navy to provide this technology for integration into naval vessels and expects to deliver the MicroFOSS box in 2020. The team is also evaluating the use of this technology on Armstrong flight vehicles as well as on launch vehicles and satellites.

Benefits

- **Compact:** Miniaturized size requires less associated hardware than existing systems
- **Low cost:** Leverages electronics designed for the smartphone and tablet industry
- **Reliable:** Components are designed for aggressive environments without compromising the form factor

Applications

- Aeronautics and launch vehicles
- Satellites
- Oil drilling, wind energy, and industrial processes

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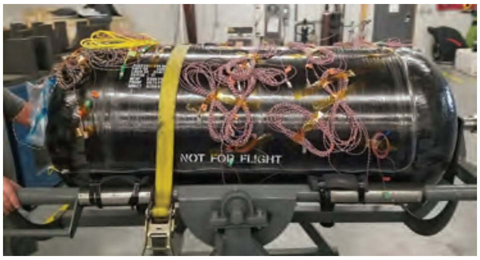
Temperature Sensing in Cryogenic Humid Environments

Armstrong researchers have developed a new manufacturing process that improves the ability of fiber optic sensing systems to measure temperature and liquid levels in humid environments. The process involves eliminating moisture from the optical fiber coating, then completing the sensor assembly within humidity-controlled conditions. The resulting sensor hardware provides precise and accurate measurements even when operating in a humid environment. Originally designed to monitor a rocket's cryogenic fuel levels in conjunction with NASA's patented FOSS, this technology can be used in many industrial, food, and medical applications.



Work to date: With funding from NASA's Center Innovation Fund, Armstrong researchers developed a two-step process to assemble the sensors. First, the bare sensor fiber is inserted into a polymer tube that isolates the fiber yet is still thin enough to provide adequate thermal transfer. Then the tube is purged with gas to expel all moisture from the fiber coating. The innovation was successfully tested at NASA's Marshall Space Flight Center.

Looking ahead: The innovation is being patented and has the potential to be licensed outside NASA.

Partner: NASA's Marshall Space Flight Center

Benefits

- **Robust:** Provides a moisture-free and mechanically isolated condition for the sensing fibers in cryogenic environments
- **Accurate:** Offers excellent thermal conductivity to surrounding area, allowing the sensing fibers to determine temperature correctly
- **Reliable:** Enables fiber optic sensing systems to operate properly in humid conditions

Applications

- **Energy:** Liquid natural gas and petrochemical storage tanks
- **Industrial:** Storing cryogenic liquids
- **Aerospace:** Liquid fuel tanks for launch vehicles

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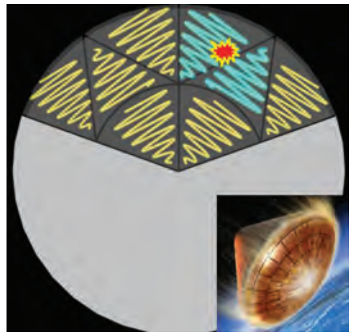
An Automated Switching Network to Enhance Structural Health Monitoring



Orbital debris is the number one threat to spacecraft and satellites, as collisions with this debris can cause damage or even catastrophic failures. Armstrong researchers are using NASA's patented Fiber Optic Sensing System (FOSS) to develop an optical fiber network to monitor the structural health of a spacecraft's thermal protection system (TPS). FOSS allows engineers to obtain up to 16,000 strain or temperature measurements at quarter-inch increments along eight independent 40-foot sensing fibers.

The new automated network integrates optical switches with FOSS to expand the sensing area by a factor of 24 or greater with limited additional weight and cost for flight applications. The total potential sensor count increases from 16,000 per system to 192,000 sensors to significantly improve performance and reliability of TPS structural health monitoring.

Work to date: Funding from NASA's Center Innovation Fund enabled Armstrong researchers to develop a working prototype by integrating the system onto a lab-scale TPS and conducting thermal tests. With this approach, FOSS is time-synchronized with up to 24 optical switches that cycle through sensing fibers periodically until an event is triggered, at which point a switch automatically activates to retrieve dense information about a specific region. The use of peripheral sensors provides feedback to the optical switches to intelligently interrogate sensing fibers of interest temporarily, then resume periodic switching.

Looking ahead: With funding, researchers will extend testing to a variety of test articles. In addition, the FOSS team is evaluating use of this automated switching technology with the FOSS portfolio.

Benefits

- **Detailed:** Automatically detects damage at a granular level
- **Expands monitoring area:** Enables FOSS to cover a much larger surface area
- **Connective:** Establishes communication between FOSS and optical switches

Applications

- Spacecraft TPS
- Many structural health monitoring applications

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Fiber Optic Technology Enhances Tank Gauging Applications

Armstrong's Fiber Optic Sensing System (FOSS) technology enables a highly accurate method for measuring liquid levels in challenging situations, such as cryogenic fluids or liquids with stratification that makes gauging challenging. Unlike gauges that rely on discrete measurements to give broad approximations of liquid levels, Armstrong's CryoFOSS technology provides measurements at quarter-inch intervals within a tank. The system actively discerns between the liquid and gas states along a continuous fiber to pinpoint the liquid level. Originally designed to monitor a rocket's cryogenic fuel levels, the technology offers numerous benefits for a variety of other industries including oil and gas industry, where users need to determine boundary layers between different fluids and substances, such as oil, water, detergent, sand, and gravel.

Work to date: This fully developed technology has been demonstrated in multiple environments using conventional validation techniques. During testing at NASA's Marshall Space Flight Center, the team developed a method to bundle a resistive heater wire with the optical fiber. The heater is pulsed to induce a local temperature change along the fiber, and a fiber Bragg grating monitors the subsequent cooling. Across NASA, FOSS could be used as a tank gauging system for liquid nitrogen environments. Companies are exploring implementation for a use as a gauging system to determine stratification of different substances within a tank.

Benefits

- **Increases efficiency:** Enables accurate measurement of fluid levels, reducing error margins and excess fuel needs
- **Simple design:** Requires just one fiber optic strand and one metallic wire
- **Robust:** Can be used in corrosive or toxic liquids and extreme environments

Applications

- Aerospace liquid nitrogen tanks
- Chemical and refinery plants
- Industrial tanks

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X-56A Research Leverages Fiber Optic Technology

The real-time processing capability of NASA's Fiber Optic Sensing System (FOSS) makes it an excellent choice to benefit research involving the unmanned X-56A Multi-Utility Technology Testbed (MUTT). The X-56A is a modular, remotely piloted experimental aircraft tasked with investigating flexible wings to improve safety, efficiency, and ride quality. It is being tested using flight profiles where flutter occurs in order to demonstrate that onboard instrumentation can predict, sense, and suppress aeroelastic instabilities. By quickly collecting strain data, FOSS is enabling researchers to see dynamic changes on the wings that could result in flutter.

Work to date: The FOSS team built a small interrogator specifically for the X-56A and installed optical fibers on the wings. During multiple flight tests, FOSS collected strain and 2D shape data that correlated with models.

Looking ahead: The team is examining the flight data to determine how to process shape information and feed it back in real time into a flight control computer to dampen or suppress the flutter while in flight. The next set of X-56A flight tests will involve replacing the highly flexible wings with stiffer ones, and FOSS will be part of these flights.

Benefits

- **High spatial resolution:** Enables measurements approximately every 0.25 inches
- **Small and light:** Offers 100 times the number of measurements at 1/100 the total sensor weight

Applications

- Aeronautics

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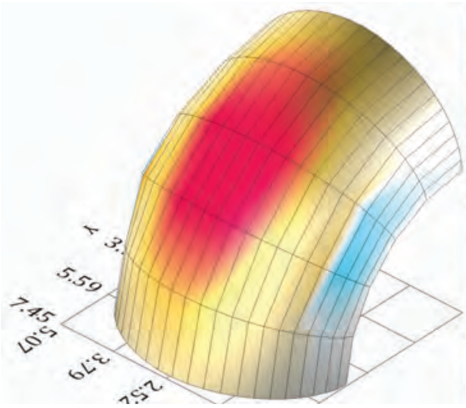
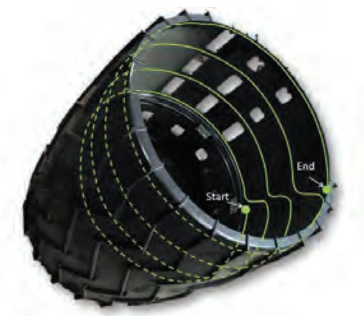
Tactile Sensing with Fiber Optics to Enhance Rovers





Armstrong researchers are collaborating with engineers at NASA's Jet Propulsion Laboratory (JPL) to develop and test a sensing system that can provide information about the health of robotic wheels. This research began after JPL scientists observed structural damage in the wheels of the Mars Curiosity Rover due to punctures and metal fatigue. In preparation for future robotic wheels, this project is embedding various test wheels with fiber optic sensors to provide information about the shape of the wheel as it rolls over objects. Armstrong researchers are using NASA's patented FOSS to monitor and provide detailed information about these structural deformations.

Work to date: The Armstrong FOSS team instrumented one-third of a mesh wheel with multi-core fiber optic sensors. The sensor line was routed through the wheel at 15° arc intervals. The distributed strain output of each arc was processed individually by a curvature-to-shape algorithm, and the resulting shapes were tied together to form a 3D virtual mesh. An intensity color map was applied to the 3D virtual mesh to distinguish inward and outward deformations as well as magnitude. Researchers determined that the deformation sensing had a good balance between providing insight into the wheel's external environment and providing information about its internal state.

Looking ahead: Plans are underway to fully instrument four wheels and integrate them into a rover for testing and demonstration. Potential follow-on research could involve development of a "synthetic skin" embedded with distributed sensors that could be molded to various wheel types.

Partners: NASA's Jet Propulsion Laboratory and Glenn Research Center

Benefits

- **Preventive:** Offers the potential to improve robotic rover locomotion and prevent premature structural failure
- **Greater capabilities:** Provides tactile sensing to mechanical systems
- **Responsive:** Enables mechanical systems to adapt to unexpected disturbances in an operational environment

Applications

- Rovers
- Aerospace structures
- Deformation studies for terrestrial structures

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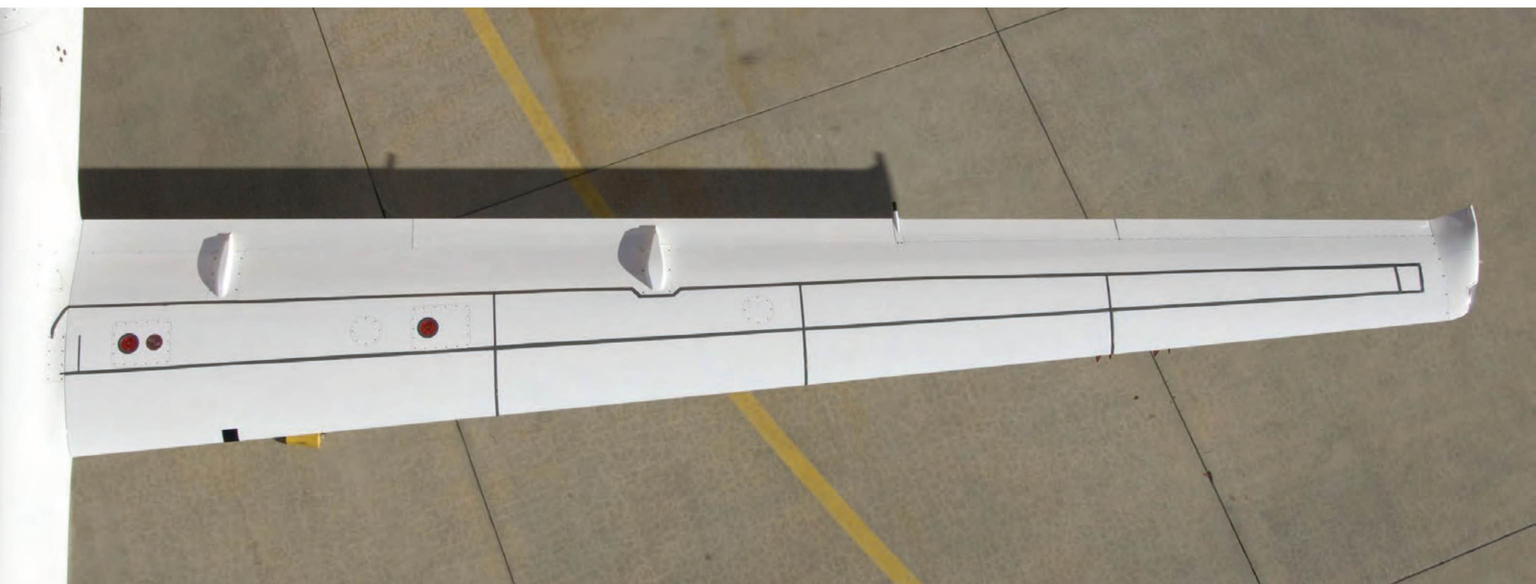
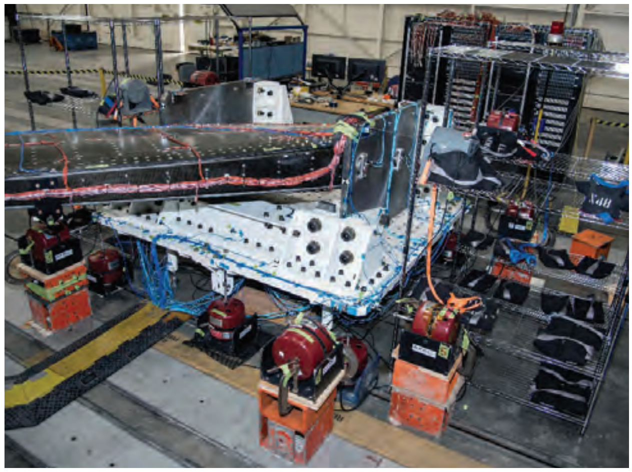


Flight Loads Laboratory

The Flight Loads Laboratory (FLL) is a unique national lab where structural tests are conducted to support flight research and structures projects. The technical staff provides expertise in test design, test operations, load and stress analysis, thermal analysis, instrumentation, and systems development.

With a sophisticated data acquisition and control system, the FLL is playing an important role in the next generation of flight and structural research for advanced aerospace and hypersonic programs.

Testing on the wing of the X-57 all-electric experimental aircraft marked the first time the FLL has used a center-line reaction structure to perform a loads calibration test of an off-aircraft wing, where the entire wing was attached while loading the left and right sides of the wing. The reaction test fixture was conceptualized, designed, and fabricated in about a year. As is the case with many one-of-a-kind items tested in the FLL, systems were set up, evaluated, and monitored to ensure safety of the test and personnel.



Fixed Base Correction Method for Ground Vibration Testing

Armstrong and industry partner ATA Engineering are evaluating a modal testing technique to measure fixed base modes from a test article mounted to a dynamically active static test fixture. When mounted onto the wing loads text fixture, the boundary conditions of the Passive Aeroelastic Tailored (PAT) wing are not ideal for ground vibration testing (GVT) because the fixture is not rigid.

The Fixed Base Correction (FBC) method enables GVT for articles with non-ideal modal testing boundary conditions (e.g., load testing) that can complicate testing and increase costs and schedules. Because connection stiffness of boundary conditions greatly changes modal response, the FBC method employs multiple electromagnetic shakers simultaneously rather than the usual one or two shakers used in conventional GVT. The fixture excitation accelerations are used as references when calculating frequency response functions instead of traditional shaker forces. The FBC technique analytically removes and decouples the fixture response from the wing response to aid in comparing modal ground test results to finite element model results.

Work to date: Researchers demonstrated in summer 2018 the feasibility of using the FBC method to successfully acquire decoupled wing modes.

Looking ahead: The team is continuing to evaluate use of the FBC method for other aircraft applications.

Partner: ATA Engineering, Inc.

Benefits

- **Enables valid testing:** Allows for decoupled test article data from a test fixture
- **Confirming:** Enables comparison of test results to an analytical model

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Soft-Support System for Ground Vibration Testing

Armstrong researchers designed a bungee-based soft-support system and utilized it to simulate free-free boundary conditions similar to flight during ground vibration tests (GVTs) of the X-57 Maxwell electric propulsion experimental aircraft. As part of the required airworthiness process for developing the X-57, the GVTs will allow researchers to validate the structural finite element model for flutter and make any necessary updates. This soft-support system is planned for use on multiple GVTs during the X-57 aircraft's development.

Work to date: Researchers completed detailed characterization testing of the bungee rings and measured their isolation frequency (»1 Hz) and usable weight range (350 to 550 lbs per bungee ring). Testing demonstrated that the bungee rings have minimal creep elongation when under load for many hours. Test data were used to design the soft-support system, which was successfully used to conduct the X-57 Mod II aircraft GVT.

The bungee-based system used commercial-off-the-shelf bungee rings interfaced to standard aircraft ground support equipment to suspend the aircraft. The X-57 main landing gear axles served as the primary bungee lifting points, and a lifting strap placed around the nose gear bulkhead served as the forward bungee lift point. The system suspends the aircraft and allows it to bounce on the bungee rings, providing rigid body aircraft motion at very low frequencies. Using prescribed shaker excitation over wide frequency ranges, researchers measured the aircraft structural elastic modes. The soft-support system separates rigid body frequencies from the aircraft structural elastic modes of interest, enabling more accurate measurement of aircraft modal response and comparison of the GVT data to a free-free finite element modal analysis.

Looking ahead: The soft-support system will be used with slightly different bungees to conduct the X-57 Mod III aircraft GVT.

Partner: ATA Engineering, Inc.

The soft-support system suspended the aircraft by using bungee rings to hold the main landing gear axles.

The forward bungee lift point was a lifting strap placed around the front of the aircraft.

Benefits

- **Adaptable:** Allows for use of bungees for soft support of general aviation and similar aircraft, which often do not have overhead jacking points
- **Effective:** Provides clean aircraft modal test data for validating finite element models to support airworthiness certification and readies aircraft for future testing and development

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X-57 Mod III Wing Ground Vibration Test

Armstrong researchers completed ground vibration testing (GVT) on the wing that will be integrated into the final configuration of the X-57 Maxwell experimental aircraft. The goal of the Mod III GVT was to gather wing modal data in order to correlate fundamental wing modes with the finite element model (FEM) without any complicated wing structures, such as motor mounts, nacelles, or propellers. This data will help researchers understand the wing's aeroelastic behavior. Early characterization of the basic Mod III wing structure will reduce programmatic risk that otherwise would have been added to future GVT, further complicating those tests and FEM update efforts.

Work to date: In summer 2019, researchers successfully measured the desired Mod III wing frequencies, mode shapes, and damping. Specifically, two GVT configurations were completed:

- Clean wing with wingtip cruise nacelle mass simulators
- Clean wing only

Tests were performed with flaps stowed and fully deployed with ailerons locked and unlocked. A total of 192 test runs were completed that measured approximately 300 accelerometer responses.

Looking ahead: Next steps are completing post-test data analysis, correlating the wing FEM to test data, and running a preliminary flutter analysis. There will be a Mod III full aircraft GVT prior to Mod III flights in 2021.

Benefits

- **Reduces program risk:** Component wing GVT enables analytical models to be correlated to test data earlier in the project life cycle.

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Flight and Ground Experimental Test Technologies

Armstrong conducts innovative flight research that continues to expand its world-class capabilities, with special expertise in research and testbed platforms, science platforms, and support aircraft. Researchers place particular emphasis on providing accurate flight data for research aimed at designing next-generation flight vehicles.

Described here are research projects that are seeking to increase safety, reduce costs, and dramatically decrease testing and approval times.

Armstrong Lends Flight Expertise to Pilot Safety Effort

Armstrong researchers are contributing to a NASA effort to increase pilot safety. The Pilot Breathing Assessment (PBA) program is working to better understand how flight conditions may cause pilots to experience potential life-threatening physiological episodes (PEs) resulting in cognitive impairments, numbness, tingling, lightheadedness, behavioral changes, and fatigue. The NASA Engineering and Safety Center (NESC) tapped Armstrong to conduct the PBA flights to leverage the center's F/A-18A/B and F-15D aircraft, which are equipped with oxygen systems used on modern military aircraft. Past research has focused on studying aircraft to reduce PEs. NESC is now working to understand pilot response to various flight conditions. NASA will use the data gathered through PBA flights in the development of new oxygen masks and aircraft equipment systems.

Work to date: At Armstrong, the effort involved five pilots, four aircraft, two aircrew equipment configurations, and approximately 90 hours of flight. Pilots flew scripted profiles representing a variety of conditions experienced throughout the aircraft operating envelope, including high-altitude flights at 40,000 to 50,000 feet; aerobatic flights; a combination of loops, rolls and dives, also known as a squirrel cage flight; and low-altitude flights through canyons.

Looking ahead: NESC will study the data set from each flight to compare data among pilots, flights, configurations, and aircraft performance, looking for patterns or unexpected results that may help researchers understand the causes of PEs. Planning is underway for an additional 50 flight hours of study and assessment.

Benefits

- **Improves pilot safety:** Extends understanding of physiologic responses to various flight conditions

Applications

- Military and research aircraft
- Spacecraft

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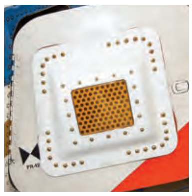
Lightweight Antenna Boosts Aircraft and Antenna Performance

A cross-center collaboration has yielded a novel lightweight antenna designed to boost aircraft and antenna performance. Fabricated with aerogels—which consist of 90 percent air—the conformal antenna is intended for beyond line-of-sight communications on small- to medium-scale unmanned aerial systems (UAS). A phased array chipset reduces radio interference to ground stations to address concerns related to UAS being integrated into the National Airspace System.



This multi-center effort was conducted under the Conformal Lightweight Antenna Structures for Aeronautical Communications Technologies (CLAS-ACT) activity within the Convergent Aeronautics Solutions project.

Work to date: At Armstrong, integration tests involved a newly developed robotic antenna scanner for extended preflight evaluation and verification. These tests measured the antenna's pattern characteristics to determine the feasibility of interference-mitigation techniques. The team then performed five flight tests with the antenna installed on the luggage door of a T-34C aircraft. The tests included four antenna configurations within a variety of flight altitudes and demonstrated the ability of the phased array to lower side lobes (i.e., unintentional radiation from the antenna) as the antenna delivered its signal to its intended target.

Collaborators: The antenna was designed and tested in the anechoic chamber at NASA's Glenn Research Center. The on-aircraft modeling of the antenna's performance happened at NASA's Langley Research Center. The preflight planning was accomplished at NASA's Ames Research Center.

Benefits

- **Fabricated with aerogels:** The antenna is thin and flexible and offers improved gain, bandwidth, and efficiency.
- **Aerodynamic:** The antenna's design minimizes drag for better fuel efficiency, whereas conventional satellite dishes are heavy, bulky, and require a gimbal to maneuver and point toward communication satellites.

Applications

- Small and medium UAS

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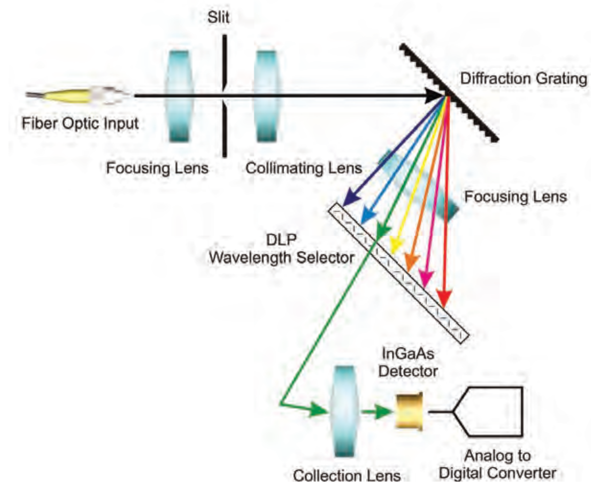
Pyrometer Improves In-Flight Temperature Measurements

Armstrong researchers have demonstrated a compact and robust prototype pyrometer capable of measuring aircraft surface temperatures and emissivity. Pyrometers measure high temperatures by observing emitted radiation. However, aircraft vibrations can render unreliable pyrometer measurements during flight. This device employs a spectrometer with a digital light processor (DLP) to measure the intensity of multiple wavelengths in the near-infrared (0.9-1.7 micron) range.



Work to date: The invention uses existing components in a new way. Developed for use in televisions, the DLP technology is used here within a robust scanning array that is nearly impervious to vibration and requires a single detector, as opposed to more complex, multi-element array detectors. The result is a mechanically stable device that is the first use of a spectrometer of this type for temperature measurements.

Looking ahead: Further work will refine the device and seek to develop a ruggedized version that can be used for actual aircraft flight measurements.

Benefits

- **Compact:** Employs a single detector rather than the array of detectors often present in conventional pyrometers
- **Robust:** Can be mounted onto various aircraft to provide in-flight temperature measurements
- **Highly accurate:** Allows for increased control over wavelength measurement in the near-infrared range via a digital interface

Applications

- Avionics
- Space exploration
- Glass, metal processing, and ceramics industries

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Airvolt Single Propulsor Test Stand

A modular test stand developed at Armstrong is helping researchers conduct extensive measurements for efficiency and performance of electric propulsion systems up to 100 kilowatts (kW) in scale. The Airvolt test stand enables evaluations of subsystem interactions as well as efficiencies of different batteries, motors, controllers, and propellers. The test stand offers opportunities to determine effective test techniques for electric propulsion innovations. Its large suite of sensors gathers extensive data on torque, thrust, motor speed, vibration/acceleration, voltages and currents, temperatures, and more. The Airvolt test stand is allowing the aviation industry to test a wide range of electric propulsion systems to understand efficiencies and identify needed design improvements.

Work to date: The Airvolt test stand supported testing of the X-57 Maxwell experimental aircraft cruise motor and cruise motor controller. The X-57 aircraft will be used to demonstrate aerodynamic efficiency of an optimized distributed electric propulsion wing. The 30-kW propulsor system is under development and requires testing to demonstrate operational capability for endurance, command, and control. More than 80 hours of run time have been conducted. Airvolt testing enabled improvements to wiring, temperature sensor placement, command protocol, and motor tuning parameters. Other issues such as electro-magnetic interference of ground test sensors were also identified. The test operations also provided training for working around high-voltage systems.

Looking ahead: The team will support other electric propulsion testing research, as needed.

Benefits

- **Highly efficient:** Offers high-speed sampling rates, up to 2.5 million samples per second per channel
- **Modular:** Allows researchers to test a variety of motors, controllers, and batteries as well as a wide range of parameters
- **Flexible:** Accommodates different motors, up to 100 kW, through the use of motor adapter plates

Applications

- Characterize new electric propulsion technologies
- Refine simulation models
- Develop best practices for testing procedures

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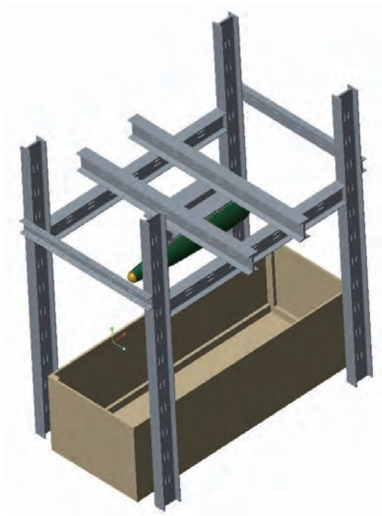
Store Separation Structural Analysis and Test Development

Future research at Armstrong will require analysis and test capabilities that enable safe and acceptable store separation. The goal of this research effort is to perform a store-release test in the Flight Loads Laboratory (FLL) and compare test data to analysis models. Displacements, velocities, accelerations, and loads will be recorded to compare with analysis models. The capabilities and techniques developed during this Center Innovation Fund project will help ensure that Armstrong has the analysis and testing capability to lead future innovations in the air launch and unmanned aerial system (UAS) store separation research communities.



Work to date: Initial modeling and simulation have been completed. Researchers have assembled the test setup with instrumentation, designed and fabricated a fire control system, and documented test procedures and hazards. The next steps are to collect acceleration data using a six degree-of-freedom telemetry kit mounted in the fuse well of the nose of the test article, collect displacement data using high-speed video, and collect reaction load data between the store and the release hardware.

Looking ahead: Testing is expected early in 2020.

Benefits

- **Forward thinking:** Expands Armstrong's dynamic loading analysis and testing expertise
- **Capability building:** Extends FLL's dynamic testing methods to support future store separation demonstrations

Applications

- Conventional store separation projects
- UAS/drone deployment and docking demonstrations

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Improving Aerospace Vehicle Efficiency

Increasing efficiency in aerospace vehicles is a key goal across the spectrum of NASA operations. Armstrong researchers are constantly striving to build efficiency into all phases of flight projects, through development, fabrication, and operations processes.

From a new wing design that could exponentially increase total aircraft efficiency to novel test techniques that evaluate sensor suites and calibration systems, our researchers are finding unique solutions that increase efficiency.

NASA Armstrong's PRANDTL-D1 wing is autographed by all the interns who worked on the project. The wing will be featured in the Innovation Gallery of the Smithsonian Institution's National Air and Space Museum.

PRANDTL-D Flying Wing

Armstrong researchers are continuing to test a new wing shape that could significantly increase aircraft efficiency. The team has built upon the research of German engineer Ludwig Prandtl to design and validate a scale model of a non-elliptical wing that reduces drag and increases efficiency. By allowing for longer wingspans, the new design produces 12 percent less drag than current solutions. In addition, the approach to handling adverse yaw employs fine wing adjustments rather than an aircraft's vertical tail. In a propeller application, efficiency could increase by 13 percent. If the concept continues to prove its value, it could advance NASA's research goals to verify technologies leading to significant fuel economy and emissions reduction.

Work to date: The team has developed, demonstrated, and validated scale models of an improved PRANDTL-D wing, and their flight experiments have unequivocally established proverse yaw. The innovation was patented, and research has led to work on an autopiloted flying wing designed to land on Mars. In 2018 and 2019, the team completed test flights incorporating pressure sensors embedded in the wing. Preliminary data demonstrated the projected lift distribution.

Looking ahead: Researchers are exploring ways this innovation can benefit NASA projects. In addition, the wind energy industry is open to new bladed designs that improve efficiency, and this market segment is large and growing.

Benefits

- **Highly efficient:** Increases total aircraft efficiency by as much as 62 percent, including efficiency increases in drag reduction (12 percent) and when used in propeller systems (13 percent)
- **Economical:** Improves fuel efficiency by allowing aircraft to fly faster
- **Safer:** Reduces adverse yaw when correcting for roll

Applications

- Mid-size commercial aircraft
- Drones and unmanned aircraft
- Energy delivery systems
- Wind turbines
- Industrial fans

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New Propeller/Fan Increases Efficiency

Armstrong researchers are working on design processes for propeller blades that are intended to increase efficiency and reduce aerodynamic noise. Based on wing design improvements derived from the PRANDTL aircraft, this innovative design uses an alternative spanload to redistribute the propeller loading. These designs are intended to optimize the power needed to rotate a propeller or fan. Initial estimates indicate 15 percent improvement in propulsive efficiency and noise reduction. If successful, the benefits could be realized for a wide range of propeller and fan designs.

Work to date: The current research effort focuses on a propeller/fan redesign to be used as comparison and quantification of results. Researchers will use the modeling and analysis of a known and tested propeller to generate models, compare these results to wind tunnel results, and refine a workflow to assess future propeller configurations. The end result is expected to be a simplified design process resulting from modeling and testing.

Benefits

- **Efficient:** Redistributes lift and drag along the propeller or fan blade, reducing power consumption while producing the designed thrust
- **Economical:** Allows blades to use less power, reducing fuel costs
- **Quieter:** Produces less noise than conventional blade designs
- **Simpler:** Provides a solution that can be coupled with several airfoil designs

Applications

- Propellers
- Industrial fans
- Axial compressors
- Power turbines

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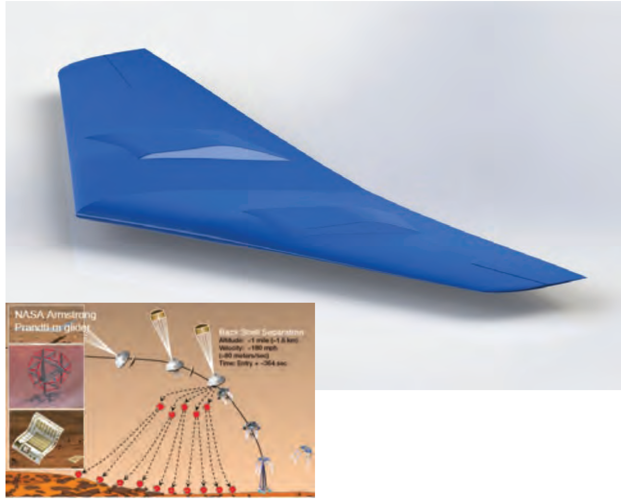

Glider Swarm Sensor Distribution

Martian surface observations are collected remotely via satellites or with localized landers and rovers. Researchers from Armstrong and NASA's Jet Propulsion Laboratory are collaborating to create preliminary concepts, systems development, and prototypes for small unmanned aerial systems (UAS) capable of deployment and flight on Mars. The goal of the UAS swarm is to deliver sensors through the atmosphere to create a distributed mesh sensor network to collect surface and atmospheric measurements. The technology could also be used on Earth for atmospheric observations.

Work to date: With NASA's Center Innovation Fund resources, the team developed designs for prototype Mars gliders that span 13 inches, 18 inches, and 24 inches. They then fabricated and flew a 24-inch model on a UAS mothership. In order to prototype the glider swarm on Earth, researchers developed balloon and blimp operations concepts. They designed, developed, and operated a gondola from a tethered blimp. The 24-inch model was then flown from the tethered blimp to conduct tests of release, handling, and glider performance.

Looking ahead: The 13-inch and 18-inch gliders will be flown in 2020. System-level swarm testing in a low-altitude setting is also planned for 2020.

Collaborators: NASA's Jet Propulsion Laboratory

Benefits

- **Breakthrough:** Characterizes small glider distribution performance in free and directed flight
- **Efficient:** Provides a low-cost, low-mass sensor distribution architecture for novel atmospheric observations
- **Innovative:** Enables Armstrong researchers to analyze, develop, and test in a new flight regime while participating in planetary science platform development

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Investigating Laminar Flow

Researchers at NASA's Langley Research Center have developed a new crossflow suppression technique for aircraft wings with moderate sweep. Armstrong is contributing to the effort with flight tests to confirm that the new technique works as predicted in a flight environment. Known as Crossflow Attenuated Natural Laminar Flow (CATNLF), the technique enables laminar flow by reshaping wing airfoils to obtain specific pressure distribution characteristics that control the crossflow growth near the leading edge. This research could potentially be useful in future commercial transports to reduce aerodynamic drag and increase efficiency.

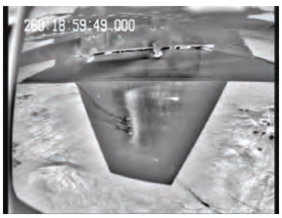
The CATNLF research is three separate flight test efforts.

ReHEAT

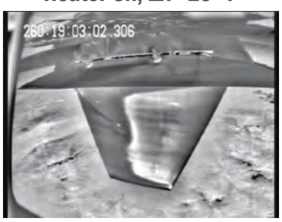
ReHEAT is the first flight test of a technology previously tested in a wind tunnel to improve flow visualization of the boundary layer. Testing involves painting a carbon-based, electrically conductive coating onto a test surface. Electrical current is passed through the coating, which heats the surface. In a wind tunnel, the coating is covered with temperature-sensitive paint for flow visualization. During flight tests, an infrared camera is used for visualization.

- **Work to date:** The coating was applied to a supersonic natural laminar flow test article at Armstrong. The coated test article was flown on the centerline pylon of the F-15B research testbed, along with an infrared camera system. During flight tests in summer 2019, the heating layer worked as expected and the infrared camera successfully visualized the boundary layer state.
- **Looking ahead:** Next steps are to coat the CATNLF test article with the same coating to achieve similar improvements to the flow visualization of the boundary layer.

Heater off



Heater on; ΔT=20° F

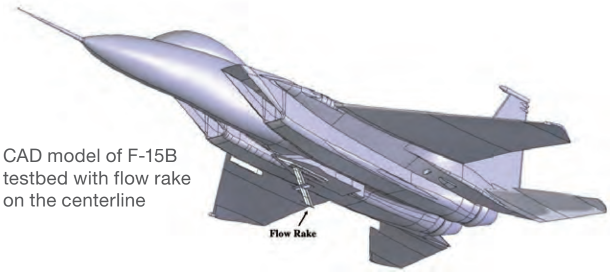


An electrically conductive heating layer and infrared camera enabled flow visualization of the boundary layer during flight tests.

CLIP Flow Rake

CLIP Flow Rake is a vertically oriented instrumentation rake with air data and disturbance probes that will map the flow field under the F-15B testbed to support the follow-on test with the CATNLF laminar flow test article. Flow field mapping will be instrumental for understanding the data that will be collected during the CATNLF flight tests.

- **Work to date:** A contractor has completed the mechanical design and fabrication and will deliver the rake to Armstrong early in 2020.
- **Looking ahead:** The team expects to flight-test the rake in summer 2020.

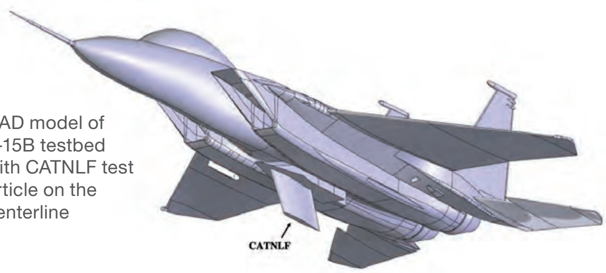


CAD model of F-15B testbed with flow rake on the centerline

CATNLF Laminar Flow Test Article

The CATNLF laminar flow test article is a stub wing mounted vertically under the F-15B testbed aircraft. Langley researchers are designing the test article to achieve significant runs of natural laminar flow at Reynolds numbers up to 30 million. A leading-edge sweep of 35 degrees will demonstrate that the technology can attenuate the crossflow boundary layer transition mechanism, which is the dominant transition mechanism on wings with moderate to high sweep.

- **Work to date:** The design of the outer mold line necessary to achieve natural laminar flow will be completed in early 2020. An outside contractor will then perform the detailed mechanical design and fabricate the test article.



CAD model of F-15B testbed with CATNLF test article on the centerline

Partner: NASA's Langley Research Center

Benefits

- **Informs wing design:** Helps researchers and designers understand key laminar flow phenomena
- **Enables access to actual flight conditions:** Flight tests allow data to be collected in conditions similar to those faced when wings are integrated into an aircraft design

Applications

- Commercial subsonic transports

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Spanwise Adaptive Wing Research

Researchers recently concluded the feasibility assessment of the Spanwise Adaptive Wing (SAW) concept, which will allow part of an aircraft's wing to fold in flight, boosting efficiency and performance. SAW seeks to enhance aircraft performance by allowing the outboard portions of wings to fold according to various flight condition demands. A mechanical joint, acting as a hinge line for rotation, makes the freedom of movement possible. New advancements in shape memory alloy (SMA) actuators allow tighter packaging, enabling the folding of much smaller wing sections.

Work to date: To demonstrate SAW in flight, researchers designed an experiment to fly on the Prototype-Technology Evaluation Research Aircraft (PTERA), developed by Area-I. In a three-flight series, the outer portion of the wing was folded through a range of +70° to –70°. These tests demonstrated that SAW augmented the yaw control of the aircraft to a point where the rudder could be entirely removed while still maintaining controlled flight. Additionally, an algorithm was developed that incorporated the flight test data to continuously change wing tip position to identify the lowest drag setting, thus increasing fuel efficiency.

Parallel to the flight test effort, researchers at NASA's Glenn Research Center developed, built, and tested a full scale SMA actuator for the outer portion of an F/A-18 wing to demonstrate actuator scalability. The actuator is capable of 20,000 inch-pounds of torque and can articulate over 90°.

Looking ahead: A follow-on project is being formulated in which SAW can be tested at an even more relevant scale.

Partners: NASA's Langley and Glenn Research Centers, The Boeing Company, and Area-I

Benefits

- **Increased efficiency:** Increases aircraft stability and wing compression lift
- **Increased performance:** Augments yaw power and stability
- **Adaptive:** Enables optimal wing position for all flight positions

Applications

- Commercial, military, and general aviation aircraft

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Airborne Research Test System (ARTS) for Small Unmanned Aircraft

This research effort evaluated the feasibility of the ARTS, acting as a flight controller, to command the outboard ailerons on movable-span sections of the Prototype-Technology Evaluation and Research Aircraft (PTERA) testbed. The ARTS is a hardware and software platform for testing advanced control and sensor concepts. It reduces the effort and cost of flight-testing research by providing a flexible, reconfigurable computing platform for hosting research experiments. This research was part of the Spanwise Adaptive Wing (SAW) project, which investigated the use of control surfaces to allow the outboard portions of wings to adapt, or fold, to adjust to various flight condition demands.

Work to date: The ARTS box was tested in full non-linear simulation, and the PTERA testbed and the ARTS successfully exchanged sensor information and control surface commands. The system was also successfully tested in hardware-in-the-loop in a real-time operating environment. Three flight tests gathered data that was used to update the ARTS control laws. In late 2018 and with the ARTS box onboard, the PTERA testbed was destroyed during a crash into the dry lakebed outside Armstrong, and there are no plans for future flight tests. This research contributed valuable information to NASA's research knowledge about aircraft with wings that have movable spans.

Looking ahead: The PTERA simulation with the ARTS setup is being actively used for student research.

Benefits

- **Compatible with Simulink® software:** Saves time and resources
- **Flexible:** Provides an array of options to test and implement advanced control concepts
- **Configurable:** Can be quickly customized for various experiments
- **Partitioned:** Separates research experiments from the core system

Applications

- Operate as a flight controller
- Validate new flight control concepts
- Test aircraft limits

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Avionics and Instrumentation Technologies

Armstrong innovators design and integrate data acquisition systems for research, support, and one-of-a-kind platforms. In many cases, these systems leverage commercial off-the-shelf parts to keep costs low and facilitate integration with legacy systems. At the same time, these cutting-edge data systems are finding innovative ways not only to collect data efficiently but also to flexibly configure collection parameters.

Real-Time Parameter Identification

Armstrong researchers have implemented a technique for real-time, control room–based estimation of the aerodynamic parameters that describe an aircraft's stability and control characteristics. Oftentimes, aerodynamic modeling is performed on recorded data after test flights and then used in simulations. The drawback with this approach is that, if the collected data are not complete or of high quality, additional and costly flight tests must be scheduled.

In this innovative approach, Armstrong's real-time parameter estimation automates the process and runs during flight, enabling researchers in the control room to evaluate and adjust flight maneuvers to ensure data quality. The technology increases the efficiency and productivity of flight tests, as researchers can determine during the tests if they have collected the data needed for specific modeling simulations.

Work to date: The system successfully evaluated data from the Gulfstream III aircraft as part of the Adaptive Compliant Trailing Edge (ACTE) project and is currently being used in Armstrong control rooms to evaluate data collected during test flights and in-flight maneuvers. Researchers have continued to improve the system display and refine the way that results are presented.

Looking ahead: A capability to compare the estimated parameters to preflight predicted values is being added, which will make it possible to evaluate the aerodynamic effects of aircraft modifications. The system is expected to become part of Armstrong's control room toolset for use with upcoming X-planes and other projects. Accordingly, researchers are working to implement an updated version of the code for the X-57 Maxwell all-electric aircraft.

Benefits

- **Automates data collection:** Estimates in real time the parameters for aircraft stability and control
- **Improves data quality:** Enables adjustments during flight tests to ensure correct data acquisition
- **Saves time and resources:** Decreases the duration and number of flight tests

Applications

- Aerodynamic modeling

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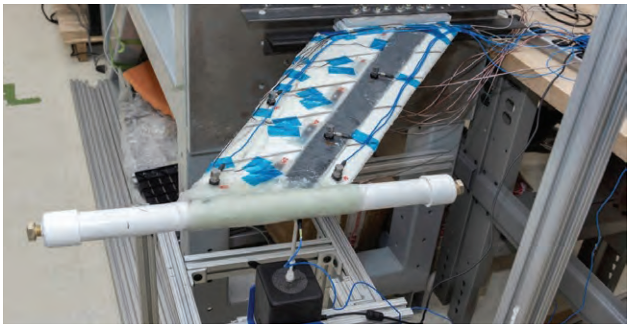

Mechanoluminescent Materials for Structural Health Monitoring

Aerospace structures are composed of fiber-reinforced polymer composites that are susceptible to interior delamination during high-frequency vibrations. Armstrong and university researchers are collaborating to design and test a mechanoluminescent optoelectronic (MLO) material that can autonomously detect internal delamination. Composed of a conductive polymer with a photoactive layer and an elastomer embedded with crystals, the material converts mechanical energy into light energy to provide information about the structure and its properties. These flexible, self-powered multi-functional MLO materials could be a lightweight, sensitive solution for warning when a wing or other aerostructure is enduring excessive strain or is at risk of catastrophic failure.

Work to date: Researchers conducted vibration tests on an MLO-equipped cantilevered wing in the Flight Loads Lab at Armstrong in summer 2019. Measurements were compared to those from conventional strain gauges and accelerometers.

Looking ahead: The team will use lessons learned during vibration tests to improve sensor manufacturing techniques to increase robustness and operability. Next steps are to develop consistent fabrication techniques to meet quality control standards and calibration techniques to capture sensor behavior for comparison. The team will repeat ground testing on an aerospace test article to verify sensor improvements and further characterize the technology's potential for use in structural health monitoring.

Partners: University of New Mexico, New Mexico Institute of Mining and Technology, and New Mexico State University

Benefits

- **Safety enhancing:** Detects internal delamination of aerospace composite materials
- **Self-powering:** Generates power from mechanical vibrations

Applications

- Structural health monitoring
- Power generation

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ARMD Flight Data Portal (AFDP)

Armstrong is taking the lead on a NASA-wide effort in the Aeronautics Research Mission Directorate (ARMD) that will enhance flight research and test capabilities by improving the management of test data. The AFDP will replace the legacy Flight Data Access/Archival System (FDAS), in place since 1980. An effective resource for its time, FDAS archives flight data but offers no corresponding analysis or related information. The new data portal will archive all test flight data for the four NASA centers involved in flight testing along with contextual information needed to understand and analyze the data. Such information includes mission overviews, flight profiles, daily summaries, mission debriefs, and more. A robust search mechanism and intuitive graphical user interface (GUI) will further make the AFDP a meaningful flight test resource. Online and accessible to all with NASA credentials, the AFDP will increase collaboration across NASA centers.

Work to date: Work began in 2016 and is proceeding in three phases. Phase 1 involves the upfront work to build the portal, and Armstrong is leading this effort. The team is focusing on the X-57 Maxwell airplane as a test case, including all flight data and contextual information to ensure the portal operates as intended.

Looking ahead: Future phases will intended to include various flight test projects from NASA's other three ARMD Centers—Ames, Glenn, and Langley Research Centers.

Benefits

- **Enhances research capabilities:** Enables rapid location of test flight, simulation, and loads test data along with corresponding contextual information
- **Increases collaboration:** Accessible to all NASA personnel via online system
- **Is easy to use:** Features a user-friendly GUI and search mechanism

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Atmospheric Science Team Supports Key Flight Missions

For the atmospheric science team at Armstrong, every day is different as they work to support the center's many research projects. The team's capabilities and activities are as broad and as varied as the efforts they support and the types of data they provide to science, aeronautics, and other missions.

In addition to weather forecasts—needed for flight safety and mission planning—the team provides post-flight information that is critical for engineering analysis, such as atmospheric references for air data calibrations and airspeed data for determining errors in aircraft measurements.

The team uses its wide knowledge base and state-of-the-art technology to support a variety of efforts, each with its own unique requirements. For example, some research projects need to know wind conditions every 5 minutes, whereas others need wind measured just once an hour. The team is also responsible for helping determine if conditions are appropriate for testing, and the requirements range the spectrum. To continue with the wind example, some projects cannot operate with wind speeds over 5 knots, others can operate in winds up to 30 knots, and for some, wind speeds do not matter at all.

The team leverages numerous cutting-edge tools to achieve useful results for the widely varying projects:

- Surface measurement systems determine temperature, pressure, humidity, wind speed and direction, solar radiation, precipitation, air quality, and more.
- Balloon systems measure temperature, humidity, and pressure while using GPS to determine wind speed and direction. Armstrong has three balloon systems, and the team can send them as high as 130,000 feet to collect samples at multi-second intervals, depending on project requirements.
- Sodar anemometers use sound to measure wind speed and direction at various altitudes. The team uses its 2,000- and 4,000-hertz systems to leverage data on atmospheric turbulence and the scattering of sound waves for needed measurements.

Other key tools include lidar and radar systems for various wind measurements, towers for heat stress measurements, and tethersondes for obtaining atmospheric boundary layer measurements. Here are just a few examples of how Armstrong's atmospheric science team has supported NASA research.

Acoustic Research Measurement (ARM) Flights

The ARM project tested technologies to pinpoint airframe noise sources during landings. To enable the analysis, the team monitored atmospheric conditions while a Gulfstream-III aircraft flew 700 feet above a microphone array in a lakebed. Tools included a weather tower on the lakebed and a tethersonde unit to measure temperature, pressure, relative humidity, and wind speed and direction at 1-second intervals.

Low-Boom Flight Demonstration (LBFD)

One of the goals of the LBFD mission is to gather data on human responses to sonic booms. For the Quiet Supersonic Flights 2018 (QSF18) research, the team launched balloons that collected atmospheric data, enabling pilots to place sonic booms in specific locations.

Stratospheric Observatory for Infrared Astronomy (SOFIA)

In addition to weather forecasts, the team provides water vapor loading information to the SOFIA crew. This information enables the crew to understand the amount of water vapor in the upper atmosphere, aiding telescope views. The team also provides real-time satellite and other data, enabling the crew to compare this data with that of their instruments and monitors.

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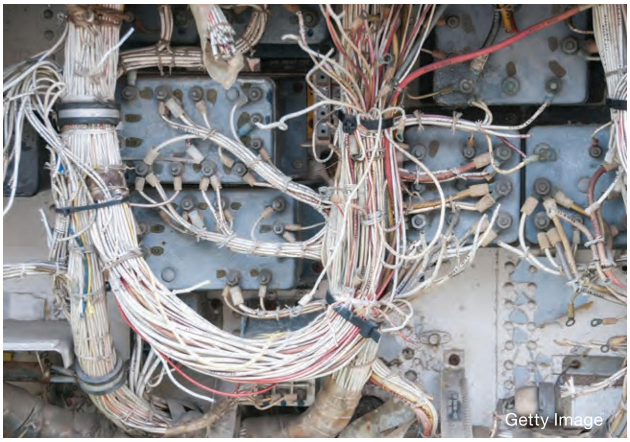

Advanced Wireless Flight Sensor System

Researchers at Armstrong are developing a system that eases integration of wireless sensors into existing aircraft avionics. Currently, adding wireless sensors to avionics systems is time consuming and expensive due to integration requirements. This innovation streamlines that process, eliminating the need to overhaul preexisting avionics systems to integrate new sensors. Key to the innovation is a software-defined radio device that implements into software the capabilities of individual wireless protocols and systems. If applied throughout the aviation industry, this approach would enable a clear transition path from experimental use of wireless sensors to practical implementation.

Work to date: Benefitting from NASA's Center Innovation Fund, researchers purchased software-defined radio devices and created a preliminary architecture. The team demonstrated in the laboratory the ability for dissimilar wireless devices to communicate without any hardware modifications. The group also worked with two small businesses to test the unique wireless technology on Armstrong aircraft. A resulting analysis recommends its adoption in wireless avionics.

Looking ahead: Next steps are to continue to test the technology in aircraft.

Benefits

- **Saves time:** Streamlines testing and implementation of wireless technology
- **Adds capabilities:** Allows new mechanisms and devices to be added to aircraft
- **Reduces costs:** Simplifies the process of integrating wireless sensors

Applications

- Avionics
- Instrumentation systems
- System health monitoring

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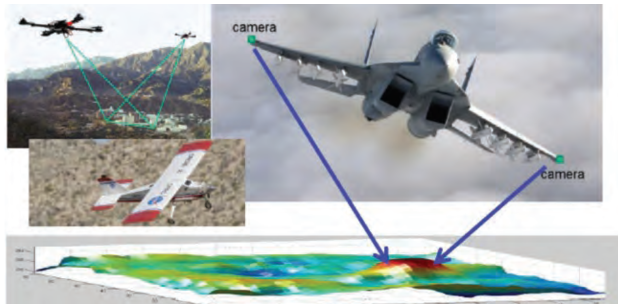

Visual Radar

Researchers at Armstrong and NASA's Jet Propulsion Laboratory (JPL) are collaborating to validate and test a stereo vision technology for terrain-relative navigation. Stereo vision utilizes two cameras with the same field of view to generate ranging data from a binocular image using the known distance between the cameras. JPL researchers developed the technology for robust, vision-based, terrain-relative navigation based on two non-static cameras. Armstrong researchers are integrating and flight testing the new technology on an F-18 aircraft. The innovation could lead to advances in aircraft sensor systems.

Work to date: With funding from NASA's Center Innovation Fund, Armstrong and JPL researchers collaborated to develop flight hardware to validate the technology. The Armstrong team integrated the cameras into two instrumentation pods that will be fitted onto the wing tips of an F-18 aircraft. To save resources, researchers used existing aircraft and instrumentation pod wiring. Significant accomplishments include:

- Retrofitted Navy instrumentation pods with camera systems
- Completed environmental testing
- Finalized flight planning
- Completed integration design

Looking ahead: Following integration and flight testing, the system will be used by NASA's Resilient Autonomy project for unmanned aircraft research.

Partner: NASA's Jet Propulsion Laboratory

Benefits

- **Innovative:** Demonstrates the ability to use cameras as visual sensors
- **Advanced:** Enables a new type of 3D mapping for the unmanned aircraft world
- **Rugged:** Useful for detecting hazards in flight environments

Applications

- Autonomous flight techniques
- Automatic collision avoidance technologies
- 3D modeling of terrain and structures
- Passive object detection

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Ethernet via Telemetry (EVTM)

This research effort is focused on developing a network-based telemetry system that transmits data between ground stations and research aircraft using less bandwidth than traditional telemetry methods. The EVTM system is an improvement over static, one-way pulse code modulation–based systems that crowded the frequency spectrum as research projects became more complex and involved larger amounts of data. The new system can move data at 40 megabits per second (Mbps), 10 times faster than current systems Armstrong researchers are using. EVTM establishes a dynamic link between ground stations and research aircraft, enabling users to specify data rates and reallocate resources to free up space for other applications.

Work to date: In 2017, EVTM was utilized in a flight-testing environment when Armstrong hosted a captive carry test by Generation Orbit. The launch services company needed a telemetry system that easily integrated with its embedded data system. EVTM was utilized along with custom Python® software to integrate Generation Orbit's parameters into the programming language displays.

In 2018, further work was done to better utilize EVTM in a method to allow dynamic subscription to instrumentation data. Using standard network technologies allows tools to change the telemetry stream dynamically. With funds from NASA's Center Innovation Fund, researchers developed a ground-based system to prove this concept.

Looking ahead: The team is investigating how to use EVTM to advance flight test data acquisition capabilities.

Benefits

- **Versatile:** Features direct Ethernet network compatibility and provides bidirectional communication
- **Efficient:** Allows for real-time ground-based experiment control while using less bandwidth
- **Reconfigurable:** Allows the downlink data architecture to be configured as needed
- **Convenient:** Allows frequency spectrum reallocation

Applications

- Commercial, military, and general aviation aircraft

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Python is a registered trademark of the Python Software Foundation.

Flight Test Instrumentation for Advanced Propulsion Systems

Armstrong researchers are working to identify, develop, and test new instrumentation components and systems that can effectively evaluate next-generation integrated propulsion systems. A wide variety of legacy instrumentation exists to effectively characterize and provide flow measurements and visualization on and off surfaces around an aircraft propulsion system. However, as novel propulsion systems and configurations evolve, new instrumentation will be needed to evaluate them. Future technologies will be looking to exploit the unique complexities of advanced propulsion system configurations to increase efficiency, and the challenge is to develop appropriate flight test instrumentation tools and methods.

Heater off

Heater on; ΔT=20° F

An electrically conductive heating layer and infrared camera enabled flow visualization of the boundary layer during flight tests.

Work to date: Capabilities currently in development include:

- Low-profile conformal pressure sensors
- Low-profile conformal shock and transition detection sensors
- Carbon-based heating layer for laminar/turbulent flow visualizations
- Pressure-sensitive paint for in-flight use
- Wireless sensor and instrumentation sensor technologies

Looking ahead: Armstrong researchers have identified several tools and methods for further research and development:

- Improved off-surface flow measurements and visualization (e.g., particle image velocimetry)
- Improved flight-capable pressure sensors
- Less intrusive sensors and visualization techniques
- Improved engine modeling for flight tests

Benefits

- **Enabling:** Supports NASA's efforts to facilitate development of future propulsion systems
- **Informing:** Aids in determining how to apply resources for next-generation technologies

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Armstrong Operates and Maintains Flying Observatory

The Stratospheric Observatory for Infrared Astronomy (SOFIA) is a Boeing 747SP jetliner modified to carry a 106-inch diameter reflecting telescope. It is a joint project of NASA and the German Aerospace Center, DLR.

Flying in the stratosphere at 38,000 to 45,000 feet puts SOFIA above 99 percent of Earth's infrared-blocking atmosphere, allowing researchers to study the solar system and beyond in ways that are not possible with ground-based telescopes. During hours-long flights, SOFIA's telescope instruments—cameras, spectrometers, and polarimeters—operate in the near-, mid-, and far-infrared wavelengths to study various phenomena and gather data.

Armstrong operates and maintains the aircraft. Unlike space-based telescopes, SOFIA lands after each flight, so its instruments can be exchanged, serviced, and/or upgraded to leverage new technologies, retaining state-of-the-art capabilities. As a working observatory with a vigorous outreach program, SOFIA is a place for scientific exploration.

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Wireless Miniature Biosensor

This research effort produced a wireless miniature biosensor for real-time in-flight physiological monitoring of the aircrew in high-performance aircraft. The size of a postage stamp, this battery-free sensor measures oxygen saturation, heart rate, heart rate variability, and body temperature. The device was designed specifically to monitor a pilot's brain oxygen saturation during high-*g* flight maneuvers. Current oxygenation measurement devices are large and bulky, thus not suitable for use on pilots in high-*g* conditions. Though designed for pilots, this biosensor offers uses for astronauts, athletes, military personnel, and patients in acute trauma situations.

Work to date: The sensor technology is functional. Remote sensing and reflective capabilities increased its ease of use and variety of potential applications.

Looking ahead: The biosensor's light weight and small size enable the possibility of developing similar sensors to measure additional parameters. For example, cuffless blood pressure monitoring would be useful in high-performance aviation and numerous other situations.

Partners: Wearifi, Inc., and Northwestern University Center for Bio-Integrated Electronics

Benefits

- **Powerful:** Enables real-time physiological monitoring
- **Compact:** Features a small and lightweight form factor ideal for use in high-*g* conditions

Applications

- Aviation
- Spaceflight
- Athletics
- Acute care medicine
- Trauma care

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Space and Hypersonics Technologies

A key objective of space research at Armstrong is to leverage our center's expertise in aircraft flight testing, instrumentation, avionics development, simulation, and operations to assist NASA with space exploration. Our researchers are discovering innovative ways to use aircraft to develop new space capabilities and test space technologies in a relevant environment.

Hypersonics research is important both for aeronautics and space research to enable extremely fast travel on Earth as well as for future space exploration. Armstrong has a long history of pioneering research in this area.

Textile-Based Load-Limiting Device for Mid-Air Retrieval

This research effort tested the capability of a textile-based load-limiting device (LLD) as part of a mid-air retrieval (MAR) system to recover valuable and heavy space assets that return to Earth. MAR offers a significant opportunity to reduce costs associated with rocket launches, as it enables the reuse of expensive components. In development for years, the MAR system is now in its third generation and offers low-speed, low-*g* retrieval of payloads suspended under a parafoil.

The device attaches to the cargo hook of a helicopter and prevents hook overload during payload capture and ferry. Selected for its reliability, light weight, and low manufacturing cost, the textile-based LLD has a variable stroke length that pays out during load transfer. If the maximum length is exceeded, the device safely separates the payload from the helicopter. This technology can be used for no-impact recovery of payloads weighing up to 10,000 pounds.

Work to date: In 2018, with support from NASA's Center Innovation Fund, contractor Airborne Systems developed and ground-tested a stitched textile-based LLD to verify its load-limiting characteristics. Thirteen samples of varying configurations were successful evaluated. Nearly half of the samples experienced webbing failure or damage and did not function properly the entire stroke. The testing identified a sample configuration that will reliably allow the LLD assembly to accomplish the most work without overloading the helicopter cargo hook.

Looking ahead: Additional testing is required to evaluate whether increasing the number of energy modulators could increase payout force.

Collaborators: Airborne Systems and United Launch Alliance

Benefits

- **Strong:** Offers low-speed, low-*g* airborne retrieval of expensive assets weighing up to 10,000 pounds
- **Safe:** Protects the helicopter and crew by preventing overload of the cargo hook in the event of excessive capture loads
- **Flexible:** Accommodates different recovery weight payloads by adding or reducing the number of textile elements

Applications

- High-value reusable hardware
- Sensitive payloads that cannot survive shock impacts

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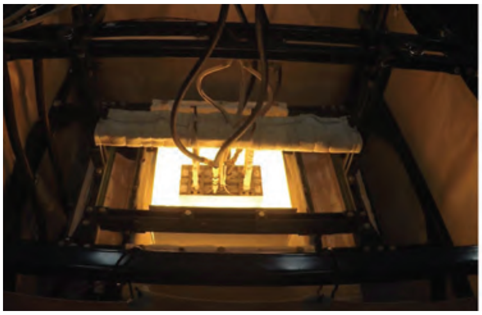
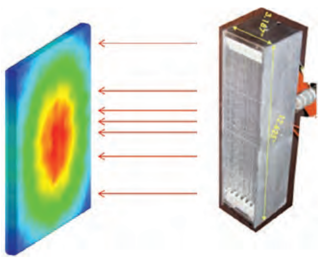
Heat Flux Mapping System

The Flight Loads Laboratory at Armstrong uses radiant heaters to simulate thermal loads imparted to vehicle structures during hypersonic flight. Radiant heater layouts are used to apply a specific heat flux distribution to the test structure surface to match predicted flight conditions and measure the response of the test structure. Researchers at Armstrong have developed a technique to map the heat flux distribution by quantifying the heat flux distribution of the heater array and demonstrating how it changes with different characteristic parameters.



Work to date: Testing occurred in spring and summer 2018. Two student interns performed the tests, analyzed the data, and aided in planning the work required to complete the effort. One student designed a heat exchanger that will be used to operate the test setup at higher energy output levels than previously achievable. Two engineers analyzed legacy instrumentation data quality and identified improvements required to obtain the data of interest. A computational model study was also performed to evaluate the contribution of each reflector face to the total heat flux distribution.



Looking ahead: Research will continue in 2020. The team will continue to collect data on different lamp configurations, perform analyses to ensure data are valid, and interpret the results for application to a characteristic model useful for pre-test heater array design, pre-test prediction, and post-test analyses.

Benefits

- **Visual:** Provides a two-dimensional map of the heat flux distribution as a function of the characteristic parameters for a given configuration of radiant heaters
- **Accurate:** Increases the accuracy with which the heat flux distribution of a heater array can be quantified for the purpose of improving correlations
- **Improved simulation:** Enables design of an improved heater for more flight-like simulation during tests

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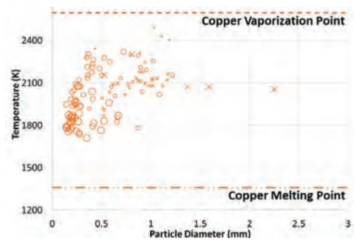
Quantitative Thermal Imaging Using Conventional High-Speed Video (HSV) Cameras

Armstrong researchers developed a method for using conventional HSV cameras to make quantitative thermal imaging measurements for objects hot enough to emit in the visible spectrum. The advancement occurred during a project that required temperature measurements on metal particles ejected during an electrical arc event in vacuum conditions. Commercially available systems did not have the combination of high spatial resolution and high frame rates necessary to resolve the particles in both space and time to obtain the temperature measurements. Researchers determined they could use HSV cameras because the particles would be hot enough to emit in the visible spectrum and they would be able to eliminate sources of visible light during testing.

Work to date: After calibrating the HSV with a blackbody source, measurements revealed the particles were larger and much hotter than anticipated and maintained their heat long enough to remain super-heated as they traversed the volume that would be occupied by an astronaut. Two different brands of high-speed cameras were used, with calibrations evaluated over several months for repeatability and stability. Noise sources also were evaluated. Researchers had an unexpected opportunity to image melting metal filaments with a known temperature, allowing the system's measurement performance to be validated. Testing occurred in summer and fall 2018, and a final report was drafted in spring and summer 2019.



Looking ahead: The team anticipates publishing a conference paper in spring 2020.

Benefits

- **Versatile:** Using conventional HSV cameras as imaging radiometers provides a far greater range of potential frame rates and spatial resolution.
- **Stable:** Conventional HSV detectors have significant stability and robustness of response, providing accurate and repeatable calibrations—within 2 to 3 percent—over months of use.

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Armstrong Contributes to Successful Artemis Launch Abort Test

Armstrong researchers developed several systems designed to test the launch abort system (LAS) that will pull astronauts to safety during a launch emergency. The 3-minute test, called Ascent Abort-2 (AA-2) occurred on July 2, 2019, and was an important safety milestone in the agency's preparation for crewed flights of the Orion vehicle.

In the AA-2 flight test, a test version of the Orion crew module (CM) launched from Space Launch Complex 46 at Cape Canaveral Air Force Station in Florida. The launch occurred on a modified Peacekeeper first-stage rocket motor procured through the U.S. Air Force and built by Northrop Grumman. The Orion test spacecraft traveled to an altitude of about 6 miles, at which point it experienced transonic, high-stress aerodynamic conditions expected during ascent. The abort sequence was triggered, and in less than 180 milliseconds the abort motor fired to pull the CM away from the rocket. The attitude control motor flipped the capsule end-over-end to properly orient it. Then the jettison motor fired, releasing the CM for splashdown in the Atlantic Ocean.

Among Armstrong's numerous critical contributions were systems engineering support; the AA-2 developmental flight instrument subsystem, which collected and transmitted all the engineering data; and an onboard separation video system that allowed the Orion engineering team to show that the 38 flight test objectives were achieved. Armstrong team members were on hand at the test to monitor data from the booster, the separation ring, and the video system as well as instrumentation from the CM and LAS.

Launch data were successfully downloaded from all 12 ejectable data recorders. The team has reviewed the data, which NASA will use for final certification that the LAS is safe for human space flight.

Members of the Armstrong AA-2 management and engineering team contributed to the launch abort system test.

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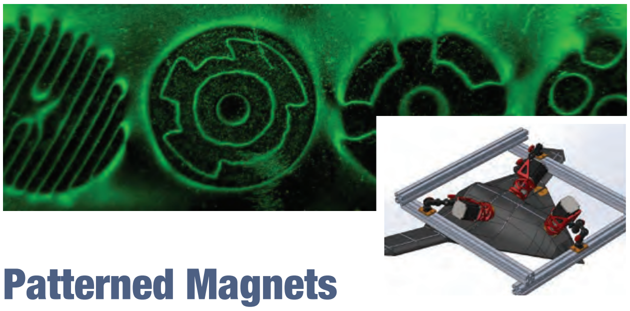

Patterned Magnets for Hold-Separate Techniques

Pyrotechnic separation events—such as those involving rockets and drones—are associated with shock and debris, requiring significant measures to protect payloads and aerostructures. Armstrong researchers are testing the feasibility of using finely patterned magnets to enable two-body separation events. If proven, hold-and-release mechanisms involving these flexible and versatile patented patterned magnets have the potential to revolutionize numerous aerospace activities.

Work to date: Researchers have taken a two-path approach to demonstrate the feasibility and practicality of using finely patterned magnets from Correlated Magnetics as the basis for separation mechanisms. One path is the development of a heavyweight release mechanism that mimics traditional store-release equipment and has demonstrated a release of 200 pounds. The other path is the development of a lightweight reconfigurable release mechanism intended to hold onto various shapes at various angles. This unit has demonstrated a hold of a 10-pound mock drone. With both demonstration units, the magnet-based mechanisms smoothly release at a touch of a button and can be scaled up or down to accommodate the size of an attached body. The team has also prototyped a slim-line minimalistic mechanism to release a PRANDTL-M aircraft from a small unmanned aircraft.

Looking ahead: With continued positive results, the team will investigate the feasibility of using these patterned magnets to reconnect stores—for example, individual drones that could reconnect to a drone mothership after mission deployment.

Benefits

- **Safer and more efficient:** Eliminates design time, costs, and safety measures associated with pyrotechnic separation events
- **Versatile:** Attaches to a wide variety of surfaces and object shapes
- **Flexible and lightweight:** Increases functionality of magnet systems, opening new application fields

Applications

- In-flight payload release
- Multi-body separation
- Mothership-Drone release and recapture
- Space assembly
- Space docking

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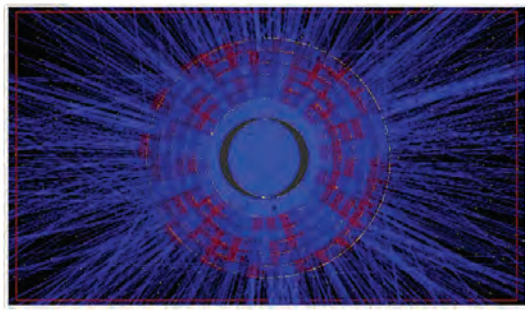
Radiation Shielding System

Space radiation can penetrate habitats, spacecraft, equipment, and spacesuits. Minimizing the effects of space radiation exposure is one of the biggest challenges in keeping astronauts healthy and fit during space exploration. Many researchers have proposed forming large electromagnetic fields around a spacecraft to mimic the protection provided by Earth's magnetosphere. The challenge in this approach is to develop a system that can distribute a sufficient magnetic field over a large volume while simultaneously being compact, lightweight, and power efficient. This research effort aims to develop an active radiation shielding simulation architecture that rapidly evaluates how magnetic fields can be oriented to effectively shield astronauts from radiation exposure.



Work to date: Armstrong researchers designed a simulation architecture to evaluate magnetic active radiation shielding configurations that incorporate lattices of Helmholtz coil arrays located at a distance from a spacecraft. It was determined that individual rows of Helmholtz coils can be configured to have a magnetic field that points in either the positive or negative direction depending on the direction of the applied current through each coil.

Looking ahead: Next steps are to integrate optimization algorithms into an overarching simulation architecture to reduce the time required to evaluate various shielding configurations, a primary challenge identified above.

Benefits

- **Enabling:** Facilitates evaluation of radiation shielding configurations to determine how magnetic fields can be oriented to shield spacecraft from harmful radiation
- **Flexible:** Enables testing of a variety of shielding configurations

Applications

- Spacecraft and habitats
- Space instrumentation and equipment

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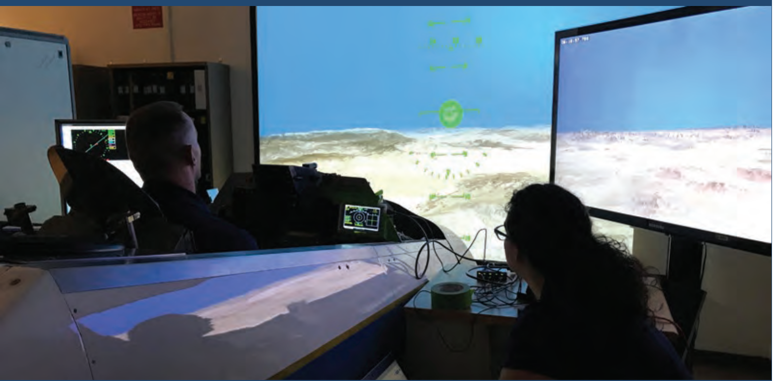
Virtual and Augmented Reality Techs



Innovators at Armstrong are exploring how virtual reality (VR) and augmented reality (AR) can progress from the laboratory to the cockpit to help accomplish research missions, inspire current and next-generation workforces, and publicize our center activities.

VR typically refers to replacing reality with a completely virtual environment, and AR refers to layering virtual components into a reality environment. Current and recent activities include:

- Enabling safer and more efficient operation of unmanned aerial systems in the National Airspace System
- Exploring safer and more efficient flight testing at Armstrong
- Helping with aircraft maintenance for our fleet
- Highlighting to the public the exciting research we are conducting

Activities are funded through NASA's Aeronautics Research Mission Directorate, NASA Center Innovation Fund, and innovation time. This research provides an opportunity to share ideas, collaborate, recruit new members, and showcase center accomplishments. Future plans include a VR/AR Demonstration Day and VR/AR courses as part of the Armstrong University curriculum.

Using Virtual and Augmented Reality Platforms to Build Trust in Autonomous Systems

Armstrong researchers are collaborating on an effort to build a basis for certification of autonomous systems by defining metrics for trustworthiness and developing a simulation environment in which these concepts are explored. Part of the Convergent Aeronautics Solutions Project, the Autonomy Teaming and Trajectories for Complex Trusted Operational Reliability (ATTRACTOR) sub-project employs multi-agent team interactions, explainable artificial intelligence (XAI), persistent modeling and simulation, and analyzable trajectories in the context of mission planning and execution. The simulation environment is similar to online gaming environments in which participants interact with each other, affect their environment, and expect the simulation to persist and change.

The focus of ATTRACTOR at Armstrong is working with small autonomous unmanned aerial systems (UAS) in a simulation environment to evaluate how virtual and augmented reality systems can be useful during mission planning, real-time execution, and post-test analysis for simulated and real-world environments.

Work to date: Armstrong researchers are leveraging the built-in gaze, gesture, and voice features of a HoloLens® headset for mission planning and real-time execution tasks.

Looking ahead: Post-test analysis is the focus of future development. The team is working to import lidar data into the simulation environment where researchers can view datasets in 3D perspective.

Partners: NASA's Langley and Ames Research Centers

Benefits

- **Ground-breaking:** Paves the way for autonomous systems into aviation
- **Advanced:** Offers the capability to view, adjust, and augment mission plans from a 3D perspective
- **Reliable:** Demonstrates transparency in decision making of autonomous systems

Applications

- Simulation and modeling
- Mission planning

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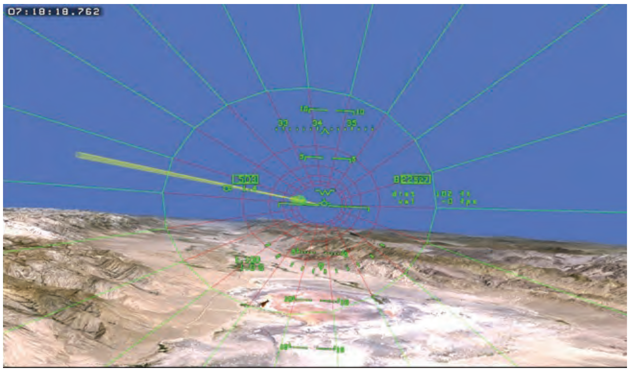

Virtual and Augmented Reality Systems for Flight Research

Armstrong researchers are investigating how virtual and augmented reality (VR and AR) systems can make it easier for pilots to receive and visualize critical information during flight testing. Current visualization aids involve 2D displays, requiring pilots to process multiple sources of information while performing flight tasks, such as approach a runway at a specific speed, altitude, and engine setting. Because VR and AR systems excel at gathering, processing, and digesting large sets of data from multiple sources, they can be useful in providing pilots with intuitive flight information. A team is developing a head-up display system that augments reality with virtual objects to decrease pilot workload and improve test point execution during flight testing.

Work to date: The team purchased hardware and completed laboratory tests simulating an AR environment in an existing simulator to better understand and compare head-down and head-up displays. While investigating mixed reality systems, researchers learned that most AR systems do not have a wide enough field of view; therefore, they developed a system that uses a VR headset with cameras porting in the outside world. The current prototype ports simulation position data into a VR headset, enabling a pilot to wear the VR headset but fly a simulation that includes AR graphics.

Looking ahead: The team is continuing to investigate and refine hardware and simulation data integration. Next steps are to tackle the hurdles of integrating the system into an aircraft for testing.

Benefits

- Decreases pilot workload
- Improves test point navigation
- Enhances data quality

Applications

- Flight testing
- Commercial and general aviation

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Aeronautics AR Educates Public on X-Plane Research

Armstrong personnel are seeking to increase the visibility of NASA's aeronautics projects and attract students to science, technology, engineering, and math (STEM) fields. A strong contingent of student interns collaborated with Armstrong researchers and the Office of STEM Engagement to develop an augmented reality (AR) mobile application to educate the public about NASA's X-planes and aviation research programs. NASA Aeronautics AR showcases advancements and far-reaching impacts that NASA has on the aviation industry.

When the user points a mobile phone's camera at a flat surface, the free app digitally materializes 3D AR versions of the X-59 Quiet Supersonic Technology (QueSST), X-57 Maxwell all-electric experimental aircraft, and G-III Gulfstream jet aircraft. Users can pinch, zoom, and drag to interact with the models. Some of the model features are animated; for example, users can move the propellers on the X-57 aircraft. While viewing a 3D model, users can read summary information or follow a link to learn more online. The app is available in both Android and iOS versions.

Work to date: Developed by four student interns working in succession beginning in spring 2018, the app was accomplished with gaming, 3D modeling, and photo editing software. The students imported the actual models NASA engineers used for aircraft flight simulation into the gaming software for animation.

The Android version of this education and outreach tool was released in December 2018 and was developed using Unity® gaming software, C# programming language, and Blender® 3D model editing software. Released in July 2019, the iOS version was developed with Swift™ programming language, the Xcode® developer software, and Blender software.

Looking ahead: Next, integrate more aircraft into the app.

Benefits

- **Versatile:** Increases visibility of NASA's aeronautics
- **Fun:** Generates excitement for STEM among students

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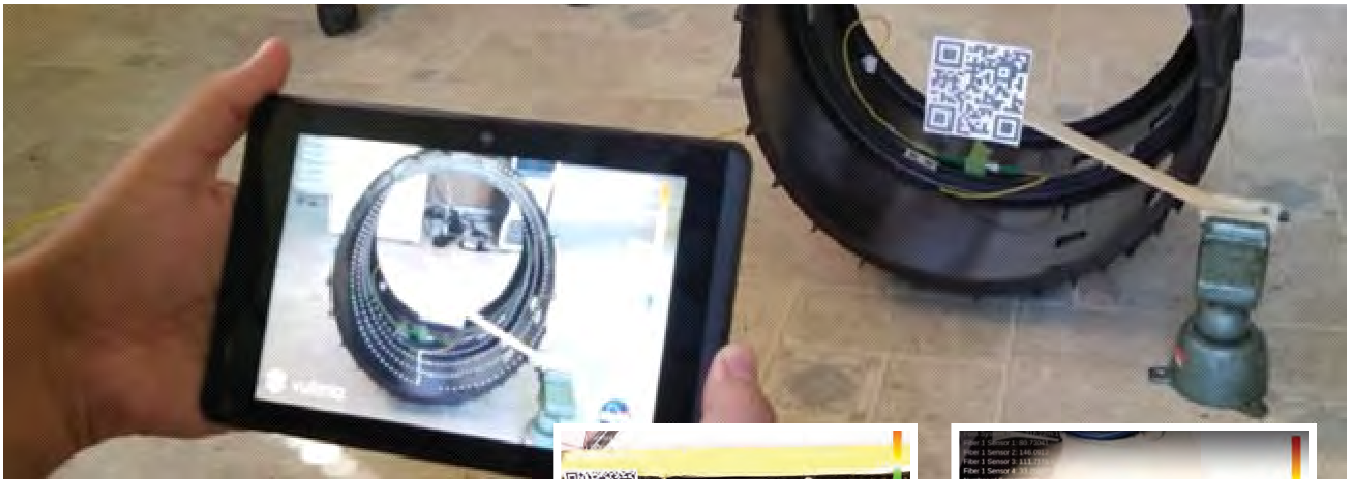
Interns: Alex Passofaro, Univ. of Minnesota Duluth; Kendrick Morales, Univ. of Puerto Rico at Rio Piedras; Christopher Morales, Univ. of Puerto Rico at Arecibo; Daniel Williams, Antelope Valley College

Fiber Optic Augmented Reality System (FOARS)



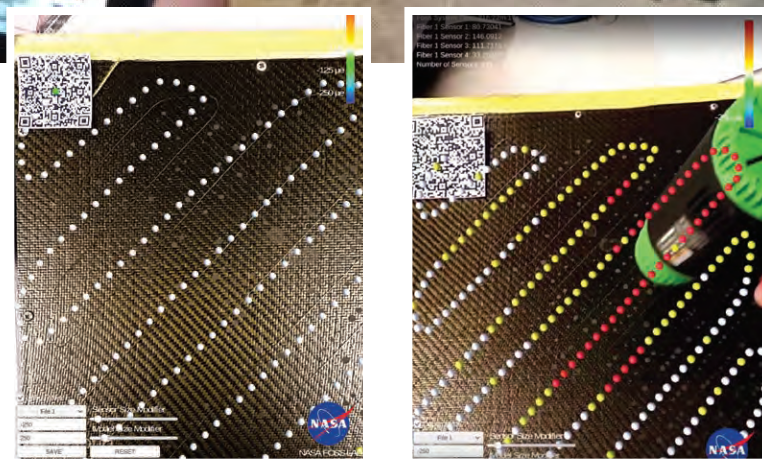


Figure 1 (above): Screenshot of the app.

Figure 2 (right): Display demonstrates how heating the real sensors with a heat gun causes augmented sensors to reflect the impact by changing color to red.

This research effort is working to visualize the individual measurements that Armstrong's patented Fiber Optic Sensing System (FOSS) provides in a way that helps users understand how to view and analyze the data.

FOARS is a mobile data visualization application that receives FOSS data via a wireless connection and then creates a 3D augmented version, superimposing it over a target image. Currently, users must review and analyze FOSS data via conventional methods such as with Excel® spreadsheet software or LabVIEW® programming, which require on-site computers. In contrast, the stand-alone FOARS app can be downloaded onto any mobile device for easy, portable use. The goal is for users to be able to interact with the app without support from the FOSS team.

Work to date: Work began in 2016. Resources from NASA's Center Innovation Fund provided a license for 3D gaming software and time to complete the work. The app was completed at the end of 2017 and is ready to be used as an additional feature to FOSS.

The current version reads an Excel file with information on xyz point locations to create the virtual model of the sensors (Figure 1) as well as the strain input data from the user. The QR code serves as location guidance in superimposing the model over the image of the actual sensors. The model changes color to display strain or temperature changes (Figure 2). In addition to real-time data visualization and analysis, the technology is useful for pretest assessments to ensure that fibers are in place and functioning correctly.

Benefits

- **Real-time visualization:** Enables users to quickly interpret FOSS data
- **Automated:** Creates color 3D augmented model with upload of target image files
- **Portable:** Works on a mobile device, without the need for a computer

Applications

FOARS can be used in all FOSS applications:

- Aerospace
- Energy
- Transportation
- Infrastructure
- Medical

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Appendix

X-57 Experimental Aircraft

NASA to Test New Propulsion Technology
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Supersonics Technologies

Shock-Sensing Probe to Study Sonic Booms
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Armstrong Prepares for Arrival of X-59 Quiet Supersonic Aircraft
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Flying Qualities for Low-Boom Vehicles
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Brian Ambelis | 661-276-7075 | Brian.A.Ambelisgonzalez@nasa.gov

Simulating Malfunctions of the X-59's External Vision System
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Using Schlieren Techniques to Understand Sonic Booms
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Ed Haering | 661-276-3696 | Edward.A.Haering@nasa.gov

Quantifying and Measuring Sonic Booms
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Ed Haering | 661-276-3696 | Edward.A.Haering@nasa.gov

Mitigating Sonic Booms
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Enhanced ADS-B System for Supersonics
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Supersonic Plasma Acoustic Reduction Concept (SPARC)
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Autonomous Systems

Artificial Intelligence for Object Recognition with Small UAS
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Improved Ground Collision Avoidance System (iGCAS)
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Resilient Autonomy
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Unmanned Aircraft System (UAS) Integration in the National Airspace System (NAS) Project
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Miniaturized Radar for Small Unmanned Aerial Systems (UAS)
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Technologies to Enable Urban Air Mobility
Curtis Hanson | 661-276-3966 | Curtis.E.Hanson@nasa.gov

X-56A Multi-Utility Technology Testbed (MUTT)

Multi-Utility Testbed Advances Aeroservoelastic Technologies
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Jeff Ouellette | 661-276-2152 | Jeffrey.A.Ouellette@nasa.gov
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X-56A Controllers Safely Stabilize Flutter
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Structural Dynamics Ground Testing Enables Model Validation
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System Identification for Flexible Aircraft
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Integrated Flight Dynamics and Aeroservoelastic Modeling and Control
Jeffrey Ouellette | 661-276-2152 | Jeffrey.A.Ouellette@nasa.gov

Fiber Optic Sensing System (FOSS)

FOSS Addresses Technical Challenges Across the Agency
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NASA's 'Rocket Box' FOSS to Fly on Launch Vehicles
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MicroFOSS Technology Leverages Low-Cost Components for High-Performance Tasks
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Temperature Sensing in Cryogenic Humid Environments
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Shideh Naderi | 661-276-3106 | Shiden.Naderi@nasa.gov

An Automated Switching Network to Enhance Structural Health Monitoring
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Fiber Optic Technology Enhances Tank Gauging Applications
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X-56A Research Leverages Fiber Optic Technology
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Tactile Sensing with Fiber Optics to Enhance Rovers
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Flight Loads Laboratory

Fixed Base Correction Method for Ground Vibration Testing
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Rachel Saltzman | 661-276-2906 | Rachel.Saltzman@nasa.gov

Soft-Support System for Ground Vibration Testing
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Rachel Saltzman | 661-276-2906 | Rachel.Saltzman@nasa.gov

X-57 Mod III Wing Ground Vibration Test
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Natalie Spivey | 661-276-2790 | Natalie.D.Spivey@nasa.gov

Flight and Ground Experimental Test Technologies

Armstrong Lends Flight Expertise to Pilot Safety Effort
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Lightweight Antenna Boosts Aircraft and Antenna Performance
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Pyrometer Improves In-Flight Temperature Measurements
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Airvolt Single Propulsor Test Stand
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Store Separation Structural Analysis and Test Development
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Improving Aerospace Vehicle Efficiency

PRANDTL-D Flying Wing
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New Propeller/Fan Increases Efficiency
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Glider Swarm Sensor Distribution
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Investigating Laminar Flow
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Spanwise Adaptive Wing Research
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Airborne Research Test System (ARTS) for Small Unmanned Aircraft
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Avionics and Instrumentation Technologies

Real-Time Parameter Identification
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Mechanoluminescent Materials for Structural Health Monitoring
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ARMD Flight Data Portal (AFDP)
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Atmospheric Science Team Supports Key Flight Missions
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Advanced Wireless Flight Sensor System
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Visual Radar
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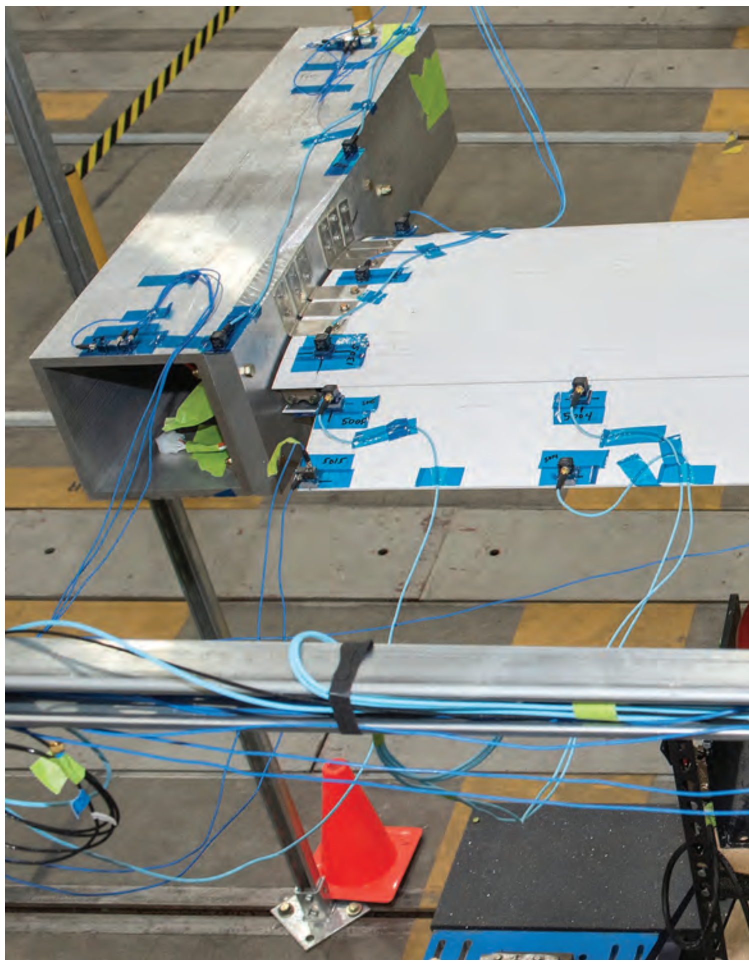

Ethernet via Telemetry (EVTM)
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Flight Test Instrumentation for Advanced Propulsion Systems
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Armstrong Operates and Maintains Flying Observatory
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Wireless Miniature Biosensor
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Space and Hypersonics Technologies

Textile-Based Load-Limiting Device for Mid-Air Retrieval
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Heat Flux Mapping System
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Quantitative Thermal Imaging Using Conventional High-Speed Video (HSV) Cameras
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Armstrong Contributes to Successful Artemis Launch Abort Test
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Virtual and Augmented Reality Techs

Using Virtual and Augmented Reality Platforms to Build Trust in Autonomous Systems
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Virtual and Augmented Reality Systems for Flight Research
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Aeronautics AR Educates Public on X-Plane Research
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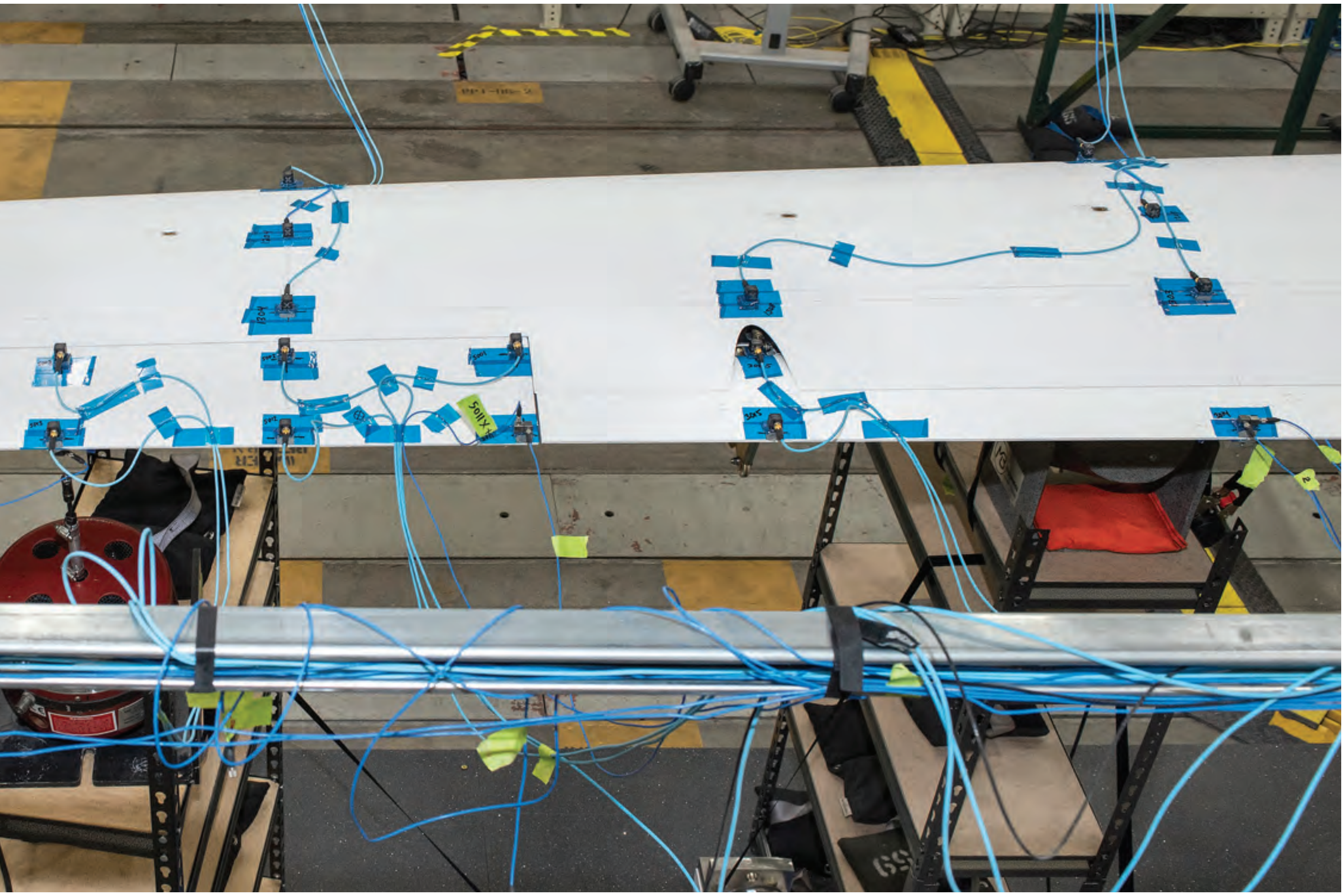

NASA Armstrong's PRANDTL-D1 is autographed by all the interns who have worked on the project. PRANDTL-D1 is being shipped to the Smithsonian Institution's National Air and Space Museum to be featured in its Innovations Gallery.

National Aeronautics and Space Administration

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