2021 Research and Development Annual Review

December 2022

U.S. Department of Transportation
Federal Aviation Administration

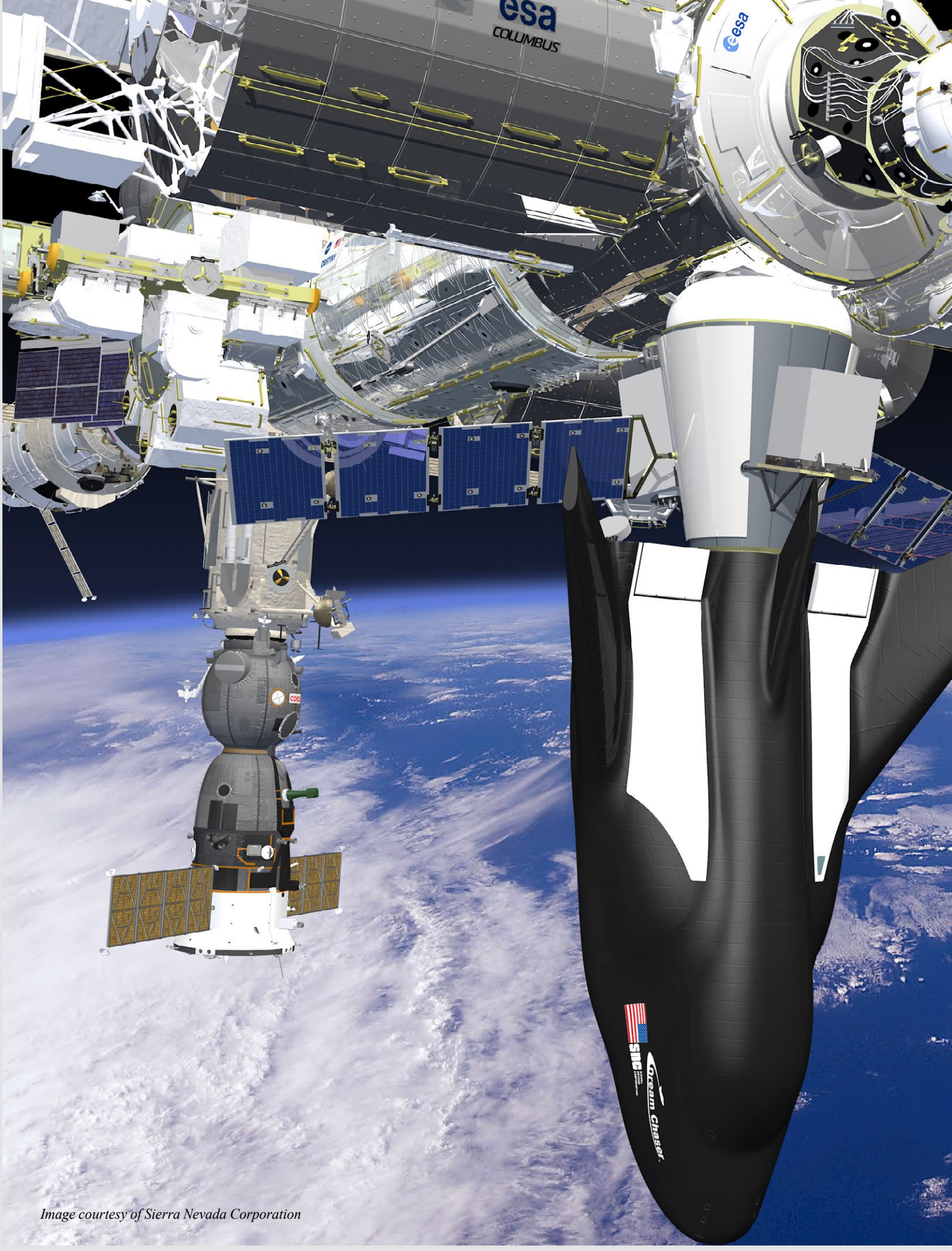


Image courtesy of Sierra Nevada Corporation

Contents

2021 Annual Review

February 2022

The Research and Development Annual Review is a companion document to the National Aviation Research Plan, a report of the Federal Aviation Administration to the United States Congress pursuant to section 44501(c)(3) of title 49 of the U.S. Code. This document is available online at *faa.gov/go/narp*.

Foreword

Aviation plays a central role in the business we conduct, the products we ship and receive, and the physical connectedness of our nation. While the United States has the largest and safest aviation system in the world, we also strive to have the cleanest and most environmentally-friendly system possible.

The FAA's Research and Development (R&D) Management Division is responsible for producing the congressionally-mandated National Aviation Research Plan (NARP) and this R&D Annual Review on behalf of the FAA Administrator.

The Annual Review is a companion document to the NARP. While the NARP is forward looking and describes planned research activities over the next five years, the Annual Review provides a snapshot of R&D work from the previous fiscal year, highlighting major accomplishments, R&D goals, and current fiscal year performance information.

FAA research and development supports National Airspace System (NAS) modernization by enabling technological, policy, and procedural advancements with a focus on safety and environmental responsibility. The FAA's robust R&D portfolio encompasses the aviation ecosystem from air traffic control; airport safety and inspections; and standards for airport design, construction, and operation to regulating flight inspection standards; and advancing satellite and navigation technologies.

Even as the agency continued to deal with a global pandemic in 2021, the FAA successfully advanced research on infrastructure improvements at airports and terminals, more efficient fuels and hybrid-electric propulsion, noise reduction in communities of concern, and improved weather prediction and mitigation strategies for the NAS.

Performance Results

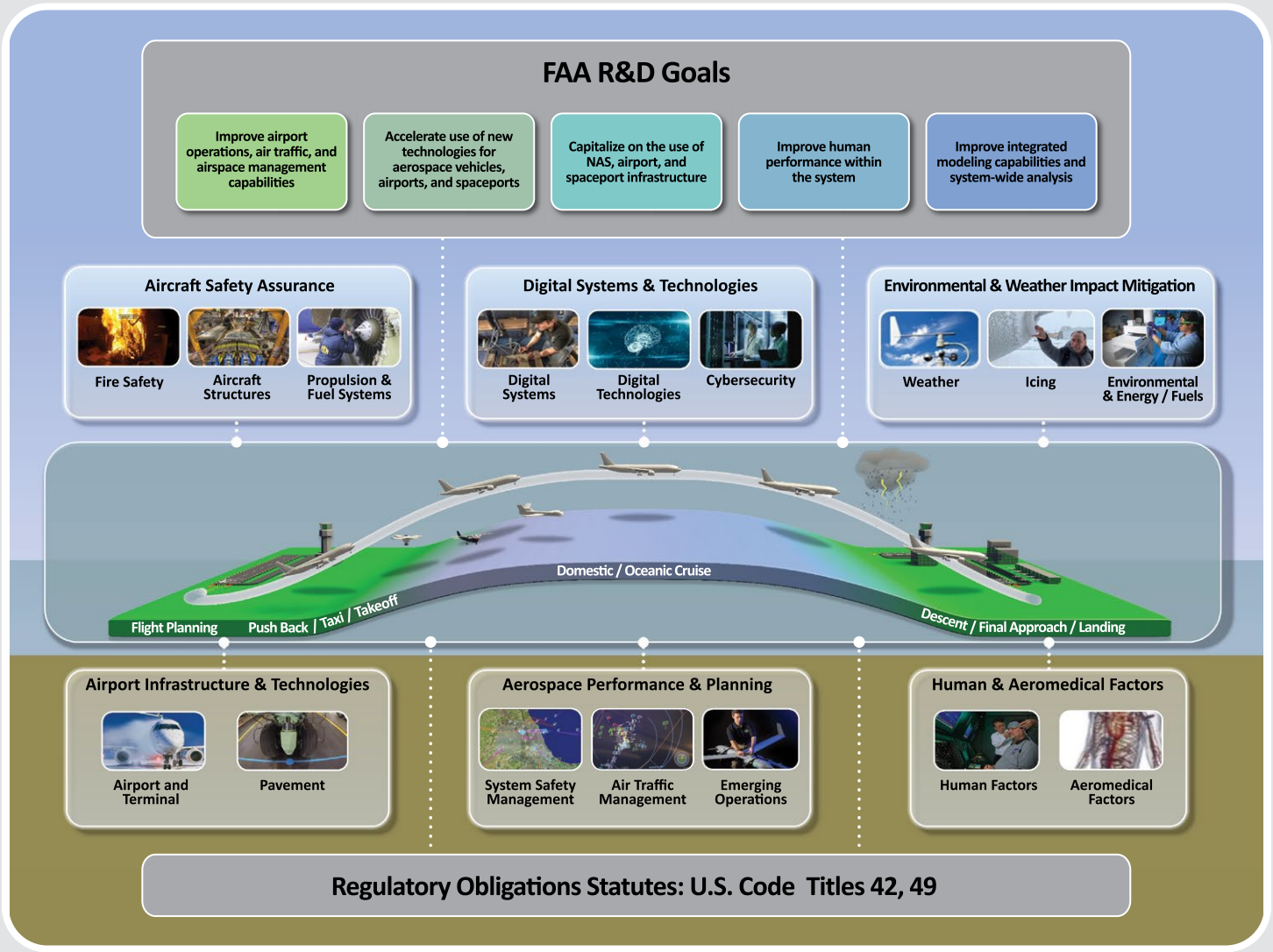
Overview

The FAA uses research and development (R&D) to support policymaking and planning, regulation, certification, standards development, and modernizing the National Airspace System (NAS). The FAA R&D portfolio supports day-to-day operations in the NAS and balances near-, mid-, and long-term aviation needs.

The following sections contain a description of FAA goals, status of research outputs planned for FY 2021, and success stories organized by goal. The output charts and success stories provide highlights of the research being performed, as well as snapshots of National Aviation Research Plan (NARP) output performance and key 2021 R&D results.

The FAA's R&D goals are focused on researching and identifying solutions for:

1. **Improving operations and management capabilities**
2. **Accelerating the use of new technologies**
3. **Capitalizing on infrastructure use**
4. **Improving human performance**
5. **Improving integrated modeling and system-wide analysis.**



This abstract graphic represents FAA research and development domain areas. White dotted lines indicate areas of impact before, during, and after flight. These connections are notional and not intended to be comprehensive.

Goal 1: Improve airport operations, air traffic, and air space management capabilities

Efficient airport operations, together with enhanced air traffic and airspace management capabilities, are key to maintaining the world's most complex airspace system. Research under this goal supports airport and spaceport systems/operations, air traffic management in the air and on airport surfaces, integrated weather information, aerospace vehicle operations, and noise and emissions management. This work also continues to integrate unmanned aircraft systems (UAS) and space vehicles into the NAS.

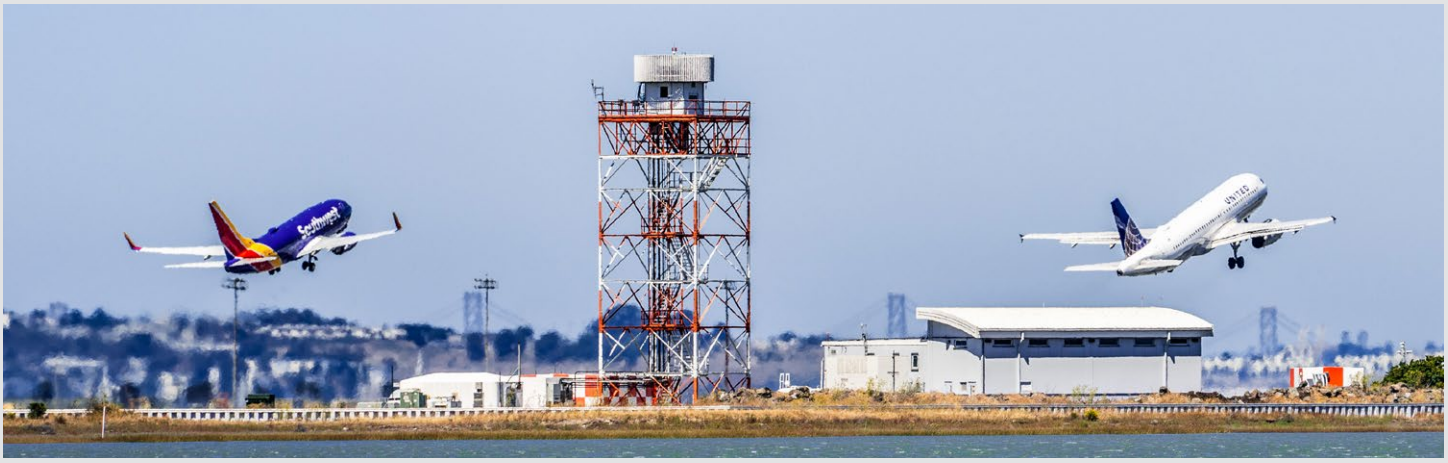
Goal 1 Research Activity Status and Success Stories

Strategic Flow Management Research Activity

Activity Name	Results	Status	FY 2022–2026 NARP Location
Performance Based Flow Management Sensitivity Analysis	Analysis to identify the impact of trade-offs among performance metrics for a given value of National Airspace System performance goals	Completed	Page 11

Closely Spaced Parallel Runway Research Activity

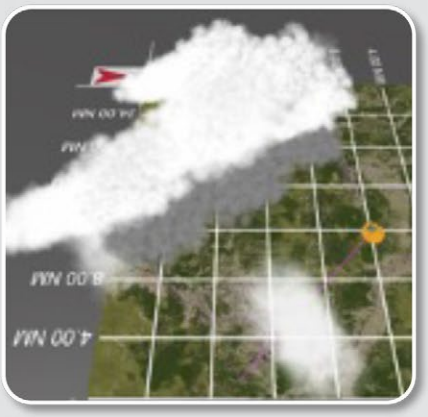
Activity Name	Results	Status	FY 2022–2026 NARP Location
Support the FAA's Air Traffic Organization in publication of a document change proposal for the Air Traffic Control Handbook	Reduces current separation standards for closely spaced parallel operations	Completed	Page 13



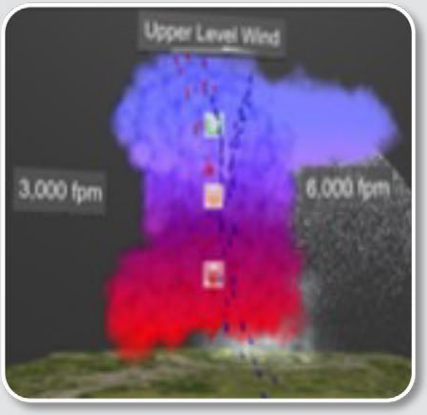
Augmented Reality Weather Training

The FAA completed a demonstration version of an interactive augmented-reality training program that enables pilots to experience the various stages of a thunderstorm. The software uses a three-dimensional thunderstorm model that runs on the WeatherXplore application. The prototype will be used to evaluate the benefits of incorporating interactive three-dimensional models for pilot weather training.

The WeatherXplore app displays a single-cell thunderstorm lifecycle visualization.



The WeatherXplore app features a scenario-based activity where a multi-cell thunderstorm impacts the decision to land at an airport.



Color, symbol, and number overlays are used to visually depict thunderstorm hazard information in the WeatherXplore app.

Rotorcraft Technology Dashboard and Development of Gap Resolutions

Under a grant from the FAA, the Partnership to Enhance General Aviation Safety, Accessibility, and Sustainability (PEGASAS), an FAA center of excellence, completed an analysis of rotorcraft technology and created a dashboard to develop gap resolutions.

The PEGASAS team also developed a lexicon for pilot reports (PIREP) based on more than 400 recordings. Pilots submit PIREPs to air traffic control towers or flight service stations to report weather conditions experienced during flight. These reports are important because they warn other pilots, flight service specialists, and air traffic controllers of potential weather hazards in a particular area, and they provide these observations for input into weather models to enhance the quality of forecasts.

Using the newly developed lexicon and machine learning, the team evaluated the concept of using multiple voice recognition systems to properly prepare PIREPs for submission. The goal of the project is to help increase the quantity, quality, and utility of PIREPs.

Weather Training Courses

Ten mini-weather training courses developed by the FAA continue to assist flight instructors in teaching weather. The lessons use augmented reality to enhance weather training as compared to conventional classroom instruction, which uses printed materials.

In the first quarter of FY 2021, the 10 mini-courses were transitioned to a YouTube channel, Western Michigan University's undergraduate curriculum, and other aviation schools and flight instructors for use. The YouTube channel reported that 24,977 visitors viewed at least one of the training sessions in FY 2021, while Western Michigan University reported that 230 undergraduate aviation students completed all of the lessons.

Industry groups have also shown interest in the courses, as evidenced by the leadership of the Malibu M-Class Owners and Pilots Association requesting FAA personnel to present multiple weather safety training forums at their annual convention.

Weather Cameras to Improve Visibility Estimates

Weather observation data is the backbone of accurate weather prediction and has a high impact on the aviation community. Researchers explored the concept of using visibility estimates derived from FAA aviation weather cameras (AvCams) to supplement traditional observations in Alaska. The visibility estimates used in the study were generated by the Visibility Estimation through Image Analytics (VEIA) algorithm, which identifies edges in AvCam images and compares the strength of those edges with a synthesized clear day image.

Developed by the Massachusetts Institute of Technology-Lincoln Laboratory and sponsored by the FAA, the VEIA algorithm utilizes the strong correlation between the edge strength ratio of the two images and the meteorological visibility to provide visibility estimates in locations where traditional meteorological observations are not available.

Study results suggest that the VEIA estimates can capture low-visibility conditions and have the potential to improve the surface analyses of visibility during instrument flight rules conditions in the Real-Time Mesoscale Analysis (RTMA), a tool used for weather forecasting.

Once operational, VEIA output will be available for integration into the RTMA or other weather models. Pending a successful safety risk management panel review, VEIA will be displayed directly on the *FAA weather camera* website as supplemental weather information for direct use by pilots, dispatchers, meteorologists, and flight service centers.

Localized Aviation Model Output Statistics Program

The National Weather Service (NWS) implemented upgrades to the Localized Aviation Model Output Statistics Program (LAMP), which included sky cover improvements sponsored and funded by the FAA.

LAMP is a statistical system that uses observations, model output statistics, and direct model output to provide guidance for aviation forecasting. The expanded sky cover guidance leverages data from the High-Resolution Rapid Refresh (HRRR) and Rapid Refresh (RAP) numerical weather prediction models in areas over the continental United States, Canada, Gulf of Mexico, as well as oceanic airspace. *LAMP guidance* is available on the web and is embedded in various tools on the NWS *Aviation Weather Center* site.

Aviation-focused Numerical Weather Prediction Models

The RAP and HRRR are the primary prediction models used in aviation. The FAA sponsored aviation-focused improvements to both models. RAP version 5 and HRRR version 4 provide safety benefits to the NAS, particularly in the general aviation community, by helping pilots avoid flying into adverse weather conditions. Major enhancements and improvements in 2021 included:

- **An extended forecast period from 36 to 48 hours in the HRRR**
- **New observation sources**
- **More accurate short-term convective weather forecasts**
- **Improved representation of lakes, leading to better precipitation predictions downwind of the Great Lakes**
- **Overall improved cloud representation**
- **Better upper-air and surface forecasts of temperature, humidity, and winds.**

Aviation applications that use RAP or HRRR include the Graphical Turbulence Guidance, current and forecast icing products, Traffic Flow Management Convective Forecast (TCF), Extended TCF for longer range convective forecasts, and Consolidated Storm Prediction for Aviation.

FAA funding and collaboration with the NWS on these numerical weather prediction models ensure that aviation users receive the benefits of NWS modeling upgrades to enhance the safety and efficiency of the NAS.

High Resolution Ensemble Forecast

The High Resolution Ensemble Forecast (HREF) is a collection of high-resolution weather prediction models that are packaged together to provide probabilistic and uncertainty information for the continental United States. Version 3 of HREF was implemented into NWS operations, eliminating poorer-performing models.

HREF version 3 provides improved convective weather forecasts along with other weather parameters. While operated and maintained by the NWS, the version 3 upgrade was sponsored and developed by the FAA. The NWS Aviation Weather Center website is relying more upon HREF as a contributor to the TCF, a tool used by air traffic managers in their daily coordination of the NAS.

Goal 2: Accelerate the use of new technologies for aerospace vehicles, airports, and spaceports

The advancement and introduction of non-traditional aviation industries are pushing the boundaries of technology into all corners of the NAS. Research under this goal supports applied innovation that identifies and demonstrates new aerospace vehicle, airport, and spaceport technologies; certificating and licensing of aerospace operators and vehicles; the study of alternative fuels for general and civil aviation; and provides decision makers essential data to analyze that will shape the future of the NAS.

Goal 2 Research Activity Status and Success Stories

Supersonic Aircraft Research Activity

Activity Name	Results	Status	FY 2022–2026 NARP Location
Assess aircraft technology and modeling	A technology-level and flight-level workshop, the assessment of mission specification changes, and a fleet demonstration	Completed	Page 23

UAS Detection at Airports Research Activity

Activity Name	Results	Status	FY 2022–2026 NARP Location
Install and test 10 unmanned aircraft systems (UAS) detection and mitigation technologies at Atlantic City International Airport	Analysis of technology performance against live UAS targets	Delayed	Page 24

Support U.S. climate goals for 2030

On September 9, 2021, the White House held a sustainable aviation event where government and industry leaders discussed actions to coordinate innovation across the federal government and with aircraft manufacturers, airlines, fuel producers, airports, and nongovernmental organizations to advance the use of cleaner and more sustainable fuels in American aviation.

These actions will support progress toward U.S. climate goals for 2030 and are essential to working toward a fully zero-carbon aviation sector by 2050. The goals set forth by President Joe Biden during the event were based in part on FAA research — including data and tools agency researchers developed to analyze the environmental performance of the NAS, both historically, and in response to projected future scenarios.

Flight crew medical standards and spaceflight participants medical acceptance guidelines

The FAA's Center of Excellence (COE) for Commercial Space Transportation in collaboration with the University of Texas-Medical Branch, Baylor College of Medicine, FAA's Civil Aerospace Medical Institute, and the Mayo Clinic (in Jacksonville and Scottsdale) — performed research to improve operational spaceflight safety. Results of the research are detailed in the report titled, "Flight Crew Medical Standards and Spaceflight Participants Medical Acceptance Guidelines for Commercial Space Flight."

As part of this work, FAA researchers studied common medical conditions present in populations representing the general public (non-crew), as well as the effects of radiation on implanted electronic devices and wearable biomedical equipment for spaceflight participants. Current regulations require a class two medical certificate for spaceflight crew pilots. This report suggests that operators should require the more stringent class one certificate.

The report is being used as a baseline around the world and is a primary source of information to develop guidance, screening criteria, and standards for spaceflight participants. Additionally, many of the researchers who helped develop this guidance report to the aerospace industry are now heading research organizations and operators' medical groups.

In addition, several of the COE's reports on medical guidance and standards for crew and spaceflight participants were used as the primary source to inform the report to Congress titled, "*FAA Evaluation of Commercial Human Spaceflight Safety Frameworks and Key Industry Indicators*." The standards being proposed to the FAA by ASTM International's committee on commercial spaceflight will be based on this congressional report.

Unmanned Aircraft Systems Detection at Airports

Researchers completed construction of a temporary UAS detection and mitigation test complex at the FAA's William J. Hughes Technical Center. The site consists of six trailers that will house detection and mitigation equipment used by vendors and provide workspaces for researchers to conduct testing.

The FAA also selected four airports to serve as hosts for the UAS detection and mitigation program. The airports are Syracuse Hancock International Airport in New York; Rickenbacker International Airport in Ohio; Huntsville International-Carl T. Jones Field Airport in Alabama; and Seattle-Tacoma International Airport in the state of Washington.

Continuous Lower Energy, Emissions, and Noise Phase II

During FY 2021, a number of companies completed their environmental aircraft technology research and development activities under the Continuous Lower Energy, Emissions, and Noise (CLEEN) Phase II program, contributing to the achievement of the FAA's environmental goals for NextGen modernization.

- **Advanced Aerodynamic Designs – The Pratt & Whitney company delivered fuel efficiency benefits to engines through the development of advanced aerodynamic designs for engine compression and turbine systems. From 2016 through 2020, these technologies were designed, prototyped, and rig tested, proving their viability and benefits. These technologies are estimated to provide a two-percent fuel burn reduction and are now available for Pratt & Whitney to use in a number of upcoming geared turbofan engine designs and improvement packages.**
- **Sustainable Aviation Fuels – The Rolls-Royce company completed studies of drop-in sustainable aviation fuels. The testing supported the advancement of new fuel pathways for approval and use in current jet engines and other aircraft. These new pathways provide opportunities for lower life-cycle emissions. The Rolls-Royce CLEEN Phase II sustainable aviation fuel program has succeeded in promoting the introduction of a viable 100-percent sustainable aviation fuel as a possible future candidate fuel.**
- **Engine Nacelle and Inlet Technologies – Collins Aerospace researchers focused on the development of technologies for engine nacelles and inlets, including innovative noise-reducing liners that also decrease drag and save fuel. The combined technology package will provide a one-percent reduction in fuel burn and a two-decibel decrease in certification noise levels while also enabling quiet and efficient ultra-high bypass engines.**

The work under CLEEN significantly matured these technologies, some of which are already being incorporated into future product designs to provide benefits to the fleet in the coming years.

Helicopter Noise Abatement

The FAA, in conjunction with NASA and the U.S. Army, conducted 10 separate evaluations of helicopter noise. The goals of the project were to develop noise abatement procedures to reduce community annoyance, and acquire data to improve and validate helicopter noise models. Researchers at NASA and the FAA's Center of Excellence for Alternative Jet Fuels and Environment are working with researchers at Pennsylvania State University to develop the models.

The NASA-authored paper resulting from this research titled, "Development and Validation of Generic Maneuvering Flight Noise Abatement Guidance for Helicopters," was named by the Vertical Flight Society (VFS) as best paper for the acoustics sessions and best overall paper at the VFS annual forum in October 2020. The report describes an extensive flight test campaign conducted over multiple years to develop actionable advice to help helicopter pilots reduce their acoustic footprint.

Fire and Research Safety

The National Fire Protection Association accepted two FAA research papers on the topic of automatic fire detection for dissemination at the association's international conference. This well-regarded annual event provides a forum to discuss the latest developments in research, technology, and applications for the fire protection community.

The first of the two papers detailed work on characterizing the transport of artificial smoke generators, which are used to show compliance with *14 CFR 25.858* and *Advisory Circular (AC) 25-9A — Smoke Detection, Penetration, and Evacuation Tests and Related Flight Manual Emergency Procedures*. This work is being used by the Cargo Smoke Detection Task Group in an effort to standardize current smoke detector certification methods.

The second paper detailed work to improve test methods for characterizing the flammability hazards associated with lithium-ion batteries. The two papers were published as part of the conference proceedings and were presented at the event in Duisburg, Germany.

Microscale Combustion Calorimeter

Researchers continue to find applications across many industries for the FAA's patented microscale combustion calorimeter (MCC), a tool originally developed to test the flammability of aircraft materials and improve fire safety. The device allows scientists to conduct high-temperature (greater than 1300 °C) combustion experiments of fire gases at controlled fuel/oxygen ratios.

Scientists at Germany's Federal Institute for Materials Research and Testing published a study in which the MCC was compared to several other more prevalent and established methods to detect and quantify microscopic plastic particle contamination (microplastics) in the environment. Results showed that compared to the other methods, the MCC could be used as a fast and simple screening method for the identification and quantification of a potential microplastic load of standard polymers in unknown samples.

Researchers noted that the plastics exhibited high heats of combustion, but the environmental samples did not, resulting in little interference with the measurement from the background. This research was published in Volume 152 of the Journal of Analytical and Applied Pyrolysis, 2020.

The FAA filed U.S. Patent Application Number 16/840,556 with the U.S. Patent and Trademark Office for the MCC in April 2020. This patent application is directed to measuring the toxins generated by cabin materials over a full range of conditions in aircraft cabin fires, from early stage (oxygen rich) to late stage (oxygen starved), where toxic gases are produced.

Lithium Batteries and Hazardous Materials Transport

Thermal runaway is a chemical reaction within a battery cell that results in a dramatic, uncontrolled increase in temperature and pressure. Thermal runaway in lithium battery cells has resulted in numerous fires. FAA personnel, along with representatives from Underwriters Laboratories (UL), lithium battery experts, battery-package manufacturers, and others participated in the development of a new standard adopted by UL to address this issue onboard aircraft.

UL-5800 is a consensus-based standard for containment bags used to hold personal electronic devices that can undergo thermal runaway such as laptops, phones, and tablets. The standard is intended for aircraft applications and includes fire test requirements.

Many airlines use containment devices that do not adhere to any specified standards, so information is limited as to their effectiveness. The new standard will provide consistency across the airline industry and assurance that approved containment bags are safe for use onboard aircraft.

In related work, the FAA published a new *Cargo Risk Mitigation* website in support of *AC 120-121 – Safety Risk Management Involving Items in Aircraft Cargo Compartments*. The new website integrates information relevant to hazards, risks, and mitigation strategies related to transporting hazardous goods by aircraft. This information will help airlines and air cargo operators improve their safety management system programs, further assess and mitigate the risks onboard aircraft, and develop enhanced methods to screen and report such items.

Laptop computers are among several types of personal electronic devices that can catch fire due to thermal runway in the batteries that power the equipment.

The FAA is studying containment equipment used onboard aircraft to store personal electronic devices that have the potential to undergo thermal runaway.

Onboard Inert Gas Generation System

In July 1996, TWA Flight 800 experienced a fuel tank explosion, killing all 230 passengers and crew onboard. Following this tragedy, the FAA's Fire Safety Research Branch committed significant resources to further the knowledge of aircraft fuel tank flammability and potential mitigation methods to prevent a similar accident from occurring again.

The work included tests to evaluate jet fuel vapor flammability characteristics and the resulting limiting oxygen concentration (the level of oxygen that prevents ignition) throughout the flight profile, fuel tank ignition sources, and a variety of fuel tank inerting methodologies.

This research culminated in flight testing of a prototype Onboard Inert Gas Generation System that renders the fuel tank non-flammable through the use of hollow-fiber membrane technology that creates nitrogen-enriched air.

The research supported the development of the Fuel Tank Flammability Reduction Rule, which was published in July of 2018. The rule requires owners of aircraft deemed to be at risk of a fuel tank explosion to use the FAA's Fuel Tank Flammability Assessment Method to reduce fuel tank ignition sources and flammability exposure.

Based on this rule, and following the agency's analysis of fuel system reviews conducted by the manufacturer, the FAA issued a series of airworthiness directives in October 2020 affecting more than 300 Boeing 747s and 767s. The agency issued the directives to prevent ignition sources inside the center fuel tank, which in combination with flammable fuel vapors could result in a fuel-tank explosion and consequent loss of the airplane. The airworthiness directives provide 72 months for the manufacturer to modify the fuel quantity indication systems in the affected airplanes.

Piston Aviation Fuel Initiative

Over 170,000 piston-engine general aviation aircraft currently in use rely on aviation gasoline (avgas) for safe operation, the only remaining transportation fuel in the United States that contains lead. The lead additive creates the very high-octane levels required to prevent detonation (engine knock) in high-power aircraft engines. Operating an aircraft with inadequate fuel octane can result in engine failure and aircraft accidents.

The FAA, fuel suppliers, and aerospace manufacturers continue to develop high-octane, unleaded fuel formulations. The goal of this effort is to identify a fuel that provides an operationally safe alternative to leaded avgas. The FAA's William J. Hughes Technical Center is providing engine-testing services through Cooperative Research and Development Agreements with individual fuel companies.

Researchers completed comparative detonation onset testing with four unleaded fuel candidates, each formulated to a different supercharge performance number per ASTM International D909 standards, as well as a 100-octane low-lead minimum specification reference fuel.

One of the fuel companies is using the data to support their efforts to refine fuel formulation for Piston Aviation Fuel Initiative qualification testing and to meet the objectives of section 565 of the FAA Reauthorization Act of 2018, which requires the FAA Administrator to authorize an unleaded replacement fuel for general aviation upon determining there is a qualified, safe alternative.

STEM Outreach

The Association for Unmanned Vehicle Systems International showcased the "STEM: Helping Aviation Skills Take Root" panel at the FAA UAS Symposium. Representatives from the University of Alaska-Fairbanks, University of Alabama-Huntsville, and the FAA hosted the panel focused on the ongoing efforts by the FAA's Center of Excellence for UAS to bring practical knowledge and hands-on experience to populations underrepresented in Science, Technology, Engineering, and Math (STEM) fields.

University of Alabama representatives described their educator-based approach of "teaching the teachers," which will yield results for many years to come by developing curricula and lesson plans for educators. The speaker from the University of Alaska focused on the school's rural outreach and the unique regional qualities that affect not only students but also families and elders living in rural Alaskan cities.

Despite challenges associated with the pandemic, these efforts are just a sampling of work the center of excellence is doing to reach populations underrepresented in STEM and the aerospace industry.

Goal 3: Capitalize on the use of NAS, airport, and spaceport infrastructure

A durable, long-life, and resilient infrastructure forms the backbone of an efficient, safe, and secure NAS. Research under this goal includes airport runways, taxiways, air traffic management, and aircraft systems and networks, as well as electrical airport sub-infrastructures and lighting.

Research focuses on increasing the useful life of this infrastructure and decreasing maintenance and repair costs, NAS operations recovery from disruptive events, and cybersecurity research that protects and defends FAA systems from both internal and external threats due to rapid advances and sophistication of cyber-attacks.

Resulting research will lead to a longer-lasting, lower-cost, dependable infrastructure defended against cyber events.

Goal 3 Research Activity Status and Success Stories

Activity Name	Results	Status	FY 2022–2026 NARP Location
No Activities were scheduled for completion in FY 2021			

Aqueous Film Forming Foams

Airports are required to have a minimum supply of fire extinguishing agents — known as Aqueous Film Forming Foams (AFFF) — available at all times for use in emergency situations. Some of the chemicals used in AFFF, such as fluorine, may be of concern for the environment and human health. The FAA has been conducting research over the past few years to find an AFFF alternative.

The COVID-19 pandemic forced the FAA to stop testing in March 2020. The agency quickly created a plan to resume research and ensure the delay did not impact congressional deadlines for this work. By following all appropriate health and safety guidelines, using a limited number of staff at the testing facility, and making use of remote heat-resistant cameras to manage and monitor progress of the testing, this critical research resumed and has continued through FY 2021.

Researching Expandable Variable Autonomy Architecture for General Aviation Use

The FAA is collaborating with NASA to incorporate the Expandable Variable Autonomy Architecture (EVAA) into general aviation aircraft. EVAA is an enhanced autopilot system that uses an embedded Automatic Ground Collision Avoidance System and an Airborne Collision Avoidance System. The technologies have been successfully installed in all U.S. Air Force F-16 Falcons.

Researchers use a Cozy MK IV aircraft to test the Expandable Variable Autonomy Architecture, an enhanced autopilot technology for general aviation.

Researchers integrated EVAA hardware into a general aviation test aircraft. Initial flight tests have determined that the EVAA software is compatible with the general aviation test platform. The goal of this effort is to test the feasibility of using the autopilot technology in general aviation aircraft and developing certification paths for its use.

Cybersecurity for Flight Deck Data Exchange

The Flight Deck Data Exchange program assesses cybersecurity risks and data exchange formats to enable enhanced and secured transmission of information between onboard avionics and ground systems. The FAA published a paper titled, "Cybersecurity for Flight Deck Data Exchange," for the Digital Avionics Systems Conference. The concepts and findings captured in the document provide the basis for future research that could be applicable to many programs that depend on internet protocol data link between aircraft and ground systems.

The security controls and architecture proposed in the paper provide a high-level approach to mitigate vulnerabilities that can be introduced through Electronic Flight Bag applications, which are used to exchange safety and other important information with ground systems.

Air-Ground Trajectory Synchronization

The Air-Ground Trajectory Synchronization (AGTS) program improves operational predictability and strategic management of air traffic by synchronizing trajectory data between NAS systems and the aircraft. This research will lead to increased situational awareness and efficiency in the overall system. FAA researchers completed the AGTS 1.0 prototype, which focuses on the Traffic Flow Management System. The agency successfully transferred the technology, materials, and components to the FAA's William J. Hughes Technical Center.

The AGTS program also completed a benefits analysis through simulation activities and presented the results to project sponsors. The identified solutions will provide key trajectory information for any given flight in the NAS.

Accurate aircraft trajectory data allows traffic flow managers to more efficiently plan and strategically manage air traffic.

Goal 4: Improve human performance within the system

Advanced technologies and capabilities challenge human operators and maintainers, including aircraft and UAS remote pilots, cabin crew, maintenance personnel, air traffic controllers, and others.

The impact of design, technology, new concepts of operation, and physiological and psychological stressors can have a profound effect on human performance, which can result in less than optimal responses during normal and emergency events.

Research in this goal area seeks to optimize human performance through capability assessments, training, and operational evaluations. Activities address human and medical factors related to an individual's ability to meet flight demands. Optimized human performance is fundamental to the safe operation of the NAS and inherent to the safety of the aerospace community, especially the flying customer, who relies on the FAA to provide the safest air transportation system in the world. Research includes passenger safety in flight and during emergencies.

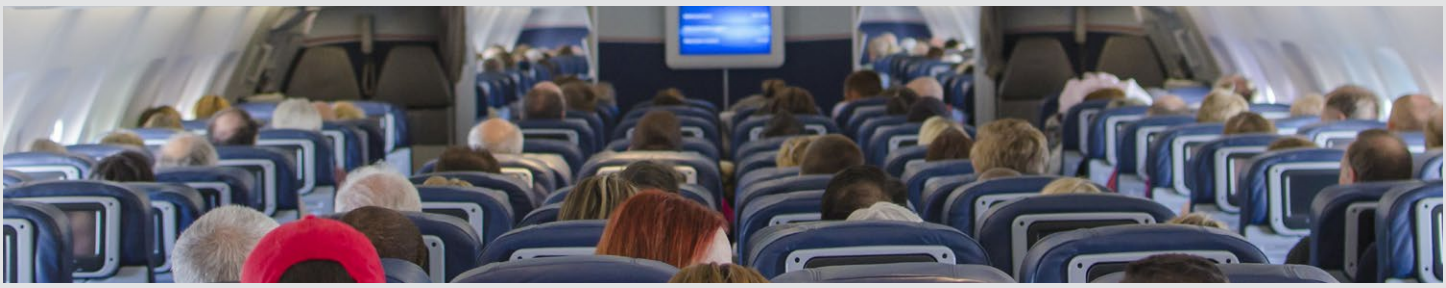
Goal 4 Research Activity Status and Success Stories

Seat Pitch and Width Research Activity

Activity Name	Results	Status	FY 2022–2026 NARP Location
Distribute a draft report/ summary document on the effects of seat pitch and width minima and passenger exit times	Socialization of research results	Completed	Page 36

Airliner Cabin Environment Research Activity

Activity Name	Results	Status	FY 2022–2026 NARP Location
Assess the current state of tools, and plan engine stand and instrument package tests	Identification of sensor technologies to detect cabin air contamination	Completed	Page 39



Effects of Airplane Cabin Interiors on Passenger Egress

The ability of passengers to move from their seats to available exits in an emergency is a key element of occupant safety. Airliners currently in service have seating arrangements with a variety of seat pitches and widths, which may have an impact on evacuation time.

Using the FAA's Civil Aerospace Medical Institute's (CAMI) Flexible Cabin Simulator, researchers conducted 48 evacuation trials using a total of 775 research subjects. Research evaluated the effects of seating arrangement, as well as the impact of an occupant's size, form, and functional capacity on the time it takes to exit the aircraft.

The results were summarized in a draft report in 2021. In accordance with the FAA Reauthorization Act of 2018, section 577, data derived from this work will help the agency create regulatory standards and requirements for minimum aircraft seat pitch and width.

Transport of COVID-19 Vaccines

Since the onset of the COVID-19 pandemic, the FAA has worked proactively with other U.S. government agencies, air carriers, and aviation stakeholders to ensure the safe transport of personnel and critical medical supplies onboard aircraft, including COVID-19 vaccines. The FAA's Office of Aviation Safety worked with CAMI to create guidance, recommendations, and documentation for the safe transport of large amounts of dry ice to safely store and ship COVID-19 vaccines. This included the publication of Safety Alerts for Operators, safety guidance, and recommendations for large Part 121 air carriers and small aircraft.

Development of Airbag Certification Requirements

As with automobiles, airbags can provide significant protection for aircraft passengers during crashes. Airbags have the potential to increase the level of occupant safety. Deployment of and passenger interaction with an airbag can also introduce injury risks that were not present in aircraft seats with conventional restraint systems. Airbags that deploy from seat belts have been used in aircraft for many years. In response, the FAA issued special conditions defining certification requirements to minimize potential injury risks.

Aircraft manufacturers are now proposing the use of airbags that deploy from the aircraft structure. CAMI researchers were able to draw on knowledge gained through their extensive research related to injury biomechanics to recommend certification criteria to mitigate injury risks posed by the introduction of these new airbag designs. These criteria may be utilized by FAA policymakers to create initial requirements for approval of structure-mounted airbags in transport aircraft seats.

Airliner Cabin Environment (Air Quality)

Reports of cabin air contaminants can often be linked to fluids being ingested into the engine, drawn into the air supply, and distributed throughout the cabin and flight deck. Smoke, odors, and fumes can enter the environmental control system used for ventilation, pressurization, and temperature control of the airplane.

Research activities completed in 2021 related to the cabin environment in passenger aircraft include: assessing the current state of knowledge of airplane bleed air contaminants,

specifically those resulting from engine oil, hydraulic fluid, and deicing fluids; establishing partnerships and collaborating with industry working groups; and planning engine stand and sensor instrument package tests. Outputs included: multiple interim reports that were consolidated into a final report, a research protocol to conduct engine stand and sensor instrument package tests, and recommendations for sensor technologies to detect airplane cabin air contamination.

Air Traffic Controller Virtual Training

CAMI researchers conducted a study to assess the characteristics of successful air traffic controller trainees. During the pandemic, CAMI collaborated with the FAA Academy to transition data collection from an in-person format to an online survey platform. This transition enabled data collection to continue while upholding safe social distancing practices.

Researchers are using data collected through the online survey to evaluate new virtual air traffic controller training courses at the academy by assessing perceptions of the virtual learning environment, technology use, and trainee success. This information will be used to develop future virtual training programs, and help researchers provide recommendations and best practices for air traffic controller training.

Standard Terminal Automation Replacement System Display Research

The FAA has long been interested in the use of color on air traffic controller displays. The Standard Terminal Automation Replacement System (STARS) gives air traffic controllers a complete, precise picture of the airspace, enabling them to manage the aircraft they are tracking.

Controllers use STARS to provide air traffic control services in the airspace immediately surrounding major airports, including separation and sequencing of air traffic, conflict and terrain avoidance alerts, weather advisories, and radar vectoring for departing and arriving traffic.

FAA human factors experts developed a rigorous process for selecting, evaluating, and implementing colors for new STARS functions and capabilities, such as Terminal Sequencing and Spacing numbers, which are used for scheduling and metering capabilities. This research leveraged standards, guidance, and expertise developed through the R&D program and will lead directly to STARS system specifications and requirements that follow human factors best practices and improve controller performance and safety.

Goal 5: Improve integrated modeling capabilities and system-wide analysis

Research associated with this goal includes developing a scientific understanding of aerospace systems used to develop NAS improvements; analytical and predictive capabilities used in the capture, parsing, analysis, and sharing of data; and a toolset to evaluate NAS system-wide performance, especially given the introduction of new and emerging technologies. This work will enable NAS effectiveness in delivering the highest quality service to the greatest number of stakeholders in a timely, safe, and practical manner. Integrated modeling capabilities and system-wide analyses will facilitate the FAA's ability to produce state-of-the-art quantitative and qualitative analyses of complex systems. Work in this goal area improves the robustness, adaptability, flexibility, and accuracy of these integrated analytical and computational modeling tools.

Goal 5 Research Activity Status and Success Stories

Activity Name	Results	Status	FY 2022–2026 NARP Location
No Activities were scheduled for completion in FY 2021			

Disinfecting Aircraft Seating

As a result of the COVID-19 pandemic, aircraft owners and operators have increased the frequency that aircraft interiors are disinfected, including areas not previously cleaned. Although this process is not directly related to aircraft airworthiness, too frequent or improper application of these disinfecting chemicals could result in negative impacts, including corrosion, embrittlement, increased flammability, and electrical short circuits.

The FAA completed phase one of testing and evaluation to research the effects of disinfecting materials and methods on aircraft performance. Research focused on the impacts of disinfecting fluids on aircraft seating materials. Researchers conducted tensile testing on polymer and webbing materials, as well as flammability testing on all materials. Results were published in FAA technical reports and shared with the aviation industry and the general public.

Emerging Metallic Structures Technology Fuselage Testing

The FAA, in partnership with Arconic and Embraer S.A, is investigating safety and structural integrity issues related to emerging metallic structures technology (EMST) applied to fuselage structures.

Aircraft manufacturers are increasingly using emerging metallic structures in new aircraft designs, including advanced alloys and hybrids, which are stronger and lighter than metals commonly used to build older aircraft. These new technologies, and the risks they pose as they age, are not as well understood as the traditional systems they replace.

Using the FAA's Full-Scale Aircraft Structural Test Evaluation and Research fixture, researchers were able to make comparisons to companion panels made with varying emerging technologies. All phases of fatigue testing for EMST panel 2 (constructed using advanced aluminum-lithium) were completed and compared to the baseline fuselage (composed of conventional materials developed through traditional processes).

For the damage scenarios considered, the advanced fuselage panel exhibited an improvement of approximately 30 percent in fatigue life compared to the baseline panel. Data from this research will support certification and continued airworthiness of these emerging materials, structures, and fabrication methods.

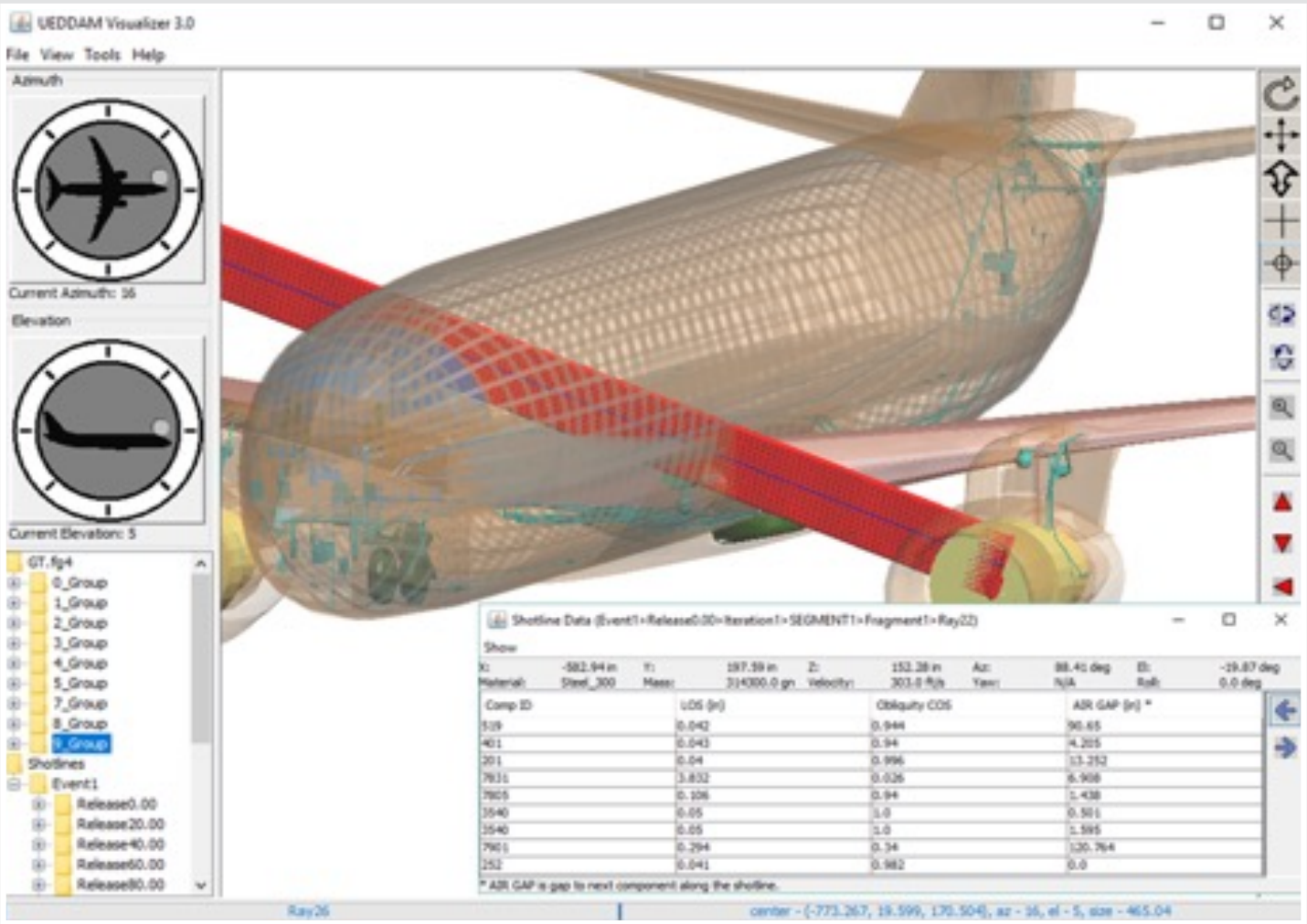
Uncontained Engine Debris Damage Assessment Model

Uncontained engine failures occur when high-energy rotating parts inside a jet engine fail — breaking into fragments that escape the engine case and impact other parts of the aircraft. Although these events are rare, uncontained failures continue to occur, posing a serious threat to the safe return of the aircraft. FAA regulations require that manufacturers must take design precautions to minimize the hazards to the airplane in the event of an uncontained engine failure.

Through an interagency agreement with the Naval Air Warfare Center, the FAA developed the Uncontained Engine Debris Damage Assessment Methodology (UEDDAM) software package to aid in the complex task of evaluating and mitigating aircraft vulnerability to uncontained engine debris. UEDDAM allows the user to tailor the analysis to their particular aircraft and engine configuration, automates complex hazard analysis calculations, and presents the data in a graphical visualizer — helping the user identify vulnerable critical systems.

Design improvements can be simulated using UEDDAM to see if protection through repositioning, shielding, or additional redundancy can further reduce the safety threat. This software tool was recently released as version 6 with upgraded features, including the capability to model the simultaneous impact of multiple different size fragments.

UEDDAM version 6 was demonstrated in a joint training session held with industry and FAA representatives in March 2021. The new version was also applied to a generic twin-engine aircraft vulnerability analysis using the latest uncontained engine debris fragment model, which incorporated recent in-service data.



Version 6 of the Uncontained Engine Debris Damage Assessment Methodology software provides researchers with aircraft visualizations.

Remote Oceanic Meteorological Information Operational

The Remote Oceanic Meteorological Information Operational (ROMIO) viewer provides revolutionary inflight access to real-time weather depictions, rapidly updated convective weather information in oceanic regions, and advanced warnings to pilots of convective hazards along their route of flight to enhance safety and route efficiency. The satellite- and lightning-based convection hazard products provide coverage in regions without ground-based weather radar.

The FAA recently demonstrated strategies and benefits of using rapidly updated Cloud Top Height and Convection Diagnosis Oceanic products through ROMIO. A benefits analysis showed ROMIO provided an average of 10 minutes of additional time to plan weather deviations when compared to using onboard weather radar. This resulted in increased margins of safety from convective weather. These updates will be used by aircrew, air traffic controllers at en route centers for oceanic airspace, and for airline flight dispatch operations.

Researchers also concluded that ROMIO reduced emissions by saving an average of 355 pounds of fuel per flight, or roughly 6.8 million pounds of fuel annually. Unsolicited feedback from pilots using ROMIO was extremely positive on its safety and efficiency benefits.

The Cloud Top Height and Convection Diagnosis Oceanic products compare the forward-looking view of the onboard weather radar (red half circle) to the expanded view provided by the Remote Oceanic Meteorological Information Operational (ROMIO) viewer. The planned flight route is shown by the magenta line. The aircraft position was determined using FlightAware.

The ROMIO viewer is displayed on an iPad as it would look in the aircraft in night mode.

Partnerships

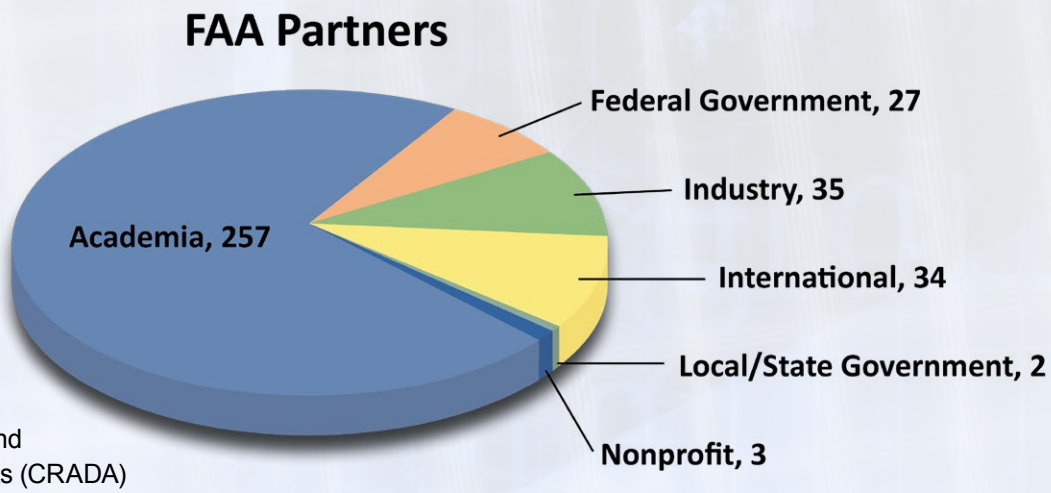
In pursuit of the agency's mission, the FAA maintains partnerships with over 350 stakeholders representing federal agencies, academia, industry, international entities, and technical societies.

358 Total Legal Vehicles

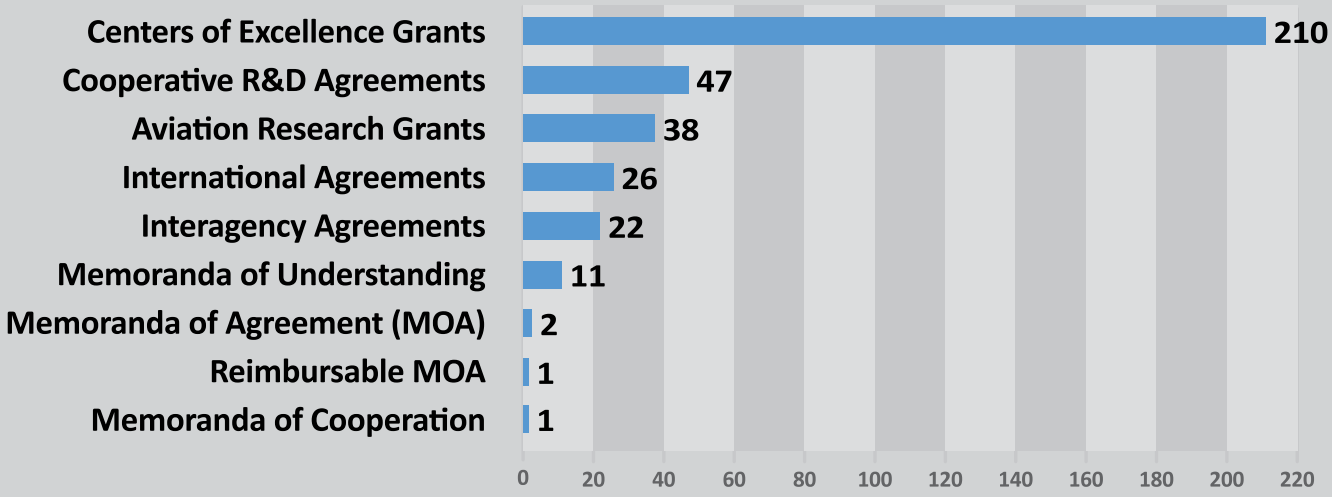
142 Unique Stakeholders

The FAA's partners include aircraft and parts manufacturers, design and engineering companies, nonprofits, external testing facilities, domestic and international organizations, and representatives of large and small businesses.

Due to wide-ranging research needs and partnering opportunities, the FAA uses a variety of available mechanisms. These include grants, interagency agreements, memoranda of cooperation, memoranda of agreement (MOA), reimbursable agreements, and other vehicles. The agency also leverages unique opportunities offered by Cooperative Research and Development Agreements (CRADA) to enable many of these partnerships.



FAA Legal Vehicles



Federal, Interagency, and Nonprofit

The FAA leverages the research capabilities of federal partners and nonprofit organizations to advance national and aviation objectives through interagency and reimbursable agreements.

Federal Partners

In FY 2021, the FAA maintained 27 active agreements with federal partners. These included NASA, representing the agency's largest collaborator with 14 agreements, the Department of Defense with six agreements, and the National Transportation Safety Board with two agreements. The FAA held individual agreements with the Department of Agriculture, Department of Energy, Department of Justice, Department of Transportation, and the Smithsonian Institute.

22	Interagency Agreements
3	Nonprofit Agreements
2	Memoranda of Agreement (MOA)
1	Memorandum of Understanding
1	Memorandum of Cooperation
1	Reimbursable MOA

The FAA and NASA are partnering for the following research:

- **Ground icing experiments and analytical research using wind tunnels and other methods in support of the Aviation Rulemaking Advisory Committee's Ice Crystals Icing Working Group**
- **Inflight radar algorithms to detect high ice water crystal conditions**
- **Advanced manufacturing technologies**
- **Aircraft structures and materials**
- **Verification and validation of safety for batteries used in aerospace applications**
- **Development and evaluation of seats in vertical takeoff and landing vehicles**
- **Reliability and safety testing for complex digital airborne systems, as well as risk assessment and verification — including aircraft systems, hardware, software, cybersecurity, installation, and maintenance**
- **Stabilized approach criteria using human-in-the-loop flight simulations culminating in an American Institute of Aeronautics and Astronautics Journal of Air Transportation publication titled, "*Go-Around Criteria Refinement for Transport Category Aircraft*."**
- **Performance-based standards for novel cockpit pilot interfaces of optionally piloted vehicles to support regulatory, standards, and guidance development**
- **Improved methodologies for certifying general aviation aircraft**
- **Technology and training solutions to improve go-around safety.**

The FAA collaborates with other federal agencies on the following research:

- **Using the Naval Air Warfare Center's Reusable Energy Absorbing Lab seats to reduce the risk of blunt force trauma in crashes involving legacy rotorcraft**
- **Developing vertiport electrical infrastructure**
- **Researching aircraft rescue and firefighting using live fire testing and analysis, fire and safety standards, and acquisition of new and superior firefighting agents and equipment, including the newest generation of fire and rescue vehicles**
- **Conducting transport aircraft safety regulation and analysis for engine related impact failures**
- **Reducing and mitigating wildlife strikes by aircraft**
- **Identifying bird species involved in aircraft strikes.**

FAA Collaborates with NOAA to improve Aviation Weather Forecasts

The FAA partners with several National Oceanic and Atmospheric Administration (NOAA) research laboratories, including the NOAA Global Systems Laboratory (GSL).

The FAA funds the NOAA GSL to research and improve weather prediction models and low ceiling and restricted visibility forecasts, as well as to conduct quality assessments of FAA-developed products and services for weather operations.

Incident command meteorologists use GSL-developed weather models to direct firefighting operations during wildfires.

Every five years, NOAA convenes a panel of experts, including FAA scientists, to review the research conducted at its laboratories. This ensures that the work is linked to the NOAA strategic plan, mission, and priorities, and it meets the needs of stakeholders.

At the 2021 meeting, the panel consisted of representatives from the FAA, Department of Energy, University of Washington, University of Iowa, Arizona State University, the National Center for Atmospheric Research, the United Kingdom Meteorological Office, and The Weather Company (an IBM business). The review panel issued its summary report in May of the same year, noting that the lab conducts preeminent research, and its scientific and technical products represent significant contributions to the scientific community.

GSL researchers evaluate the performance of winter weather forecast ensembles for snow at airports.

The panel also issued recommendations for the GSL to expand its success by increasing its number of publications, expanding its far-term research portfolio, and improving branding and promotion of its intellectual leadership and strengths to reinforce the importance of GSL services to the general public.

Weather is the most common reason for air traffic delays. GLS researchers are working to provide accurate and meaningful weather information to pinpoint conditions that may impact air traffic flow. (Image courtesy of NASA)

Improving Fire Safety in the Air

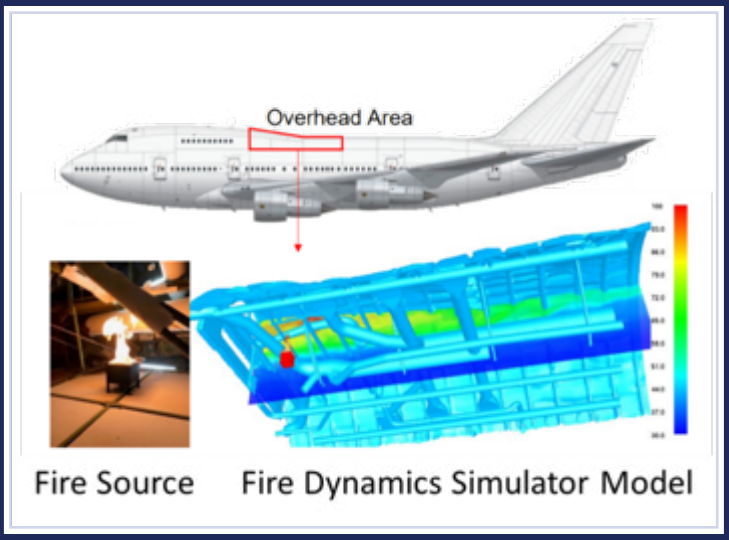
Aircraft have very effective systems to detect fires. Sensors are placed in locations where hot gases, smoke, and heat are likely to travel in a blaze. However, some of these places are inaccessible, making it hard to extinguish a fire.

To address this challenge, the FAA and National Institute of Standards and Technology (NIST) collaborated in critical research to understand and predict where heat and smoke travel in irregular-shaped spaces in the aircraft, such as airliner overhead areas.

The team modeled overhead space in NIST's Fire Dynamics Simulator and then collected real-world data in a fire test aircraft parked at the FAA's William J. Hughes Technical Center.

Using light detection and ranging technology, the team collected thousands of three-dimensional measurements to validate and reliably model the behavior of a fire.

The FAA documented the findings in a report released in March 2021 titled, "*Experimental Tests and Numerical Simulations of Boeing 747 Overhead Inaccessible-Area Fires*." The team will apply the newly-acquired knowledge to design more effective detection and fire suppression systems in the future.



Nonprofit Partners

The FAA maintains formal agreements with nonprofit institutions in a variety of aerospace research areas.

- **The National Institute of Aerospace (NIA) conducts testing and analyses for the FAA to investigate damage modes in lightweight sandwich structures for the Composite Materials Handbook-17. The guidebook provides properties of polymer, metal, and ceramic matrix composite materials, as well as guidance for design, analysis, material selection, manufacturing, quality control, and repair of products made with these materials.**

  The FAA-NIA agreements also support developing a framework for partnering with academic institutions for science, technology, engineering, and mathematics (STEM), internships, and STEM learning initiatives for kindergarten through 12th grade.
- **The FAA continues its long-standing commitment to supporting Battelle as the secretariat in the development of the Metallic Materials Properties Development and Standardization (MMPDS) Handbook. The guidebook is the primary authority for metallic materials and fasteners for aerospace applications around the world.**

  The FAA continued to report findings from its advanced research at the semiannual MMPDS committee meetings held in March and September of 2021. Over 100 experts attended the event, representing the federal government, more than 30 aerospace entities, and nine countries.
- **The FAA partners with the Southwest Research Institute to study probabilistic integrity and risk assessment of turbine engines, and evaluate structural integrity assessment tools for higher criticality metal additive manufacturing parts.**

The agency also continues its essential participation in over 40 standards-setting bodies and professional organizations, as well as several working groups focused on specific aviation safety challenges.

The FAA awards the Southwest Research Institute a Grant to Study Turbine Engine Failures

The FAA continued its commitment to further understand the impact of cyclic stresses and high temperatures on critical aircraft engine parts. In April 2021, the agency initiated a four-year, $4.5 million cooperative agreement with the Southwest Research Institute (SwRI) to advance the DARWIN® tool.

The FAA and SwRI, in collaboration with the aviation industry, developed the Design Assessment of Reliability with Inspection, or DARWIN®, to determine the probability of failure in critical engine parts.

When engine parts crack and break apart due to abnormalities in the metal, fragments can escape the engine case and impact other parts of the aircraft. These uncontained engine failures pose a serious threat to passengers and the continued safe operation of the aircraft. Aircraft manufacturers use the DARWIN® software in the design phase to develop engines resistant to such cracks.

SwRI's principal investigator, Dr. Craig McClung, noted that the software is already used "to predict the probability of fracture during the entire lifetime of each engine over the whole fleet of engines."

The new grant marks the second phase of research in the FAA's effort to model probabilistic integrity and conduct risk assessments for turbine engines. Research will further advance DARWIN® and lead to improved damage-tolerant designs.

Researchers at the Southwest Research Institute are assessing the risk of engine rotor fractures.

Academic

The FAA collaborates with academic institutions through a variety of mechanisms, including centers of excellence (COE) grants, aviation research grants, and participation in the Joint University Program for Air Transportation Research.

These partnerships benefit FAA research initiatives by providing access to key academic scholars and practitioners while promoting invaluable work experience for students. In addition, participants may elect to continue to pursue a career in aviation-related research.

210	Center of Excellence Grants
38	Aviation Research Grants
7	Cooperative R&D Agreements
3	Joint University Program Partners

Centers of Excellence

COEs are a unique mechanism enabling the FAA to collaborate with leading academic institutions to advance aviation research objectives. The FAA has partnerships with more than 40 universities, colleges, and institutes through the program. The mission of the FAA's COE program is to help develop the nation's technology base while educating the next generation of aviation professionals.

The program enables collaboration and coordination between government, academia, and the aerospace industry to advance aviation technologies and expand FAA research capabilities through congressionally-required matching contributions. Once selected, the core and affiliate university members and industry partners serve as a primary source of subject-matter-expertise to the FAA for a 10-year period.

	FY 2020	FY 2021
Grants	217	210
Awards	$76.8M	$83.3M

The FAA substantially increased investment in the program. COEs support technology transfer and research in the following core areas:

- **Unmanned aircraft systems**
- **Alternative jet fuels and environment**
- **Advanced materials**
- **General aviation safety**
- **Technology training and human performance**
- **Commercial space transportation**

COEs focus on a broad range of current and emerging critical research needs. For example, Wichita State University received grants to develop aircraft design and certification guidance for polymer-based additive manufacturing technologies. The University of Dayton Research Institute is investigating alternative jet fuels.

Other areas of research focus on validating low-altitude detect-and-avoid standards for unmanned aircraft systems (UAS), community measurement of aviation emissions on ambient air quality, assessment of supersonic aircraft noise in high-altitude airspace, disaster preparedness and response, and cybersecurity.

FAA & MIT: 50 Years of Advancing Aerospace Safety

The year 2021 marked the 50th anniversary of the FAA's partnership with its Federally Funded Research and Development Center counterpart, the Massachusetts Institute of Technology (MIT).

Current collaborative efforts focus on a range of critical challenges, including safely increasing autonomy, developing innovative artificial intelligence (AI) and machine learning (ML) capabilities, and enabling growth in unmanned aircraft systems (UAS) operations.

In June 2021, MIT convened the "*Aviation Technologies from MIT Lincoln Laboratory*" webinar. The event described recent advances in technologies for UAS airspace integration, air traffic control decision support, and AI/ML applications for advanced weather. Other sessions included MIT achievements in support of the Small Airport Surveillance Sensor and a predictive maintenance capability using aircraft data.

The FAA and MIT continue to work closely to advance the Airborne Collision Avoidance System–X (ACAS-X). The next generation of this technology, ACAS-Xu, will help maintain separation between manned and unmanned aircraft.

The team has conducted flight tests of ACAS-Xu, demonstrating that UAS can safely and autonomously maneuver vertically and horizontally using a variety of sensors. This research supports the FAA's commitment to leverage ACAS-X to meet future collision avoidance requirements as identified in the FY 2021 Air Traffic Organization Business Plan.

Federal Aviation Administration

FAA TEST TEAM XIII SEMPER TUTUM

Massachusetts Institute of Technology

Aviation Research Grants

Congress established the aviation research grants program in 1990 to encourage advanced research to benefit civil aviation's long-term growth, prevent catastrophic failure of aircraft, and contribute to the FAA's overall mission of improving aviation safety, capacity, efficiency, and security. In 2021, the agency continued to rely on this successful investment, awarding over $25 million through 37 grants to 29 academic institutions. The awards funded critical research into current and emerging topics including:

- **Ice accretion on swept-wing aircraft, and electric vertical takeoff and landing vehicles**
- **Advanced materials research, including assessing the structural integrity of metal additive manufacturing parts, and evaluating bonded repairs and damage tolerance**
- **Damage modes in lightweight sandwich structures**
- **Fire protection of commercial aircraft systems and mitigation of fire propagation in hidden areas of commercial airplane cabins**
- **Probabilistic integrity and risk assessment of turbine engines**
- **Flight loads and airframe usage analysis of next-generation air tankers**
- **Flight deck vision systems**
- **Occupant safety in aircraft seats mounted obliquely (at an angle).**

Critical Research into Ice Accretion on Commercial Aircraft Wings

The University of Washington continued its critical research into the effects of ice on three-dimensional swept wings. Representative of those seen on a typical commercial airliner, the wings are tested in a wind tunnel using a variety of analysis methods.

The research includes conducting surface pressure measurements, wake surveys, as well as surface oil and smoke flow visualizations. The resulting data advances the FAA's ability to model ice accretion and further enhance the safety of air travel.

Ice builds up on a large-scale, three-dimensional swept wing during testing.

Cooperative Research and Development Agreements

In FY 2021, the FAA's academic CRADA partners included Clarkson, Fairfield, Rowan, and Rutgers universities, as well as George Mason University (GMU) and the University of Dayton Research Institute.

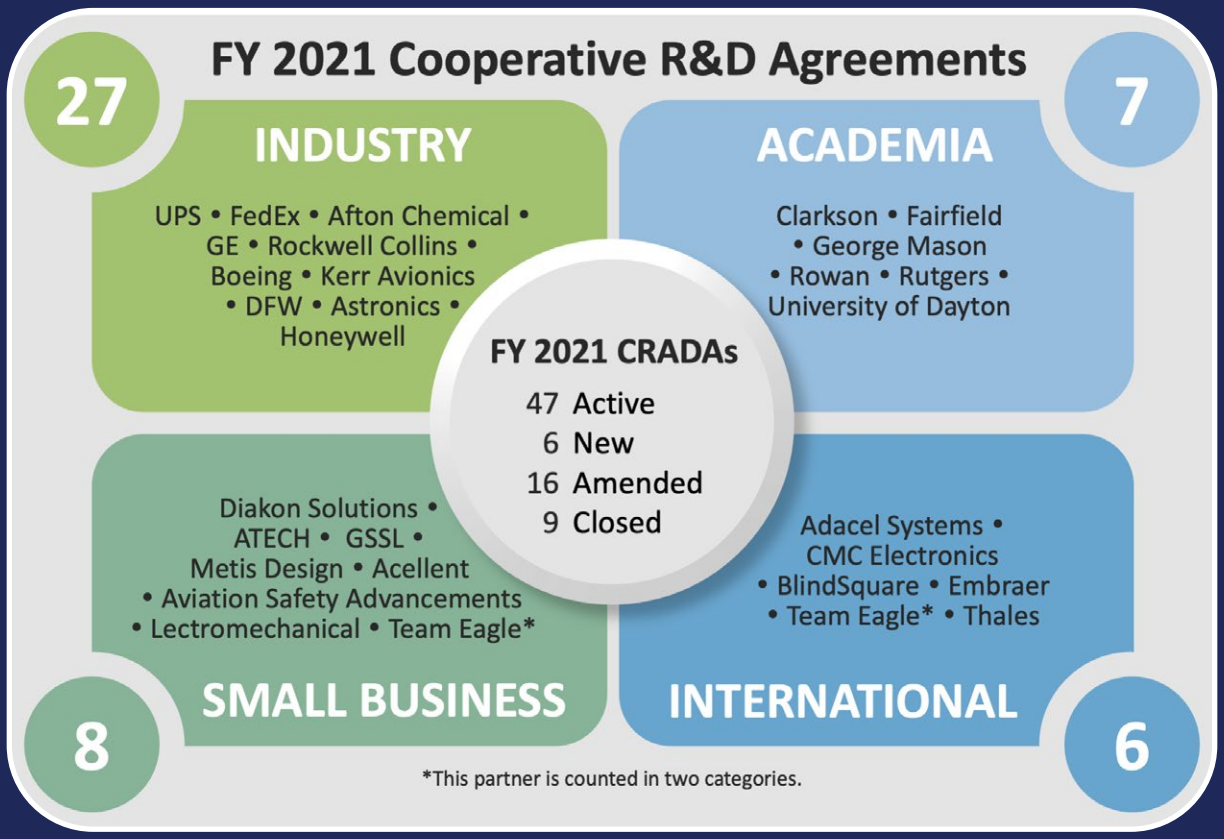
These agreements promoted research into testing and model validation of structural health monitoring systems, enhancing aircraft conflict-probe tools and algorithms, creating state-of-the-art airport pavement design methods and materials, and studying the airworthiness of next generation solid-state battery technology.

The CRADA with GMU's School of Business culminated in June 2021 with the submission of a book chapter on organizational change management, describing the FAA's successful implementation of the Workforce of the Future initiative. The GMU author described how the FAA successfully implemented the change management program for the agency's Flight Standards Service, which has become a model for others in the federal government to follow.

Stimulating Collaboration through Cooperative Research and Development Agreements

The FAA encourages important cutting-edge research with industry, academic, small business, and international partners through Cooperative Research and Development Agreements. These unique vehicles can be implemented much more rapidly than traditional contracts because federal legislation exempts them from typical procurement requirements.

Although FAA partners do not receive government funds, they gain substantial benefits from access to unsurpassed facilities and expertise. In return, the agency is able to evaluate upcoming advanced technologies and processes to facilitate their certification and safe integration into the National Airspace System.



Joint University Program for Air Transportation Research

The Joint University Program funds graduate-level research into technologies and methods that have the potential to improve the safety and efficiency of the National Airspace System.

The FAA's partnerships with the Massachusetts Institute of Technology and Ohio University focus on emerging capabilities. A key benefit of the research is providing students valuable firsthand experience managing research for real-world aviation challenges.

FY 2021 Joint University Program research topics included:

- **Researching multi-spectral sensors for airport surfaces using semi-autonomous platforms for runway inspection**
- **Using a hybrid camera-light detection and ranging technology system for trilateration positioning when GPS is not available**
- **Leveraging the Airborne Collision Avoidance System–X for detect and avoid in low-level operations**
- **Using machine learning techniques to understand and predict the braking action of landing aircraft**
- **Data mining Automatic Dependent Surveillance–Broadcast data to identify common behaviors underlying airspace structure for trajectory prediction and collision avoidance**
- **Identifying historically-based airspace and procedure design constraints that may be mitigated by existing and future advances in surveillance and navigation technologies**
- **Using archived radar reflectivity observations and historical flight tracks to automate flight deck assessments and tactical planning for convective weather avoidance**
- **Investigating methods for flight radar data clustering and processing to facilitate more efficient use of airspace.**

Industry

The FAA engages with industry partners using a variety of vehicles, including MOAs and CRADAs. MOAs are used to leverage federal laboratory resources in collaboration with industry. MOA partners include the Delaware River and Bay Authority, Metropolitan Airports Commission, National Institute of Aerospace, Port of Seattle, and the University of Pennsylvania.

These partnerships allow the FAA to develop research infrastructure at local airports. Work includes quantifying the safety benefits of foreign object debris detection systems and indoor navigation aids to help blind and visually impaired passengers traverse airports.

CRADAs enable the aerospace industry to access federally-developed and funded state-of-the-art laboratories, facilities, services, and associated intellectual property. The agency benefits from the innovations, knowledge, and drive of these capable partners. The FAA's most common CRADA partner is industry, accounting for 30 active agreements in 2021.

The collaborative research pursued under these CRADAs represents a broad range of technologies and aviation challenges, including:

- **Researching solid-state power control and protective devices, as well as electronic power distribution systems for aircraft applications to support the development of industry standards**
- **Collecting full-scale fuselage panel test data to evaluate how emerging metallic structure technologies impact durability and damage tolerance when compared to current aluminum fuselage structures**
- **Evaluating performance of the latest generation of enhanced and synthetic vision systems on the flight deck and for helicopter operators**
- **Developing beyond-visual-line-of-sight inspection procedures for UAS operations**
- **Researching safety and airframe integrity of bonded repairs**
- **Conducting real-time, real-weight pavement testing at the FAA's National Aviation Pavement Test Facility to determine wheel interaction effects, followed by pavement failure criteria testing**
- **Researching a vendor's electrical propulsion system to collaboratively advance understanding of the safety risks and hazards associated with using this technology in aircraft as the primary source of propulsion and aiding in the development of safety standards**
- **Evaluating the performance of passive surveillance technologies to determine their viability in meeting future needs**
- **Developing unleaded fuels to replace the leaded aviation gasoline used in most piston-engine general aviation aircraft.**

Reducing Aviation Noise and Emissions Since 2010

The FAA continued to evolve its successful industry partnership through the Continuous Lower Energy, Emissions, and Noise (CLEEN) program. Since 2010, CLEEN has completed phases one and two of planned research.

CLEEN Phase III focuses on:

- **Further advances in wing technologies**
- **Aircraft systems technologies**
- **Engine fan, nacelle, and nozzle technologies**
- **Engine core turbomachinery technologies**
- **Protective engine coatings**
- **Aircraft engine system integration.**

In support of these environmental and energy initiatives, the FAA has entered into numerous cooperative agreements, issued multiple centers of excellence grants, and entered into Cooperative Research and Development Agreements with industry partners.

The FAA awarded four cooperative agreements in 2021 to America's Phenix, Boeing, Honeywell, and Pratt & Whitney to further mature technologies and sustainable aviation fuels that will reduce fuel burn, emissions, and noise.

Ultra-High Bypass Propulsion System Technologies

Researchers studied aerodynamic performance, as well as mechanical and acoustic characteristics of advanced fan system technologies that would contribute to the overall benefits provided in a new geared turbofan engine.

Open Rotor Engine

GE and NASA developed open rotor designs for efficiency and low community noise.

Ceramic Matrix Composite Acoustic Nozzle

Researchers tested the Ceramic Matrix Composite Acoustic Nozzle on the Boeing 787 ecoDemonstrator. This advanced material system enables lighter, quieter, and more efficient engines.

International

The FAA engages with partners outside of the United States through international and cooperative agreements to share resources and harmonize operations. The knowledge capital obtained through the FAA's research and development investments is necessary for the safe and efficient evolution of domestic and international air travel.

FAA representatives and researchers hold positions on global harmonization and standards-setting bodies and serve as world-renowned subject matter experts on many topics. Their contributions enable the United States to drive international standards and increase America's economic advantage in aviation.

Among the FAA's international partners are Transport Canada, National Resource Council of Canada, European Union Aviation Safety Agency, Eurocontrol, United Kingdom Civil Aviation Authority, Civil Aviation Authority of Singapore, Brazil's National Civil Aviation Agency, and the Technical University of Denmark. Areas of research include aircraft icing, advanced materials, wake turbulence, and air traffic management collaboration.

The FAA also maintains cooperative agreements with other aviation organizations in Europe, North America, and Asia to participate in aviation safety and air traffic modernization programs, leverage research activities that harmonize operations, and promote a seamless and safe air transportation system worldwide. These organizations include the European Organization for the Safety of Air Navigation, International Civil Aviation Organization, Single European Sky Air Traffic Management Research Joint Undertaking, Japan's Civil Aviation Bureau, and Warsaw Institute of Aviation.

CRADAs with International Partners

The FAA held CRADAs with six international partners in FY 2021, representing Australia, Brazil, Canada, Finland, and France. The companies included Adacel, CMC Electronics, Embraer S.A, MIPsoft OY, Team Eagle, and Thales Avionics SAS.

Two of these CRADAs focus on the application of enhanced vision systems, including synthetic vision and combined vision systems, for helicopter operations. Researchers are studying ways to use these technologies to enhance safety during adverse weather conditions.

In a CRADA with MIPsoft OY which concluded in 2021, researchers evaluated how BlindSquare indoor navigation technology could be used to mitigate the wayfinding challenges faced by blind and visually impaired passengers as they navigate through airport terminals.

In its CRADA with Embraer, the FAA is testing panels with various structural health monitoring technologies to help the SAE International Aerospace Industry Steering Committee develop a reliable commercial standard methodology for use on U.S. civil aircraft.

Under the Team Eagle CRADA, the FAA is researching technologies for evaluating and measuring the effects of contaminants on aircraft wheel braking performance. The project, which was extended through 2024, measures aircraft anti-skid brake system forces and correlates them to actual aircraft landing performance. Accurate assessment of braking friction is important in predicting the braking performance of subsequent aircraft landings.

Participation in Professional and Technical Societies

Professional and technical societies bring together experts, knowledge, and technology for the purpose of sharing information; creating industry standards; and developing design standards for technology, processes, and systems.

FAA experts provide substantial contributions and guidance in these areas by serving on boards of directors and as chairpersons, committee and subcommittee members, technical experts, and general members for over 40 separate organizations across nearly 100 focus areas.

FAA participation in technical societies includes the following organizations:

- **Aerospace Medical Association**
- **American Institute of Aeronautics and Astronautics**
- **American Meteorological Society**
- **American Society of Mechanical Engineers**
- **ASTM International**
- **Coordinating Research Council Aviation Gasoline and Piston Fuels Group**
- **European Organisation for Civil Aviation Equipment Enhanced Vision/Synthetic Vision Systems Working Group**
- **General Aviation Manufacturers Association**
- **Human Factors and Ergonomics Society**
- **Institute of Noise Control Engineering**
- **International Academy of Aviation and Space Medicine**
- **International Association for Fire Safety Science**
- **International Association of Forensic Toxicologists**
- **International Society of Air Safety Investigators**
- **SAE International**
- **Society of Forensic Toxicologists Inc.**
- **Society of United States Naval Aerospace and Operational Physiologists**
- **Space Weather Operations Research and Mitigation Task Force**
- **Underwriters Laboratories**
- **United Nations Working Group on Lithium Batteries**
- **Vertical Flight Society.**

Safer Operations for Aerospace Systems through Artificial Intelligence

The introduction of new capabilities such as artificial intelligence (AI) can promote safer aerospace operations, but it must be carefully implemented to ensure safety.

Representatives from several FAA organizations participated in the July 2021 SAE International plenary session, which focused on the development of new standards for this transformative technology. SAE is a global association of engineers and technical experts, and a standards developing organization.

FAA representation at the event included agency experts in software, electronics, policy, certification, and innovation. Aviation industry members represented original equipment manufacturers, suppliers, and academia from all over the world. SAE International's G-34 Committee for Applied Artificial Intelligence in Aviation Systems develops and maintains SAE technical reports, practices, and standards for the implementation and certification of AI technologies for onboard and off-board systems.

The meeting was held jointly with members of the EUROCAE Working Group 114, which is also pursuing the development of standards for AI applications for aerospace systems and vehicles. The committee reviewed the "Use Case Aerospace Information Report" and a flow chart depicting the design, development, verification, and implementation of AI and machine learning systems. The committee continues to meet biweekly to mature standards for the safe integration of AI into aerospace operations.

Research Deployed

The FAA research and development portfolio is a collection of programs spanning multiple research areas. The FAA's unsurpassed laboratories and expertise enable cutting-edge research in the following domains:

- **Airport Infrastructure and Technologies**
- **Aircraft Safety Assurance**
- **Digital Systems and Technologies**
- **Environmental and Weather Impact Mitigation**
- **Human and Aeromedical Factors**
- **Aerospace Performance and Planning.**

The resulting technical knowledge and products from this research enhance the safety, capabilities, and efficiency of the National Airspace System (NAS).

Technology Transfer

The FAA Technology Transfer program implements the policy framework established by legislation requiring federal agencies to promote the benefits of taxpayer investments in research and development to all segments of society.

The program advocates for:

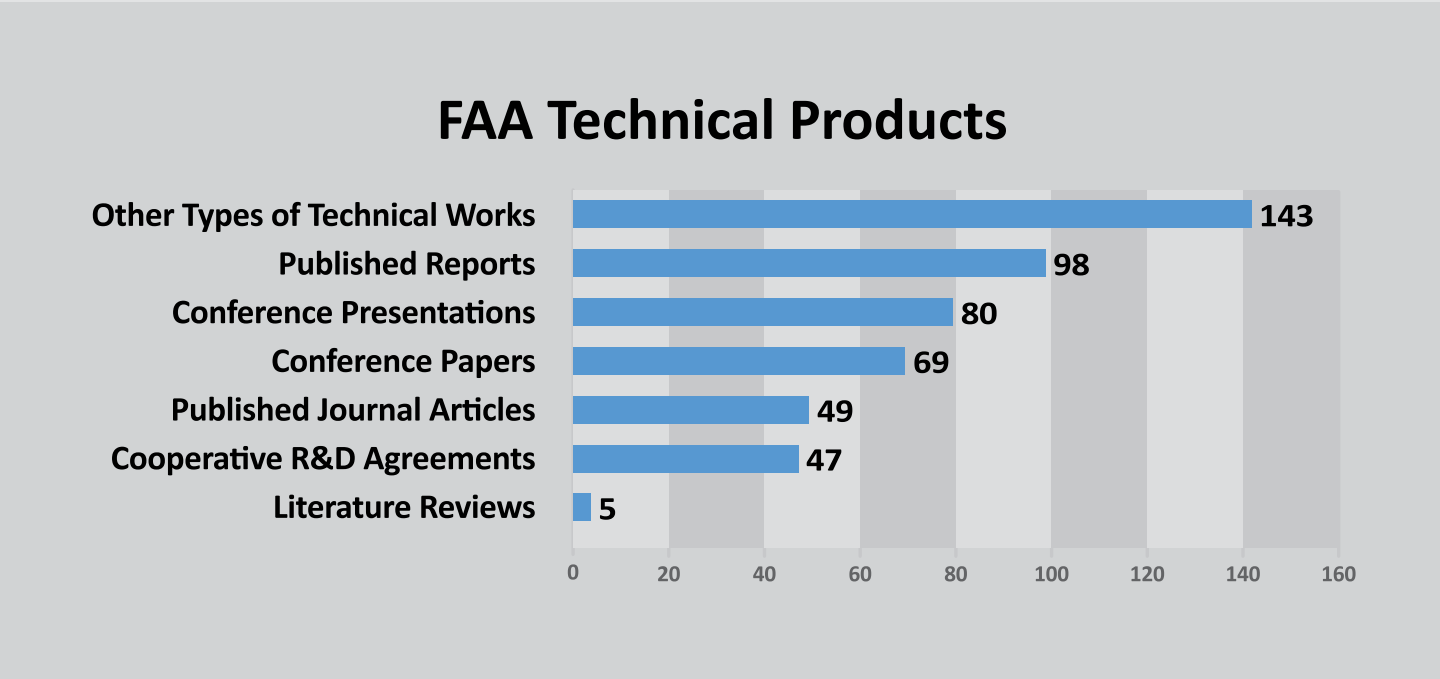
- **Protection and commercialization of new technologies developed by agency personnel or in collaboration with external partners**
- **Maximizing the return on investment for federally-funded research and development**
- **Sharing scientific advances to improve U.S. security and socioeconomic wellbeing.**

The FAA's knowledge-sharing mechanisms include physical results, as well as other equally important collaborations and partnerships. Through the Technology Transfer program, the agency shares a range of information from formal reports, standards, software, and patents to technical knowledge, innovative ideas, and new processes and practices.

Although in-person conferences were significantly reduced in 2021 due to the COVID-19 pandemic, the agency continued to meet its regulatory and technical mandates to produce advisory circulars, engineering briefs, orders, statutes, and regulations.

The FAA produced over 400 research products in 2021, including nearly 100 technical reports, 80 virtual conference briefings, and a number of journal articles. The sustained quality and technical merit of FAA products continued to resonate within the research community, as evidenced by the nearly 2,000 publications citing FAA products.

In addition to these formal products, the FAA collaborated with other federal agencies, universities, industry, and standards-setting organizations to share expertise and resources to promote national, Department of Transportation, and agency objectives.



Successful FY 2021 FAA Technology Transfer Accomplishments

Report on Infectious Disease Mitigation and Preparing Airports for Communicable Disease Threats

The FAA's Airport Cooperative Research Program (ACRP) studies a range of topics impacting airport operations. Among them is an airports and pandemics project which aims to reduce the spread of communicable diseases. Two reports published by the program in 2020 remained popular, "Infectious Disease Mitigation" and "Preparing Airports for Communicable Disease Threats." Both documents have been downloaded over 10,000 times since they were published. More than 8,000 downloads occurred in 2021 by users in all 50 states and over 70 countries worldwide.

FAA Safety Improvements in Hawaii

The *FAA Weather Camera Program* improves safety and efficiency by providing pilots with near real-time, visual weather information to improve safety and pilot decision making. The program began in Alaska in 1999 and currently provides images of severe and rapidly changing conditions every 10 minutes from over 230 cameras across the state.

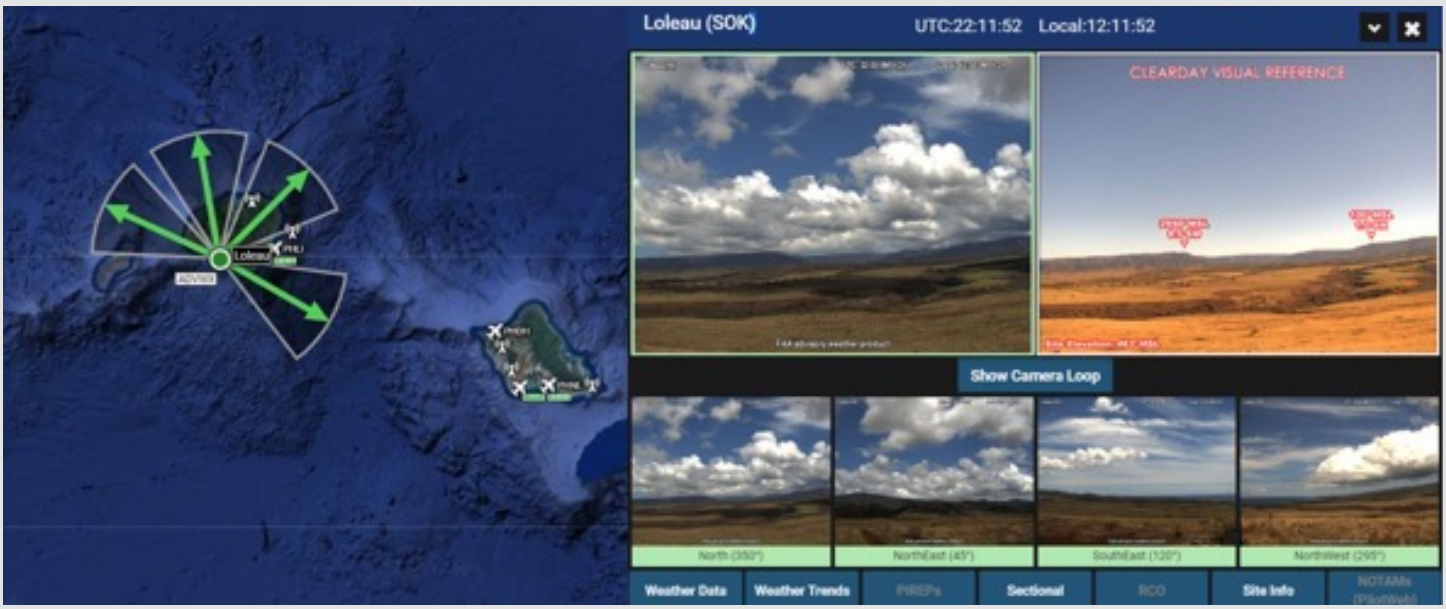
The enhanced safety benefits prompted the FAA to expand the program to the lower 48 states and, in early 2021, to Hawaii. When fully implemented, 23 camera facilities will be installed across the Hawaiian islands of Kauai, Lanai, Maui, and Molokai in locations where adverse weather conditions are common.

Technical Report on UAS Detect and Avoid Alerts

A critical safety consideration when integrating unmanned aircraft systems (UAS) into U.S. airspace is providing effective alerts for UAS pilots when there is traffic nearby. Recently, the RTCA Special Committee 228 Detect and Avoid Working Group issued performance standards for detect-and-avoid (DAA) systems.

The RTCA standard categorizes the DAA Preventative Alert as a caution-level alert, which by FAA regulations dictates immediate flight crew awareness and response. However, the alert is only intended to gain flight crew awareness and may not require a response. Effective pilot performance, particularly when in proximity to another aircraft, is critical.

FAA researchers from the Office of Aerospace Medicine investigated the impact that a caution versus an advisory alert might have on pilots. Over 30 UAS pilots participated in the simulation, which evaluated both alert levels. Preliminary findings detailed in a technical report issued in 2021 titled, "*Evaluating the Preventive Alert Function for UAS Detect and Avoid Systems*," suggest an advisory alert does not reduce a pilot's ability to remain clear of nearby traffic or impact a pilot's response time. This is one example of the essential research that is required to ensure the safe integration of these vehicles into the NAS.



The FAA Weather Camera Program displays images of conditions in Loleau on the island of Kauai, HI.

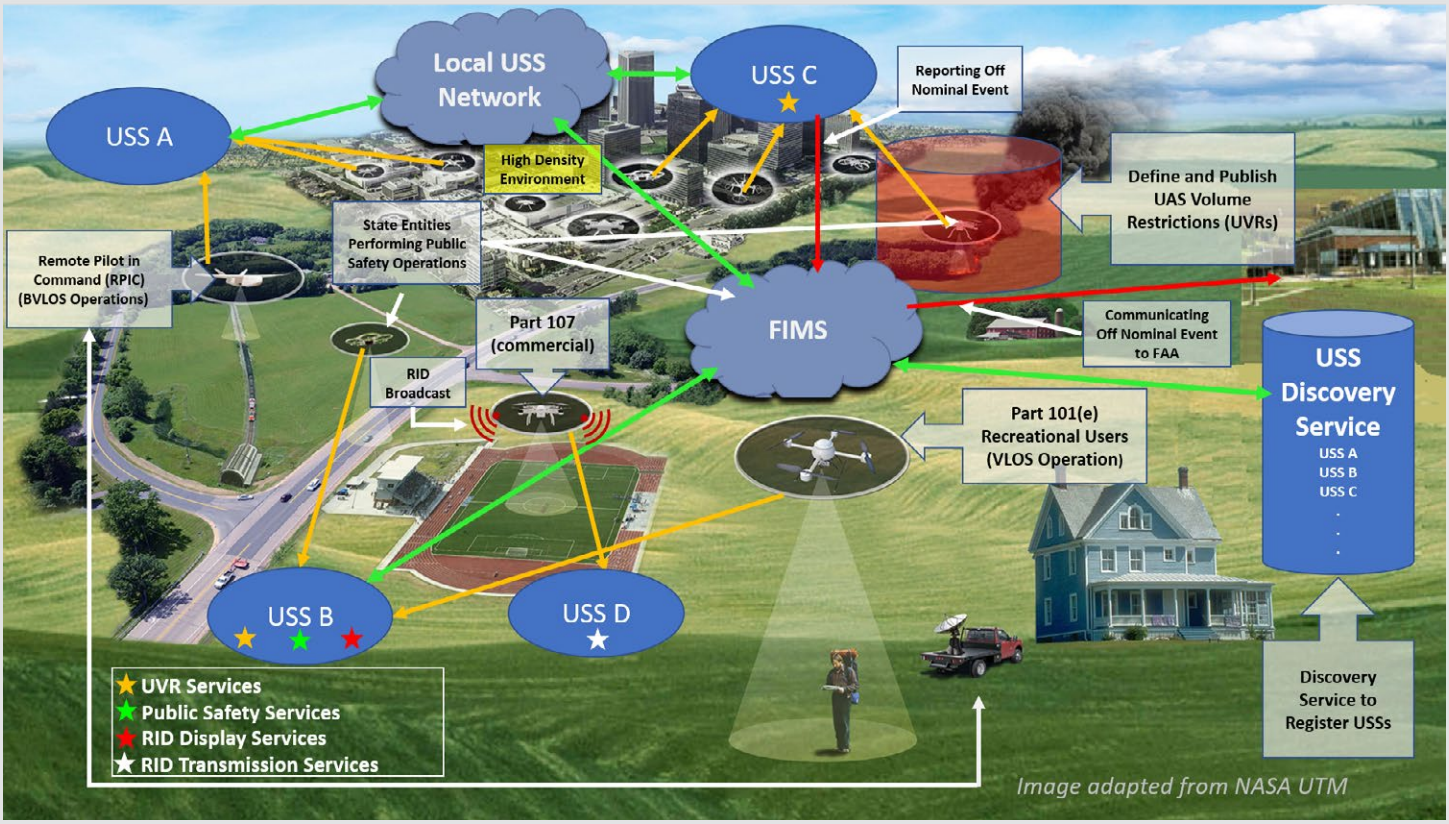
UAS Traffic Management Makes Significant Strides

UAS use continues to expand dramatically, but there is still limited infrastructure to manage these operations. In July 2021, the FAA and NASA made strides in addressing these needs with their joint report documenting phase two of the *UAS Traffic Management (UTM) Pilot Program*.

The research demonstrated several essential capabilities in support of beyond-visual-line-of-sight operations, including:

- **Access to information from industry and other stakeholders through the FAA's flight management system prototype and infrastructure**
- **New technologies and data to validate the latest standards for remote ID and support authorized users with specific operator data**
- **Inflight separation from other unmanned or crewed aircraft in high-density airspace, validating proposed international UTM standards to help unmanned aircraft avoid each other**
- **The ability to reserve airspace and notify UAS operators of emergencies**
- **Secure information exchanges between the FAA, industry, and authorized users to ensure data integrity.**

The report took years of planning and research. The FAA and NASA first identified the challenge in 2016 when the agencies met with industry leaders to begin developing requirements for situational awareness and cooperative separation for these new vehicles.



High-level Operational Concept of the Unmanned Aircraft Systems Traffic Management Pilot Program

Successful FY 2021 FAA Technology Transfer Accomplishments (continued)

Commercial Spaceflight History

In July 2021, the nation witnessed the expansion of space tourism. Two unique spacecraft carried members of the public to the edge of space for a few minutes of microgravity.

In September of the same year, another milestone occurred: four amateur astronauts soared into space to gaze upon the earth for three days from a vantage point higher than the International Space Station or even the Hubble Space Telescope. The previous year saw the first-ever NASA-crewed mission licensed by the FAA under the Commercial Crew Program.

The FAA Commercial Space Transportation Office plays a significant role in enabling these spaceflight operations — licensing launches and reentries, approving spaceport operator licenses, permitting experimental launches, issuing safety approvals, and monitoring active missions.

In March of 2021, the FAA helped set the stage for the first space tourism flights by issuing the *Streamlined Launch and Reentry License Requirements Final Rule*.

This rule provides flexibility in the FAA's commercial space launch and reentry regulations, and consolidates multiple regulations into a single set of licensing and safety requirements across several types of operations and vehicles. These changes will help accommodate a constantly evolving aerospace industry that is seeking to open new markets for satellites, space tourism, and potentially suborbital point-to-point regional and intercontinental travel.

Safety Innovation for General Aviation Pilots

The FAA sponsored research into an innovative concept that may help mitigate loss of control and controlled flight into terrain, factors that account for an estimated 85 percent of general aviation fatalities. A software tool called EZ-Fly Prime simplifies stick and rudder skills, and provides envelope protections to keep the aircraft within prescribed limits.

During testing, pilots flew with the EZ-Fly Prime system for about an hour. One of the pilot participants noted that the tool addressed loss of control, so the pilot could not stall the airplane. The pilot further stated if he pulled back on the stick, the protection system prevented overstressing the airframe and allowed the pilot to maneuver at will without breaking the airplane.

The algorithm used in the software is based on an earlier simplified vehicle operations concept designed in the 1990s. The new design used in EZ-Fly Prime combines an automated flight control system with a modified pilot interface in a fly-by-wire aircraft using a highly-modified display. Advances in automation software and computer electronics since the original design have further contributed to the concept's success.

Stakeholders and researchers inspect the flight controls of a Navion aircraft equipped with EZ-Fly Prime software.

Successful FY 2021 FAA Technology Transfer Accomplishments (continued)

2021 FAA Challenge: Smart Airport Student Competition Winner Announced

The FAA partnered with the National Institute of Aerospace to manage a second annual smart airport competition. The contest challenged university teams to focus on improving smart technology efficiency and effectiveness in and around the airport environment while enhancing the overall traveling experience. The top prize was $25,000.

Three finalist teams were chosen from the 21 proposals submitted — Rowan, Embry Riddle Aeronautical, and Hampton universities.

The finalist, the Rowan University team, submitted a cloud-based mobile software platform to connect first responders with life-saving information before arriving on the scene of an accident. Known as ARKE, the software includes modules for after-action reporting, analytics, and asset tracking.

Embry Riddle demonstrated the use of UAS to help with wildlife management by using images and GPS timestamping to identify materials that may attract animals. Hampton University students combined a UAS and a rover to inspect runway conditions and autonomously remove foreign objects.

Rowan University's First Responder Mobile Platform

Embry Riddle Aeronautical University's Unmanned Aircraft Systems for Wildlife Management

Hampton University's Unmanned Aerial Vehicle/Rover for Runway Safety

Conclusion

FAA research and development fosters the creativity needed to provide safe, efficient, and environmentally-sound solutions beyond today's boundaries and prioritizes the integration of advanced technologies into the National Airspace System. To learn more about FAA's planned research activities, view the Annual Review's companion document, the *National Aviation Research Plan*.