SUBCOMMITTEE ON SPACE AND AERONAUTICS
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

HEARING CHARTER

"NASA's Aeronautics Mission: Enabling the Transformation of Aviation"

June 26, 2019
2:00 p.m.
2318 Rayburn House Office Building

PURPOSE

The purpose of the hearing is to review the programs, activities and plans of the National Aeronautics and Space Administration's Aeronautics Research Mission Directorate, and associated issues.

WITNESSES

- **Dr. Jaiwon Shin,** Associate Administrator, Aeronautics Research Mission Directorate, National Aeronautics and Space Administration
- **Dr. Alan H. Epstein,** R.C. Maclaurin Professor Emeritus of Aeronautics and Astronautics, Massachusetts Institute of Technology; Chair, Aeronautics and Space Engineering Board, National Academies of Sciences, Engineering, and Medicine
- **Dr. Ilan Kroo,** Professor of Aeronautics and Astronautics, Stanford University
- **Dr. Mark Lewis,** Director, IDA Science & Technology Policy Institute; Professor Emeritus of Aerospace Engineering, University of Maryland

OVERARCHING QUESTIONS

- *What are the emerging challenges and opportunities in aeronautics and aviation, and to what extent is NASA positioned to address them?*
- *How does the NASA Aeronautics Research Mission Directorate prioritize its research activities and programs?*
- *What is NASA's role in increasing the efficiency, safety, and sustainability of the United States' aviation system?*
- *What facilities, workforce skills, and capabilities are needed to enable the transformation of aviation, and how can NASA help meet those needs?*

BACKGROUND

Aviation is critically important to the U.S. economy, accounting for more than $1.6 trillion of U.S. economic activity in 2014.[1] A global leader, the U.S. aerospace industry operates at a positive trade balance ($87.7 billion in 2018).[2] The NASA Aeronautics Research Mission Directorate (ARMD) plays a key role in conducting research and solving problems for the future of aviation. NASA's legacy began in aeronautics—the science of traveling through the air—with its predecessor, the National Advisory Committee for Aeronautics (NACA), which was established by Congress in 1915 as an independent agency that reported to the President. The National Aeronautics and Space Act of 1958 that established NASA incorporated the activities of NACA and included among the eight objectives of the nation's aeronautical and space activities both "*the improvement of usefulness, performance, speed, safety, and efficiency of aeronautical and space vehicles*" and "*the preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere.*"[3] NASA has a history of meeting these objectives by performing basic research and development (R&D) and providing research findings to the aviation industry and broader community.

Aeronautics Research Mission Directorate Activities

NASA's aeronautics research directly affects the success and future of the U.S. air transportation system. Technologies developed by NASA are on board every U.S. commercial aircraft. The

[1] "The Economic Impact of Civil Aviation on the U.S. Economy," FAA, November 2016. Available at: https://www.faa.gov/about/plans_reports/media/2017-economic-impact-report.pdf
[2] "Leading Indicators for the U.S. Aerospace Industry," International Trade Administration, March 15, 2019. Available at: https://www.trade.gov/td/otm/assets/aero/LeadingIndicators.pdf
[3] Title 51, U.S. Code, Section 20102(d)

figure above highlights NASA's contribution to commercial aviation.[4] In addition, NASA has a history of working with the Federal Aviation Administration (FAA), the United Nations' International Civil Aviation Organization (ICAO), and standards bodies to conduct underlying research and tests and deliver the data and tools to help inform the development of aviation regulations and standards.[5]

NASA's ARMD is guided by a strategic implementation plan,[6] which lays out the approach for addressing growing demand for global air mobility, increasing demands for energy efficiency and sustainability, and enabling convergence between traditional aeronautics disciplines and other emerging technologies. The plan identifies six research thrusts:

(1) Safe, Efficient Growth in Global Operations,
(2) Innovation in Commercial Supersonic Aircraft,
(3) Ultra-Efficient Commercial Vehicles,
(4) Transition to Alternative Propulsion and Energy,
(5) Real-Time System-Wide Safety Assurance, and
(6) Assured Autonomy for Aviation Transformation.

According to the strategic implementation plan, the ARMD formulated these "Strategic Thrusts" to "*act as the link between its strategic vision and its research plans*" and that, taken together, they "*constitute a vision for aviation and the ARMD's plan to enable the transformation of aviation to meet future needs.*" To address these strategic thrusts, ARMD manages four major programs, each focused on a specific research area:

- Airspace Operations Safety Program (AOSP), which safely increases the throughput and efficiency of the National Airspace System (NAS).
- Advanced Air Vehicles Program (AAVP), which enables advances for a wide range of civil aircraft that are safer, more energy efficient, and have smaller environmental impact.
- Integrated Aviation Systems Program (IASP), which conducts research on promising concepts and technologies at an integrated system level.
- Transformative Aeronautics Concepts Program (TACP), which demonstrates initial feasibility in multi-disciplinary concepts, including where non-aeronautics technologies converge with aeronautics, to create new opportunities in aviation.

Aeronautics Research Mission Directorate Fiscal Year 2020 Request

The NASA Fiscal Year (FY) 2020 budget request for ARMD, as detailed in the table below, proposed a total of $666.9 million, a $58.1 million (8 percent) reduction from the FY 2019 enacted appropriation. The proposed reduction is largely due to the transfer of $56 million for the

---

[4] NASA Image, "NASA Aeronautics Research Onboard: Decades of Contributions to Commercial Aviation." Available at: https://www.nasa.gov/sites/default/files/files/c_litho_12_07_09_v2.pdf
[5] "NASA's Research Efforts and Management of Unmanned Aircraft Systems" NASA OIG, IG-17-025. September 2017. https://oig.nasa.gov/docs/IG-17-025.pdf
[6] "NASA Aeronautics: Strategic Implementation Plan, 2017 Update." Available at: https://www.nasa.gov/aeroresearch/strategy

management of the Aeronautics Evaluation and Testing Capabilities (AETC) Project[7] out of ARMD and into the Safety, Security, and Mission Services account.

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Airspace Operations and Safety Program	118.7	--	**121.2**	130.6	133.5	136.2	138.9
Advanced Air Vehicles Program	237.7	--	**188.1**	203.3	212.2	219.3	224.2
Integrated Aviation Systems Program	221.5	--	**233.2**	209.4	202.2	97.1	87.2
Transformative Aero Concepts Program	112.2	--	**124.4**	130.3	132.3	134.6	136.7
Total Budget	**690.0**	**725.0**	**666.9**	**673.6**	**680.3**	**587.1**	**587.0**
Change from FY 2019			**-58.1**				
Percentage change from FY 2019			**-8.0%**				

Energy Efficiency and Environmental Sustainability

According to the International Air Transportation Association (IATA), the number of passenger airplane trips could nearly double by 2037,[8] raising concerns about broader environmental and community impacts, including attendant increases in carbon dioxide (CO_2) emissions and noise. Aviation currently accounts for about 2 percent of global annual CO_2 emissions, and 90 percent of those emissions are from aircraft carrying 100 or more passengers.[9] A 2016 National Academies report, *Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions*,[10] recommended that agencies and organizations in government, industry, and academia prioritize efforts to reduce aviation CO_2 emissions over the next 10-30 years, including advances in aircraft-propulsion integration, such as changes in aircraft configurations; improvements in the efficiency of gas turbine engines (jet engines); development of turboelectric propulsion systems; and advances in sustainable alternative jet fuels, which can be used with existing jet propulsion systems to reduce carbon emissions.

NASA contributes to increasing energy efficiency and environmental sustainability through several ARMD programs and projects. In collaboration with industry partners, NASA developed hybrid gas-electric propulsion concepts and demonstrated a 500 kilowatt hybrid electric powertrain system. NASA also started work on an X-57 Maxwell experimental aircraft, which will inform the ability to design, build, and operate an all-electric system. In addition, NASA has collaborated with partners to test blends of alternative fuels in aircraft operations. NASA's work on noise reduction includes testing technologies to reduce landing gear noise and demonstrating a technology to reduce the drag within a jet engine that lowered noise during take-off-and-landing. Among activities planned for FY 2020 are continued work on advanced wing concepts

[7] The AETC Project, currently managed under the ARMD account, consists of NASA's aerosciences test facilities, primarily wind tunnels. ARMD is the primary user of the AETC facilities, but the Human Exploration and Operations, Science, and Space Technology mission directorates are also users.
[8] "IATA Forecast Predicts 8.2 billion Air Travelers in 2037." IATA, October 2018. https://www.iata.org/pressroom/pr/Pages/2018-10-24-02.aspx
[9] "Fact Sheet: Climate Change and CORSIA." IATA, May 2018. https://www.iata.org/pressroom/facts_figures/fact_sheets/Documents/fact-sheet-climate-change.pdf
[10] National Academies of Sciences, Engineering, and Medicine. 2016. *Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions*. Washington, DC: The National Academies Press. https://doi.org/10.17226/23490.

that have the potential to lead to quieter, lighter, and more efficient aircraft and plans to carry out the first test flight of the X-57 Maxwell aircraft to test electrical systems. NASA also plans, in FY 2020, to begin an effort to achieve, over multiple years, a 1 megawatt power electric propulsion system, which has been found to potentially benefit a range of aircraft sizes.

Supersonic Flight

Typical commercial airplanes cruise at speeds of 450-550 miles per hour, well below the speed of sound, which is approximately 770 miles per hour. A supersonic aircraft travels faster than the speed of sound and produces a continuous stream of shock waves. A listener on the ground below a supersonic plane hears a loud, thunder-like clap of sound called a "sonic boom" from the sudden changes in air pressure from the shock wave. In addition to causing the loud noise, sufficiently intense sonic booms can even break glass or otherwise damage structures. Civil and commercial supersonic flight over land has thus been banned in the U.S. since 1973.[11]

The Concorde, developed by companies in Great Britain and France, was the only commercial supersonic airliner and flew transatlantic routes from 1978 until its retirement in 2003. Through many years of basic R&D in supersonics, NASA has developed designs for aircraft that increase efficiency and significantly reduce the strength of the sonic boom. NASA has also developed sophisticated tools and techniques for testing, collecting and analyzing data, and modeling supersonic flight.[12] To that end, NASA initiated in 2018 the Low Boom Flight Demonstration (LBFD) mission, which starts with the development of the X-59 Quiet Supersonic Technology (QueSST) aircraft, designed with a unique shape that minimizes the sonic boom. NASA will then perform test flights of the X-59 over diverse populations and geographical locations within the U.S. "*to develop a low-boom community response database that will be provided to U.S. and international regulators in support of their development of a noise-based standard for supersonic overland flight*."[13] NASA expects to deliver finalized LBFD data in FY 2025 to FAA and ICAO to inform the development of regulations allowing for supersonic overland flights.

Safe Integration of UAS into the Airspace

Commonly referred to as a "drone," an unmanned aircraft system (UAS) is any aircraft that operates without a pilot or crew on board, either remotely or entirely autonomously. While UAS already play a significant role in military applications, they also could have wide applications in civil aviation. NASA is particularly focused on developing the technologies and providing the data to enable the safe integration of UAS into the airspace. In FY 2020, NASA plans to complete the UAS Integration into the National Airspace (NAS) and UAS Traffic Management (UTM) projects, the results of which will be delivered to the FAA.

---

[11] Title 14, U.S. Code of Federal Regulations, Section 91.817

[12] "70 Years of Supersonic Flight: NASA Continues to Break Barriers." Available at: https://www.nasa.gov/centers/armstrong/feature/70_years_supersonic_flight.html

[13] NASA FY 2020 Budget Request, Congressional Justification. Available at: https://www.nasa.gov/sites/default/files/atoms/files/fy_2020_congressional_justification.pdf

Urban Air Mobility

Urban Air Mobility (UAM) refers to a new air transportation concept for short-distance flight (few to tens of miles) within a major metropolitan area by aircraft carrying either passengers or cargo and controlled either manually or autonomously. Examples of potential UAM systems range from "last-mile" small package delivery to multi-passenger "air taxis" that offer on-demand private transport for 2-5 people at a time as app-based services do now by car. UAM systems are generally envisioned to be electric vertical takeoff and landing aircraft (eVTOLs), requiring no runways, instead landing in open spaces or on city rooftops. The current era of public and private UAM development was catalyzed by a NASA aerospace engineer's 2010 paper on electric propulsion as a "*game changing technology*" for eVTOLs.[14]

UAM has the potential to fundamentally alter urban transportation by lifting some of the traffic congestion on the street to the air.[15] For some use cases, UAM passenger transportation could reduce greenhouse gas emissions: a recent study concluded that "*[electric] VTOLs offer fast, predictable transportation and could have a niche role in sustainable mobility.*"[16]

Companies around the world, including ones based in the U.S., Europe, Brazil, and China, are making significant investments in UAM R&D and have begun test flights. Governments beyond the U.S. are also looking toward a UAM future: for example, in 2018, Japan's government funded a public-private partnership to enable a viable UAM market by 2023.[17]

NASA recently commissioned two UAM market analyses, both of which were released in November 2018. One study carried out by Booz Allen Hamilton[18] found that markets for air taxis and airport shuttles could be viable, with a best-case scenario combined market value of $500 billion. The second study, by Crown Consulting, Inc.,[19] found that last-mile package delivery could be profitable by 2030, with 500 million annual deliveries. That study also found that "air metro," with pre-determined routes and schedules, and set stops in high traffic areas, could be profitable by 2028 with 130 million passenger trips, and grow to 740 million passenger trips in 2030. Both studies caution that their results significantly depend on overcoming challenges in a number of areas, including safety, technology, regulations, and public acceptance.

---

[14] Moore, Mark. "NASA Puffin Electric Tailsitter VTOL Concept." 10th American Institute of Aeronautics and Astronautics Aviation Technology, Integration, and Operations Conference Proceedings, September 2010. https://doi.org/10.2514/6.2010-9345

[15] Arieno, Vanessa. "Are Flying Cars Just Science Fiction? Urban Air Mobility Could Solve Some of Transportation's Most Pressing Problems." *Newsweek*. February 1, 2019. https://www.newsweek.com/flying-cars-science-fiction-urban-air-mobility-solve-transportation-problems-1309638

[16] Kasliwal, Akshat; Furbush, Noah J.; Gawron, James H.; et al. "Role of Flying Cars in Sustainable Mobility." *Nature Communications*, 10: 1555. April 9, 2019. https://www.nature.com/articles/s41467-019-09426-0

[17] Boyd, John. "Japan's Roadmap for Flying Cars." *IEEE Spectrum*. February 11, 2019. https://spectrum.ieee.org/cars-that-think/transportation/alternative-transportation/japan-wont-be-grounded-when-it-comes-to-flying-cars

[18] "Executive Briefing: Urban Air Mobility (UAM) Market Study." Booz Allen Hamilton for NASA. Available at: https://www.nasa.gov/sites/default/files/atoms/files/bah_uam_executive_briefing_181005_tagged.pdf

[19] "Urban Air Mobility (UAM) Market Study." Crown Consulting, Inc. for NASA. Available at: https://www.nasa.gov/sites/default/files/atoms/files/uam-market-study-executive-summary-v2.pdf

NASA ARMD's primary role in UAM is targeted at advancing the safe integration of UAM vehicles into the national airspace system, including addressing challenges across operations and community acceptance. In 2020, NASA plans to initiate a Grand Challenge, an annual series of UAM ecosystem-wide safety and integration scenarios that would both promote public confidence in UAM safety and facilitate community-wide learning.[20] NASA issued a request for information (RFI) from stakeholders to inform the Grand Challenge in fall 2018.[21]

NASA ARMD reactivated the National Academies of Sciences, Engineering, and Medicine's Aeronautics Research and Technology Roundtable[22] in 2018 to focus on UAM. NASA has also contracted the National Academies to conduct a consensus study to assess the feasibility of a safe and efficient UAM system. The study is anticipated to be released in 2020.[23]

Hypersonics

While "supersonic" flight is at any speed above the speed of sound, flight faster than five times the speed of sound is generally referred to as "hypersonic." Advancement of hypersonic missiles that can travel at ten to twenty times the speed of sound, or "hypersonics," is a near-term priority of the U.S. military to improve the capabilities of air defense and attack, especially as foreign allies and adversaries make advances in the technology.[24] NASA's role is in fundamental hypersonics research for potential civil applications—like reaching low Earth orbit (LEO) or commercial air travel—and the agency carries out that research in partnership with the FAA and Department of Defense (DoD).

NASA ARMD funds hypersonics research in the Advanced Air Vehicle Program budget line. As an example, NASA works on hypersonics propulsion R&D because "*one of the key challenges for hypersonics is creating a propulsion system that can operate at slower speeds for takeoff and landing and transition to high-speed operation in flight.*"[25] NASA's hypersonics research activities include propulsion methods and the accompanying algorithms and techniques to improve that transition for both national security and aviation industry purposes.

---

[20] NASA UAM Grand Challenge project page: https://www.nasa.gov/uamgc
[21] ARMD UAM RFI available at: https://www.fbo.gov/spg/NASA/DFRC/OPDC20220/18AFRC19S0001/listing.html
[22] Aeronautics Research and Technology Roundtable of the National Academies of Sciences, Engineering, and Medicine. Project information page: https://www8.nationalacademies.org/pa/projectview.aspx?key=50607
[23] "Urban Air Mobility Research and Technology" Study Committee of the National Academies of Sciences, Engineering, and Medicine. Project information page: https://www8.nationalacademies.org/pa/projectview.aspx?key=51434
[24] Smith, R. Jeffrey. "Hypersonic Missiles are Unstoppable. And They're Starting a New Global Arms Race." *The New York Times Magazine*. June 19, 2019. https://www.nytimes.com/2019/06/19/magazine/hypersonic-missiles.html
[25] NASA FY 2020 Budget Request, Congressional Justification. Available at: https://www.nasa.gov/sites/default/files/atoms/files/fy_2020_congressional_justification.pdf