NASA'S CONTRIBUTIONS TO AERONAUTICS

VOLUME 2

FLIGHT ENVIRONMENT

OPERATIONS

FLIGHT TESTING AND RESEARCH

More than 87,000 flight take place each day over the United States. The work of NASA and others has helped develop ways to ensure safety in these crowded skies. Richard P. Hallion.

CASE 3

The Quest for Safety Amid Crowded Skies

James Banke

Since 1926 and the passage of the Air Commerce Act, the Federal Government has had a vital commitment to aviation safety. Even before this, however, the NACA championed regulation of aeronautics, the establishment of licensing procedures for pilots and aircraft, and the definition of technical criteria to enhance the safety of air operations. NASA has worked closely with the FAA and other aviation organizations to ensure the safety of America's air transport network.

WHEN THE FIRST AIRPLANE LIFTED OFF from the sands of Kitty Hawk during 1903, there was no concern of a midair collision with another airplane. The Wright brothers had the North Carolina skies all to themselves. But as more and more aircraft found their way off the ground and then began to share the increasing number of new airfields, the need to coordinate movements among pilots quickly grew. As flight technology matured to allow cross-country trips, methods to improve safe navigation between airports evolved as well. Initially, bonfires lit the airways. Then came light towers, two-way radio, omnidirectional beacons, radar, and—ultimately—Global Positioning System (GPS) navigation signals from space.[1]

Today, the skies are crowded, and the potential for catastrophic loss of life is ever present, as more than 87,000 flights take place each day over the United States. Despite repeated reports of computer crashes or bad weather slowing an overburdened national airspace system, air-related fatalities remain historically low, thanks in large part to the technical advances developed by the National Aeronautics and Space Administration (NASA), but especially to the daily efforts of some 15,000 air traffic controllers keeping a close eye on all of those airplanes.[2]

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[1] Edmund Preston, *FAA Historical Chronology, Civil Aviation and the Federal Government 1926–1996* (Washington, DC: Federal Aviation Administration).

[2] NATCA: *A History of Air Traffic Control* (Washington, DC: National Air Traffic Controllers Association, 2009), p. 16.

From an Australian government slide show in 1956, the basic concepts of an emerging air traffic control system are explained to the public. Airways Museum & Civil Aviation Historical Society, Melbourne, Australia (*www.airwaysmuseum.com*).

All of those controllers work for, or are under contract to, the Federal Aviation Administration (FAA), which is the Federal agency responsible for keeping U.S. skyways safe by setting and enforcing regulations. Before the FAA (formed in 1958), it was the Civil Aeronautics Administration (formed in 1941), and even earlier than that, it was the Department of Commerce's Aeronautics Bureau (formed in 1926). That that administrative job today is not part of NASA's duties is the result of decisions made by the White House, Congress, and NASA's predecessor organization, the National Advisory Committee for Aeronautics (NACA), during 1920.[3]

At the time (specifically 1919), the International Commission for Air Navigation had been created to develop the world's first set of rules for governing air traffic. But the United States did not sign on to the convention. Instead, U.S. officials turned to the NACA and other organizations to determine how best to organize the Government for handling

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[3] Alex Roland, *Model Research: The National Advisory Committee for Aeronautics 1915–1958,* NASA SP-4103 (Washington, DC: NASA, 1985).

all aspects of this new transportation system. The NACA in 1920 already was the focal point of aviation research in the Nation, and many thought it only natural, and best, that the Committee be the Government's all-inclusive home for aviation matters. A similar organizational model existed in Europe but didn't appear to some with the NACA to be an ideal solution. This sentiment was most clearly expressed by John F. Hayford, a charter member of the NACA and a Northwestern University engineer, who said during a meeting, "The NACA is adapted to function well as an advisory committee but not to function satisfactorily as an administrative body."[4]

So, in a way, NASA's earliest contribution to making safer skyways was to shed itself of the responsibility for overseeing improvements to and regulating the operation of the national airspace. With the FAA secure in that management role, NASA has been free to continue to play to its strengths as a research organization. It has provided technical innovation to enhance safety in the cockpits; increase efficiencies along the air routes; introduce reliable automation, navigation, and communication systems for the many air traffic control (ATC) facilities that dot the Nation; and manage complex safety reporting systems that have required creation of new data-crunching capabilities.

This case study will present a survey in a more-or-less chronological order of NASA's efforts to assist the FAA in making safer skyways. An overview of key NASA programs, as seen through the eyes of the FAA until 1996, will be presented first. NASA's contributions to air traffic safety after the 1997 establishment of national goals for reducing fatal air accidents will be highlighted next. The case study will continue with a survey of NASA's current programs and facilities related to airspace safety and conclude with an introduction of the NextGen Air Transportation System, which is to be in place by 2025.

NASA, as Seen by the FAA

Nearly every NASA program related to aviation safety has required the involvement of the FAA. Anything new from NASA that affects—for example, the design of an airliner or the layout of a cockpit panel[5] or the introduction of a modified traffic control procedure that relies on

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[4] Roland, *Model Research*, p. 57.

[5] *Part 21 Aircraft Certification Procedures for Products and Parts,* Federal Aviation Regulations (Washington, DC: FAA, 2009).

new technology[6]—must eventually be certified for use by the FAA, either directly or indirectly. This process continues today, extending the legacy of dozens of programs that came before—not all of which can be detailed here. But in terms of a historical overview through the eyes of the FAA, a handful of key collaborations with NASA were considered important enough by the FAA to mention in its official chronology, and they are summarized in this section.

Partners in the Sky: 1965

The partnership between NASA and the FAA that facilitates that exchange of ideas and technology was forged soon after both agencies were formally created in 1958. With the growing acceptance of commercial jet airliners and the ever-increasing number of passengers who wanted to get to their destinations as quickly as possible, the United States began exploring the possibility of fielding a Supersonic Transport (SST). By 1964, it was suggested that duplication of effort was underway by researchers at the FAA and NASA, especially in upgrading existing jet powerplants required to propel the speedy airliner. The resulting series of meetings during the next year led to the creation in May 1965 of the NASA–FAA Coordinating Board, which was designed to "strengthen the coordination, planning, and exchange of information between the two agencies."[7]

Project Taper: 1965

During that same month, the findings were released of what the FAA's official historical record details as its first joint research project with NASA.[8]

A year earlier, during May and June 1964, two series of flight tests were conducted using FAA aircraft with NASA pilots to study the hazards of light to moderate air turbulence to jet aircraft from several perspectives. The effort was called Project Taper, short for Turbulent Air Pilot Environment Research.[9] In conjunction with ground-based wind tunnel runs and early use of simulator programs, FAA Convair 880 and

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[6] *Aeronautical Information Manual: Official Guide to Basic Flight Information and ATC Procedures* (Washington, DC: FAA, 2008).

[7] Preston, *FAA Chronology,* p. 108.

[8] Ibid., p. 109.

[9] William H. Andrews, Stanley P. Butchart, Donald L. Hughes, and Thomas R. Sisk, "Flight Tests Related to Jet Transport Upset and Turbulent-Air Penetration," *Conference on Aircraft Operating Problems,* NASA SP-83 (Washington, DC: NASA, 1965).

Boeing 720 airliners were flown to define the handling qualities of aircraft as they encountered turbulence and determine the best methods for the pilot to recover from the upset. Another part of the study was to determine how turbulence upset the pilots themselves and if any changes to cockpit displays or controls would be helpful. Results of the project presented at a 1965 NASA Conference on Aircraft Operating Problems indicated that in terms of aircraft control, retrimming the stabilizer and deploying the spoilers were "valuable tools," but if those devices were to be safely used, an accurate g-meter should be added to the cockpit to assist the pilot in applying the correct amount of control force. The pilots also observed that initially encountering turbulence often created such a jolt that it disrupted their ability to scan the instrument dials (which remained reliable despite the added vibrations) and recommended improvements in their seat cushions and restraint system.[10]

But the true value of Project Taper to making safer skyways may have been the realization that although aircraft and pilots under controlled conditions and specialized training could safely penetrate areas of turbulence—even if severe—the better course of action was to find ways to avoid the threat altogether. This required further research and improvements in turbulence detection and forecasting, along with the ability to integrate that data in a timely manner to the ATC system and cockpit instrumentation.[11]

Avoiding Bird Hazards: 1966

After millions of years of birds having the sky to themselves, it only took 9 years from the time the Wright brothers first flew in 1903 for the first human fatality brought about by a bird striking an aircraft and causing the plane to crash in 1912. Fast-forward to 1960, when an Eastern Air Lines plane went down near Boston, killing 62 people as a result of a bird strike—the largest loss of life from a single bird incident.[12]

With the growing number of commercial jet airplanes, faster aircraft increased the potential damage a small bird could inflict and the larger airplanes put more humans at risk during a single flight. The need to address methods for dealing with birds around airports and in the skies also rose in priority. So, on September 9, 1966, the Interagency Bird

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[10] Ibid.

[11] Philip Donely, "Safe Flight in Rough Air," NASA TM-X-51662 (Hampton, VA: NASA, 1964).

[12] Micheline Maynard, "Bird Hazard is Persistent for Planes," *New York Times* (Jan. 19, 2009).

A DeTect, Inc., MERLIN bird strike avoidance radar is seen here in use in South Africa. NASA uses the same system at Kennedy Space Center for Space Shuttle missions, and the FAA is considering its use at airports around the Nation. NASA.

Hazard Committee was formed to gather data, share information, and develop methods for mitigating the risk of collisions between birds and airplanes. With the FAA taking the lead, the Committee included representatives from NASA; the Civil Aeronautics Board; the Department of Interior; the Department of Health, Education, and Welfare; and the U.S. Air Force, Navy, and Army.[13]

Through the years since the Committee was formed, the aviation community has approached the bird strike hazard primarily on three fronts: (1) removing or relocating the birds, (2) designing aircraft components to be less susceptible to damage from bird strikes, and (3) increasing the understanding of bird habitats and migratory patterns so as to alter air traffic routes and minimize the potential for bird strikes. Despite these efforts, the problem persists today, as evidenced by the January 2009 incident involving a US Airways jet that was forced to ditch in the Hudson River. Both of its jet engines failed because of

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[13] John L. Seubert, "Activities of the FAA Inter-Agency Bird Hazard Committee" (Washington, DC: FAA, 1968).

bird strikes shortly after takeoff. Fortunately, all souls on board survived the water landing thanks to the training and skills of the entire flightcrew.[14]

NASA's contributions in this area include research to characterize the extent of damage that birds might inflict on jet engines and other aircraft components in a bid to make those parts more robust or forgiving of a strike,[15] and the development of techniques to identify potentially harmful flocks of birds[16] and their local and seasonal flight patterns using radar so that local air traffic routes can be altered.[17]

Radar is in use to warn pilots and air traffic controllers of bird hazards at the Seattle-Tacoma International Airport. As of this writing, the FAA plans to deploy test systems at Chicago, Dallas, and New York airports, as the technology still needs to be perfected before its deployment across the country, according to an FAA spokeswoman quoted in a *Wall Street Journal* story published January 26, 2009.[18]

Meanwhile, a bird detecting radar system first developed for the Air Force by DeTect, Inc., of Panama City, FL, has been in use since 2006 at NASA's Kennedy Space Center to check for potential bird strike hazards before every Space Shuttle launch. Two customized marine radars scan the sky: one oriented in the vertical, the other in the horizontal. Together with specialized software, the MERLIN system can detect flocks of birds up to 12 miles from the launch pad or runway, according to a company fact sheet.

In the meantime, airports with bird problems will continue to rely on broadcasting sudden loud noises, shooting off fireworks, flashing strobe lights, releasing predator animals where the birds are nesting, or, in the worst case, simply eliminating the birds.

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14. Maynard, "Bird Hazard is Persistent for Planes."

15. M.S. Hirschbein, "Bird Impact Analysis Package for Turbine Engine Fan Blades," *23rd Structures, Structural Dynamics and Materials Conference, New Orleans, LA, May 10–12, 1982.*

16. E.B. Dobson, J.J. Hicks, and T.G. Konrad, "Radar Characteristics of Known, Single Birds in Flight," *Science*, vol. 159, no. 3812 (Jan. 19, 1968), pp. 274–280.

17. Bruno Bruderer and Peter Steidinger, "Methods of Quantitative and Qualitative Analysis of Bird Migration with a Tracking Radar," *Animal Orientation and Navigation* (Washington, DC: NASA, 1972), pp. 151–167.

18. Andy Pasztor and Susan Carey, "New Focus Put on Avoiding Bird Strikes," *Wall Street Journal* (Jan. 26, 2009), p. A3.

Applications Technology Satellite 1 (ATS 1): 1966–1967

Aviation's use of actual space-based technology was first demonstrated by the FAA using NASA's Applications Technology Satellite 1 (ATS 1) to relay voice communications between the ground and an airborne FAA aircraft using very high frequency (VHF) radio during 1966 and 1967, with the aim of enabling safer air traffic control over the oceans.[19]

Launched from Cape Canaveral atop an Atlas Agena D rocket on December 7, 1966, the spin-stabilized ATS 1 was injected into geosynchronous orbit to take up a perch 22,300 miles high, directly over Ecuador. During this early period in space history, the ATS 1 spacecraft was packed with experiments to demonstrate how satellites could be used to provide the communication, navigation, and weather monitoring that we now take for granted. In fact, the ATS 1's black and white television camera captured the first full-Earth image of the planet's cloud-covered surface.[20]

Eight flight tests were conducted using NASA's ATS 1 to relay voice signals between the ground and an FAA aircraft using VHF band radio, with the intent of allowing air traffic controllers to speak with pilots flying over an ocean. Measurements were recorded of signal level, signal plus noise-to-noise ratio, multipath propagation, voice intelligibility, and adjacent channel interference. In a 1970 FAA report, the author concluded that the "overall communications reliability using the ATS 1 link was considered marginal."[21]

All together, the ATS project attempted six satellite launches between 1966 and 1974, with ATS 2 and ATS 4 unable to achieve a useful orbit. ATS 1 and ATS 3 continued the FAA radio relay testing, this time including a specially equipped Pan American Airways 747 as it flew a commercial flight over the ocean. Results were better than when the ATS 1 was tested alone, with a NASA summary of the experiments concluding that

> The experiments have shown that geostationary satellites can provide high quality, reliable, un-delayed communications

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[19] J.N. Sivo, W.H. Robbins, and D.M. Stretchberry, "Trends in NASA Communications Satellites," NASA TM-X-68141 (1972).

[20] A.N. Engler, J.F. Nash, and J.D. Strange, "Applications Technology Satellite and Communications Technology/Satellite User Experiments for 1967-1980 Reference Book," NASA CR-165169-VOL-1 (1980).

[21] F.W. Jefferson, "ATS-1 VHF Communications Experimentation," FAA 0444707 (1970).

> between distant points on the earth and that they can also be used for surveillance. A combination of un-delayed communications and independent surveillance from shore provides the elements necessary for the implementation of effective traffic control for ships and aircraft over oceanic regions. Eventually the same techniques may be applied to continental air traffic control.[22]

Aviation Safety Reporting System: 1975

On December 1, 1974, a Trans World Airlines (TWA) Boeing 727, on final approach to Dulles airport in gusty winds and snow, crashed into a Virginia mountain, killing all aboard. Confusion about the approach to the airport, the navigation charts the pilots were using, and the instructions from air traffic controllers all contributed to the accident. Six weeks earlier, a United Airlines flight nearly succumbed to the same fate. Officials concluded, among other things, that a safety awareness program might have enabled the TWA flight to benefit from the United flight's experience. In May 1975, the FAA announced the start of an Aviation Safety Reporting Program to facilitate that kind of communication. Almost immediately, it was realized the program would fail because of fear the FAA would retaliate against someone calling into question its rules or personnel. A neutral third party was needed, so the FAA turned to NASA for the job. In August 1975, the agreement was signed, and NASA officially began operating a new Aviation Safety Reporting System (ASRS).[23]

NASA's job with the ASRS was more than just emptying a "big suggestion box" from time to time. The memorandum of agreement between the FAA and NASA proposed that the updated ASRS would have four functions:

> 1. Take receipt of the voluntary input, remove all evidence of identification from the input, and begin initial processing of the data.
> 2. Perform analysis and interpretation of the data to identify any trends or immediate problems requiring action.

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[22] "VHF Ranging and Position Fixing Experiment using ATS Satellites," NASA CR-125537 (1971).

[23] C.E. Billings, E.S. Cheaney, R. Hardy, and W.D. Reynard, "The Development of the NASA Aviation Safety Reporting System," NASA RP-1114 (1986), p. 3.

3. Prepare and disseminate appropriate reports and other data.
4. Continually evaluate the ASRS, review its performance, and make improvements as necessary.

Two other significant aspects of the ASRS included a provision that no disciplinary action would be taken against someone making a safety report and that NASA would form a committee to advise on the ASRS. The committee would be made up of key aviation organizations, including the Aircraft Owners and Pilots Association, the Air Line Pilots Association, the Aviation Consumer Action Project, the National Business Aircraft Association, the Professional Air Traffic Controllers Organization, the Air Transport Association, the Allied Pilots Association, the American Association of Airport Executives, the Aerospace Industries Association, the General Aviation Manufacturers' Association, the Department of Defense, and the FAA.[24]

Now in existence for more than 30 years, the ASRS has racked up an impressive success record of influencing safety that has touched every aspect of flight operations, from the largest airliners to the smallest general-aviation aircraft. According to numbers provided by NASA's Ames Research Center at Moffett Field, CA, between 1976 and 2006, the ASRS received more than 723,400 incident reports, resulting in 4,171 safety alerts being issued and the instigation of 60 major research studies. Typical of the sort of input NASA receives is a report from a Mooney 20 pilot who was taking a young aviation enthusiast on a sightseeing flight and explaining to the passenger during his landing approach what he was doing and what the instruments were telling him. This distracted his piloting just enough to complicate his approach and cause the plane to flare over the runway. He heard his stall alarm sound, then silence, then another alarm with the same tone. Suddenly, his aircraft hit the runway, and he skidded to a stop just off the pavement. It turned out that the stall warning alarm and landing gear alarm sounded alike. His suggestion was to remind the general-aviation community there were verbal alarms available to remind pilots to check their gear before landing.[25]

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[24] C.E. Billings, "Aviation Safety Reporting System," p. 6.

[25] "Horns and Hollers," *CALLBACK From NASA's Aviation Safety Reporting System,* No. 359 (Nov. 2009), p. 2.

Although the ASRS continues today, one negative about the program is that it is passive and only works if information is voluntarily offered. But from April 2001 through December 2004, NASA fielded the National Aviation Operations Monitoring Service (NAOMS) and conducted almost 30,000 interviews to solicit specific safety-related data from pilots, air traffic controllers, mechanics, and other operational personnel. The aim was to identify systemwide trends and establish performance measures, with an emphasis on tracking the effects of new safety-related procedures, technologies, and training. NAOMS was part of NASA's Aviation Safety Program, detailed later in this case study.[26]

With all these data in hand, more coming in every day, and none of them in a standard, computer-friendly format, NASA researchers were prompted to develop search algorithms that recognized relevant text. The first such suite of software used to support ASRS was called QUOROM, which at its core was a computer program capable of analyzing, modeling, and ranking text-based reports. NASA programmers then enhanced QUOROM to provide:

- Keyword searches, which retrieve from the ASRS database narratives that contain one or more user-specified keywords in typical or selected contexts and rank the narratives on their relevance to the keywords in context.
- Phrase searches, which retrieve narratives that contain user-specified phrases, exactly or approximately, and rank the narratives on their relevance to the phrases.
- Phrase generation, which produces a list of phrases from the database that contain a user-specified word or phrase.
- Phrase discovery, which finds phrases from the database that are related to topics of interest.[27]

QUORUM's usefulness in accessing the ASRS database would evolve as computers became faster and more powerful, paving the way for a new suite of software to perform what is now called "data mining." This in turn would enable continual improvement in aviation safety and

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[26] "NAOMS Reference Report: Concepts, Methods, and Development Roadmap" Battelle Memorial Institute (2007).

[27] Michael W. McGreevy, "Searching the ASRS Database Using QUORUM Keyword Search, Phrase Search, Phrase Generation, and Phrase Discovery," NASA TM-2001-210913 (2001), p. 4.

Microwave Landing System hardware at NASA's Wallops Flight Research Facility in Virginia as a NASA 737 prepares to take off to test the high-tech navigation and landing aid. NASA.

find applications in everything from real-time monitoring of aircraft systems[28] to Earth sciences.[29]

Microwave Landing System: 1976

As soon as it was possible to join the new inventions of the airplane and the radio in a practical way, it was done. Pilots found themselves "flying the beam" to navigate from one city to another and lining up with the runway, even in poor visibility, using the Instrument Landing System (ILS). ILS could tell the pilots if they were left or right of the runway centerline and if they were higher or lower than the established glide slope during the final approach. ILS required straight-in approaches and separation between aircraft, which limited the number of landings allowed each hour at the busiest airports. To improve upon this, the FAA, NASA, and the Department of Defense (DOD) in 1971 began developing the Microwave Landing System (MLS), which promised,

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[28] Glenn Sakamoto, "Intelligent Data Mining Capabilities as Applied to Integrated Vehicle Health Management," *2007 Research and Engineering Annual Report* (Edwards, CA: NASA, 2008), p. 65.

[29] Sara Graves, Mahabaleshwa Hegde, Ken Keiser, Christopher Lynnes, Manil Maskey, Long Pham, and Rahul Ramachandran, "Earth Science Mining Web Services," *American Geophysical Union Meeting, San Francisco, Dec. 15–19, 2008.*

among other things, to increase the frequency of landings by allowing multiple approach paths to be used at the same time. Five years later, the FAA took delivery of a prototype system and had it installed at the FAA's National Aviation Facilities Experimental Center in Atlantic City, NJ, and at NASA's Wallops Flight Research Facility in Virginia.[30]

Between 1976 and 1994, NASA was actively involved in understanding how MLS could be integrated into the national airspace system. Configuration and operation of aircraft instrumentation,[31] pilot procedures and workload,[32] air traffic controller procedures,[33] use of MLS with helicopters,[34] effects of local terrain on the MLS signal,[35] and the determination to what extent MLS could be used to automate air traffic control[36] were among the topics NASA researchers tackled as the FAA made plans to employ MLS at airports around the Nation.

But having proven with NASA's Applications Technology Satellite program that space-based communication and navigation were more than feasible (but skipping endorsement of the use of satellites in the FAA's 1982 National Airspace System Plan), the FAA dropped the MLS program in 1994 to pursue the use of GPS technology, which was just beginning to work itself into the public consciousness. GPS signals, when enhanced by a ground-based system known as the Wide Area Augmentation System (WAAS), would provide more accurate position information and do it in a more efficient and potentially less costly manner than by deploying MLS around the Nation.[37]

Although never widely deployed in the United States for civilian use, MLS remains a tool of the Air Force at its airbases. NASA has

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[30] Preston, *FAA Chronology,* p. 188.

[31] D.G. Moss, P.F. Rieder, B.P. Stapleton, A.D. Thompson, and D.B. Walen, "MLS: Airplane System Modeling," NASA CR-165700 (1981).

[32] Jon E. Jonsson and Leland G. Summers, "Crew Procedures and Workload of Retrofit Concepts for Microwave Landing System," NASA CR-181700 (1989).

[33] S. Hart, J.G. Kreifeldt, and L. Parkin, "Air Traffic Control by Distributed Management in a MLS Environment," *13th Conference on Manual Control, Cambridge, MA, 1977.*

[34] H.Q. Lee, P.J. Obrien, L.L. Peach, L. Tobias, and F.M. Willett, Jr., "Helicopter IFR Approaches into Major Terminals Using RNAV, MLS and CDTI," *Journal of Aircraft,* vol. 20 (Aug. 1983).

[35] M.M. Poulose, "Terrain Modeling for Microwave Landing System," *IEEE Transactions on Aerospace and Electronic Systems,* vol. 27 (May 1991).

[36] M.M. Poulose, "Microwave Landing System Modeling with Application to Air Traffic Control Automation," *Journal of Aircraft,* vol. 29, no. 3 (May–June 1992).

[37] "Navigating the Airways," *Spinoff* (Washington, DC: NASA, 1999), p. 50.

employed a version of the system called the Microwave Scan Beam Landing System for use at its Space Shuttle landing sites in Florida and California. Moreover, Europe has embraced MLS in recent years, and an increasing number of airports there are being equipped with the system, with London's Heathrow Airport among the first to roll it out.[38]

NUSAT: 1985

NUSAT, a tiny satellite designed by Weber State College in northern Utah, was deployed into Earth orbit from the cargo bay of the Space Shuttle Challenger on April 29, 1985. Its purpose was to serve as a radar target for the FAA.

The satellite employed three L-band receivers, an ultra high frequency (UHF) command receiver, a VHF telemetry transmitter, associated antennas, a microprocessor, fixed solar arrays, and a power supply to acquire, store, and forward signal strength data from radar. All of that was packed inside a basketball-sized, 26-sided polyhedron that weighed about 115 pounds.[39]

NUSAT was used to optimize ground-based ATC radar systems for the United States and member nations of the International Civil Aviation Organization by measuring antenna patterns.[40]

National Plan for Civil Aviation Human Factors: 1995

In June 1995, the FAA announced its plans for a joint FAA–DOD–NASA initiative called the National Plan for Civil Aviation Human Factors. The plan detailed a national effort to reduce and eliminate human error as the cause of aviation accidents. The plan called for projects that would identify needs and problems related to human performance, guide research programs that addressed the human element, involve the Nation's top scientists and aviation professionals, and report the results of these efforts to the aviation community.[41]

NASA's extensive involvement in human factors issues is detailed in another case study of this volume.

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[38] Brian Evans, "MLS: Back to the Future?" *Aviation Today* (Apr. 1, 2003).

[39] R.G. Moore, "A Proof-of-Principle Getaway Special Free-Flying Satellite Demonstration," *2nd Symposium on Space Industrialization* (Huntsville, AL: NASA, 1984), p. 349.

[40] Charles A. Bonsall, "NUSAT Update," *The 1986 Get Away Special Experimenter's Symposium* (Greenbelt, MD: NASA, 1987), p. 63.

[41] FAA, "National Plan for Civil Aviation Human Factors: An Initiative for Research and Application" (Washington, DC: FAA, 1990).

Aviation Performance Measuring System: 1996

With the Aviation Safety Reporting System fully operational for two decades, NASA in 1996 once again found itself working with the FAA to gather raw data, process it, and make reports—all in the name of identifying potential problems and finding solutions. In this case, as part of a Flight Operations Quality Assurance program that the FAA was working with industry on, the agency partnered with NASA to test a new Aviation Performance Measuring System (APMS). The new system was designed to convert digital data taken from the flight data recorders of participating airlines into a format that could easily be analyzed.[42]

More specifically, the objectives of the NASA–FAA APMS research project was to establish an objective, scientifically and technically sound basis for performing flight data analysis; identify a flight data analysis system that featured an open and flexible architecture, so that it could easily be modified as necessary; and define and articulate guidelines that would be used in creating a standardized database structure that would form the basis for future flight data analysis programs. This standardized database structure would help ensure that no matter which data-crunching software an airline might choose, it would be compatible with the APMS dataset. Although APMS was not intended to be a nationwide flight data collection system, it was intended to make available the technical tools necessary to more easily enable a large-scale implementation of flight data analysis.[43]

At that time, commercially available software development was not far enough advanced to meet the needs of the APMS, which sought identification and analysis of trends and patterns in large-scale databases involving an entire airline. Software then was primarily written with the needs of flight crews in mind and was more capable of spotting single events rather than trends. For example, if a pilot threw a series of switches out of order, the onboard computer could sound an alarm. But that computer, or any other, would not know how frequently pilots made the same mistake on other flights.[44]

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[42] Preston, *FAA Chronology*, p. 301.

[43] Irving Statler, "APMS: An Integrated Set of Tools for Measuring Safety," *ISASI Flight Recorder Working Group Workshop, Santa Monica, CA, Apr. 16–18, 1996.*

[44] Statler, "The Aviation Performance Measuring System (APMS): An Integrated Suite of Tools for Measuring Performance and Safety," *World Aviation Congress, Anaheim, CA, Sept. 28–30, 1998.*

The FAA's air traffic control tower facility at the Dallas/Fort Worth International Airport is a popular site that the FAA uses for testing new ATC systems and procedures, including new Center TRACON Automation System tools. FAA.

A particularly interesting result of this work was featured in the 1998 edition of NASA's annual *Spinoff* publication, which highlights successful NASA technology that has found a new home in the commercial sector:

> A flight data visualization system called FlightViz™ has been created for NASA's Aviation Performance Measuring System (APMS), resulting in a comprehensive flight visualization and

> analysis system. The visualization software is now capable of very high-fidelity reproduction of the complete dynamic flight environment, including airport/airspace, aircraft, and cockpit instrumentation. The APMS program calls for analytic methods, algorithms, statistical techniques, and software for extracting useful information from digitally-recorded flight data. APMS is oriented toward the evaluation of performance in aviation systems, particularly human performance. . . . In fulfilling certain goals of the APMS effort and related Space Act Agreements, SimAuthor delivered to United Airlines in 1997, a state-of-the-art, high-fidelity, reconfigurable flight data replay system. The software is specifically designed to improve airline safety as part of Flight Operations Quality Assurance (FOQA) initiatives underway at United Airlines. . . . Pilots, instructors, human factors researchers, incident investigators, maintenance personnel, flight operations quality assurance staff, and others can utilize the software product to replay flight data from a flight data recorder or other data sources, such as a training simulator. The software can be customized to precisely represent an aircraft of interest. Even weather, time of day and special effects can be simulated.[45]

While by no means a complete list of every project NASA and the FAA have collaborated on, the examples detailed so far represent the diverse range of research conducted by the agencies. Much of the same kind of work continued as improved technology, updated systems, and fresh approaches were applied to address a constantly evolving set of challenges.

Aviation Safety Program

After the in-flight explosion and crash of TWA 800 in July 1996, President Bill Clinton established a Commission on Aviation Safety and Security, chaired by Vice President Al Gore. The Commission's emphasis was to find ways to reduce the number of fatal air-related accidents. Ultimately, the Commission challenged the aviation community to lower the fatal aircraft accident rate by 80 percent in 10 years and 90 percent in 25 years.

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45. "Improving Airline Safety," *Spinoff* (Washington, DC: NASA, 1998), p. 62.

NASA's response to this challenge was to create in 1997 the Aviation Safety Program (AvSP) and, as seen before, partner with the FAA and the DOD to conduct research on a number of fronts.[46]

NASA's AvSP was set up with three primary objectives: (1) eliminate accidents during targeted phases of flight, (2) increase the chances that passengers would survive an accident, and (3) beef up the foundation upon which aviation safety technologies are based. From those objectives, NASA established six research areas, some having to do directly with making safer skyways and others pointed at increasing aircraft safety and reliability. All produced results, as noted in the referenced technical papers. Those research areas included accident mitigation,[47] systemwide accident prevention,[48] single aircraft accident prevention,[49] weather accident prevention,[50] synthetic vision,[51] and aviation system modeling and monitoring.[52]

Of particular note is a trio of contributions that have lasting influence today. They include the introduction and incorporation of the glass cockpit into the pilot's work environment and a pair of programs to gather key data that can be processed into useful, safety enhancing information.

Glass Cockpit

As aircraft systems became more complex and the amount of navigation, weather, and air traffic information available to pilots grew in abundance, the nostalgic days of "stick and rudder" men (and women) gave way to "cockpit managers." Mechanical, analog dials showing a

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[46] Jaiwon Shin, "The NASA Aviation Safety Program: Overview," NASA TM-2000-209810 (2000).

[47] Lisa E. Jones, "Overview of the NASA Systems Approach to Crashworthiness Program," *American Helicopter Society 58th Annual Forum, Montreal, Canada, June 11–13, 2002*.

[48] Doreen A. Comerford, "Recommendations for a Cockpit Display that Integrates Weather Information with Traffic Information," NASA TM-2004-212830 (2004).

[49] Roger M. Bailey, Mark W. Frye, and Artie D. Jessup, "NASA-Langley Research Center's Aircraft Condition Analysis and Management System Implementation," NASA TM-2004-213276 (2004).

[50] "Proceedings of the Second NASA Aviation Safety Program Weather Accident Review," NASA CP-2003-210964 (2003).

[51] Jarvis J. Arthur, III, Randall E. Bailey, Lynda J. Kramer, R.M. Norman, Lawrence J. Prinzel, III, Kevin J. Shelton, and Steven P. Williams, "Synthetic Vision Enhanced Surface Operations With Head-Worn Display for Commercial Aircraft," *International Journal of Aviation Psychology,* vol. 19, no. 2 (Apr. 2009), pp. 158–181.

[52] "The Aviation System Monitoring and Modeling (ASMM) Project: A Documentation of its History and Accomplishments: 1999–2005," NASA TP-2007-214556 (2007).

A prototype "glass cockpit" that replaces analog dials and mechanical tapes with digitally driven flat panel displays is installed inside the cabin of NASA's 737 airborne laboratory, which tested the new hardware and won support for the concept in the aviation community. NASA.

single piece of information (e.g., airspeed or altitude) weren't sufficient to give pilots the full status of their increasingly complicated aircraft flying in an increasingly crowded sky. The solution came from engineers at NASA's Langley Research Center in Hampton, VA, who worked with key industry partners to come up with an electronic flight display—what is generally known now as the glass cockpit—that took advantage of powerful, small computers and liquid crystal display (LCD) flat panel technology. Early concepts of the glass cockpit were flight-proven using NASA's Boeing 737 flying laboratory and eventually certified for use by the FAA.[53]

According to a NASA fact sheet,

> The success of the NASA-led glass cockpit work is reflected in the total acceptance of electronic flight displays beginning with the introduction of the Boeing 767 in 1982. Airlines and their passengers, alike, have benefitted. Safety and efficiency of flight have been increased with improved pilot understanding of the airplane's situation relative to its environment.

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[53] Lane E. Wallace, "Airborne Trailblazer: Two Decades with NASA Langley's 737 Flying Laboratory," NASA SP-4216 (1994).

> The cost of air travel is less than it would be with the old technology and more flights arrive on time.[54]

After developing the first glass cockpits capable of displaying basic flight information, NASA has continued working to make more information available to the pilots,[55] while at the same time being conscious of information overload,[56] the ability of the flight crew to operate the cockpit displays without distraction during critical phases of flight (takeoff and landing),[57] and the effectiveness of training pilots to use the glass cockpit.[58]

Performance Data Analysis and Reporting System

In yet another example of NASA developing a database system with and for the FAA, the Performance Data Analysis and Reporting System (PDARS) began operation in 1999 with the goal of collecting, analyzing, and reporting of performance-related data about the National Airspace System. The difference between PDARS and the Aviation Safety Reporting System is that input for the ASRS comes voluntarily from people who see something they feel is unsafe and report it, while input for PDARS comes automatically—in real time—from electronic sources such as ATC radar tracks and filed flight plans. PDARS was created as an element of NASA's Aviation Safety Monitoring and Modeling project.[59]

From these data, PDARS calculates a variety of performance measures related to air traffic patterns, including traffic counts, travel times between airports and other navigation points, distances flown, general traffic flow parameters, and the separation distance from trailing

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[54] "The Glass Cockpit: Technology First Used in Military, Commercial Aircraft," FS-2000-06-43-LaRC (2000).

[55] Marianne Rudisill, "Crew/Automation Interaction in Space Transportation Systems: Lessons Learned from the Glass Cockpit," NASA Langley Research Center (2000).

[56] Susan T. Heers and Gregory M. Pisanich, "A Laboratory Glass-Cockpit Flight Simulator for Automation and Communications Research," *Human Factors Society Conference, San Diego, Oct. 9–13, 1995.*

[57] Earl L. Wiener, "Flight Training and Management for High-Technology Transport Aircraft," NASA CR-200816 (1996).

[58] Wiener, "Flight Training and Management for High-Technology Transport Aircraft," NASA CR-199670 (1995).

[59] Thomas R. Chidester, "Aviation Performance Measuring System," Ames Research Center Research and Technology 2000 (Moffett Field: NASA, 2000).

aircraft. Nearly 1,000 reports to appropriate FAA facilities are automatically generated and distributed each morning, while the system also allows for sharing data and reports among facilities, as well as facilitating larger research projects. With the information provided by PDARS, FAA managers can quickly determine the health, quality, and safety of day-to-day ATC operations and make immediate corrections.[60]

The system also has provided input for several NASA and FAA studies, including measurement of the benefits of the Dallas/Fort Worth Metroplex airspace, an analysis of the Los Angeles Arrival Enhancement Procedure, an analysis of the Phoenix Dryheat departure procedure, measurement of navigation accuracy of aircraft using area navigation en route, a study on the detection and analysis of in-close approach changes, an evaluation of the benefits of domestic reduced vertical separation minimum implementation, and a baseline study for the airspace flow program. As of 2008, PDARS was in use at 20 Air Route Traffic Control Centers, 19 Terminal Radar Approach Control facilities, three FAA service area offices, the FAA's Air Traffic Control System Command Center in Herndon, VA, and at FAA Headquarters in Washington, DC.[61]

National Aviation Operations Monitoring Service

A further contribution to the Aviation Safety Monitoring and Modeling project provided yet another method for gathering data and crunching numbers in the name of making the Nation's airspace safer amid increasingly crowded skies. Whereas the Aviation Safety Reporting System involved volunteered safety reports and the Performance Data Analysis and Reporting System took its input in real time from digital data sources, the National Aviation Operations Monitoring Service was a scientifically designed survey of the aviation community to generate statistically valid reports about the number and frequency of incidents that might compromise safety.[62]

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60. Wim den Braven and John Schade, "Concept and Operation of the Performance Data Analysis and Reporting System (PDARS)," *SAE Conference, Montreal, 2003*.

61. R. Nehl and J. Schade, "Update: Concept and Operation of the Performance Data Analysis and Reporting System (PDARS)," *2007 IEEE Aerospace Conference, Big Sky, MT, Mar. 3–10, 2007*.

62. Battelle Memorial Institute, "NAOMS Reference Report: Concepts, Methods and Development Roadmap" (Moffett Field: NASA, 2007).

After a survey was developed that would gather credible data from anonymous volunteers, an initial field trial of the NAOMS was held in 2000, followed by the launch of the program in 2001. Initially, the surveyors only sought out air carrier pilots who were randomly chosen from the FAA Airman's Medical Database. Researchers characterized the response to the NAOMS survey as enthusiastic. Between April 2001 and December 2004, nearly 30,000 pilot interviews were completed, with a remarkable 83-percent return rate, before the project ran short of funds and had to stop. The level of response was enough to achieve statistical validity and prove that NAOMS could be used as a permanent tool for managers to assess the operational health of the ATC system and suggest changes before they were actually needed. Although NASA and the FAA desired for the project to continue, it was shut down on January 31, 2008.[63]

It's worth mentioning that the NAOMS briefly became the subject of public controversy in 2007, when NASA received a Freedom of Information Act request by a reporter for the data obtained in the NAOMS survey. NASA denied the request, using language that then NASA Administrator Mike Griffin said left an "unfortunate impression" that the Agency was not acting in the best interest of the public. NASA eventually released the data after ensuring the anonymity originally guaranteed to those who were surveyed. In a January 14, 2008, letter from Griffin to all NASA employees, the Administrator summed up the experience by writing: "As usual in such circumstances, there are lessons to be learned, remembered, and applied. The NAOMS case demonstrates again, if such demonstrations were needed, the importance of peer review, scientific integrity, admitting mistakes when they are made, correcting them as best we can, and keeping our word, despite the criticism that can ensue."[64]

An Updated Safety Program

In 2006, NASA's Aeronautics Research Mission Directorate (ARMD) was reorganized. As a result, the projects that fell under ARMD's Aviation Safety Program were restructured as well, with more of a focus on

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[63] Statler, "The Aviation System Monitoring and Modeling (ASMM) Project: A Documentation of its History and Accomplishments: 1999–2005," NASA TP-2007-214556 (2007).

[64] Michael Griffin, "Letter from NASA Administrator Mike Griffin" (Washington, DC: NASA, 2008).

aircraft safety than on the skies they fly through. Air traffic improvements in the new plan now fall almost exclusively within the Airspace Systems Program. The Aviation Safety Program is now dedicated to developing the principles, guidelines, concepts, tools, methods, and technologies to address four project areas: the Integrated Vehicle Health Management Project,[65] the Integrated Intelligent Flight Deck Technologies Project,[66] the Integrated Resilient Aircraft Control Project,[67] and the Aircraft Aging and Durability Project.[68]

Commercial Aviation Safety Team (CAST)

When NASA's Aviation Safety Program was begun in 1997, the agency joined with a large group of aviation-related organizations from Government, industry, and academia in forming a Commercial Aviation Safety Team (CAST) to help reduce the U.S. commercial aviation fatal accident rate by 80 percent in 10 years. During those 10 years, the group analyzed data from some 500 accidents and thousands of safety incidents and helped develop 47 safety enhancements.[69] In 2008, the group could boast that the rate had been reduced by 83 percent, and for that, CAST was awarded aviation's most prestigious honor, the Robert J. Collier Trophy.

NASA's work with improving the National Airspace System has won the Agency two Collier Trophies: one in 2007 for its work with developing the new next-generation ADS-B instrumentation, and one in 2008 as part of the Commercial Aviation Safety Team, which helped improve air safety during the past decade. NASA.

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[65] Luis Trevino, Deidre E. Paris, and Michael D. Watson, "Intelligent Vehicle Health Management," *41st AIAA–ASME–SAE–ASEE Joint Propulsion Conference and Exhibit, Tucson, July 10–13, 2005*.

[66] David B. Kaber and Lawrence J. Prinzel, III, "Adaptive and Adaptable Automation Design: A Critical Review of the Literature and Recommendations for Future Research," NASA TM-2006-214504 (2006).

[67] Sanjay Garg, "NASA Glenn Research in Controls and Diagnostics for Intelligent Aerospace Propulsion Systems," *Integrated Condition Management 2006, Anaheim, Nov. 14–16, 2006*.

[68] Doug Rohn and Rick Young, "Aircraft Aging and Durability Project: Technical Plan Summary" (Washington, DC: NASA, 2007).

[69] Samuel A. Morello and Wendell R. Ricks, "Aviation Safety Issues Database," NASA TM-2009-215706 (2009).

Air Traffic Management Research

The work of NASA's Aeronautics Research Mission Directorate primarily takes place at NASA Field Centers in Virginia, Ohio, and California. It's at the Ames Research Center at Moffett Field, CA, that a large share of the work to make safer skyways has been managed. Many of the more effective programs to improve the safety and efficiency of the Nation's air traffic control system began at Ames and continue to be studied.[70]

Seven programs managed within the divisions of Ames's Air Traffic Management Research office, described in the next section, reveal how NASA research is making a difference in the skies every day.

Airspace Concept Evaluation System

The Airspace Concept Evaluation System (ACES) is a computer tool that allows researchers to try out novel Air Traffic Management (ATM) theories, weed out those that are not viable, and identify the most promising concepts. ACES looks at how a proposed air transportation concept can work within the National Airspace System (NAS), with the aim of reducing delays, increasing capacity, and handling projected growth in air traffic. ACES does this by simulating the major components of the NAS, modeling a flight from gate to gate, and taking into account in its models the individual behaviors of those that affect the NAS, from departure clearance to the traffic control tower, the weather office, navigation systems, pilot experience, type of aircraft, and other major components. ACES also is able to predict how one individual behavior can set up a ripple effect that touches, or has the potential to touch, the entire NAS. This modeling approach isolates the individual models so that they can continue to be enhanced, improved, and modified to represent new concepts without impacting development of the overall simulation system.[71]

Among the variables ACES has been tasked to run through its simulations are environmental impacts when a change is introduced,[72] use

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[70] Gano Chatterji, Kapil Sheth, and Banavar Sridhar, "Airspace Complexity and its Application in Air Traffic Management," *Second USA/Europe Air Traffic Management R&D Seminar, Dec. 1–4, 1998*.

[71] Brian Capozzi, Patrick Carlos, Vikram Manikonda, Larry Meyn, and Robert Windhorst, "The Airspace Concepts Evaluation System Architecture and System Plant," *AIAA Guidance, Navigation, and Control Conference, Keystone, CO, Aug. 21–24, 2006*.

[72] Stephen Augustine, Brian Capozzi, John DiFelici, Michael Graham, Raymond M.C. Miraflor, and Terry Thompson, "Environmental Impact Analysis with the Airspace Concept Evaluation System," *6th ATM Research and Development Seminar, Baltimore, June 27–30, 2005*.

of various communication and navigation models,[73] validation of certain concepts under different weather scenarios,[74] adjustments to spacing and merging of traffic around dense airports,[75] and reduction of air traffic controller workload by automating certain tasks.[76]

Future ATM Concepts Evaluation Tool

Another NASA air traffic simulation tool, the Future ATM Concepts Evaluation Tool (FACET), was created to allow researchers to explore, develop, and evaluate advanced traffic control concepts. The system can operate in several modes: playback, simulation, live, or in a sort of hybrid mode that connects it with the FAA's Enhanced Traffic Management System (ETMS). ETMS is an operational FAA program that monitors and reacts to air traffic congestion, and it can also predict when and where congestion might happen. (The ETMS is responsible, for example, for keeping a plane grounded in Orlando because of traffic congestion in Atlanta.) Streaming the ETMS live data into a run of FACET makes the simulation of a new advanced traffic control concept more accurate. Moreover, FACET is able to model airspace operations on a national level, processing the movements of more than 5,000 aircraft on a single desktop computer, taking into account aircraft performance, weather, and other variables.[77]

Some of the advanced concepts tested in FACET include allowing aircraft to have greater freedom in maintaining separation on their own,[78] integrating space launch vehicle and aircraft operations into the

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[73] Greg Kubat and Don Vandrei, "Airspace Concept Evaluation System, Concept Simulations using Communication, Navigation and Surveillance System Models," *Proceedings of the Sixth Integrated Communications, Navigation and Surveillance Conference & Workshop, Baltimore, May 1–3, 2006*.

[74] Larry Meyn and Shannon Zelinski, "Validating the Airspace Concept Evaluation System for Different Weather Days," *AIAA Modeling and Simulation Technologies Conference, Keystone, CO, Aug. 21–24, 2006*.

[75] Art Feinberg, Gary Lohr, Vikram Manikonda, and Michel Santos, "A Simulation Testbed for Airborne Merging and Spacing," *AIAA Atmospheric Flight Mechanics Conference, Honolulu, Aug. 18–21, 2008*.

[76] Heinz Erzberger and Robert Windhorst, "Fast-time Simulation of an Automated Conflict Detection and Resolution Concept," *6th AIAA Aviation Technology, Integration and Operations Conference, Wichita, Sept. 25–27, 2006*.

[77] Banavar Sridhar, "Future Air Traffic Management Concepts Evaluation Tool," Ames Research Center Research and Technology 2000 (Moffett Field: NASA, 2000), p. 5.

[78] Karl D. Bilimoria and Hilda Q. Lee, "Properties of Air Traffic Conflicts for Free and Structured Routing," *AIAA GN&C Conference, Montreal, Aug. 2001*.

airspace, and monitoring how efficiently aircraft comply with ATC instructions when their flights are rerouted.[79] In fact, the last of these concepts was so successful that it was deployed into the FAA's operational ETMS. NASA reports that the success of FACET has lead to its use as a simulation tool not only with the FAA, but also with several airlines, universities, and private companies. For example, Flight Dimensions International—the world's leading vendor of aircraft situational displays—recently integrated FACET with its already popular Flight Explorer product. FACET won NASA's 2006 Software of the Year Award.[80]

Surface Management System

Making the skyways safer for aircraft to fly by reducing delays and lowering the stress on the system begins and ends with the short journey on the ground between the active runway and the terminal gate. To better coordinate events between the air and ground sides, NASA developed, in cooperation with the FAA, a software tool called the Surface Management System (SMS), whose purpose is to manage the movements of aircraft on the surface of busy airports to improve capacity, efficiency, and flexibility.[81]

The SMS has three parts: a traffic management tool, a controller tool, and a National Airspace System information tool.[82]

The traffic management tool monitors aircraft positions in the sky and on the ground, along with the latest times when a departing airliner is about to be pushed back from its gate, to predict demand for taxiway and runway usage, with an aim toward understanding where backups might take place. Sharing this information among the traffic control tools and systems allows for more efficient planning. Similarly, the controller tool helps personnel in the ATC and ramp towers to better coordinate the movement of arriving and departing flights and to

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[79] Sarah Stock Patterson, "Dynamic Flow Management Problems in Air Transportation," NASA CR-97-206395 (1997).

[80] "Comprehensive Software Eases Air Traffic Management," Spinoff 2007 (Washington, DC: NASA, 2007).

[81] Dave Jara and Yoon C. Jung, "Development of the Surface Management System Integrated with CTAS Arrival Tools," *AIAA 5th Aviation Technology, Integration and Operations Forum, Arlington, TX, Sept. 2005*.

[82] Katherine Lee, "CTAS and NASA Air Traffic Management Fact Sheets for En Route Descent Advisor and Surface Management System," *NATCA Safety Conference, Fort Worth, Apr. 2004*.

advise pilots on which taxiways to use as they navigate between the runway and the gate.[83] Finally, the NAS information tool allows data from the SMS to be passed into the FAA's national Enhanced Traffic Management System, which in turn allows traffic controllers to have a more accurate picture of the airspace.[84]

Center TRACON Automation System

The computer-based tools used to improve the flow of traffic across the National Airspace System—such as SMS, FACET, and ACES already discussed—were built upon the historical foundation of another set of tools that are still in use today. Rolled out during the 1990s, the underlying concepts of these tools go back to 1968, when an Ames Research Center scientist, Heinz Erzberger, first explored the idea of introducing air traffic control concepts—such as 4-D trajectory synthesis—and then proposed what was, in fact, developed: the Center TRACON Automation System (CTAS), the Traffic Manager Adviser (TMA), the En Route Descent Adviser (EDA), and the Final Approach Spacing Tool (FAST). Each of the tools provides controllers with advice, information, and some amount of automation—but each tool does this for a different segment of the NAS.[85]

CTAS provides automation tools to help air traffic controllers plan for and manage aircraft arriving to a Terminal Radar Approach Control (TRACON), which is the area within about 40 miles of a major airport. It does this by generating air traffic advisories that are designed to increase fuel efficiency and reduce delays, as well as assist controllers in ensuring that there is an acceptable separation between aircraft and that planes are approaching a given airport in the correct order. CTAS's goals also include improving airport capacity without threatening safety or increasing the workload of controllers.[86]

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[83] Gautam Gupta and Matthew Stephen Kistler, "Effect of Surface Traffic Count on Taxi Time at Dallas-Fort Worth International Airport," NASA ARC-E-DAA-TN286 (2008).

[84] John O'Neill and Roxana Wales, "Information Management for Airline Operations," Ames Research Center Research and Technology Report (Moffett Field: NASA, 1998).

[85] Heinz Erzberger and William Nedell, "Design of Automation Tools for Management of Descent Traffic," NASA TM-101078 (1988).

[86] Dallas G. Denery and Heinz Erzberger, "The Future of Air Traffic Management," *NASA–ASEE Stanford University Seminars, Stanford, CA, 1998.*

Flight controllers test the Traffic Manager Adviser tool at the Denver TRACON. The tool helps manage the flow of air traffic in the area around an airport. National Air and Space Museum.

Traffic Manager Adviser

Airspace over the United States is divided into 22 areas. The skies within each of these areas are managed by an Air Route Traffic Control Center. At each center, there are controllers designated Traffic Management Coordinators (TMCs), who are responsible for producing a plan to deliver aircraft to a TRACON within the center at just the right time, with proper separation, and at a rate that does not exceed the capacity of the TRACON and destination airports.[87]

The NASA-developed Traffic Manager Adviser tool assists the TMCs in producing and updating that plan. The TMA does this by using graphical displays and alerts to increase the TMCs' situational awareness. The program also computes and provides statistics on the undelayed estimated time of arrival to various navigation milestones of an arriving aircraft and even gives the aircraft a runway assignment and scheduled time of arrival (which might later be changed by FAST). This informa-

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[87] Harry N. Swenson and Danny Vincent, "Design and Operational Evaluation of the Traffic Management Advisor at the Ft. Worth Air Route Traffic Control Center," *United States/Europe Air Traffic Management Research and Development Seminar, Paris, June 16–19, 1997.*

tion is constantly updated based on live radar updates and controller inputs and remains interconnected with other CTAS tools.[88]

En Route Descent Adviser

The National Airspace System relies on a complex set of actions with thousands of variables. If one aircraft is so much as 5 minutes out of position as it approaches a major airport, the error could trigger a domino effect that results in traffic congestion in the air, too many airplanes on the ground needing to use the same taxiway at the same time, late arrivals to the gate, and missed connections. One specific tool created by NASA to avoid this is the En Route Descent Adviser. Using data from CTAS, TMA, and live radar updates, the EDA software generates specific traffic control instructions for each aircraft approaching a TRACON so that it crosses an exact navigation fix in the sky at the precise time set by the TMA tool. The EDA tool does this with all ATC constraints in mind and with maneuvers that are as fuel efficient as possible for the type of aircraft.[89]

Improving the efficient flow of air traffic through the TRACON to the airport by using EDA as early in the approach as practical makes it possible for the airport to receive traffic in a constant feed, avoiding the need for aircraft to waste time and fuel by circling in a parking orbit before taking turn to approach the field. Another benefit: EDA allows controllers during certain high-workload periods to concentrate less on timing and more on dealing with variables such as changing weather and airspace conditions or handling special requests from pilots.[90]

Final Approach Spacing Tool

The last of the CTAS tools, which can work independently but is more efficient when integrated into the full CTAS suite, is the Final Approach Spacing Tool. It assists the TRACON controllers to determine the most efficient sequence, schedule, and runway assignments for aircraft intending to land. FAST takes advantage of information provided by the TMA and EDA tools in making its assessments and displaying advisories to

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[88] Greg Carr and Frank Neuman, "A Fast-Time Study of Aircraft Reordering in Arrival Sequencing and Scheduling," *AIAA Guidance, Navigation and Control Conference, Boston, Aug. 10–12, 1998*.

[89] Lee, "CTAS Fact Sheets," 2004.

[90] Steven Green and Robert Vivona, "En Route Descent Advisor Multi-Sector Planning Using Active and Provisional Controller Plans," AIAA Paper 2003-5572 (2003).

the controller, who then directs the aircraft as usual by radio communication. FAST also makes its determinations by using live radar, weather and wind data, and a series of other static databases, such as aircraft performance models, each airline's preferred operational procedures, and standard air traffic rules.[91]

Early tests of a prototype FAST system during the mid-1990s at the Dallas/Fort Worth International Airport TRACON showed immediate benefits of the technology. Using FAST's runway assignment and sequence advisories during more than 25 peak traffic periods, controllers measured a 10- to 20-percent increase in airport capacity, depending on weather and airport conditions.[92]

Simulating Safer Skyways

From new navigation instruments to updated air traffic control procedures, none of the developments intended to make safer skyways that was produced by NASA could be deployed into the real world until it had been thoroughly tested in simulated environments and certified as ready for use by the FAA. Among the many facilities and aircraft available to NASA to conduct such exercises, the Langley-based Boeing 737 and Ames-based complement of air traffic control simulators stand out as major contributors to the effort of improving the National Airspace System.

Langley's Airborne Trailblazer

The first Boeing 737 ever built was acquired by NASA in 1974 and modified to become the Agency's Boeing 737-100 Transport Systems Research Vehicle. During the next 20 years, it flew 702 missions to help NASA advance aeronautical technology in every discipline possible, first as a NASA tool for specific programs and then more generally as a national airborne research facility. Its contributions to the growth in capability and safety of the National Airspace System included the testing of hardware and procedures using new technology, most notably in the cockpit. Earning its title as an airborne trailblazer, it was the Langley 737 that tried out and won acceptance for new ideas such as the glass

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[91] Christopher Bergh, Thomas J. Davis, and Ken J. Krzeczowski, "The Final Approach Spacing Tool," *IFAC Conference, Palo Alto, CA, Sept. 1994.*

[92] Thomas J. Davis, Douglas R. Isaacson, Katharine K. Lee, and John E. Robinson, III, "Operational Test Results of the Final Approach Spacing Tool," *Transportation Systems 1997, Chania, Greece, June 16–18, 1997.*

NASA's Airborne Trailblazer is seen cruising above the Langley Research Center in Virginia. The Boeing 737 served as a flying laboratory for NASA's aeronautics research for two decades. NASA.

cockpit. Those flat panel displays enabled other capabilities tested by the 737, such as data links for air traffic control communications, the microwave landing system, and satellite-based navigation using the revolutionary Global Positioning System.[93]

With plans to retire the 737, NASA Langley in 1994 acquired a Boeing 757-200 to be the new flying laboratory, earning the designation Airborne Research Integrated Experiments System (ARIES). In 2006, NASA decided to retire the 757.[94]

Ames's SimLabs

NASA's Ames Research Center in California is home to some of the more sophisticated and powerful simulation laboratories, which Ames calls SimLabs. The simulators support a range of research, with an emphasis on aerospace vehicles, aerospace systems and operations, human factors, accident investigations, and studies aimed at improving aviation

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[93] Wallace, "Airborne Trailblazer," 1994.

[94] Michael S. Wusk, "ARIES: NASA Langley's Airborne Research Facility," AIAA 2002-5822 (2002).

safety. They all have played a role in making work new air traffic control concepts and associated technology. The SimLabs include:

- Future Flight Central, which is a national air traffic control and Air Traffic Management simulation facility dedicated to exploring solutions to the growing problem of traffic congestion and capacity, both in the air and on the ground. The simulator is a two-story facility with a 360-degree, full-scale, real-time simulation of an airport, in which new ideas and technology can be tested or personnel can be trained.[95]
- Vertical Motion Simulator, which is a highly adaptable flight simulator that can be configured to represent any aerospace vehicle, whether real or imagined, and still provide a high-fidelity experience for the pilot. According to a facility fact sheet, existing vehicles that have been simulated include a blimp, helicopters, fighter jets, and the Space Shuttle orbiter. The simulator can be integrated with Future Flight Central or any of the air traffic control simulators to provide real-time interaction.[96]
- Crew-Vehicle Systems Flight Facility,[97] which itself has three major simulators, including a state-of-the-art Boeing 747 motion-based cockpit,[98] an Advanced Concept Flight Simulator,[99] and an Air Traffic Control Simulator consisting of 10 PC-based computer workstations that can be used in a variety of modes.[100]

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[95] Jim McClenahen, "Virtual Planning at Work: A Tour of NASA Future Flight Central," NASA Tech Server Document ID: 7 (2000).

[96] R.A. Hess and Y. Zeyada, "A Methodology for Evaluating the Fidelity of Ground-Based Flight Simulators," AIAA Paper 99-4034 (1999).

[97] Durand R. Begault and Marc T, Pittman, "Three Dimensional Audio Versus Head Down TCAS Displays," NASA CR-177636 (1994).

[98] Barry Crane, Everett Palmer, and Nancy Smith, "Simulator Evaluation of a New Cockpit Descent Procedure," *9th International Symposium on Aviation Psychology, Columbus, OH, Apr. 27–May 1, 1997.*

[99] Thomas J. Davis and Steven M. Green, "Piloted Simulation of a Ground-Based Time-Control Concept for Air Traffic Control," NASA TM-10185 (1989).

[100] Sharon Doubek, Richard F. Haines, Stanton Harke, and Boris Rabin, "Information Presentation and Control in a Modern Air Traffic Control Tower Simulator," *7th International Conference on Human Computer Interface, San Francisco, Aug. 24–29, 1997.*

A full-sized Air Traffic Control Simulator with a 360-degree panorama display, called Future Flight Central, is available to test new systems or train controllers in extremely realistic scenarios. NASA.

The Future of ATC

Fifty years of working to improve the Nation's airways and the equipment and procedures needed to manage the system have laid the foundation for NASA to help lead the most significant transformation of the National Airspace System in the history of flight. No corner of the air traffic control operation will be left untouched. From airport to airport, every phase of a typical flight will be addressed, and new technology and solutions will be sought to raise capacity in the system, lower operating costs, increase safety, and enhance the security of an air transportation system that is so vital to our economy.

This program originated from the 2002 Commission on the Future of Aerospace in the United States, which recommended an overhaul of the air transportation system as a national priority—mostly from the concern that air traffic is predicted to double, at least, during the next 20 years. Congress followed up with some money, and President George W. Bush signed into law a plan to create a Next Generation Air Transportation System (NextGen). To manage the effort, a Joint Planning and Development Office (JPDO) was created, with NASA, the FAA, the DOD, and other key aviation organizations as members.[101]

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[101] Jeremy C. Smith and Kurt W. Neitzke, "Metrics for the NASA Airspace Systems Program," NASA SP-2009-6115 (2009).

NASA then organized itself to manage its NextGen efforts through the Airspace Systems Program. Within the program, NASA's efforts are further divided into projects that are in support of either NextGen Airspace or NextGen Airportal. The airspace project is responsible for dealing with air traffic control issues such as increasing capacity, determining how much more automation can be introduced, scheduling, spacing of aircraft, and rolling out a GPS-based navigation system that will change the way we perceive flying. Naturally, the airportal project is examining ways to improve terminal operations in and around the airplanes, including the possibility of building new airports.[102]

Already, several technologies are being deployed as part of NextGen. One is called the Wide Area Augmentation System, another the Automatic Dependent Surveillance-Broadcast-B (ADS-B). Both have to do with deploying a satellite-based GPS tracking system that would end reliance on radars as the primary means of tracking an aircraft's approach.[103]

WAAS is designed to enhance the GPS signal from Earth orbit and make it more accurate for use in civilian aviation by correcting for the errors that are introduced in the GPS signal by the planet's ionosphere.[104] Meanwhile, ADS-B, which is deployed at several locations around the U.S., combines information with a GPS signal and drives a cockpit display that tells the pilots precisely where they are and where other aircraft are in their area, but only if those other aircraft are similarly equipped with the ADS-B hardware. By combining ADS-B, GPS, and WAAS signals, a pilot can navigate to an airport even in low visibility.[105] NASA was a member of the Government and industry team led by the FAA that conducted an ADS-B field test several years ago with United Parcel Service at its hub in Louisville, KY. This work earned the team the 2007 Collier Trophy.

In these various ways, NASA has worked to increase the safety of the air traveler and to enhance the efficiency of the global air transportation

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network. As winged flight enters its second century, it is a safe bet that the Agency's work in coming years will be as comprehensive and influential as it has been in the past, thanks to the competency, dedication, and creativity of NASA people.

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