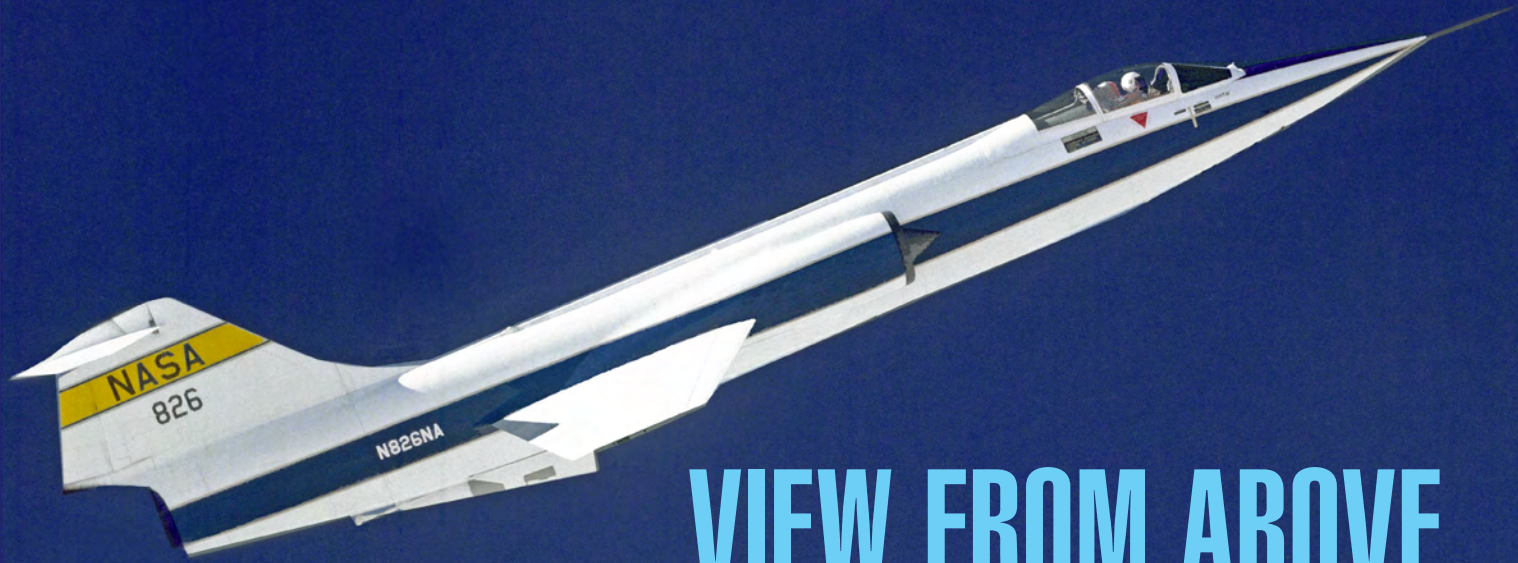




NASA HISTORY NEWS & NOTES

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NASA'S AERONAUTICS RESEARCH CONTINUES TO GENERATE LIFT

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↑ The Lockheed F-104 Starfighter in flight in 1977. The NASA Starfighters flew for 38 years, providing valuable flight research data and flying safety chase missions. (Photo credit: NASA)





From the Chief Historian

ON 3 MARCH 1915, in a largely unnoticed rider attached to the Naval Appropriations Bill, a novel organization was created. The stated purpose of this body would be to “supervise and direct the scientific study of the problems of flight, with a view to their practical solution, and to determine the problems which should be experimentally attacked, and to discuss their solution and their application to practical questions.”¹

Over the next 43 years of its existence, the National Advisory Committee for Aeronautics (NACA) dedicated its efforts to doing just that—using a ranging, experimental infrastructure to solve challenging problems and offer practical solutions.

The incorporation of the NACA into NASA on 1 October 1958 was, on the surface at least, the passing of an era. Space, not aeronautics, now appeared to be the primary font of national technological pride. The all-absorbing program to reach the Moon by the end of the decade, combined with the arms race, gave rocketry pride of place.

But the basic research thread has remained strong at NASA. Historian Robert Ferguson attributes this survival to the pace of technological change. For Ferguson, a century plus of flight research has yet to resolve fundamental challenges. Engineers “pushed aircraft performance to faster speeds and higher altitudes, and, when

they reached practical and economic barriers to going faster and higher, they turned their attention to efficiency, safety, and maneuverability.”²

Today, NASA Aeronautics continues this tradition of basic research with a focus on ultra-efficient airliners, high-speed commercial flight, future airspace and safety, and advanced air mobility.

I recently spoke with Bob Pearce, Associate Administrator of NASA’s Aeronautics Research Mission Directorate (ARMD), about the NACA heritage and the importance of history to his directorate’s work.³ Pearce has years of experience working on strategy, analysis, and planning with both industry and government—experience that includes work on the F-14 Tomcat, the Defense Advanced Research Projects Agency’s (DARPA’s) X-29 Forward Swept Wing Demonstrator, and the Federal Aviation Administration’s (FAA’s) Next Generation Air Transportation System (NextGen).

During our conversation, Pearce stressed the importance of the NACA

heritage, not only to aeronautics, but to the Agency. One of the key thrusts has been a government commitment to the research and technology transfer process. Pearce points out that “in the early days of aviation, the government oversaw much of the research and technology that ensured future vehicles and future operations would be more efficient, more effective—higher, faster, further. All of those fundamentals continue to push industry to the leading edge while we support them in the early days of the market.”⁴

The value of this history to ARMD is not lost on Pearce, who sees a clear connection between past lessons learned and current projects:



↑ In this 1955 photo, Brent Creer consults with NACA pilot George Cooper in the North American F86-A #135 aircraft on the ramp in front of hangar 211 at Ames Research Center. (Photo credit: NACA)

From the Chief Historian (continued)



↑ Bob Pearce, Associate Administrator for NASA's Aeronautics Research Mission Directorate. (Photo credit: NASA/Bill Ingalls)

History informs the future. If we don't know the history, we are doomed to repeat it. But I think the better we understand that history the more we can facilitate better planning for the future, we can set better strategy. Another thing is, and I think this is especially true in advanced concepts and technology, oftentimes, what we are looking at today is not the first time we've looked at it. Advanced air mobility—this idea of an air taxi—has been around since the beginning of aviation and there have been times in our past where there's been serious study...and it just wasn't quite ready; the technologies just weren't quite there. Nevertheless, understanding what happened during those periods, what the barriers were they couldn't overcome, what the issues were, are really useful to know.... They didn't make it in the past but we can understand why and we can

overcome those challenges. If we really believe that, then let's take the next swing at it. We are doing that with supersonics.... [Similarly for] Advanced air mobility, we know what the issues were in the past and we believe we have solutions to those as well.⁵

In response to how it feels to occupy a position once held by Neil Armstrong at ARMD, Pearce noted,

It is an honor, a privilege, and it is the best job I can imagine. I look at it as I don't have to be the smartest person in the room, I just need to enable all of the brilliant folks across NASA to come together and work for the common set of goals. That's my challenge because smart people are independent thinkers and they want to take their own paths and that's why we hire them. But we also need to inspire them to work together to make big things happen—to do the hard things that need to be accomplished. No one person can do that. We have to do it together.... The special thing that we're able to do at NASA is to motivate people with [its] awesome mission. My job is to do just that.⁶

The essays in this issue of *News & Notes* canvas important chapters in the history of aeronautics at NASA. The articles are wide-ranging, including examinations of the fundamental overlap between spaceflight and aeronautics, the historical quest to harness microwave energy for powered flight, T-38s, coaxial rotor systems for Ingenuity,

air traffic control, jet propulsion, and sustainable and supersonic flight. Tony Springer spotlights the significant contribution to capturing this history made with the Aeronautics Book Series developed by NASA ARMD.

Ultimately, we hope this issue inspires others to consider researching and learning about this important history. As the NASA Aeronautics leadership, workforce, and partners consider "Aviation Beyond 2040," it is critical that we not lose the lessons of the past and continue holding to the basic research thread at the heart of the NACA's and NASA's Aeronautics mission since 1915. ■

Brian C. Odom
Chief Historian

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Flight Craft: When Spaceflight Is Really Aeronautics

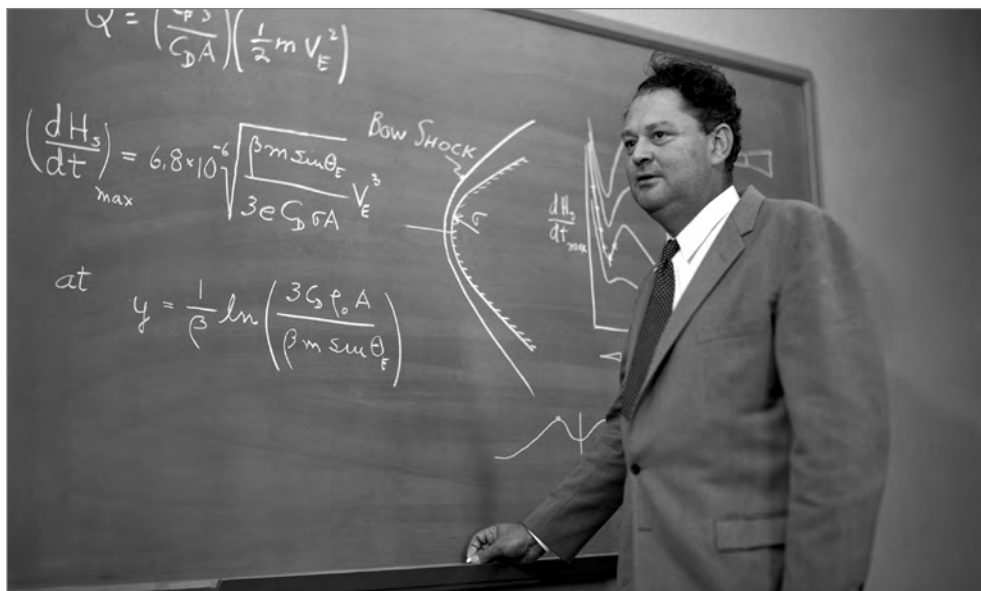
» By James Anderson, Historian, Ames Research Center

EVERY ROCKET that leaves Earth must ascend through our atmosphere. Every spacecraft that returns to Earth must survive a fiery reentry. Every mission that lands on another world with an atmosphere cannot achieve that feat with rocket science alone. Some of the most consequential advancements in the history of spaceflight have been,

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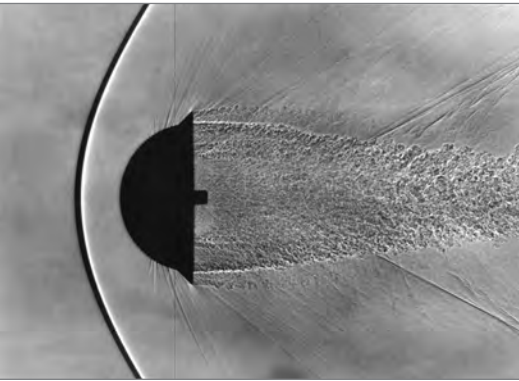
↓ H. Julian “Harvey” Allen explaining the blunt-body concept at a chalkboard in 1957, the same year that his landmark report written with Alfred Eggers was declassified. (Photo credit: NACA)



← A test model of the M-2 lifting body undergoing a heat transfer distribution test in the 1-foot hypervelocity wind tunnel at Ames in 1962. (Photo credit: NASA)

Many of those problems emerged during and shortly after World War II. In a section of his recent book published by the NASA History Division, [NACA to NASA to Now](#), former NASA Chief Historian Roger Launius summarized ten influential research and development efforts that the NACA undertook during the war. Work conducted across the three NACA research laboratories led to flight becoming more efficient, more easily controlled, and less likely to result in fatal crashes.¹ Efficiency gains were most closely associated with the development of low-drag airfoils, which increased the amount of laminar (i.e., smooth, not turbulent) flow over an aircraft’s wing. Here, the specific shape of an airfoil was the primary concern, not the material it was made of or even its weight, although those factors were important, too. Shape—a property fundamental to how we describe

Flight Craft: When Spaceflight Is Really Aeronautics (continued)



↑ The strong bow shock wave is visible here as the dark curved line extending from the top to the bottom of the image, just to the left of this finned hemispherical model, illustrating the blunt-body concept. (Photo credit: NASA)

the world around us—may seem irrelevant in the environment of outer space where air resistance does not apply, but the importance of shape is profound for moving through an atmosphere.

In the 1930s, it was already common among aerodynamicists to calculate the pressure distribution across an airfoil of a given shape. The development of laminar-flow airfoils, on the other hand, required performing “the more difficult inverse calculation of [determining] the shape to give a desired pressure distribution,” which became even more pressing during the war as planes began approaching the speed of sound.² A laborious method for solving this calculation existed, but it was simplified greatly by H. Julian “Harvey” Allen, based upon work he had started in 1936 while working in Eastman Jacobs’s Variable Density Tunnel Section at Langley Aeronautical Laboratory. The work culminated in the 1945 report, “General Theory of Airfoil Sections Having Arbitrary Shape or Pressure Distribution.”³ By that time, Allen was the head of the Theoretical Aerodynamics Section at

the recently opened Ames Aeronautical Laboratory. As World War II ended, the combination of rocket technology and the advent of nuclear weapons led to the development of intercontinental ballistic missiles, which reached speeds and altitudes high enough that their trajectories coming back down to Earth subjected the missiles to heat sufficient to destroy their cargo.

The heating problem, as it was known, required aerodynamicists to confront problems related not just to aerodynamics, but aerothermodynamics. Sleek and slender shapes had reduced drag and improved aerodynamic efficiency in both subsonic and even early supersonic flight, but reentry speeds easily surpass five times the speed of sound,

or Mach 5, which is the common marker for differentiating supersonic flight from the realm of hypersonics. Here again, shape proved to be crucial. Instead of reducing drag, the problem became what to do with the excess heat. Allen realized that if the air itself in the flow around the reentering craft absorbed more of the heat, then less of that heat energy would go into raising the temperature of the craft’s surface. A strong shock wave in front of the craft could accomplish this. The idea likely occurred to Allen in 1951. Over the course of 1952, Allen worked with his colleague, Alfred J. Eggers, to draft a paper that would be published in April 1953.⁴ Much like Allen’s approach to low drag, his and Eggers’s intention was “to simplify and generalize” the heating

↓ Alfred Eggers (second from the right) sits at a table with the three other principal contributors to the lifting-body concept, seen here in February 1963, a year before their patent for the “Flight Craft” was officially filed. George Kenyon (left) carried out the testing of the spacecraft at subsonic speeds to develop its landing capability. Seated between Kenyon and Eggers is George Edwards, who supervised the low-speed testing. Clarence Syvertson (right), a future Ames Center Director, coordinated the hypersonic testing. The scale model of the lifting body sits atop a model of a generic upper-stage booster. (Photo credit: NASA)

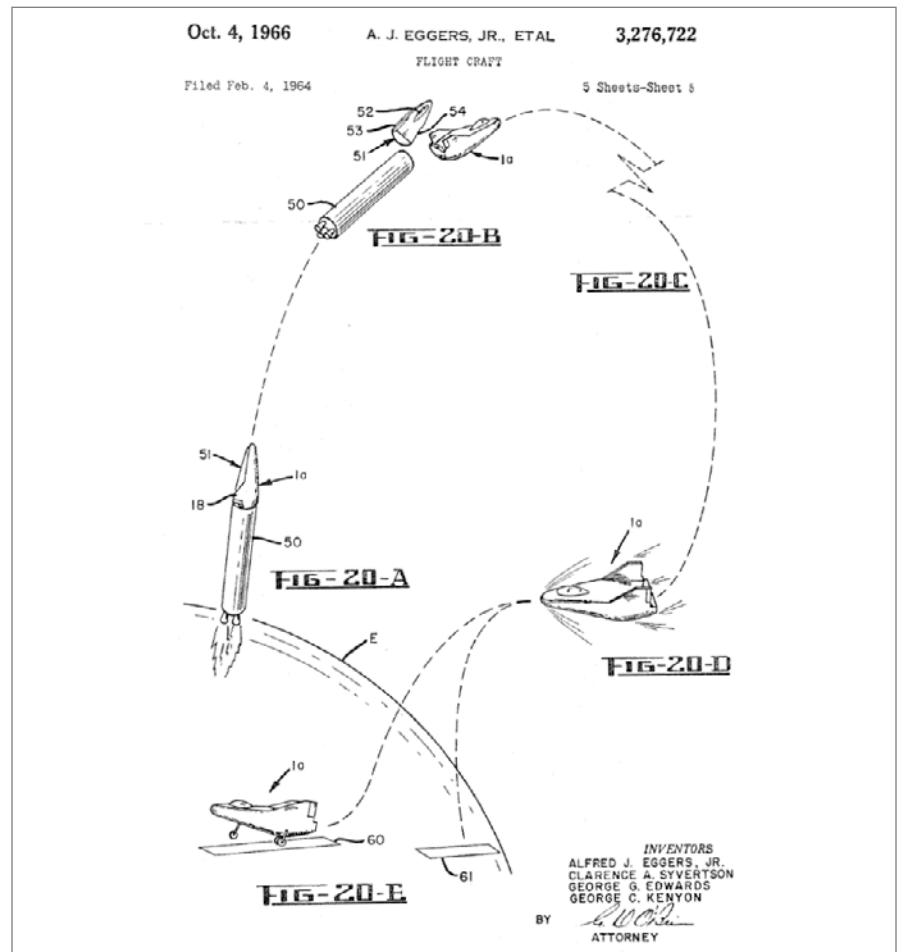


Flight Craft: When Spaceflight Is Really Aeronautics (continued)

problem, which they did, while also demonstrating the superiority of “the blunt shape.”⁵ This landmark paper—and its implications for the literal shaping of reentering craft at hypersonic speeds that eventually emerged, as adoption was not immediate—led one author to remark that, “Quite probably, it is the single most important paper ever written in the field of hypersonics.”⁶ When combined with an ablative heatshield, the amount of heat reaching the craft is reduced even further. The impact on the approach to spacecraft design eventually became significant, but the insights were not limited to just capsule-like designs.

“Quite probably, it is the single most important paper ever written in the field of hypersonics.”

Capsules are restricted in their aerodynamic capabilities, while many other shapes can incorporate the blunt body concept.⁷ Recognizing the limitations of a capsule for flight—especially given the very questionable aerodynamic stability of blunt body designs, in spite of how effective at solving the heating problem they were—Allen and Eggers led a number of subsequent NACA studies that investigated these questions of stability.⁸ Flight testing of the X-1 and the X-2 had already given indications of instability issues that would accompany hypersonic flight—another major challenge in addition to the heating problem.⁹ As Allen and Eggers conducted their stability studies, the



↑ The figures on this page of the Eggers et al. patent for the “Flight Craft” (i.e., lifting body) depict the entire voyage, beginning with launch to separation, carrying out the mission in space, and finally reentering and landing. (Source: United States Patent and Trademark Office, <http://www.uspto.gov>)

NACA and the Air Force were shaping what would become arguably the most significant testing program in the history of hypersonics: the X-15. The X-15 program was fully contracted with North American in 1956. As that program progressed and hypersonic research developed across the NACA, Eggers had turned his attention to the development of a wind tunnel that would allow a freely launched model to experience the variation in atmospheric density that accompanies reentry from the thinner outer layers down to the ground. The Atmosphere-Entry

Simulator, as it was known, was prototyped in 1956, and construction of the full-size version began in 1957.¹⁰ With Sputnik and the absorption of the NACA into the newly created NASA, the more explicit focus on spaceflight and crewed spaceflight gave Eggers a new context in which to apply these theoretical and experimental insights to aeronautical problems.

The embodiment of these years of research came together in a patent that Eggers and three of his colleagues eventually filed in 1964 with the

Flight Craft: When Spaceflight Is Really Aeronautics (continued)

very generic-sounding title: Flight Craft. The craft would be “suitable for space flight, entry from space into an atmosphere, and atmospheric flight”—achieving an entire mission to orbit or even deep space without being restricted to parachutes limiting their mobility upon landing.¹¹ The nose would be “blunted” to address the heating problem—naturally—and what further distinguished the flight craft from winged aircraft and X vehicles, like the X-15 and the X-20 Dyna-Soar, was the additional space inside the craft that the shape afforded, which was not available to any super-sleek designs. The high volume-to-surface ratio was envisioned as allowing crew, equipment, and its own

↓ R. Dale Reed with his model of the M2-F1 in front of the actual lifting body. Reed used the model to show the potential of the lifting bodies to colleagues at the Flight Research Center (present-day NASA Armstrong Flight Research Center). Dale’s wife, Donna, filmed those early tests with their 8-mm home camera. (Photo credit: NASA)



↑ The M2-F1 Lifting Body is seen here under tow, high above Rogers Dry Lake near NASA’s Flight Research Center, Edwards, California. R. Dale Reed effectively advocated the project with the support of NASA research pilot Milt Thompson. Together, they gained the support of Flight Research Center Director Paul Bikle. After a six-month feasibility study, Bikle gave approval in the fall of 1962 for the M2-F1 to be built. (Photo credit: NASA)

propulsion system. But even without its own propulsion system, it was still flight-worthy in the manner of a glider. Easily sitting atop a rocket, the flight craft was envisioned as operating across a huge range of velocities, regardless of whether it left Earth’s atmosphere or not.

The Flight Craft is what became known as a lifting body. Research into lifting bodies continued and was not limited to Eggers and his group, but it was the Eggers concept that inspired R. Dale Reed at NASA’s Flight Research Center at Edwards Air Force Base (present-day NASA Armstrong) to build his own scale model as a proof-of-concept. Reed enlisted the help of some NASA colleagues and persuaded their center’s leadership to support what became a 12-year research program in which eight different lifting body designs

were flown, beginning with the unpowered, plywood-framed “M2-F1 to the rocket-powered, extra-sleek, all-metal supersonic X-24B.”¹² The return to sleek and away from the “bulbous” shape of the M2-F1 is another story, but the blunt-body concept remains, and lifting-body research informed the development of the (winged) Space Shuttle. Numerous challenges still exist in the realm of hypersonic flight, especially the development of an air-breathing engine that can accommodate the transition from sub- and supersonic to hypersonic flight itself. And despite recent attention to—and claims about—hypersonics on the world stage, the world has yet to see a truly hypersonic plane that can surpass what the X-15 program achieved with Mach 6.7.

Flight Craft: When Spaceflight Is Really Aeronautics (continued)

For spaceflight, applications of the blunt-body concept are still visible today, from the shape of the Orion spacecraft to the heatshields of uncrewed spacecraft entering the atmospheres of other worlds....

For spaceflight, applications of the blunt-body concept are still visible today, from the shape of the Orion spacecraft to the heatshields of uncrewed spacecraft entering the atmospheres of other worlds, such as probes sent to the gas giants and the aeroshells encapsulating the rovers as they land on Mars.¹³

These present-day examples illustrate both the extent to which aeronautics research remains intimately tied to spaceflight and how practical solutions can emerge from investigating fundamental aeronautical problems. ■

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- 7 A fascinating comparison is found in the development of Soviet spacecraft designs. The Soviet approach relied upon simplicity, too, as Sergei Korolev preferred the sphere for its inherent stability and its simplicity in the design of Vostok, compared to the truncated cone of Mercury. While both shapes are blunt, the Soviets surrounded the spherical Vostok with heatshield material. That added significant weight, but it was less of a concern given the lifting capability that the Soviets possessed with their rockets. For more comparisons between the American and Soviet approaches in this era, see Ezell, Edward Clinton, and Linda Neuman Ezell, *The Partnership: A History of the Apollo-Soyuz Test Project* (Washington, DC: NASA SP-4209, 1978), pp. 66–73. And for more in-depth coverage of the Soviet program itself, see Asif A. Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA SP 2000-4408, 2000).
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- 11 Alfred J. Eggers, Jr., Clarence A. Syvertson, George G. Edwards, and George C. Kenyon, 1966, Flight Craft, U.S. Patent 3,276,722, filed 4 February 1964 and issued 4 October 1966.
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- 13 Beyond capsules and lifting bodies, aeronautics is now perhaps most visible in space exploration in the success of the Mars Helicopter, Ingenuity, and its more than 50 successful flights on Mars since achieving the first-ever test of powered flight on another planet. For more on this topic, see "Ingenuity and Coaxial Rotor Systems" later in this issue.

Flight with Light: Beam-Powered Propulsion Experiments at NASA

» By **Christian Gelzer**, Historian, Armstrong Flight Research Center

IN OCTOBER 1964 the Raytheon Company held a news conference during which employee William Brown demonstrated a scaled helicopter in flight. What made this special was that the helicopter flew not with on-board batteries or a gas engine but with power beamed to it as microwave energy. So long as the helicopter received the beam, it flew. Walter Cronkite was there and had a segment about the flight during his nightly news program. For Brown more than anyone, this was validation of a concept he'd first argued for in 1961. He kept at it, and between 1969 and 1975, he (Raytheon) led a joint NASA and U.S. Air Force project, culminating in 1975 in a demonstration at the Goldstone Complex in California that successfully transmitted a 30-kilowatt beam over 1 mile with 84 percent efficiency.

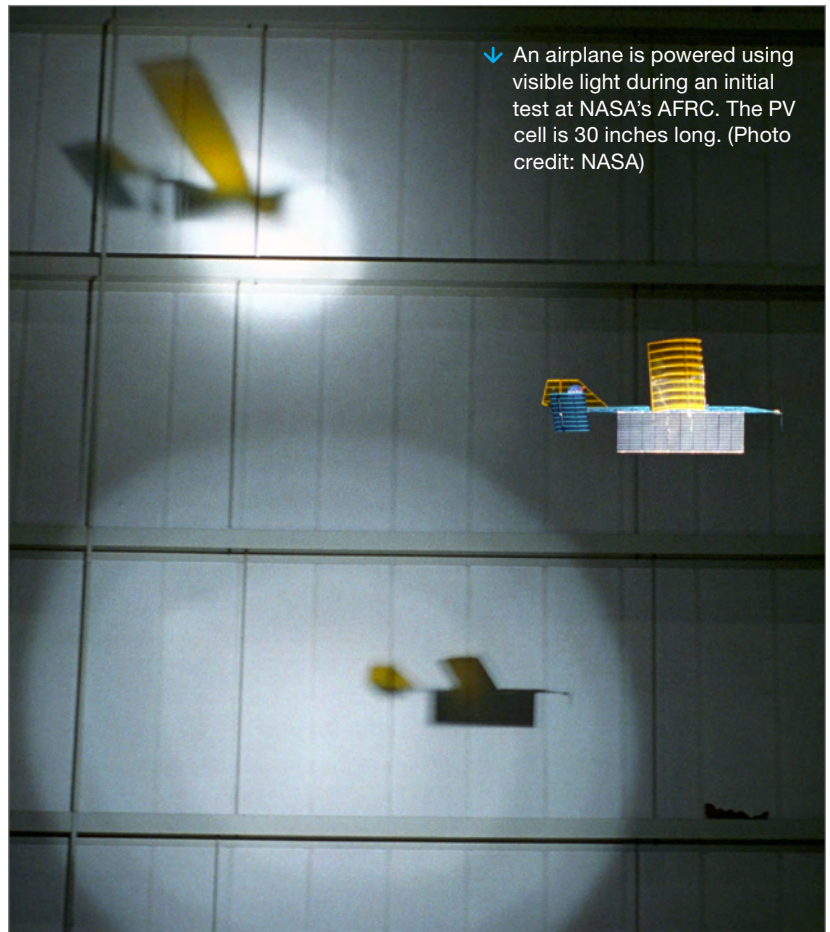
and he spent many years and a great deal of money trying to demonstrate it, with little success. Other attempts also fell short, principally because the wavelengths at which they transmitted the energy had little range: the beam dissipated logarithmically over distance. Efficiency of the transmission and reception were the pivotal issues

with power beaming. But Tesla was a believer and told *Popular Science* that someday airplanes would be “powered by wireless.”²

In the years following Brown's successes, others explored power beaming, including the experimental Canadian Stationary High Altitude Relay Platform (SHARP). An airplane with a large receiver disk as part of the fuselage, in the 1980s SHARP demonstrated that a ground-based power source could follow an aircraft in flight, and the aircraft could receive and process this beam (DC to AC) in flight wirelessly. NASA continued its investment in this concept by supporting internal research and funding studies with universities and industry.³


 Watch William Brown's helicopter flight and JPL/Goldstone tests.

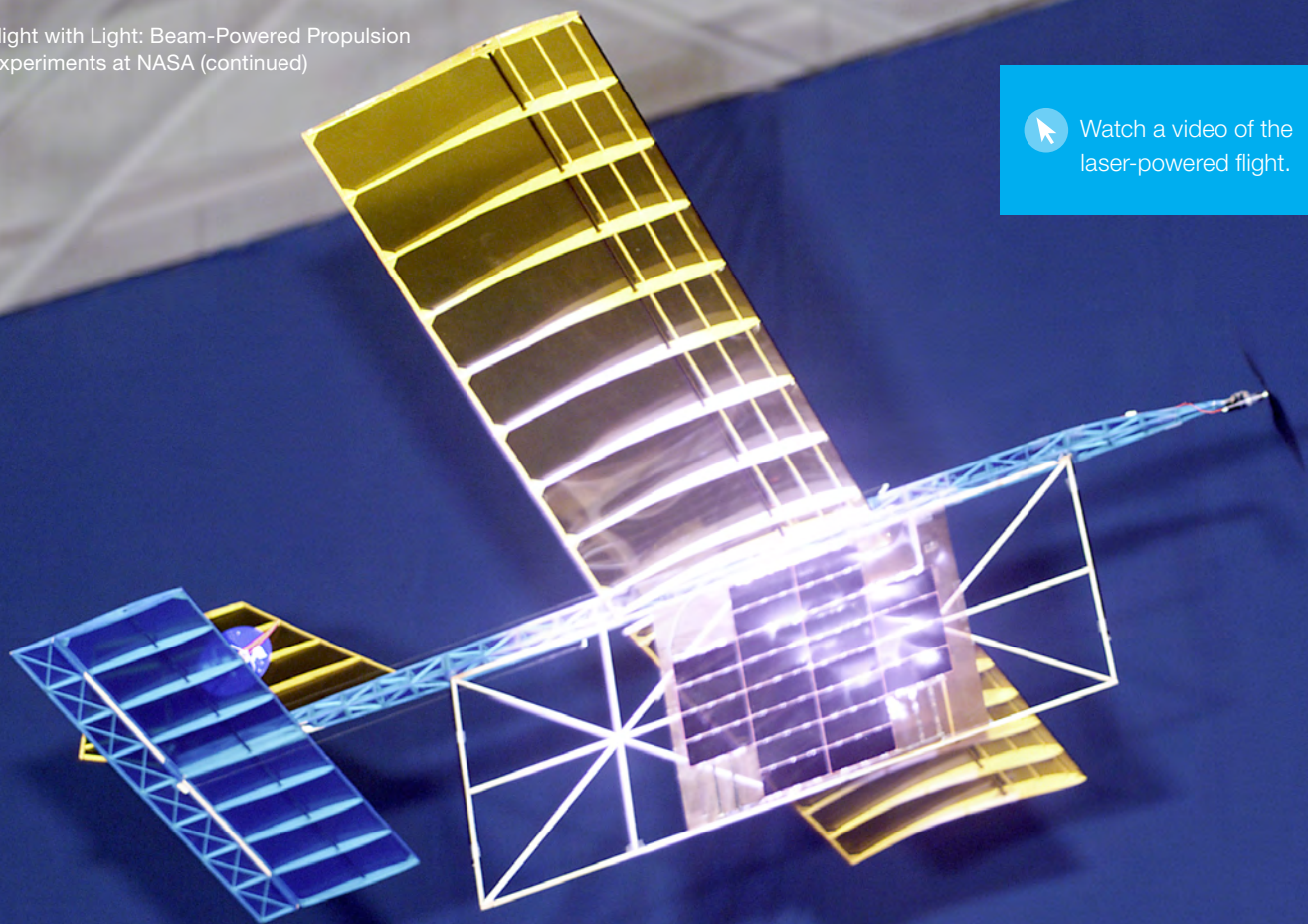
Generally speaking, “power beaming is the efficient point-to-point transfer of electrical energy across free space by a directive electromagnetic beam.”¹ Nikola Tesla was the first to suggest that “electromagnetic radiation through tuned circuitry” was possible,



↓ An airplane is powered using visible light during an initial test at NASA's AFRC. The PV cell is 30 inches long. (Photo credit: NASA)

Flight with Light: Beam-Powered Propulsion Experiments at NASA (continued)


 Watch a video of the laser-powered flight.



↑ The second iteration of the original aircraft carried a PV capable of receiving power from clustered, tunable lasers. (Photo credit: NASA)

Earth's atmosphere distorts waves passing through it, which reduces both the range and the focus of beamed energy. Visible light has the least range and power transmission. Microwave energy is less affected by such conditions, explaining its appeal. In a seemingly retrograde move, in 2002 NASA's Armstrong Flight Research Center (AFRC) began a series of tests using an 11-oz mylar, balsa wood, and carbon fiber airplane with a 6-watt electric motor turning a propeller and a large sheet of photovoltaic cells attached vertically to its ventral area. While an engineer directed a searchlight at the

photovoltaic (PV) panel, a pilot flew the airplane. Not surprisingly, the airplane's engine received only 3 watts of power at a range of 18 meters—a 4 percent transmission efficiency—but that was not the point: it was the first time that optical energy had been beamed to an aircraft to power it for stable, continuous flight. (Brown's helicopter was tethered and used microwaves.) Tim

 Watch NASA AFRC's power beaming flight that used visible light.

Blackwell notes, "The demonstration had two purposes...address the engineering issues...and increase public awareness [and] the engineers planted the seed for a practical demonstration of wireless power transmission."⁴ This investigation was not retrograde at all but, rather, one step back for two steps forward. The second phase was a collaboration with researchers at NASA's Marshall Space Flight Center (MSFC) and the University of Alabama Huntsville. Lasers might seem a logical step, but until recently they could not meet the power beaming system's needs. That changed when, in 2003,

Flight with Light: Beam-Powered Propulsion Experiments at NASA (continued)

the team flew much the same airplane at MSFC using a set of clustered, tunable lasers at the source, and similarly configured PV cells at the receiver. Two months after this demonstration, the team flew a scaled helicopter using the same system. This was the first successful transmission of power via laser to a moving machine.

Researchers are eyeing power beaming to power lunar exploration, military defense, recharging stations, or in-flight power for autonomous aircraft....

Wireless energy transmission is broadly appealing. Beaming energy to satellites in geosynchronous orbit (which consume electricity at a rate greater than can be replenished through solar arrays) or sending energy to Earth from a space-based solar farm are just a few of the potential applications. Researchers are eyeing power beaming to power lunar exploration, military defense, recharging stations, or in-flight power for autonomous aircraft, and to transmit energy via point-to-point wireless transmission on Earth when standard transmission methods are too expensive. In 2009 NASA sponsored a laser-powered space elevator competition. And of course, putting a cluster of satellites in orbit around another planet, each capable of transmitting energy via microwave or laser, could indefinitely power an airplane or a ground-based vehicle on that planet. The European Aeronautic

Defence and Space Company (EADS) has operated a scaled automobile with a laser. The power beaming research paths are diverse as optimum methods for various circumstances are not yet completely defined, but NASA's 2003 explorations of laser-beamed propulsion with a small electric airplane showed a new path in delivering power in flight was possible. ■

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The Chase Air Force: In Pursuit of the Space Shuttle Columbia



➔ Portrait of the STS-2 Chase Team including (left to right) F. Richard “Dick” Covey, Kathryn D. Sullivan, Ken Baker, Loren J. Shriver, Jeffrey A. Hoffman, and Robert L. “Hoot” Gibson. (Photo credit: NASA)

» By **Jennifer Ross-Nazzal**, Historian, Johnson Space Center

IN 1980, as NASA prepared for the launch of its first reusable spacecraft, the Space Shuttle Columbia, astronauts from the 1978 class of astronauts received their technical assignments. One of those assignments was chase crew for the orbital test flights of the Shuttle. “Everybody wanted to do that,” Richard O. Covey recalled. “That was a premier assignment,” especially for the historic STS-1 flight.¹ Pilots would fly the T-38 trainer aircraft, which sat two

people, the pilot and a backseater, who was a mission specialist.

Given the newness of the spacecraft, NASA named chase plane crews to the first four Shuttle test flights, tasked to rendezvous with Columbia as the orbiter reentered Earth’s atmosphere and landed. During these final minutes, at about 30,000 feet, the chase crews called out the altitude and air speed from their T-38s, to see if they

matched the orbiter’s. The Space Shuttle commander, then approaching the dry lakebed and preparing to land, used that information to check against the orbiter’s readings. If the vehicle’s systems were not accurate, he could rely on the chase crew’s measurements. Chase crews also documented any structural issues or visible tile damage by photographing the Shuttle from different angles as it landed.

For pilots, there was no better place to be than flying in the T-38, and Jon A. McBride, a naval aviator selected as an

The Chase Air Force: In Pursuit of the Space Shuttle Columbia (continued)



↑ The STS-1 Chase Team, joined by Sally K. Ride, poses in front of a T-38. The Shuttle Chase Team patch is shown on the left. (Photo credit: NASA/Robert L. “Hoot” Gibson)

astronaut in 1978, headed the STS-1 team. The preparation for the first flight of the Shuttle was so consuming that his classmate Sally K. Ride later joked that “everybody was part of the chase crew on STS-1!” NASA intended to land the vehicle at Edwards Air Force Base, but the team had to be prepared for other contingency landing spots, including White Sands Northrup Strip in New Mexico and Kennedy Space Center. So they trained. Maybe a bit too much. McBride and his team “practiced a thousand times, three hundred times [in] each place,” and he “knew the topography of those three sites just like [his] backyard.”²

Because this was the “world’s most complicated rendezvous and fly,” and chase crews only had a 5-second window

to catch the Shuttle, McBride’s effort quickly grew to the size of an “empire” with his team dubbed the “Chase Air Force.” Thinking back to those years, Kathryn D. Sullivan said, “It just seemed like every time you turned around there were eighteen airplanes flying off in a giant gaggle somewhere to go practice.” George D. “Pinky” Nelson, who flew with McBride on STS-1, remembered, “There were just a ton of us, and every once in a while... there’d be eleven T-38s lined up on the ramp” at NASA’s Aircraft Operations in El Paso, Texas, near White Sands.³

The crews trained using an SR-71 or a T-38 as the “spacecraft” at all three locations: Edwards, Kennedy, and White Sands. During runs, two T-38s approached the “Shuttle” working

with ground controllers at nearby Air Force bases in California, New Mexico, and Florida, as well as Kennedy Space Center. Simulations required the assistance of ground control to rendezvous with the “Shuttle” because the T-38 did not have an on-board radar system.⁴

By April 1981, the crews were ready. On the day of the STS-1 launch, Nelson was flying in the back seat of a T-38 at Cape Canaveral, where he witnessed the liftoff of the Space Shuttle Columbia. As he saw the vehicle climb, he thought of all the problems the program had tackled before this day and said, “I’ll be damned! It worked.”⁵

Two days later, in California, just after the chase crew took off to rendezvous with Columbia, the radar team in Los Angeles lost power. Fortunately, ground control at Edwards was able to take over, allowing McBride to line up with the Shuttle’s wing, so Nelson could photograph the incoming spacecraft.⁶

I’ll be damned! It worked.

— George D. “Pinky” Nelson

Everyone was jubilant at the success of the mission, especially the astronaut corps. At the STS-1 post-landing party, the Astronaut Office “royally roasted” the chase team for being overprepared. Memories of the flight were featured in a slide show and included the development of the orbiter, the crew training, and then—just for fun—someone mentioned the chase team’s preparation and included a photograph of 15 bombers. They roasted someone else,

The Chase Air Force: In Pursuit of the Space Shuttle Columbia (continued)



↑ This view of the Space Shuttle Columbia (STS-2) was made with a hand-held 70-mm camera in the rear station of the T-38 chase plane. Mission specialist/astronaut Kathryn D. Sullivan exposed the frame as astronauts Joe Engle and Richard H. Truly aboard Columbia guided the vehicle to an unpowered but smooth landing on the desert area of Edwards Air Force Base in California. The view provides a good study of the high-temperature protection material on the underside of the spacecraft that is exposed to the friction on the atmospheric entry on the return to Earth. Also note trails from the wing tips. (Photo credit: NASA)

then returned to the chase team at the Cape, “and there’d be this field full of airplanes, 1,000 airplanes in this picture.” The corps “hammered” the team because they blew their budget and flew way too often. The astronauts, Sullivan explained, “quickly turned this into large amounts of teasing at Jon that he had just ramped this all up into the world’s biggest boondoggle.” All teasing aside, George W. S. Abbey, then head of Flight Crew Operations, was not pleased with just how much NASA’s “Air Force” had spent and told

the four pilots that they could not fly for the next six months.⁷

When STS-2 came around, Robert L. “Hoot” Gibson used a different approach. He came up with a reasonable plan for training the chase crew. He determined how much training time the chase crew needed to be prepared and how many trips they should make to each possible landing site. “We actually did it without exceeding our flight time, so I got big points with George for pulling that off,” he said.⁸

As STS-2 Commander Joe Engle lined Columbia up for reentry, Gibson successfully rendezvoused with the spacecraft and recalled Kathryn Sullivan taking “one of the most gorgeous photos to come out of the chase program, and it was the underside of Columbia with the blue sky and some wispy clouds above it.”⁹

Covey led the team for STS-3, the only mission to land at White Sands. The intercept was made even more challenging because Mission Control had the STS-3 team fly a “straight-in approach” instead of the usual approach of “coming over the field and making a big turn.” On the day of landing the area experienced high winds, which also made it difficult to rendezvous with the vehicle. Covey had to fly with the landing gear down so that he and Ronald E. McNair, in the back seat, could stay with Commander Jack R. Lousma as he flew Columbia on the final approach. Otherwise, their T-38 would quickly pass the orbiter and negate their purpose. He ended up exceeding the landing gear limits for when it was down, and when he returned to El Paso, Aircraft Operations grounded his plane. Luckily, he had a spare to fly home in!¹⁰

Covey had to fly with the landing gear down so that he and Ronald E. McNair, in the back seat, could stay with Commander Jack R. Lousma as he flew Columbia on the final approach.

The Chase Air Force: In Pursuit of the Space Shuttle Columbia (continued)



↑ **Top:** The STS-3 Chase Team poses for a photo at Dryden Flight Research Center. (Photo credit: NASA) **Bottom:** Photo taken by the Shuttle Chase Team on 4 July 1984 as STS-4 touches down on the runway at Edwards Air Force Base. Another T-38 chase plane is visible in the background. (Photo credit: NASA)

For STS-4, the final flight of the test program, Jerry L. Ross and Guy S. Gardner flew Chase 1. On a very memorable Fourth of July, they met up with Columbia, and Ross snapped a picture as the wheels touched down and threw “smoke up on the runway.”¹¹

Today, there are no plans to use the T-38s to call out the altitude and speed of the Orion Multi-Purpose Crew Vehicle. Raymond Heineman of Johnson Space Center’s Aircraft

Operations explains, “It’s a different type of landing. With the Shuttle, it was just a big glider. So it made more sense [to use a chase crew], but with a capsule coming out on a parachute, it’s just not something we can do with a [T]-38.”¹²

Even though NASA will not use the jet for Artemis, the T-38 demonstrated its value to the Space Shuttle Program and the astronaut corps. The T-38 is an essential trainer designed to help

astronauts work as a crew to make time-critical decisions. Astronauts from the 1978 and 1980 classes who flew chase missions played an integral role in the orbital test flights and those, along with their other assignments, helped them feel “like we had become a real part, like a real astronaut by then, a part of the program, ready to go out and fly.” And as an added bonus, the chase crews took some amazing photos of the spacecraft during landing, some of which are shown here.¹³ ■

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Subsonic Fixed Wing to Sustainable Flight National Partnership

↑ The illustration above shows three sustainable subsonic fixed wing design concepts chosen for possible development: the “double bubble,” blended wing body, and the truss-braced wing. (Image credit: NASA)

The Evolution of NASA’s Sustainable Flight Portfolio

» By **John A. Gould**, Writer for NASA Aeronautics Research Mission Directorate

NASA’S CONTRIBUTIONS to aeronautics are numerous, wide-ranging, and fundamental. Over the decades, many technologies now commonplace in aviation—turbo-fan jet engines, glass cockpits, runway grooves, even the airfoil itself—trace their origins to NASA and its predecessor organization, the National Advisory Committee for Aeronautics (NACA). Several of these contributions led to more environmentally friendly practices such as reducing fuel burn; winglets, for instance, have saved billions of gallons of jet fuel since NASA developed them and aircraft manufacturers began introducing them.¹ The

latest iteration of NASA’s far-reaching strategic goals for aviation, the Sustainable Flight National Partnership (SFNP), is a collaboration between NASA’s Aeronautics Research Mission Directorate (ARMD) and partners in industry, government, and academia to accomplish the aviation community’s goal of net-zero carbon emissions by 2050.² The partnership includes a suite of projects across ARMD’s portfolio; for example, SFNP’s centerpiece is the recently announced Sustainable Flight Demonstrator. Under a Funded Space Act Agreement, NASA and Boeing are developing a large-scale flight demonstrator to prove an ultra-efficient

aerodynamic configuration called a Transonic Truss-Braced Wing (TTBW), as well as other new technologies.³ The Sustainable Flight Demonstrator and other projects in the Sustainable Flight National Partnership are working on a timeline to have their technologies ready for potential adoption into airliners during the 2030s. The partnership’s origins were initially organized in, and can still largely be characterized by, four major research areas: the TTBW, small-core gas turbines, high-rate composite manufacturing, and electrified aircraft propulsion—all intended for the single-aisle aircraft market, which is anticipated to face great demand for new aircraft beginning in the 2030s.⁴ Combined, these green technologies represent a significant advancement toward the goal of net-zero carbon emissions in aviation by 2050.

Subsonic Fixed Wing to Sustainable Flight National Partnership (continued)

These four areas of research go back further than the Sustainable Flight National Partnership's announcement in June 2021, however. ARMD initiated the strategy for flight research goals that would lead to the partnership's current portfolio as far back as 2007. Following an executive order and policy plan established by the Bush administration in 2006 and 2007 asserting a need for the United States to maintain leadership in aeronautics and looking forward with NASA's goals for aviation in mind, ARMD set the stage with a framework of three time periods during which research technology could feasibly transition to the aviation industry. Near-term N+1 technologies could enter service in the 2010s; mid-term N+2 in the 2020s; and far-term N+3 in the 2030s. Two projects within NASA's Fundamental Aeronautics Program—Subsonic Fixed Wing and Environmentally Responsible Aviation (ERA)—would carry out the research and development necessary to successfully identify and select the technologies that could both transition to industry in the prescribed timeframe and achieve the greatest impact on advancing aeronautical capabilities.⁵ Subsonic Fixed Wing's N+3 activities aiming at the 2030s, in particular, is where the Sustainable Flight National Partnership can trace its heritage. These projects had a critical role in narrowing down the green technologies NASA is now pursuing with more rigor. This down-selection process saw numerous concepts studied and tested, including several different aircraft configurations such as TTBW designs—close variants of the design selected for the Sustainable Flight Demonstrator.

The story of this research began in 2008 when NASA awarded research contracts

for airframe configurations as part of N+3's Phase 1 activities. Key drivers in identifying the type of research to pursue were reducing energy costs, environmental damage, and airport noise. Six teams were selected, with two working on supersonic commercial flight research and four working on NASA's energy and environment goals under Subsonic Fixed Wing—each to carry out research through 2010.⁶ The four teams included Boeing, with an electrified truss-braced wing configuration in several design variants named "Subsonic Ultra Green Aircraft Research," also known as SUGAR; the Massachusetts Institute of Technology (MIT) and Aurora, with a boundary layer ingestion design concept known as the "double bubble" for its unique twin-tubed shape; General Electric, which made a case that the 2030s may need short-range, point-to-point vehicles seating no more than 20 passengers; and Northrop Grumman, which examined a more conventional short-range tube-and-wing airframe with advanced technology.⁷

Each of these teams' ideas were studied and evaluated during Phase 1 and promising work continued into N+3's Phase 2—where their design concepts evolved, as well as the key, tall-pole technologies involved in bringing them to fruition.⁸ For example, General Electric's partner Cessna examined composite skins, and Northrop Grumman examined active flow control. MIT and Aurora's double bubble configuration was, at the time, unique in the field. N+3 gave industry the chance to examine future ideas that were riskier for them to invest in independently.⁹

In parallel with N+3 Phase 2 and the beginning of the Obama administration,

N+2 ground and flight research was occurring under the ERA project. Formulated in 2009, ERA signified a new approach for NASA in its aeronautics portfolio. NASA was able to advocate for a down-selecting process, purposing ERA to narrow down which technologies held the most promise for development, as opposed to the more common approach of specific research goals to achieve on a certain timeframe. At the time, other ARMD projects did not have this down-selection structure, and many later projects would be formulated with this approach. ERA's formulation is also of note for being the first project in some time to bring a new increase to NASA's aeronautics budget, which had significantly decreased since the 1990s.¹⁰

ERA's formulation is also of note for being the first project in some time to bring a new increase to NASA's aeronautics budget, which had significantly decreased since the 1990s.

Though ERA's mid-term N+2 research does not largely feed into what would become Sustainable Flight National Partnership research projects, a handful of key contributions are distinguishable. For example, ERA successfully built a large-scale multi-bay from stitched-resin-infused composites that gave validity to advanced composites for non-circular shapes on board aircraft.¹¹

Subsonic Fixed Wing to Sustainable Flight National Partnership (continued)

NASA Subsonic Transport System Level Metrics

.... technology for dramatically improving noise, emissions, & performance



CORNERS OF THE TRADE SPACE	N+1 (2015)*** Technology Benefits Relative to a Single Aisle Reference Configuration	N+2 (2020)*** Technology Benefits Relative to a Large Twin Aisle Reference Configuration	N+3 (2025)*** Technology Benefits
Noise (cum below Stage 4)	- 32 dB	- 42 dB	- 71 dB
LTO NOx Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33%**	-50%**	better than -70%
Performance: Field Length	-33%	-50%	exploit metroplex* concepts

- *** Technology Readiness Level for key technologies = 4-6
- ** Additional gains may be possible through operational improvements
- * Concepts that enable optimal use of runways at multiple airports within the metropolitan areas

N+1 "Conventional"



Fundamental Aeronautics Program
Subsonic Fixed Wing Project

N+2 Hybrid Wing/Body



N+3 Generation



↑ This chart, included in a presentation given in May 2010 by Rich Wahls, Ruben Del Rosario, and Greg Follen, shows metrics for the N+1, N+2, and N+3 studies. Note how N+3's studies focus on research that could reach a Technology Readiness Level of 4-6 in 2025—similar to SFNP's timeline. (Image Credit: NASA)

This work related to the blended wing body concept proposed by Boeing. In addition, ERA researched for potential acceleration to the N+2 timeframe certain N+3 concepts such as boundary layer ingestion for the double bubble.

Ultimately, much of the double bubble work would remain with Subsonic Fixed Wing and N+3. Notably, the configuration necessitated the small-core gas turbines—because the proximity of the twin engines at the aircraft's rear prevented a higher bypass ratio from

being achieved by increasing the size of the fan, the jet engine core had to be made smaller. Thus, small-core gas turbines saw their entry in support of this research.¹²

Meanwhile, Subsonic Fixed Wing continued with N+3 Phase 2, which concluded in 2014. Each of the four teams conducted a sort of capstone test of their key technologies. The first wind tunnel test involving Boeing's TTBW design occurred in 2013 at NASA's Langley Research Center in Virginia

using a 13-foot (4-meter)-long structurally scaled model.¹³ The purpose was to determine the validity of Boeing's TTBW concept—most pertinently, whether the fuel-savings estimates were indeed accurate and feasible. The test confirmed both variables were as predicted and provided confidence in the benefits of the design configuration. Amongst the four designs, the TTBW began to endure as a subject for further study, though the blended wing body and double bubble were still close contenders at the time.¹⁴

Subsonic Fixed Wing to Sustainable Flight National Partnership (continued)

In 2014, NASA began the five-year-long Advanced Composites project. The project sought to improve methods and tools to reduce the development and certification timeline for composite structures, functioning alongside composite materials research occurring in the ERA and Subsonic Fixed Wing projects.¹⁵ Notably, the Advanced Composites project saw the creation of the Advanced Composites Consortium—a public-private partnership consisting of government, industry, and academic organizations collaborating on composites research and development.¹⁶ This consortium continues to play a key role in NASA's current composites research and manufacturing activities.

In 2015, ERA concluded, but a new development arose that would inform the choices managers made on the future of ARMD's portfolio. As part of a new initiative for 21st-century transportation, the White House included in the President's Budget Request for Fiscal Year 2016 a substantial increase in funding for NASA's aeronautics research. NASA, in turn, conceived "New Aviation Horizons"—a 10-year initiative to build several new X-plane aircraft to perform major technology demonstrations alongside industry and government partners.¹⁷

Though the proposed budget increase did not ultimately occur, the discussion surrounding its possibility would lead to significant advances in NASA's strategy for flight research. NASA put out a request for proposals, conducted studies on various flight demonstrator configurations alongside industry, and established dialogue with industry leaders that proved useful to both parties.¹⁸ After a several-month process, five industry



↑ Boeing's 13-foot semi-span Subsonic Ultra Green Aircraft Research (SUGAR) model underwent testing at Langley Research Center's Transonic Dynamics Tunnel in December 2013. (Photo credit: NASA/Langley Research Center/Sandie Gibbs)

teams informed NASA about the types of airplanes and objectives best suited for their long-term needs. Combined with the N+3 down-selections, these interactions further refined areas of research to pursue for the 2030s timeframe. The TTBW configuration, for example, became a clear contender for further study. Manufacturing composites at a high rate emerged as a challenge that, if solved, could lead to wide-reaching changes in aircraft design efficiency, including use in a more fuel-efficient single-aisle aircraft that would require much higher production rates to meet demand relative to other aircraft classes.¹⁹

Additionally, with the kickoff of the X-57 Maxwell aircraft in 2016, an expanded emphasis was placed on electrification by ARMD leadership. What was previously a multi-faceted strategy became focused on future electrified powertrain demonstrations at full

demonstrator aircraft scale. Soon thereafter, the Electrified Powertrain Flight Demonstration (EPFD) project began. Subsonic Fixed Wing had envisioned a demonstrator aircraft since formulation because any move from a conventional airliner configuration would require full-scale integrated demonstration. EPFD is effectively a spinoff of Subsonic Fixed Wing focusing on electrified aircraft propulsion via a full-sized turboprop-based flight demonstrator aircraft. Subsonic Fixed Wing was transformed into today's Advanced Air Transport Technology project, and subject matter experts from the project worked to advance more technology and reduce risk for EPFD. In 2018, five areas of research were on the table: ultra-efficient airframes (TTBW and blended wing body), small-core gas turbines, electrification, advanced airframe structures (composites), and boundary layer ingestion. Ultimately, managers decided four research areas

Subsonic Fixed Wing to Sustainable Flight National Partnership (continued)

were a more effective distribution of resources, and boundary layer ingestion was not included moving forward.²⁰

Three years later, in 2021, NASA announced the Sustainable Flight National Partnership working in these four major research areas.²¹ Two new projects emerged simultaneously: Hybrid Thermally Efficient Core, working on a hybridized small-core gas turbine, and Hi-Rate Composite Aircraft Manufacturing, working to accelerate the speed of composites manufacturing. With these projects formed alongside the already established EPFD and the just recently announced Sustainable Flight Demonstrator project utilizing a TTBW configuration, NASA's Sustainable Flight National Partnership is airborne and actively working on a more sustainable future for aviation. Summed up by Dr. Richard Wahls, Subsonic Fixed Wing's project scientist and now mission integration manager of the Sustainable Flight National Partnership:

It's amazing we've been evolving this since 2008 and that it's still happening. We're a little more than halfway now to what we envisioned all those years ago. These projects we call the Sustainable Flight National Partnership are not just unfunded lines on a paper—they have backing, support, and lots of cost sharing partners. It's not a dream anymore.²² ■

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Reassessing the 50-Year Supersonic Speed Limit

» By **Jim Banke**, Senior Writer,
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JUST OVER 50 YEARS AGO, the federal government banned all civilian supersonic flights over land. The rule prohibits non-military aircraft from flying faster than sound so their resulting sonic booms will not startle the public below or concern them about potential property damage. Officially put into effect on 27 April 1973, the ban's introduction was strongly influenced by public opinion surveys in cities where supersonic military jets were flown overhead, and many said they didn't like what they heard or the way their windows rattled because of the sonic booms.

Boom Boom

The origins of supersonic flight go back to 14 October 1947, the first time the rocket-powered XS-1 airplane broke the sound barrier and initiated the heroic era of faster-than-sound research. Despite early interest in what was then a mysterious phenomenon created as airplanes fly faster than the speed of sound and generate atmospheric shock waves we hear as sonic booms, there were few tools and only limited data available to help us understand what was happening. No one gave the sonic booms a second thought, mostly because few people lived where the research was taking place. But as the Air Force and Navy began to deploy

large numbers of supersonic jets at bases around the nation, interest in sonic booms quickly grew as more of the public became exposed to the often-alarming noise.

Beginning in 1956 and continuing well into the 1960s, the Air Force, the Navy, NASA, and the Federal Aviation Administration (FAA) employed resources to study how sonic booms formed under various conditions, what their effects might be on buildings, and how the public would react in different locations. Through those years, through the use of many types of supersonic jets, residents of Atlanta, Chicago, Dallas, Denver, Los Angeles, and Minneapolis, among others, were exposed to sonic booms from military fighter jets and bombers flying overhead at high altitude. Two concentrated studies—one over St. Louis in 1961 and the other over Oklahoma City in 1964 (dubbed Bongo and Bongo II, respectively)—left no doubt the public was not fully supportive of routine sonic booms coming down from above. The tests generated national news and fueled strongly negative sentiment about supersonic flight.



↑ The U.S. Air Force B-58 Hustler supersonic bomber was one of many military jets used during the 1960s to generate sonic booms over U.S. cities to see how the public would react to the sound. The research helped lead to a ban on civilian faster-than-sound flight over land beginning in 1973. (Photo credit: U.S. Air Force)

The Supersonic Transport

As the work to better understand and predict sonic boom formation continued, it gave rise to the first notions of how to minimize a sonic boom by changing an airplane's shape. The U.S. government began to work with industry to develop the Supersonic Transport, or SST.

In June 1963, President John F. Kennedy announced the plan for a U.S. SST project aimed to produce the prototype for a new commercial supersonic airliner, capable of carrying as many as 300 passengers anywhere in the world at speeds as great as three times the speed of sound. (Note that the speed of sound varies depending on things like temperature and altitude. At sea level and 68 degrees Fahrenheit, it is 768 mph.)

The aviation community was racing to develop its understanding of supersonic shock waves to reduce the SST's potential sonic boom noise levels. But those researchers couldn't outpace the speed at which environmental concerns

Reassessing the 50-Year Supersonic Speed Limit (continued)

and policy discussions were cropping up, threatening to ground the aircraft before it was even built.

Three events during the summer of 1968 demonstrate the rising negative sentiment toward sonic booms. Firstly, on 31 May, during a ceremony at the Air Force Academy in Colorado, an F-105 Thunderchief fighter jet broke the sound barrier flying 50 feet over the school grounds. The sonic boom blew out 200 windows on the side of the iconic Air Force Chapel and injured a dozen people. A week later, on 8 June, the *New York Times* published an editorial using the incident in Colorado to underscore the danger sonic booms presented to the nation's peace and well-being, claiming many are "scared to death of it." This was followed on 21 July with Congress directing the FAA to develop standards for the "Control and Abatement of Aircraft Noise and Sonic Boom."

Within a couple of years, the FAA formally proposed a rule that would restrict operation of civil aircraft at speeds greater than Mach 1. Then in May of 1971, Congress canceled the SST program, and the rule banning civil supersonic flights over land went into effect two years later.

During this same time, Great Britain and France were developing and test-flying the Concorde, which went on to provide commercial supersonic air travel between 1976 and 2003. There were many reasons for its demise, including a deadly crash in 2000, but economic and environmental issues top the list. Restrictions against flying faster than sound over land due to the bans in the United States and elsewhere greatly limited its revenue-generating options.

↓ NASA's X-59, seen in this illustration, is designed to fly faster than sound but generate quieter sonic "thumps" rather than booms. To test the public's perception of this noise, part of the Quesst plan includes flying the X-59 over several communities to survey how people react. (Image credit: Lockheed Martin)



Speed vs. Sound

Moving ahead, to lift the ban and enable a viable market for supersonic air travel over land, the idea has been proposed to base new rules on a different standard than before. The speed limit created in 1973 didn't consider the possibility that an airplane could fly at supersonic speeds but not create sonic booms that would affect people below. It was a fair assessment at the time because the technology required to make that happen didn't yet exist.

"It's a rule that many people today aren't aware of, yet it's at the heart of what our [Quesst mission](#) with its quiet supersonic [X-59](#) airplane is all about," said Peter Coen, NASA's Quesst mission integration manager. "So, instead of a rule based solely on speed, we are proposing the rule be based on sound. If the sound of a supersonic flight isn't loud enough to bother anyone below, there's no reason why the airplane can't be flying supersonic."

NASA's X-59 is designed to fly faster than sound, but with drastically reduced noise—people below would hear sonic "thumps" rather than

booms, if they hear anything at all. To test the public's perception of this noise, part of the Quesst plan includes flying the X-59 over several communities and surveying how people react.

NASA will deliver the results to U.S. and international regulators, who will consider new rules that would lift the ban that has been in place for so long. The goal is for a regulatory shift that focuses on the sound an aircraft creates instead of a speed limit.

"We're definitely ready to write a new chapter in the history of supersonic flight, making air travel over land twice as fast, but in a way that is safe, sustainable, and so much quieter than before," Coen said. ■

A version of this article was published on www.nasa.gov on 27 April 2023 and is informed by the work of Lawrence Benson, author of [Quieting the Boom: The Shaped Sonic Boom Demonstrator and the Quest for Quiet Supersonic Flight](#).

Traffic Management in the Air and in Orbit

» By **Stephen Garber**, Historian,
NASA Headquarters¹

↑ As the number of objects orbiting Earth continues to multiply, the need for a coordinated scheme for Space Traffic Management becomes critical. The debris field shown in this artist's impression is based on actual data, but the debris objects are shown at an exaggerated size to make them visible at the scale shown. (Photo credit: ESA)

AS THE COMPLEX space operating environment becomes more crowded with more operating satellites and debris, the subjects of Space Situational Awareness (SSA) and Space Traffic Management (STM) deserve more concerted attention. While we have had more than 60 years of satellites in the large expanse of near-Earth space with only a handful of collisions, this likely will change as space becomes more congested. One model that analysts frequently invoke for STM is air traffic management (ATM), in part because of its much longer history. To appreciate some of the similarities and differences, this article takes a brief look at some specific aspects of ATM's

development and assesses a few of the similarities and differences with STM.

Virtually since its beginning, air traffic control has had to address the issue of nations lofting planes whose locations and routes they did not want to disclose, usually for military reasons. The landmark 1944 "Chicago Convention" for international aviation law, which created the International Civil Aviation Organization (ICAO), specifically excluded "state aircraft" (i.e., military airplanes; no such distinction exists for space objects).² The solution was the adoption of the "due regard" convention that permits nations not to disclose the whereabouts of military

planes provided they didn't endanger other aircraft. This "due regard" consideration also "placed the full burden for the avoidance of collision on the state aircraft in exchange for the ability of those aircraft to operate outside the common rules, including the ability to be undetectable by other operators and service providers."³ A parallel argument for STM could certainly be made, but unlike the atmosphere over a nation's landmass, orbital space is decidedly not sovereign.

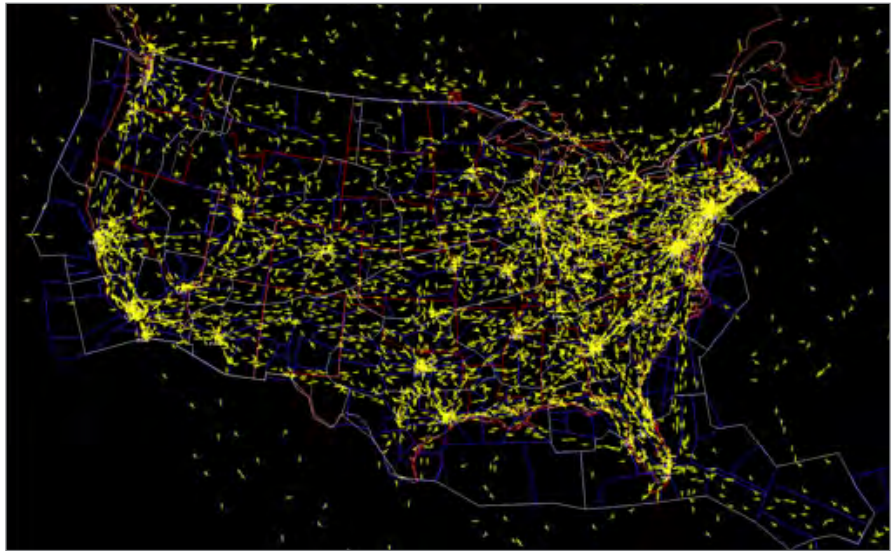
Modern air traffic control traces its origins back to a 1956 fatal mid-air collision between two planes operating over the Grand Canyon. The resulting

Traffic Management in the Air and in Orbit (continued)

1958 Federal Aviation Act transformed the existing Civil Aeronautics Authority into the Federal Aviation Administration (FAA). This legislation created an independent, unified agency to promote and develop air safety for both civilian and military aircraft.⁴ No such national or international body exists to comprehensively regulate and manage space traffic among active satellites, defunct satellites, cislunar and planetary spacecraft, and debris.

Approximately 45,000 airplanes operate in U.S. skies every day, and during busy periods, about 5,000 planes are in the air simultaneously.⁵ Once a commercial flight takes off, the pilot activates a transponder, which broadcasts a signal indicating the plane's "flight number, altitude, speed, and destination."⁶ U.S. airspace is divided into 21 zones and subdivided into sectors. Within each zone are Terminal Radar Approach Control (TRACON) airspaces that handle flights into and out of numerous airports. A useful analogy to planes being "passed off" to different flight controllers is a "zone" defense utilized by a football or basketball team.⁷ If an appropriate international regulatory body for space existed, this approach potentially could be adopted for STM.

If an appropriate international regulatory body for space existed, this approach potentially could be adopted for STM.



↑ A [visualization of air traffic](#) over the United States at a specific moment in time.

On 1 January 2020, the FAA required that aircraft operating in most controlled U.S. airspace be equipped with Automatic Dependent Surveillance-Broadcast (ADS-B) Out technology. ADS-B works by periodically, automatically, and actively broadcasting an airplane's position information to ground-based air traffic controllers, satellites overhead, and other aircraft. More than just a very useful tool for controllers, it also provides aircraft-to-aircraft communications in time-critical situations. ADS-B In is an optional tool for pilots to increase their situational awareness by obtaining information about nearby aircraft that also have this equipment aboard. ADS-B is a key technology in the FAA's Next Generation Air Transportation System (NextGen), which shifts more of air traffic control from ground-based radars to satellites.⁸ In addition to being useful for air traffic control, ADS-B technology can be invaluable for search and rescue operations and is analogous to the Personal Locator Beacons (PLBs) that many backwoods

hikers use.⁹ Some researchers have looked at analogous technologies that could be attached to spacecraft to communicate their locations to analysts on Earth; while this would certainly be helpful for global STM, there is little incentive for satellite operators to fully develop and deploy such technology at present.

Pilots of small planes ("general aviation") often operate under visual flight rules (VFR) ("see and avoid") and are encouraged, but not required, to file flight plans with the FAA. Spacecraft owner-operators are encouraged, but not required, to note planned orbital maneuvers through the www.space-track.org site. Larger commercial flights are equipped to fly in more inclement weather and thus operate under instrument flight rules (IFR) and are separated by the FAA's formal air traffic control system. Use of this system has significantly increased in the last 50 years. Since the construction of new airports and runways hasn't kept pace with the number of flights,

Traffic Management in the Air and in Orbit (continued)

the FAA and NASA have utilized new technologies such as GPS to automate the system with limited infrastructure.¹⁰ Additionally, the very rapid increase in drones (remotely piloted vehicles or unmanned aerial vehicles) over the last 10–20 years for military, hobby, remote sensing, and various other purposes has greatly complicated how airspace is used and regulated, but this is a subject for a separate discussion. Again, low-Earth orbit is becoming more crowded with the advent of commercial communication satellites, which may be analogous to drones filling the skies, but spacecraft are mostly robotic and moving much too fast for VFR to be practical anyway.

There are a few other differences between ATM and STM to keep in mind. In terms of licensure and registration, the FAA mandates certain physical fitness and medical requirements for aircraft pilots, and there are some national regulations for spacecraft such as safety regulations for launch and radio frequency usage. In terms of the right of way for aircraft, a prioritization exists for least maneuverable over most maneuverable (e.g., balloons over gliders over powered aircraft), but the vast majority of space objects (i.e., debris and small CubeSats) are not maneuverable at all. In terms of airborne hazards, typically this is not an issue, but the removal of orbital debris hazards is figuratively uncharted territory (pardon the pun) both technologically and diplomatically. Nation-states can and do establish restricted areas for aircraft “no-fly” zones (e.g., over military bases or nuclear power plants), but again, because space is not sovereign, restricted zones cannot legally be established in space. Another factor to consider is that the vast

majority of spacecraft are robotic and thus largely automated, but autopilot or the equivalent of aircraft collision avoidance systems really does not exist for spacecraft yet. Perhaps last but not least, air traffic controllers deliberately separate slower from faster aircraft to prevent collisions, but this isn’t relevant for Earth-orbiting satellites.¹¹

In previous years, some people have argued for a centralized, international body to handle STM, akin to the ICAO, which sets international standards for ATM that individual nations’ governments implement; however, changes in the commercial space sector and other factors no longer make this approach realistic.¹² As a former air traffic controller who now studies space situational awareness noted, safety on the high seas (a domain, like space, that no nation-state owns) relies on “seafaring nations of the world to enforce the agreed upon standards.” She also contends that while space technology is more similar to that of aviation, “international maritime agreements may provide the more instructive model” for STM.¹³

An important consideration for ATM and STM is whether a “top-down” or “bottom-up” system is more feasible....

An important consideration for ATM and STM is whether a “top-down” or “bottom-up” system is more feasible

for each of these domains. A top-down system entails a centralized body with enforcement authority, while a bottom-up system relies on decisions made by lower-level participants. For piloted aircraft, there is a civil national air traffic control system run by the FAA and an international one run by the ICAO that works reasonably well with centralized oversight and decentralized execution. The Pilot in Command rule still applies—the individual pilot has ultimate responsibility for the actions of their aircraft.¹⁴ This rule also applies to satellites. The Satellite Data Association is representative of a bottom-up approach: commercial satellite owner-operators needed a collision avoidance service, so they banded together and created one in the absence of a regulatory regime (it includes government agencies as members).¹⁵

Overall, more voluntary coordination is needed, both for ATM (especially given the proliferation of drones) and for STM, but many questions remain. Just as pilots file flight plans about their intended paths, a spacecraft’s insertion and intended orbit is outlined during the licensing process, but there is no comprehensive mechanism for communicating future orbital maneuvers to all relevant space operators. Just as driver’s education in the classroom and behind the wheel is incentivized through decreased insurance premiums, might educational incentives for safe and responsible space operators be a good idea? If so, how do we oversee and hold accountable the users and nations within the global commons of space? Perhaps a voluntary code of conduct or set of best practices for space owners/operators would be useful, but would this suffice?

Traffic Management in the Air and in Orbit (continued)



Visit NASA's Orbital Debris Program Office website for more information about space traffic coordination and debris remediation.

Carefully looking at precedents of how traffic has been managed in other domains should provide policy-makers and other space stakeholders with insights on the best mixes of regulatory rules and norms-based cooperation, carrots and sticks, in the increasingly complex STM environment. ATM is but one realm that may provide some instructive lessons, but the air and space domains are sufficiently different so as to warrant caution in making facile analogies. ■

Endnotes

- 1 This article is adapted from Stephen Garber and Marissa Herron, "How Has Traffic Been Managed in the Sky, on Waterways, and on the Road? Comparisons for Space Situational Awareness," 15 June 2020, parts 1 and 2, at <https://www.thespacereview.com/article/3961/1> and <https://www.thespacereview.com/article/3964/1>.
- 2 Convention on International Civil Aviation, Chicago, 7 December 1944, https://www.icao.int/publications/Documents/7300_orig.pdf, p. 3. This Chicago convention was convened during World War II in significant measure to coordinate between the United Kingdom and the United States, as well as with Canada, New Zealand, and Australia. See *Proceedings of the International Civil Aviation Conference, Chicago, Illinois, November 1–December 7, 1944, volume 1* (Government Printing Office, 1948), p. 1.
- 3 Ruth Stilwell testimony, House Subcommittee on Space and Aeronautics, 11 February 2020, available from <https://democrats-science.house.gov/imo/media/doc/Stilwell%20Testimony.pdf>, p. 13.
- 4 "A Brief History of the FAA," <https://www.faa.gov/about/history/brief-history/> (accessed 22 October 2019); John Gelder, "The Federal Aviation Act of 1958," *Michigan Law Review* 57, no. 8 (June 1959), passim.
- 5 "Air Traffic by the Numbers," 10 April 2023, https://www.faa.gov/air_traffic/by_the_numbers/.
- 6 Craig Freudenrich, "How Air Traffic Control Works," HowStuffWorks, 20 May 2021, <https://science.howstuffworks.com/transport/flight/modern/air-traffic-control.htm>. An airliner's transponder periodically communicates with satellites that can help determine its location.
- 7 Ibid.
- 8 "Automatic Dependent Surveillance-Broadcast (ADS-B)," 17 January 2023, https://www.faa.gov/air_traffic/technology/adsb; "What You Need to Know About ADS-B," <https://www.aopa.org/go-fly/aircraft-and-ownership/ads-b>. In contrast to ADS-B being active, radar identifies a plane's position passively, by reflecting a signal sent from the ground.
- 9 See, for example, Mike Collins, "ADS-B Joins Search-and-Rescue Resources: May Have Helped Find Pilot Who Ditched in Bahamas," <https://www.aopa.org/news-and-media/all-news/2020/april/22/ads-b-joins-search-and-rescue-resources>.
- 10 Freudenrich, "How Air Traffic Control Works."
- 11 For a more detailed comparison of such factors of travel in the air, space, and other domains, please see the chart accompanying the Garber and Herron article at <https://www.thespacereview.com/archive/3964.pdf>.
- 12 Daniel Oltrogge testimony, House Subcommittee on Space and Aeronautics, 11 February 2020, <https://democrats-science.house.gov/imo/media/doc/Oltrogge%20Testimony.pdf>, which cites Lt. Col. M. C. Smitham, USAF, "The Need for a Global Space-Traffic-Control Service: An Opportunity for US Leadership," Maxwell Paper No. 57, <http://www.au.af.mil/au/awc/awcgate/maxwell/mp57.pdf>.
- 13 Stilwell testimony, pp. 1 and 4.
- 14 For a cogent, accessible discussion on this point, see Barry Schiff, chapter 16, "The Responsibilities of the Pilot-in-Command" in *The Proficient Pilot*, volume 1, Aircraft Owners and Pilots Association, 1980). Schiff begins this chapter by noting that FAA regulations simply, but importantly, dictate that "The pilot in command of an aircraft is directly responsible for, and is the final authority as to the operation of[,] that aircraft" (p. 123). Two pages later, he observes that "risk management is a critical element of flight, tempered by a continual series of judgments."
- 15 See <https://www.space-data.org/sda/participants/>.

The NACA Spurs U.S. Jet Propulsion Success

» By **Robert Arrighi**, Historian,
NASA Glenn Research Center

→ Secret testing of the Bell YP-59A with its I-16 engines in the Altitude Wind Tunnel in early 1944. Bell's chief test pilot, Robert Stanley, who was the first American to fly a jet aircraft, brought the YP-59A to Cleveland for the tests. (Photo credit: NACA)



IN SUMMER 1943, military leaders brought a small group of leaders from the NACA's new Aircraft Engine Research Laboratory (AERL), which is today Glenn Research Center, for a secret briefing at General Electric's West Lynn facility, where they were shown a new type of aircraft engine, the turbojet, and informed of recent developments surrounding it. Counterparts in both Britain and Germany had not only developed their own jet engines but had successfully integrated them into aircraft. The United States was racing to catch up by trying to replicate the British design. Historians consider the failure of the NACA, the nation's premier aeronautical organization, to foresee the potential of the jet engine to be the organization's greatest failure. Over the next 15 years, however, the NACA gained expertise in jet propulsion and played a vital role in the nation's subsequent leadership in the field.

Although the NACA maintained a Power Plant Committee, and its Langley Aeronautical Laboratory included a Power Plants Division, it was primarily an aerodynamics-based organization. In 1923, a Langley researcher concluded that jet engines would be too inefficient and impractical for use in aircraft. That position held for the next 16 years as Frank Whittle and Hans von Ohain independently developed jet engines in Europe. In 1939, a pair of Langley engineers revisited the concept and constructed a test to study a ducted fan variation. Although they demonstrated the engine could produce efficient combustion, the device failed during a demonstration for NACA officials in 1942 and was given up.

Meanwhile the NACA was expanding and, at the urging of Executive Committee member Charles Lindbergh,

approved construction of a new laboratory dedicated to piston engines. Ground was broken in Cleveland for the laboratory in January 1941. Shortly thereafter, General Henry H. Arnold, Chief of the Army Air Corps, learned of the German progress on jet propulsion and witnessed first-hand the first jet-powered flight in England. In response to Arnold's alarm, the NACA established a Special Committee on Jet Propulsion that contracted with U.S. manufacturers to investigate different design options.

Bell Aircraft built the XP-59A to flight-test General Electric's (GE) first jet engine based on the Whittle model, the I-A. The initial flights in October 1942 were unsatisfactory, and subsequent flights in July 1943 with improved I-16 engines were not much better. It was in July 1943 that the AERL team was briefed on the activities.

The NACA Spurs U.S. Jet Propulsion Success (continued)

The contingent returned to Cleveland and immediately began constructing a nondescript two-cell facility specifically designed to test the GE engines. Researchers began using the facility just months later to test the I-A and I-16 in ambient conditions. By the end of the year, the new Altitude Wind Tunnel (AWT) was completed. It was the nation's only tunnel that could operate full-scale engines in simulated flight conditions. In February 1944, a Bell YP-59A with its I-16 engines was installed in the AWT. NACA researchers were able to improve the I-16's performance by 25 percent but could not overcome the engine's inherent shortcomings.

The laboratory's primary mission during the war was improving the existing piston engines that powered contemporary military aircraft. Nonetheless, there was a ramp-up of turbojet studies during the final two years of the conflict. Like the piston engine tests, these initial jet investigations were geared toward modifications that could quickly improve performance, not fundamental for long-term development. In January 1944, a YP-80A Shooting Star powered by new GE I-40 engines was studied in the AWT. The YP-80A was the first U.S.-designed jet aircraft and the nation's first to exceed 5,000 miles per hour.

Meanwhile, engineers at Westinghouse and GE's Schenectady plant were developing new jet engine designs based on the axial-flow compressor. Unlike West Lynn's centrifugal designs, which relied on a single large rotor to drive the airflow, axial-flow engines employ a series of linear fan stages to systematically compress the airflow. Power can be increased without expanding

the engine diameter by adding additional stages. The AWT tested several variations of Westinghouse's J30 and GE's J35 engines during 1944.

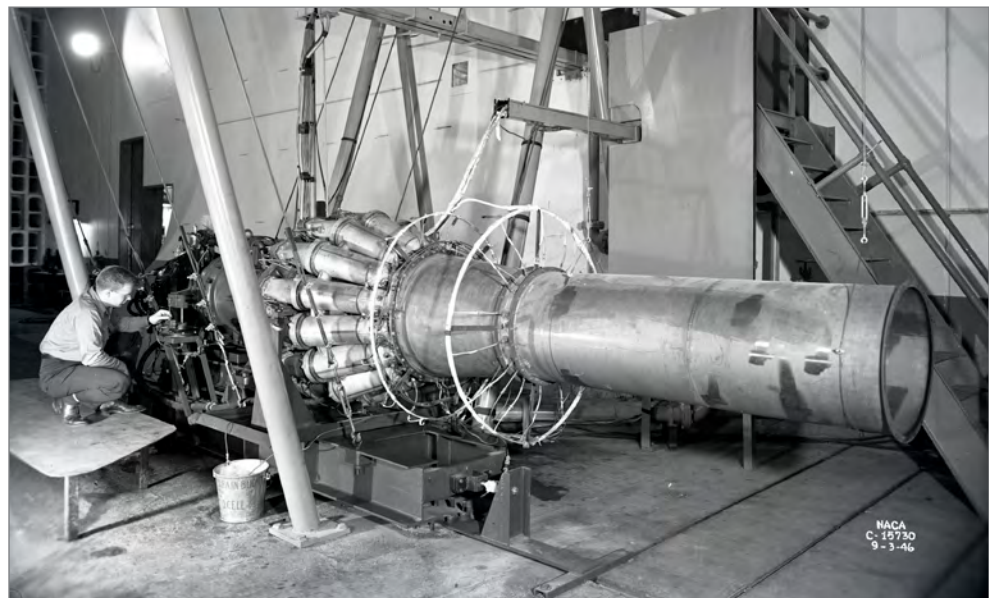
Although the Shooting Star and the J30-powered FG-Corsair flew briefly in the war, the early jet engines made little impact. It was the Allied bombers, driven by massive piston engines, that turned the tide of the war. The piston engines were reliable workhorses, but by this time their power had plateaued at around 3,550 horsepower. The addition of more cylinders and superchargers added weight and complexity, and the propeller tip speeds had reached their limits. Jet engines, particularly axial-flow engines, were the propulsion systems of the future.

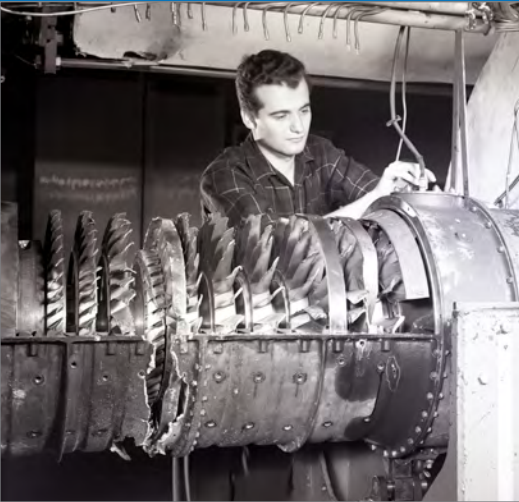
Just weeks after the war ended in the fall of 1945, the AERL underwent a swift, dramatic reorganization to concentrate nearly all of its resources on

jet propulsion. The goal was not only to catch up with the Europeans but to leapfrog them. The new focus required training for the staff, infrastructure modifications, and the construction of new facilities designed for jet engines and high-speed testing. New divisions were created to study compressor and turbine design, thrust augmentation, high-temperature materials, and high-altitude combustion. Testing was performed on components and full-scale engines in a variety of environments.

One of the first things engineers noticed is that altitude had more of an effect on jet engines than piston engines. The AWT was upgraded, and several new altitude test chambers were built. Over the next decade, nearly every U.S. model of jet engine underwent testing in simulated flight conditions at the laboratory, including the Westinghouse J34 and GE J47, the nation's first commercially successful

↓ A GE I-40 jet engine is being prepared for testing in the AERL's Engine Propeller Research Building in 1946. The facility, which was designed to test large piston engines, was quickly modified after the war for turbojets. (Photo credit: NACA)





↑ The compressor for a Westinghouse 24C (J34) engine was damaged during an altitude chamber test in 1947. The two altitude chambers were added to the Engine Research Building after the war to alleviate the backlog of turbojet tests scheduled for the AWT. (Photo credit: NACA)

jet engines. Engine flameouts and issues such as compressor windmilling were dramatically reduced. Subsequent tests included the Pratt & Whitney J57, the Rolls-Royce Nene, and GE J79.

Another issue was the need for short bursts of power, particularly for take-offs. Early jet engine nozzles were typically designed to operate at maximum speed, so their efficiency decreased at slower speeds. NACA researchers conducted extensive tests on water and alcohol injection, the variable-area nozzle, and the afterburner. The first operational afterburner was tested on a ramjet engine in the AWT in 1945.

Perhaps the laboratory's greatest contribution was in the field of turbomachinery. The compressor and turbine are the heart of the axial-flow engine. NACA engineers worked obsessively on the geometry of the compressor stator blades that pushed the air through the engine. Turbines, however, posed the greatest hurdle in engine design. A turbine must withstand the continual stream of hot exhaust gases that

The NACA Spurs U.S. Jet Propulsion Success (continued)

flow through it and maintain rotation of the drive shaft that spins the compressor. NACA researchers conducted extensive studies on the intricate turbine blade designs, complex cooling systems, and the development of high-temperature alloys.

By the late 1940s, axial-flow compressors had proven themselves in subsonic and supersonic applications, but there remained concern regarding the performance in the transonic realm. NACA researchers in Cleveland developed new stator blade designs and flow processes that increased the air pressure at each compressor stage—which allowed fewer stages. These designs were quickly adapted by manufacturers to produce lighter engines. The group went on to demonstrate that the limitations of the compressor thought to exist at transonic speeds were not valid. In 1955, the group published a secret compressor design guide that was referred to as the “Compressor Bible.”¹

The steady improvement of the axial-flow turbojet engine remains one of the NACA's most underappreciated accomplishments. The intensive effort paid off, with engine thrust increasing from 1,600 pounds to over 10,000 pounds in just a few years. The advances in propulsion were augmented with airframe improvements, the introduction of swept wings, and other technologies advanced by the NACA.

Although the military benefitted from the introduction of jet-propelled fighters and bombers in the 1940s and 1950s, the jet engine's larger legacy may be the transformation of the airline industry. Although the Europeans were first to operate jet-powered airliners in the mid-1950s, it was the introduction

of Boeing's 707 and Douglas's DC-8 (both powered by Pratt & Whitney J57 engines) in the late 1950s that set the new standard. The increase of airline seat capacity in the 1960s, which made air travel affordable for ordinary citizens, would not have been possible without the jet engine.

The new rapid growth of jet airliners in the 1960s, however, led to a number of other issues requiring attention, including fuel efficiency, emissions reduction, and noise abatement. NASA research in these areas, which continues today, has led to dramatic improvements. ■



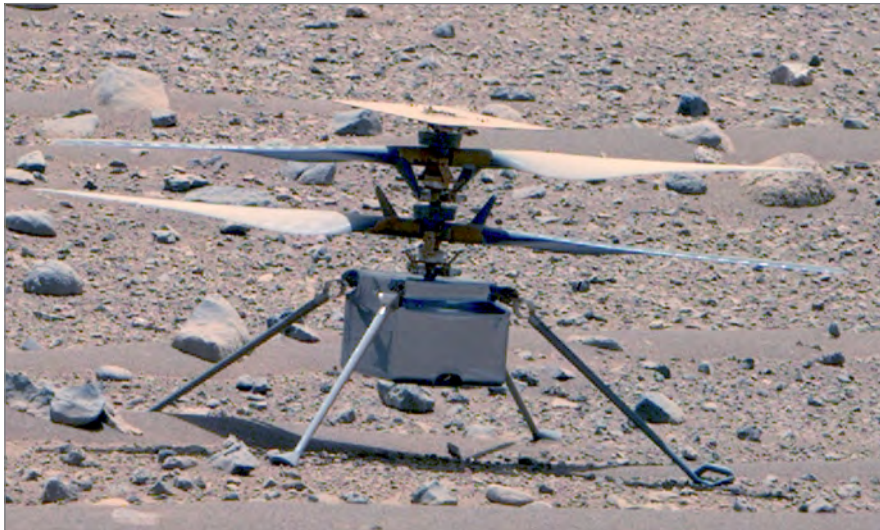
↑ A Pratt & Whitney J57 engine mounted in the AWT in early 1957. The J57, the first U.S. jet engine to exceed 10,000 pounds of thrust, was used in a host of military aircraft including the B-52 Stratofortress, F-100 Super Sabre, and U-2 spy plane. (Photo credit: NACA)

Endnote

- 1 “Aerodynamic Design of Axial-flow Compressors, Volume 1,” NACA Research Memorandum RM E56B03 (Cleveland, OH, 1 August 1956).

Ingenuity and Coaxial Rotor Systems

» By **Joshua Schmidt**, Presidential Management Fellow detailed at NASA Headquarters



↑ Nearly two years after its first flight on Mars, the Ingenuity Mars Helicopter completed its 50th on 13 April 2023, a few days before this color-enhanced photo of the rotorcraft was taken by the Perseverance rover. (Photo credit: NASA/JPL-Caltech/ASU/MSSS)

Rotors Out of This World

COMPLETING ITS FIRST FLIGHT on 19 April 2021, NASA's Ingenuity Mars Helicopter proved that flight on another planet is possible and has paved the way for future aircraft in the skies above Mars. Originally meant as a technology demonstrator with no more than five planned flights, Ingenuity has now completed more than 50 flights for a total of over 90 minutes of flight time covering a distance of just over 7 miles. Of course, flying in the thin Martian atmosphere, with a density of less than 1 percent of Earth's, presents its own unique challenges for generating the lift

required to get off the ground, and the craft's coaxial rotors have proven to be up to the task.¹

Coaxial rotor systems have two rotors stacked one atop another with enough separation to ensure the blades do not collide. Most importantly, the rotors turn in opposite directions to provide the control needed to maintain a helicopter's stability in flight. Without the anti-torque generated by the contrarotating blades, the aircraft would spin out of control. Coaxial rotor systems have the advantages of a smaller footprint and more efficient power use over other helicopter rotor systems but are in most cases more complex.

Building Ingenuity was not the first time NASA and its partners have had the opportunity to work with such rotor systems. Research into coaxial rotors began with NASA's predecessor organization, the National Advisory Committee for Aeronautics (NACA), not long after the very first flights of coaxial helicopters in the country nearly 80 years ago.

A Different Kind of System

In 1944, Stanley Hiller, a 19-year-old university student, made the first ever successful flight of a coaxial helicopter in the United States as he piloted his XH-44 aircraft into a hover and subsequently performed a small flight in the University of California's Memorial Stadium in Berkeley.² The XH-44 was quickly superseded by his next coaxial helicopter, the X-2-235. Though neither ever went into full production, the Navy's Bureau of Aeronautics (BoA) did procure an unfinished X-2-235 for testing under a previous agreement with the NACA.

In May 1945, Captain Robert Hatcher, BoA, sent a letter to the NACA specifically requesting integration of its newly acquired Hiller coaxial rotor into the existing research effort. By this point, NACA researchers had studied rotor systems on both the Sikorsky R-4 and the Piasecki PV-2 helicopters. However, both these aircraft utilized a single main rotor with a tail rotor to account for anti-torque requirements. Hiller's rotorcraft would be the first opportunity for the NACA to test a coaxial rotor system.

In accordance with previous agreements with the BoA, George Lewis, the NACA's Director for Aeronautical Research, forwarded along the request

Ingenuity and Coaxial Rotor Systems (continued)

to study the Hiller coaxial rotor to the Langley wind tunnel research team under Research Authorization (RA) No. 1354 (*Investigation of Torque and Thrust Characteristics of Co-Axial Helicopter Rotor*). The Hiller rotor arrived in Langley's Full-Scale Tunnel (FST) for testing in July 1945.³

A First and Only Test

Up until that point, Stanley Hiller had been unable to satisfactorily fly his XH-44 safely above 35 miles per hour (mph), just barely faster than the minimum test speed for the Langley FST.⁴ To alleviate this problem, Hiller modified his XH-44 design to include a semi-rigid blade mounting and increased the spacing between the rotors. Henry J. E. Reid, Engineer-in-Charge of the NACA Langley Memorial Laboratory, recommended that the X-2-235 rotor system supplied for testing be modified in line with this new configuration. It was decided that the first tests would proceed with the rotor in its current

configuration, with any further modification dependent upon results from initial testing.⁵

Unsurprisingly, those first tests of Hiller's rotor in the Langley full-scale tunnel in the summer of 1946 ran into severe challenges. Langley researchers reported they successfully obtained data on Hiller's rotor in the static position for both single and coaxial configurations. However, due to excessive vibrations introduced by the rotor system into the wind tunnel supports and balance system, researchers were unable to gather forward flight data in the coaxial configuration.

The issues in testing Hiller's rigid coaxial rotor, along with subsequent delays in Hiller providing specifications for his improved system, prompted a suggestion from Henry Reid to seek out other options so as to not "overlook a rotor system that might be useful."⁶

↓ Stanley Hiller's XH-44 coaxial helicopter was donated to the Smithsonian's National Air and Space Museum in 1953 and is on display at its Steven F. Udvar-Hazy Center in Virginia. (Photo credit: Smithsonian National Air and Space Museum)



New Opportunities

A few days before Christmas 1946, representatives of Bendix Helicopters arrived in Langley to present a film showing the capabilities of its coaxial helicopter equipped with a 25-foot rotor, like the XH-44 and the X-2-235, as well as photographs of the company's larger model with a 48-foot rotor diameter. Impressed with the demonstration, F. J. Bailey, an aeronautical engineer at Langley drafted a memo putting forth the idea of testing the Bendix helicopter:

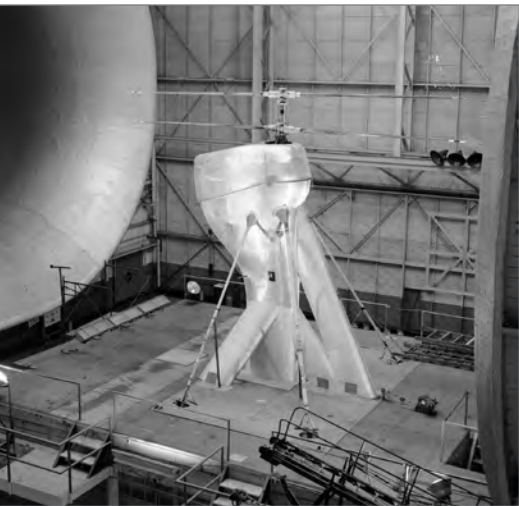
It is important that the NACA test a co-axial rotor as soon as a reasonable design becomes available. The Bendix may have such a design. The Hiller model that we now have is not. I think we should take steps to examine the Bendix machine at the earliest opportunity with the idea that it might provide a suitable rotor model for co-axial work on the test tower.⁷

With a possible alternative for testing, Reid requested that the NACA gather additional data on the Bendix coaxial rotor hub, and by the end of the summer of 1948, it had procured the coaxial rotor of the Bendix Model K. Though this system shared the 25-foot diameter of the Hiller rotor, the Bendix model had already flown successfully up to speeds of 90 mph, well above the speeds required in the full-scale tunnel.⁸

Getting Down to Business

Using the new Bendix rotor system, testing of the coaxial rotor system in the full-scale tunnel proceeded throughout the early 1950s under RA No. 1354 and a new RA, 1498 (*Investigation of Effects of Rotor Arrangement on Aerodynamic*

Ingenuity and Coaxial Rotor Systems (continued)



↑ A 25-foot-diameter coaxial rotor system is prepared for testing at Langley's full-scale tunnel in 1949. (Photo credit: NACA)

Characteristics of Helicopters). Robert Harrington, summarizing the findings, provided an important understanding of the hovering performance of a coaxial rotor in NACA Technical Note 2318.⁹ He further compared his data with information gathered from single rotor tests to compare the accuracy of power calculations between the different systems.

Richard Dingeldein later expanded upon the research in both static thrust and forward flight as a part of the test regimes he investigated. His results once again confirmed the similarities in power calculations between coaxial and single rotor systems in a static thrust condition. He also observed that in level flight, more power is required for a coaxial system than a single rotor configuration.¹⁰

While disadvantageous when compared with single rotor helicopters in that specific flight regime, Dingeldein noted that coaxial configurations

have certain advantages that may offset the higher power required in that flight regime.

The Ingenuity design team selected a coaxial rotor to utilize such advantages—specifically, the ability of coaxial rotor systems to be more physically compact, an important factor for a helicopter that needed to fit on the Perseverance rover as part of the Mars 2020 payload. Additionally, these systems are more efficient in generating lift, which is critically important in the very thin Martian atmosphere. Clearly the team of engineers who designed Ingenuity built upon this foundation of knowledge pioneered decades ago by the NACA, and their design choices led them to create an aircraft that has exceeded performance expectations. ■

Endnotes

- 1 “Mars Helicopter,” NASA, <https://mars.nasa.gov/technology/helicopter/#Helicopter-Highlights> (accessed 10 May 2023).
- 2 Stanley Hiller hadn't ever flown a helicopter before work with the XH-44 and had to teach himself while building the aircraft. Additionally, his original team did not employ an aeronautical engineer through production of either the XH-44 or the X-2-235. See Jay P. Spenser, *Whirlybirds: A History of the U.S. Helicopter Pioneers*. Seattle: University of Washington Press, 1998.)
- 3 Herbert Wilson, “Bureau of Aeronautics Project TED No. NACA 239—Helicopter rotors—Hiller Rotor,” memo for Chief of Research, 18 July 1946, “Investigation of Torque and Thrust Characteristics of Co-Axial Helicopter Rotor,” Box 543, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC (hereafter HRC).
- 4 Henry Reid to NACA, “TED No. 239—Helicopter Rotors—Hiller Rotor,” 29 October 1945, “Investigation of Torque and Thrust Characteristics of Co-Axial Helicopter Rotor,” Box 543, HRC.
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- 7 F. J. Bailey, “Visit of Messrs. J. A. Johnson and J. B. Vernon of Bendix Helicopter Company to Langley on December 19 and 20, 1946,” memo for Chief of Research, 24 December 1946, “Investigation of Torque and Thrust Characteristics of Co-Axial Helicopter Rotor,” Box 543, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
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The NASA Aeronautics Book Series

» By **Tony Springer**, Integration and Management Office Director, NASA Aeronautics Research Mission Directorate

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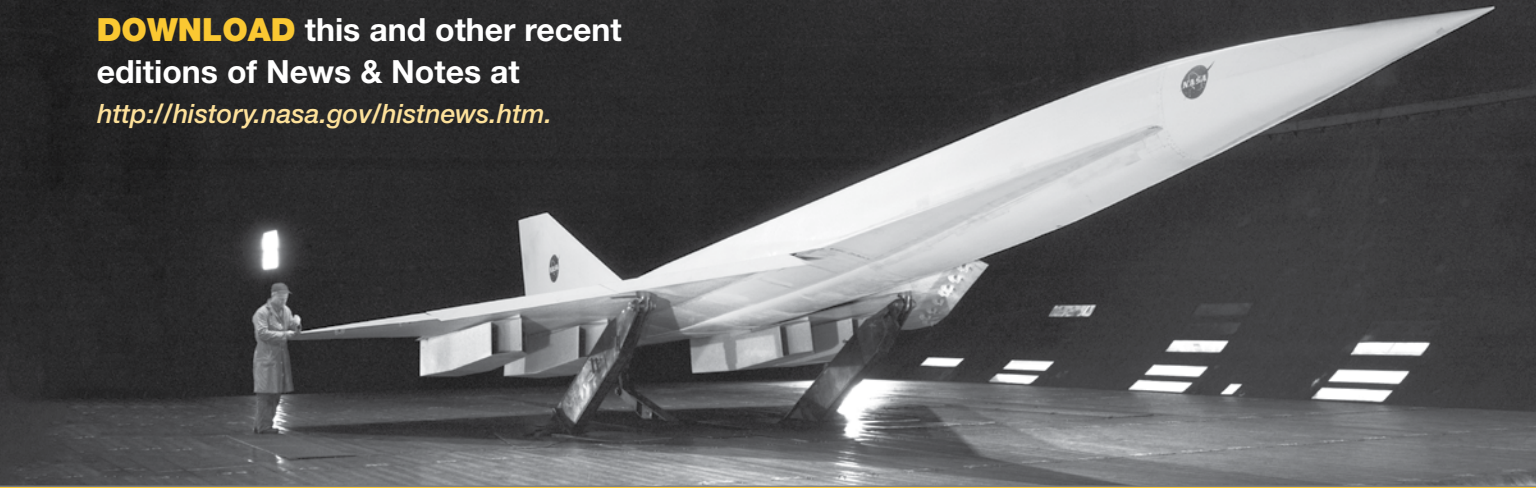
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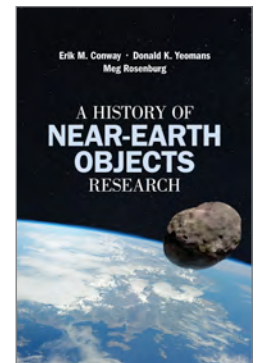
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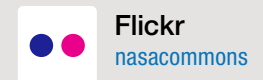
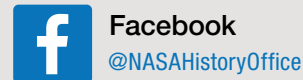


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