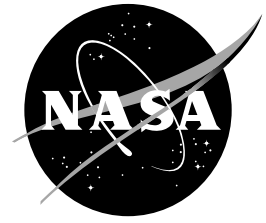


NASA Facts



National Aeronautics and
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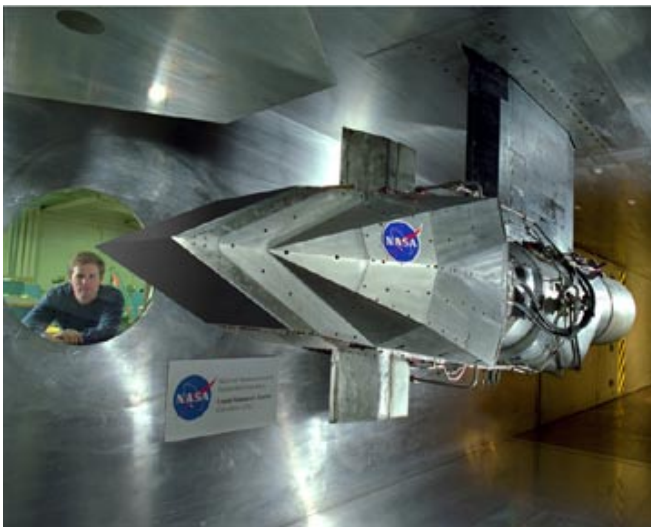
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FLYING ON THE GROUND: THE WIND TUNNELS OF GLENN RESEARCH CENTER

In its simplest form, a wind tunnel is an enclosed structure that lets researchers simulate the same conditions an aircraft would encounter as it flies through the atmosphere. In a wind tunnel, a highly instrumented aircraft model or an aircraft part (component) is held in place while air moves past it to simulate flight conditions. Wind tunnels allow researchers to safely take measurements often impossible to make while an aircraft is in flight. Computers collect the instrument readings for later analysis. Also, new design concepts are tested before any flights are made. No aircraft, spacecraft, or launch vehicle is built or committed to flight until its design and components have been thoroughly tested in wind tunnels.

The National Aeronautics and Space Administration has 42 wind tunnels, representing the largest number and variety ever operated by a single agency or company. The NASA Glenn Research Center maintains and operates five of these tunnels in accordance with its commitment to researching innovative aircraft propulsion technologies and flight safety.



An advanced supersonic inlet, one of the key components of the next-generation high-speed civil transport, is being tested in the 10- by 10-Foot Supersonic Wind Tunnel.

10- by 10-Foot Supersonic Wind Tunnel

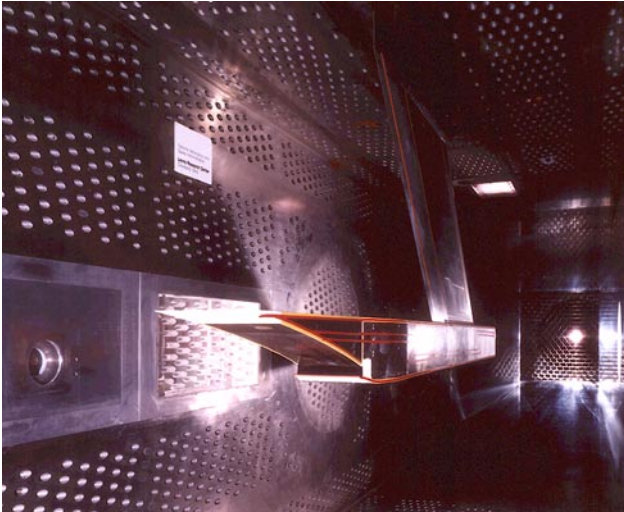
Built in the 1950's, the 10- by 10-Foot Supersonic Wind Tunnel (10×10) is the largest and fastest wind tunnel at the NASA Glenn Research Center. Although it was designed to test supersonic engine components such as inlets and nozzles, some rocket applications have also been investigated. Throughout its history, valuable contributions have been made to fundamental aircraft propulsion technology research and to vehicle-focused research programs such as the High Speed Civil Transport, the National AeroSpace Plane, and the Space Shuttle. In fact, the 10×10 has a long history of space shuttle testing during which momentary firings of one or more of the shuttle model engines were recorded and analyzed to investigate any resulting aerodynamic changes.

Simulating the flight speeds of supersonic jet aircraft, the 10×10 performs tests at airspeeds from 1400 to 2500 mph—that's up to 3.5 times the speed of sound, which is about 670 mph. The tunnel gets its name from the dimensions of its test section: 10 feet wide by 10 feet high. The tunnel loop alone is 1200 feet long with sections as large as 50 feet in diameter. Its operation relies on a host of equipment housed in 10 buildings.

The 10×10 is a dual-cycle wind tunnel. In closed-cycle operation, the tunnel air is recirculated; in open-cycle operation, the air is muffled and exhausted to the outside in a controlled discharge because combustion byproducts cannot be recirculated. The open cycle is used to test engines. During these tests, engines are run in the same way they would be on aircraft and spacecraft.

To generate the tremendous airspeeds required for testing, the 10×10 uses two compressors. When working together, they can move 100,000 cubic feet of air per second, which is about equal to all the air in 20 average houses. The compressors are powered by a series of 40,000-horsepower electric motors. The four motors on the main compressor combined with the three motors on the secondary compressor can produce 250,000 horsepower. Depending on test conditions in the tunnel, the motors can consume from 20 to 200 million watts of electricity per hour.

Raw power alone is not enough to generate the supersonic speeds needed. The air from the compressors must be channeled through a nozzle and accelerated. Just as putting your thumb over the end of a garden hose will make the water go faster and farther, the airspeed in the 10×10 can be increased by flexing (pinching) the stainless steel sidewalls of the tunnel. Although flexible, they are far from flimsy: each wall is 1 3/8 inches thick, 10 feet high, and 78 feet long. A series of hydraulic jacks pinch these walls over a distance of 4 feet and control the exactness of their contour to within five-thousandths of an inch (less than the thickness of this paper).



A hydrogen-fueled exhaust nozzle is being tested in the 8- by 6-Foot Supersonic Wind Tunnel in support of an environmentally friendly, supersonic commercial transport.

8- by 6-Foot Supersonic Wind Tunnel

Plans for the 8- by 6-Foot Supersonic Wind Tunnel (8×6) were underway before the first aircraft broke the “sound barrier” in 1947. Testing in the 8×6 began in 1948 and in the following years, cutting-edge flight technology research was conducted. Jet engines, supersonic fighter models, and rocket engine models were all tested.

One of the most challenging areas of aeronautical research is transonic speeds, from Mach 0.8 (about 600 mph), to Mach 1.2 (about 900 mph). During transonic flight, although the entire aircraft is traveling at less than Mach 1.0, the air moving over a wing can travel from subsonic to supersonic and back. The shock wave produced by supersonic airspeeds across the wing produces unique conditions that are explored in the 8×6.

The 8×6 is named from its test section dimensions: 8 feet high by 6 feet wide. Drilled in the 1-inch-thick stainless walls of the tunnel test section are holes through which air is sucked out to keep the shock waves that form on the walls from interfering with test models. (Air along the walls is called boundary layer air.) These holes also allow an efficient transition from subsonic to supersonic airflow.

Originally open at both ends, it was soon discovered that the 8×6 was an “87,000-horsepower bugle aimed at the heart of Cleveland.” This “bugle” was actually a series of giant electric drive motors and the compressor they power to generate the airspeeds and simulate the atmosphere needed for testing. When moving up to speed, these motors produce 87,000 horsepower (about as much as 750 family-size cars) and require up to 65,000 kilowatts electric power. In 1 hour of peak use, the 8×6 uses as much electricity as 35 all-electric homes use in 1 month. The compressor moves up to 56,000 cubic feet of air per second (it could reduce the air pressure from nearly 40 average living rooms to a vacuum in one second) and creates pressures from sea level to higher than 7 miles. In the early days, air, engine exhaust, and noise were vented from the tunnel to the outside. Eventually, to be a good neighbor to the surrounding communities, Glenn completely enclosed the facility.

In addition to using the compressors to control tunnel airspeed, the 8×6 has two 1-inch-thick stainless steel flexible walls that operate the way those in the 10×10 section do. Another similarity is that the 8×6 is a dual-cycle wind tunnel; of all the NASA supersonic wind tunnels, these two are the only ones that have this capability.

Since its construction in 1947, the facility has been aggressively used to support the Nation’s aeronautics programs by serving private industry, academia, and NASA’s in-house efforts such as the Advanced Turboprop, and cooperative programs such as the National AeroSpace Plane, the Advanced Tactical Fighter, and the High Speed Civil Transport.



The 9- by 15-Foot Low-Speed Wind Tunnel plays a major role in reducing jet engine noise.

9- by 15-Foot Low-Speed Wind Tunnel

After a survey of existing aeronautics facilities at the NASA Glenn Research Center, the construction of a low-speed test section in the return leg of the 8×6 began in 1967. The 9×15 is named from the size of its test section: 9 feet high by 15 feet wide. The final dimensions of the test

section were determined from the maximum amount and speed of air available in that part of the 8×6 facility. Also, the 9×15 is large enough to accommodate models with large airflows similar to those of full-scale aircraft.

In 1969 when the 9×15 began to operate, it was a test facility for vertical/short takeoff and landing (V/STOL) research. The 9×15 was built to reproduce crossflow conditions because the requirements for early V/STOL aircraft revealed several problems that had to be solved through experimentation. One problem was to determine how crossflow (air traveling in different directions) affected aircraft engines. Crossflow occurs when aircraft change from hover to horizontal flight and back to hover. For some V/STOL aircraft, the air flowing down must turn 90° to enter the engine.

The 9×15 has also been used for research into delaying or preventing hot engine exhaust gases from entering the engine of V/STOL aircraft and for studying how these gases flow around the aircraft when it is near the ground. V/STOL aircraft (jump jets), such as the U.S. Marine AV-8B Harrier, can fly faster than 600 miles per hour and can take off and land vertically using the exhaust of their jet engines. However, directing jet exhaust at the ground can result in the hot gases being sucked back into the engine where they can cause failure.

The 9×15 is now used for extensive low-speed and near-ground research. The reason for this change is that aeronautical researchers are interested in not only what happens when aircraft travel at high speeds, but also in what takes place when they travel at slow speeds during takeoff and landing. At these times, community concerns about noise and safety are greatest. Therefore, airspeeds from 0 to 175 miles per hour and aircraft behavior near the ground are investigated because at an altitude of 10 feet, there is little margin for error.

In addition to near-ground research, the 9×15 plays a major role in acoustic research on jet engines. It is also used to conduct noise tests on models and jet engine designs. Up to 20 microphones on the floor and walls of the acoustically treated test section surround the model to record data. A jet exhaust rig capable of pumping 3500 °F gases through test nozzles is used to check the noise levels of jet engine designs.

One of the major advances in aircraft propulsion has been the advanced turboprop. This type of engine mates a standard jet engine with a new, highly efficient propeller. In some cases, such engines can increase fuel efficiency by 30 percent in comparison with traditional turboprops.

Icing Research Tunnel

The Icing Research Tunnel (IRT) test section, 6 feet high by 9 feet wide, can accommodate large models and some full-size aircraft components. Thus, like most wind tunnels, the (IRT) allows researchers to take aerodynamic measurements, such as lift and drag, which are often impossible to take while an aircraft is flying. It simulates actual flying conditions by providing airspeeds ranging

from 50 to 430 miles per hour. Unlike the other wind tunnels at Glenn, its cooler and spray bars can produce the artificial clouds and low air temperatures necessary to study how ice forms on aircraft. Electrically heated windows provide a view of the test area from the control room. This view is important because much of the data are gathered by high-speed photography and videotaping.

To simulate icing conditions, temperatures ranging from 28 °F above zero to 22 °F below zero are achieved by cooling the air with a 2100-ton air conditioner. It has enough cooling power to air-condition more than 600 homes and was designed by Willis Carrier, the founder of the Carrier Air Conditioning Company.

The cooler works in conjunction with the IRT's spray bars to produce icing conditions. Nozzles in 10 spray bars produce supersonic water droplets between 10 and 50 microns in diameter (about the size of a pollen grain). The average droplet size in a cloud is about 20 microns. Because of the way they are formed, the droplets are not yet frozen even though they are less than 32 °F. However, they do freeze when they strike something, just as cloud droplets freeze when they strike an aircraft. This imitation of cloud moisture is what makes the IRT such a good simulator.

The wind in the tunnel comes from a fan that looks like a giant 12-bladed propeller. A 5000-horsepower electric motor drives the 25-foot fan, which can rotate up to more than 7.5 times per second. Each of the fan's 12 blades is made of laminated Sitka spruce, chosen because the tight grain pattern gives the wood uniform mechanical properties.

The IRT was built during World War II to prevent aircraft accidents due to icing. These accidents exacted a



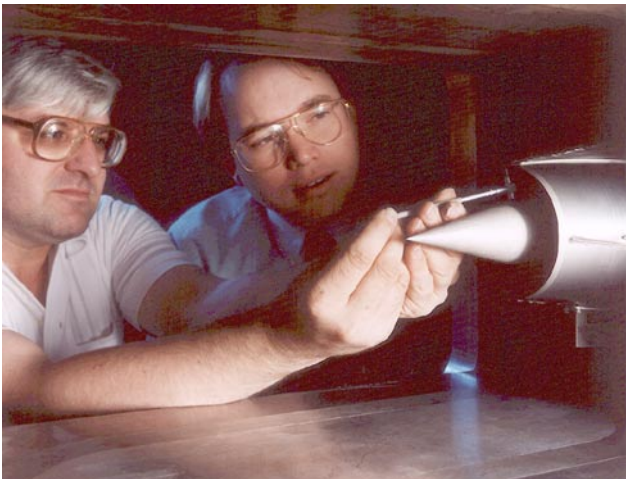
A full-size aircraft component, such as this helicopter radar housing, is being tested in the Icing Research Tunnel.

heavy toll of supply airplanes “flying the hump” over the Himalayan mountains into China. Investigation of piston-driven aircraft icing began in 1944 and continued until the advent of jet aircraft. At this time, work in the IRT tapered off to the point that it could have been closed because it

seemed that a permanent solution to icing problems was available through heated jet engine air (jets produced so much hot air that some of it could be bled off the engine to keep the aircraft ice free). However, along with the increased commercial use of jets came the wide use of helicopters—which kept the IRT open for rotor aircraft icing research. Ice is particularly dangerous to helicopters because it quickly accumulates on the thin rotor blades causing them to lose their lifting power and to severely vibrate.

The problem of icing resurfaced when the fuel crisis of the 1970's required that high-efficiency jet engines be designed to save fuel. This requirement made it less affordable to use hot engine air to melt ice; therefore, in the 1980's aircraft manufacturers turned to the IRT to investigate low-power de-icing methods that do not depend on jet engine air. This work continues today.

Although the IRT has been designated an International Historic Mechanical Engineering Landmark by the American Society of Mechanical Engineers, does this mean that it is a museum piece? Far from it. The NASA Glenn Research Center expects the IRT to contribute to aircraft safety well into the 21st century where it will continue to “freeze to please.”



A subscale supersonic inlet is undergoing checkup prior to testing in the 1- by 1-Foot Supersonic Wind Tunnel.

1- by 1-Foot Supersonic Wind Tunnel

The 1- by 1-Foot Supersonic Wind Tunnel (1×1), so named because its test section is 12.2 inches wide by 12 inches high, was built in the 1950's in the Glenn Research Center's Engine Research Building. Tests are performed at airspeeds from 900 to over 4000 miles per hour—up to six times the speed of sound. To put it another way, it can simulate flight speeds from that of a supersonic jet fighter to twice the speed of a rifle bullet.

Why would such a small wind tunnel be used? There are several reasons, all based on lower operation costs:

High Mach numbers: Much less equipment and support are needed to achieve Mach 6 in a small tunnel than are needed for larger scale wind tunnels. Also, this

speed is higher than almost any other achievable in a continuous-airflow wind tunnel.

Economy of scale: When small, simple models are tested, they are much less expensive to make and modify than full-size components are.

Power requirements: Less equipment and power are required to achieve supersonic speeds in a 1- by 1-foot tunnel. The 1×1 uses one-tenth the electrical power that a large supersonic wind tunnel may use to conduct a test, which can be about 200 megawatts.

Preliminary testing: Researchers can conduct proof-of-concept tests in the 1×1. If the outcome is promising, they can scale up their models for testing in larger tunnels, thus avoiding the cost of full-scale modeling and testing.

Another advantage the 1×1 offers is up-close viewing of conditions in the tunnel. Special 2-inch-thick glass windows that are able to withstand the 4 tons of pressure can be inserted into the tunnel walls in place of the test section's removable sidewall ports (12 inches high by 16 inches long). Items undergoing tests are viewed using a video camera and a monitor in the control room. Photographs can be taken by the tunnel's remotely operated 35-mm camera.

To get the most value from the 1×1 wind tunnel test results, engineers try to match nature as closely as possible. This means simulating the proper temperatures, pressures, airspeeds, and air conditions. Temperature is one of the most important variables because being able to control the temperature allows engineers to test over a wider range of simulated flight conditions. For example, to simulate speeds faster than Mach 4, a 665,000-watt electric heater is used to preheat the air in the tunnel to 650 °F.

Although it is one of the smallest NASA wind tunnels, the 1×1 makes as great a contribution to aeronautical research as any of the largest wind tunnels in operation.

Rooms With a View

Windows in the wind tunnel test sections are used for conducting laser measurements. Since air is not visible, engineers have found a way to see how the air is behaving around a test model. Imaging systems using argon lasers and a steam generator create a sheet of light around test items to make airflow visible.

Another laser system is used to measure the speed of air flowing around different parts of a model. Instead of inserting probes that might distort the airflow, the laser can make these measurements with no detectable change to the airstream. An added advantage is that the laser measuring devices can be operated by remote control while the tunnel is running.

**For more information,
visit the Aeronautics Test Facilities Website at:
<http://www.grc.nasa.gov/WWW/FMPO/>**