Significance

The 16-Foot High-Speed Tunnel was the first facility built in Langley’s West Area and the last American wind tunnel to enter service before the nation’s entry into World War II. Although a shortage of available electricity in the area limited its power and maximum speed, its dynamometers allowed it to effectively test full-scale engine nacelles and propellers during the war.

After a major rebuilding, the tunnel became the NACA’s second wind tunnel with slotted walls for transonic operation, and the first very-large one with this capability. Renamed the 16-Foot Transonic Tunnel, it was repeatedly upgraded and used extensively for aircraft and spacecraft aerodynamic testing from 1950 through the 2004.

Description

The 16-Foot Transonic Tunnel (16-Foot TT) is a large, externally braced, steel wind tunnel located in Langley’s West Area. When built as the 16-Foot High-Speed Tunnel (16-Foot HST) in 1941, it was the NACA’s second wind tunnel constructed in this manner (the first having been the 19-Foot Pressure Tunnel). Its rebuilding into the 16-Foot TT in 1950 utilized the same design for the new portions, giving it a homogeneous appearance. The original two-story, brick building approximately 30 feet by 105 feet on the tunnel’s north side contained staff offices and model-preparation shops. Wings were later added to the original building; the final building exterior modification extended the front of the original office building slightly beyond the front of the wings. A 30-foot-wide high-bay area, also of brick, rises another 20 feet above
the back center of the building. It originally extended further south to cover the test section and provide space for model handling, but this overhead service area was enlarged significantly with the addition of a metal addition during the 1950 conversion to the 16-Foot TT.¹

As built, the 16-Foot HST measured 140 feet by 360 feet, plus the office and air-exchange tower footprint. This air-exchange tower, which exchanged 5-20 percent of the tunnel’s air with outside air to control temperature, rose above the tunnel approximately 40 feet ahead of turn 3. Approximately 40- by 100-feet in plan and 75-feet tall, it featured a roof exhaust grill and intake louvers around its upper sides. Because of the tunnel’s 58-foot-diameter settling chamber, its centerline was approximately 30 feet above the ground throughout the circuit. This centerline height was retained during the 1950 rebuilding, but the west end was extended about 50 feet to reduce the flare in the diffuser and improve flow quality. The resulting circuit measured 930 feet along its centerline. Early photographs seem to indicate that the tunnel was originally painted silver, but it has been white in recent decades. Either color is effective in minimizing the amount of solar heat buildup in the tunnel.²

The original design located the dual 8,000-horsepower drive motors and fans in a single nacelle just after the second turn, but this changed completely during the conversion. Two 30,000-horsepower motors driving 34-foot-diameter, counter-rotating fans were mounted in the new section between turns 1 and 2. The two fan shafts, which were enclosed in a continuous streamlined fairing, extended from each fan out the corners to the motors. The entire drive system was mounted at the tunnel’s centerline height atop a trio of concrete pedestals, with the motors housed in semi-cylindrical enclosures.³

As in most modern wind tunnels, the 16-Foot TT’s diameter gradually increased from 16 feet (actually 15½ feet across the flats of an octagon) in the test section to 34 feet in the fan
section, and ultimately to 58 feet in the settling chamber. This yielded a 13.3:1 contraction ratio into the test section. Two anti-turbulence screens in the settling chamber also helped smooth the flow. A 32-foot-diameter plenum surrounds the test section. After 1961, an air-extraction system could remove up to 956,000 cubic feet of air per minute from the plenum, which allowed the tunnel to achieve a maximum speed of Mach 1.3. This system was located in the central courtyard, with its 36,000-horsepower motor and compressor inside a rectangular metal building.⁴

History

Although the NACA had received substantial funds and built several new wind tunnels at Langley during the depression-ridden 1930s, it was not alone in doing so. Several European nations, the most worrisome being Fascist Italy and Nazi Germany, had started constructing new aeronautical laboratories of their own or adding to existing ones. New advanced wind tunnel facilities were badly needed, since the “design revolution” had begun to transform aircraft design and capabilities. Metal started to replace wood and fabric, and structural design started to reflect the properties of the new material. Large, internally braced wings became practical, eliminating the wasteful drag of struts and wires. Performance-enhancing devices, such as wing flaps and retractable landing gears, helped expand the envelope as well, and new engine and propeller designs dramatically increased the available power. This revolution demanded research tools well beyond the capabilities of those in existence.*

* The earliest use of the term “design revolution” to describe the extensive changes in airplane design and construction during the late 1920s and 1930s appears to be by Laurence K. Loftin, Jr., an NACA/NASA researcher and manager, who used it as the title for Chapter 4 of his book, Quest for Performance: The Evolution of Modern Aircraft (Washington: National Aeronautics and Space Administration, 1987).
For a time, these European nations substantially outbuilt the United States, but the NACA kept watch on their activities through its Paris office, manned by John Jay Ide. Ide visited most of these new facilities and submitted detailed reports to NACA Director of Aeronautical Research George Lewis. Concerned over Ide’s reports, Lewis visited Europe to see for himself in 1936. Although an isolationist Congress was slow to act, the NACA finally secured $11 million for a major expansion in 1939. The largest portion of these funds allowed the NACA to begin construction of a new West Coast laboratory, named the Ames Aeronautical Laboratory in 1940, but a $1.5 million appropriation initiated a major change in the look and capability of the Langley Laboratory as well.5

Both Ames and Langley soon began to build 16-foot high-speed tunnels. They were quite similar, except for power. Once again, the shortage of power in Hampton limited the Langley 16-Foot High-Speed Tunnel (16-Foot HST) to 16,000 horsepower and, thus, about Mach 0.7. (While substantial, this was less than 60 percent of the power installed in its counterpart at Ames.) The Langley tunnel was authorized a few months before the one at Ames, but construction proceeded at a slightly slower pace, so it entered service a few weeks later. One of the reasons is that the 16-Foot HST broke new ground—quite literally—at Langley. Between expansions of both NACA and Army Air Corps facilities, there simply was little room left for a new wind tunnel on the east side of Langley Field, so the NACA looked west to find room on the other side of the field. The 16-Foot HST was a large machine, and it became the first tunnel built in the West Area. It was also the last wind tunnel to go on-line in 1941, opening only two days before the Japanese attack on Pearl Harbor.6

Knowing that electrical power was in short supply, David J. Biermann and Lindsey I. Turner, Jr., the lead design engineers, had developed the rationale for the 16-Foot HST carefully.
Clearly it would not be useful for the most advanced aerodynamical studies—the Ames tunnel was for that—but the 16-foot size would be perfect to investigate engine-cooling problems. Years earlier, the NACA cowling had vastly improved the cooling of air-cooled radial engines and lowered drag as well. By the late-1930s, these early single-row radial engines had grown into two-row models, and cooling the second row of cylinders emerged as a major problem, one that no existing wind tunnel had both the size and speed to help solve.\textsuperscript{7}

Propeller research was another serious need, particularly to determine the optimal settings for variable-pitch propellers under various conditions. Variable-pitch propellers had been developed during the 1930s, but much remained to be learned about how they could best be used throughout the flight envelope. The 16-Foot HST’s power would allow it to cover the entire speed range of propeller-driven planes and make it ideal for propeller investigations.

With these goals in mind, Biermann and Turner’s team designed a closed-circuit, atmospheric tunnel with an air-exchange tower that would maintain reasonable temperatures in the tunnel as well as replace a significant portion of engine exhaust gas with fresh air during operation. They chose to use a design similar to one pioneered by the Wright Brothers Wind Tunnel in 1938 at the Massachusetts Institute of Technology and employed in Langley’s 19-Foot Pressure Tunnel a year later. While the 16-Foot HST would not be pressurized like these two tunnels, its large size made the externally braced, steel-shell design the best choice for strength and economy. Equipped with 2,000- and 6,000-horsepower electric dynamometers, the tunnel could operate full-sized propellers at airspeeds up to around 500 miles per hour. The dynamometers provided accurate measurements of the amount of power a given propeller could efficiently handle, and helped determine its optimum operating conditions (revolutions per minute and pitch angle) for a variety of flight conditions.
Tests of two-row radial engines engine running at flight airflows with thermocouples mounted to measure the temperatures at critical spots helped engineers design and adjust internal baffles to alter the airflow and better cool hot areas. These tests proved difficult, however, due to choking in the tunnel around Mach 0.6, and they were discontinued in 1943, after the Lewis Flight Propulsion Laboratory in Cleveland opened with facilities better suited to the task.8

While not state of the art in speed, the 16-Foot HST was well engineered and suited to its wartime mission. After World War II, however, transonic (generally defined as being between Mach 0.7 to 1.2) research suddenly became a top priority with the advent of jet engine powered aircraft. As discussed in the 8-Foot High-Speed Tunnel section, choking problems prevented stable wind-tunnel operation near the speed of sound until Langley’s Ray Wright developed a practical slotted-wall design in 1950. By that time, the NACA had decided to rebuild the 16-Foot HST with more power, so Section Chief John Stack included a new, slotted-wall test section in the rebuilding project.

The 16-Foot HST’s position as the first facility in Langley’s West Area plus its looming role in post-war transonic research uniquely suited it to serve as host for no fewer than five small tunnels built to inexpensively try out new concepts for trans- and supersonic research. Such parasitic tunnels that utilized the power, support facilities, and staffs of their hosts were not uncommon at Langley, and several have already been noted, but the number and variety supported by the 16-Foot TT during the late 1940s is unusual. Since these tunnels were often “proof-of-concept” devices, research work done in them rarely warranted technical papers, nor did the NACA publish descriptive publications. Thus, comparatively little is now known about them, but one memorandum answering an inquiry about Langley’s supersonic facilities at least furnishes some basic information:9
Facility Name                Throat Size               Max. Speed  Built
Model Supersonic Tunnel 7½ in. x 7½ in.  Mach 1.7  1944
Supersonic Display Tunnel 2 in. x 8 in.  Mach 1.68  1945
Facility Name                Throat Size               Max. Speed  Built
Supersonic Flexible-Wall Tunnel 2 in. x 4¾ in.  Mach 1.6  1946
Parasite Tunnel 12 in. diameter  Mach 1.1  1947
Supersonic Plug Tunnel 2 in. x 5 in.  Mach 1.8  1947

The most influential of these was the Parasite Tunnel, which was built to evaluate slotted test section designs and their effectiveness in the reduction of choking near Mach 1. Designed by Vernon G. Ward, this little tunnel, which tapped into the 16-Foot HST to use its fans for draft, strongly influenced the slotted-wall modifications made to both the 8- and 16-Foot HSTs.\textsuperscript{10}

Two additional facilities associated with the 16-Foot HST team were not wind tunnels, \textit{per se}, but they were built for high-speed aeronautical testing:

Facility Name                     Type Device                              Max. Speed  Built
Supersonic Free-Flight Apparatus Catapult in a cylindrical tank  Mach 2.0  1946
                                      Max. test body, 6-in. diameter
Supersonic Sphere\textsuperscript{†} Whirling arm in a sphere  Mach 3.0  1946
                                      Max. radius, 3 ft.

None of these seven small facilities survive.

The rebuilt tunnel, renamed the 16-Foot Transonic Tunnel (16-Foot TT), opened in 1950 with a 15½-foot, octagonal test section and a dual-motor/fan drive totaling 60,000 horsepower.

\textsuperscript{†} The Supersonic Sphere is probably best known for a test program to improve not airplanes, but wind tunnels, specifically flutter in wooden fan blades. See John E. Baker and Russell S. Paulnock, “Experimental Investigation of Flutter of a Propeller with Clark Y Section Operating at Zero Forward Velocity at Positive and Negative Blade-
The new motors and fans were mounted on massive concrete pedestals with the motors outside the tunnel and the counter-rotating fans relocated between the first and second corners. The tunnel’s west end was also lengthened to provide a longer diffuser to improve flow quality leading in to the fan drive section. The slots were placed at the intersections of the test section wall panels, and a large plenum was erected around it, along with a 6-story-high metal service building. The upper three test section panels and the top of the plenum opened to allow insertion of test items. Several model mounts were provided, including a sting and sidewall supports. A hydrogen peroxide system enabled hot exhaust simulation in models of jet engines and aircraft.11

Researchers rapidly booked the 16-Foot TT with a wide variety of test programs, particularly programs involving jet engine inlets and exhausts, and their interactions with the airframes. Engineers learned much about how the design of these components affected the performance of both engines and aircraft.

When opened in 1950, the 16-Foot TT could reach a maximum speed of Mach 1.08, but researchers discovered that measurements above Mach 1.03 were inaccurate, due to wall reflected shock waves from the model nose. The slotted wall design was not perfect and model blockage effects tended to become significant at high subsonic Mach numbers. During the 1950s, studies indicated that air removal from the plenum and test section could help reduce model blockage effects, and the newly created NASA approved the addition of an air removal system. Installed in 1961, an axial-flow compressor driven by a 36,000-horsepower motor extracted up to 956,000 cubic feet of air per minute—approximately 4.5 percent of the tunnel’s total flow—from the plenum. This served to reduce model blockage effects near Mach = 1 and the total energy needed for the main drive to overcome both shock and diffuser losses. The net effect raised the maximum stable speed to Mach 1.3 at a lower cost than increasing the main

drive power. The higher speed capability allowed models of up to 6 feet long to be tested without reflected shock interactions at speeds above approximately Mach 1.15.

Further changes to the 16-Foot TT included the addition of improved tunnel controls, new sitka spruce fan blades, and an on-site data-acquisition system in 1977. These features were again upgraded in 1989-91 to keep the tunnel up to date.

Changes to the 16-Foot TT over the years revealed that the original slot shape selected in 1950 needed further refinement to obtain optimal performance. This was especially true after the addition of the plenum air extraction system raised the top speed. Theory provided some initial guidance to these studies, but most of the refinement was an empirical process. No less than 11 different shapes were tried before one known as “slot shape 29” proved suitable for speeds up to Mach 1.3.

Changes in the nature of aeronautical research, including the growth of computerized fluid dynamics (CFD), coupled with an overall reduction in the number of advanced aircraft programs, gradually reduced the tunnel’s workload during the 1990s. This, coupled with budget constraints and the availability of other tunnels with similar capabilities, led NASA to close the 16-Foot TT in 2004. While it currently remains in place, NASA hopes to demolish it in the near future.

Illustrations
This photo and plan drawing show the 16-Foot High-Speed Tunnel as it was completed in 1941. Though a modern tunnel, a 16,000-horsepower drive limited its maximum speed to Mach 0.7.

An XA-26 nacelle and propeller in the 16-Foot High-Speed Tunnel ca. 1942.

The 12-inch-diameter Parasite Tunnel used to test slotted walls and choking near Mach 1.
This phantom drawing of the rebuilt 16-Foot Transonic Tunnel shows the massive pedestals needed to support the two 30,000-horsepower motors and dual propeller fans, as well as the plenum installed around the new slotted-wall test section. The tunnel reopened in 1950.

These two views show the 15½-foot octagonal test section. The slots are at the intersections of the wall panels. Note at right how the top three panels open for model installation. Also visible are the sting model mount and its support, which can vary the angle of attack during operation.
This plan drawing shows the current configuration of the 16-Foot Transonic Tunnel. The plenum exhaust system in the center, installed in 1961, improved high-transonic stability and made low-supersonic operation practical.

One of the two 34-foot-diameter fans in the 16-Foot Transonic Tunnel. The second fan is partially visible in the background. Note the spruce blades, typical for many tunnels.

The 36,000-horsepower plenum exhaust system that could extract up to 956,000 cubic feet of air per minute. The compressor is at the far end, with its exhaust vertically upward to the atmosphere.
A model of the Space Shuttle Orbiter in the 16-Foot Transonic Tunnel, ca. 1978. Note the reaction control system exhaust openings in the model’s nose, an indicator that this test involves the orbiter’s descent from orbit.
This aerial view of the 16-Foot Transonic Tunnel shows its 2004 appearance.

Notes

1 The NACA did not publish a descriptive paper for the original tunnel, so most dimensional data were measured from available drawings and must be considered approximate. Most Transonic Tunnel dimensions and performance figures are from Francis J. Capone, Linda S. Bangert, Scott C. Asbury, Charles T. L. Mills, and Ann Bare, “The NASA Langley 16-Foot Transonic Tunnel,” Technical Paper 3521 (Washington: National Aeronautics and Space Administration, 1995).

2 Capone, Bangert, Asbury, Mills, and Bare, 3-6.

3 Ibid, 5-6.


7 Baals and Corliss, 37.

8 Ibid, 37.
9 The descriptive data for facilities shown here are from H. J. E. Reid to [Ralph E.] Ulmer, re. List of supersonic facilities, Oct. 27, 1947, National Archives and Records Administration, Mid-Atlantic Region Facility, Philadelphia, PA, Record Group 255, Box 422.


11 Hansen, 464-466. Also Capone, Bangert, Asbury, Mills, and Bare, 1, 4-5, 19-22.

12 Capone, Bangert, Asbury, Mills, and Bare, 7-8.

13 Ibid, 2.

14 Ibid, 10-11.