ANNULAR TRANSONIC TUNNEL (ATT)

Significance

The Annular Transonic Tunnel (ATT) was a novel attempt to find some means of performing transonic research in a laboratory setting before slotted walls made such research practical in a conventional wind tunnel. It was a unique combination of wind-tunnel and whirling-arm technologies to circumvent the choking problem that plagued existing wind tunnels as their speeds approached Mach 1. While limited in size and performance, the ATT did host some post-World War II airfoil research at low transonic speeds.

Description

The Annular Transonic Tunnel was not a wind tunnel in the conventional sense, although its tubular shape did not appear significantly different from other open-circuit tunnels. It was really a whirling arm, a sophisticated version of an 18th-century invention that mounted a model on the end of an arm that was then rotated to move the model through the air.¹ The core of the ATT was a rotating disk, or rotor, 57 inches in diameter, that was driven by dual 200-horsepower direct-current (DC) motors to a maximum speed of about 4,300 revolutions per minute. The disk rotated about a horizontal axis, and its diameter matched that of the inner of two concentric cylinders.²

Two concentric cylinders, with a 3-inch annulus between them, formed the tunnel portion of the ATT. Air drawn in through a bell-mouth entrance at one end flowed through the annular passage, induced by an axial-flow fan downstream from the rotor. This fan was driven by a 200-horsepower DC motor, and the combination could produce a maximum axial velocity through the annulus of about 250 feet per second (170 miles per hour).
The outer cylinder had a double flare to 108 inches in diameter at the entrance, and in necked down to approximately 36 inches in diameter at the fan. The inner cylinder served to enclose the rotor drive and as a duct for boundary layer removal. One end terminated with an exhaust cone after the fan, and the other emerged from the bell-mouth entrance as a duct to the boundary-layer extraction blower, a centrifugal fan driven by a 300-horsepower motor that exhausted to atmosphere. Also connected to this duct were three circular plenums that surrounded the outer cylinder ahead of the rotor, though two were removed early in the ATT’s life. The arrangement provided for boundary layer extraction from both surfaces of the annulus.

A single airfoil model was attached to the rotor. Access was through a hatch in the outer cylinder. The model’s spanwise dimension was always slightly less than 3 inches so that it essentially spanned the annulus without touching the outer surface. The maximum practical chordwise dimension was 4 inches. These airfoils were unique in that they were twisted so that their effective angles of attack remained constant over the full span, even though the rotary motion caused the tangential velocity of a tip to be greater than that of a root. This was possible because the test velocity was the vector sum of the model’s rotational velocity and the axial velocity of the annular airstream.3

While the model’s rotational velocity was far greater than the annular air velocity, the air flow provided three advantages. First, it kept the model from operating in its own wake—a classic problem for all whirling arms. In essence, the model cut a helical path through air it had not yet disturbed. Its second contribution was to allow the angle of attack to be varied by changing the airspeed. Since velocity is a vector quantity, changing the magnitude of one variable causes the resultant angle—the angle of attack—to change as
well. The third contribution, and the primary reason the ATT was built, was that the air motion had the same effect as increasing a tunnel’s height, thus reducing blockage, in minimizing shock reflection off its walls. The large height-to-model thickness ratio minimized choking effects and made velocities at and slightly above Mach 1 possible. The ATT ran tests in the range of Mach 0.6 to 1.01.

The entire apparatus was supported with its centerline approximately 8 feet above the floor on steel bents resting on a concrete foundation. Its enclosing cinder-block structure stood in the West Area approximately where the Jet Exit Test Facility (Building 1234) now stands.

**History**

Between 1943 and 1950, engineers at Langley and elsewhere desperately needed a viable means to investigate the complex aerodynamic regime between about Mach 0.7 and 1.2, now known as the transonic regime. The complex mix of sub- and supersonic flows in this speed range made theoretical analysis very difficult, and shock waves that reflected off tunnel walls prevented empirical testing through most of the regime. With no effective ground-based transonic facility, most available data came from tests of models dropped from airplanes or launched on top of rockets.⁴

Engineers around the world experimented with novel ideas to circumvent the choking problem. Most of these involved removing a portion of the test-section walls—a concept that ultimately worked—but the early experiments left much to be desired. Langley engineer Coleman DuPont Donaldson proposed an entirely different concept in 1944. Donaldson’s scheme was based on an old device known as a whirling arm. With a whirling
arm, a model was mounted on the end of an arm that was then rotated so that the model moved in a circular path. The concept was viable, and with sufficient power Mach 1 could be attained, but after its first revolution the model would be moving through its own wake, not still air, so the actual test conditions could not be known.

Donaldson suggested that the arm be changed to a disk, or rotor, within a controlled airflow. This could be done by creating an annular passage using two concentric cylinders. His rotor would have the same diameter as the inner cylinder, and a model mounted on its rim would extend the width of the annulus, coming as close as possible to the outer cylinder without striking it. With a small tip clearance, the flow would be two-dimensional, simplifying analysis of the data. The rotor would rotate fast enough to produce the desired tangential speed at the model. Moving air axially through the annulus would keep the model in clean air and out of its wake. In fact, changing the air velocity would have the effect of changing the angle of attack, since the model’s test velocity would be the vector sum of the model-rotation and axial-airflow velocities.5

The practical execution of this idea had problems, but other engineers at Langley had already developed some of the solutions while working on other problems. One such problem involved the varying spanwise velocity of the rotating model, but this was solved by twisting the model spanwise to make the resultant vector (test velocity) the same at all points.

From the outset, Donaldson presumed the primary measurements would be of static pressure distributions read through small holes (ports) across the model’s chord at mid-span. While easy to do in conventional tunnels, the most difficult challenge in the ATT project proved to be finding a way to connect static pressure ports on the rapidly spinning model to
stationary manometers outside the tunnel. Fortunately, engineer Blake W. Corson, Jr., in the 16-Foot High-Speed Tunnel had designed what he called a pressure transfer device for use with studies of axial compressors in that tunnel. It was simple in concept, using mercury that inertia held against the inside of a drum spinning with the rotor to form a seal between the drum and stationary baffles inside that formed isolated voids, one for each static pressure port. Jack Runckel, Richard Davey, and Mason Miller worked to solve the practical design issues, and the pressure transfer device was adapted to the ATT. It worked, but a later device that replaced the mercury with synthetic rubber seals proved to perform well and be simpler to use.6

Another significant problem to overcome involved the boundary layers along both annular walls. With only a 3-inch-span model, any boundary layer would have a significant detrimental effect. The team designed the ATT with three sets of circumferential slots in both cylinders, believing that multiple extractions of air next to the walls would deliver almost boundary-free air to the model. The inner cylinder served as the plenum for the inner slots, and three circumferential ducts around the outer cylinder conveyed their extraction air. A duct conveyed all of this air to a 300-horsepower exhaust fan. During start-up testing, the data revealed that this 3-slot system, distributed over a 10-foot-long annulus, had little effect on the boundary layer. The length of the annular path apparently generated greater boundary-layer thickness than the extraction system could remove. To correct the problem, the team decided to remove the first two sets of slots and the long entrance section, leaving only one set of slots and an entrance only 2-feet long. This reduced the boundary layer to almost zero over 70 percent of the span and significantly reduced it at the root and tip.7
The ATT opened in 1947, and it functioned more or less as intended after the boundary-layer problem was solved. It could produce stable test conditions from approximately Mach 0.6 to just over Mach 1. While the team initially hoped to achieve Mach 1.1 or 1.2, some structural concerns, apparently stemming from the slightly unbalanced rotor with one model attached, convinced them not to exceed Mach 1. Over the course of five years, the team tested five airfoil models, beginning with the NACA 66-006 design. Data from the ATT generally matched that from other tests, but the pressures measured in the ATT were always slightly higher. The reason for that was never understood.

By 1952, Langley’s Ray Wright had demonstrated that slotted walls were a very effective way to achieve stable transonic speeds in conventional wind tunnels, and Langley had installed them in its 8-foot and 16-foot high-speed tunnels, with impressive results. With its limitation to small, unique airfoil models and complexity of set-up and operation, the ATT was abandoned and decommissioned in 1952, and subsequently demolished. No portion of it survives.⁸
Illustrations

A view of the Annular Transonic Tunnel shortly after its completion with the long entrance and three boundary-layer removal duct rings still intact. Louis W. Habel (R) looks on as R. Turner inspects the rotor.

The pressure transfer device used mercury as the seal between rotating and stationary components. Each space between two baffles continuously conveyed the static pressure at one port on the model airfoil to a manometer outside the tunnel.

These diagrams show the general arrangement of the Annular Transonic Tunnel as originally built (top) and after its modification to reduce the boundary layer (bottom).
Notes

1 Benjamin Robins is generally credited with building the first whirling arm in 1746 and using it to test the aerodynamic drag of different projectile shapes. Thomas Smeaton built the second one in 1759 to evaluate windmill sails.


3 Ibid, 1.

4 The problem of wind tunnel “choking” as speed approached Mach 1 is covered more thoroughly under other tunnels, notably the Langley 8-Foot High-Speed Tunnel, so those details are not repeated here.


6 Ibid, 81-82. Also Habel, Henderson, and Miller, TR 1106, 4.

7 Habel, Henderson, and Miller, TR 1106, 2-3.

8 Becker, High Speed Frontier, 82.