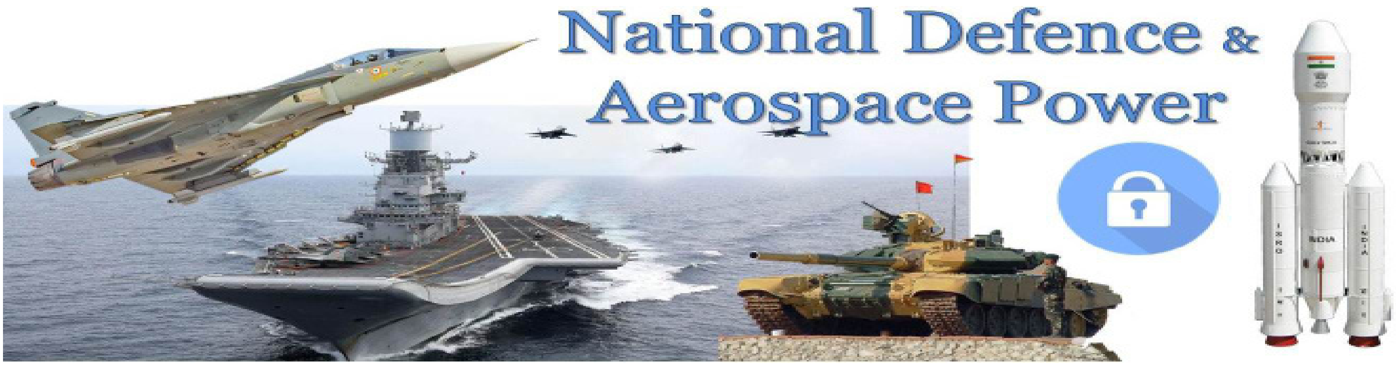
Centre for Air Power Studies



Centre for Air Power Studies
ISSUE BRIEF
153/22
16 January 2022

WIND TUNNEL TESTING – COMPLEX BUT IMPORTANT

Air Marshal Anil Chopra
Director General, Centre for Air Power Studies

Wind tunnels allow experimenting with new designs or improving the efficiency of existing ones, thus making better and safer vehicles.

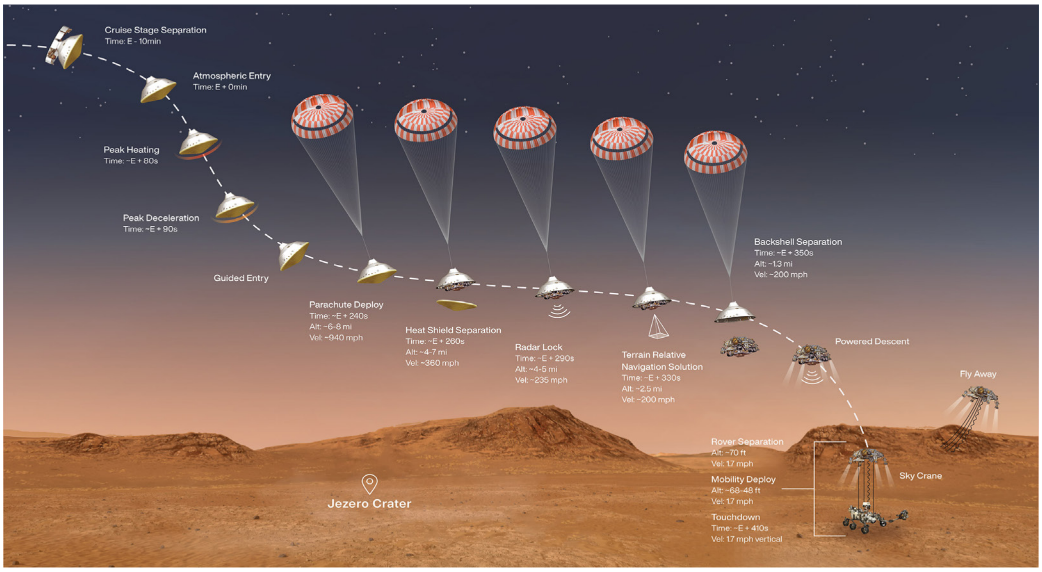
Wind tunnels are essentially large tubes with air moving inside. These are used for testing scale models of aircraft, spacecraft, drones, rockets, missiles, parachutes, trains, cars, motorcycles, bicycles, speed skates, high-rise buildings, bridges, and many other objects that move through or face high velocity air. The testing could be of the full-sized vehicle or object, a scaled down model or even a sub-part like the wing or fuselage.[1] Normally, the model under testing is anchored to stay in place. High speed wind is generated using powerful fans or suction, or combinations of both, to flow over the object. The test model has sensors to measure pressure, temperature, angle of airflow, and other parameters. In doing so, it simulates as if the object is moving relative to the air. Smoke or dye could be injected into the airflow for better visualisation. The entire activity is also videotaped using high speed cameras.

Figure 1: Wind Tunnel and Scale Model Picture

Source: NASA[2]

Wind tunnels allow experimenting with new designs or improving the efficiency of existing ones, thus making better and safer vehicles. Many designs get rejected at this stage itself, thus saving time and costs. While spacecraft and many rockets travel to space where there is no air, but these still have to be tested because their significant transit is through the atmosphere. Also, many have to return back into the atmosphere. Some of the planets, like Mars have thin atmosphere. The rover and sensors on Mars are normally parachuted down.

Figure 2- NASA's Perseverance Rover Mars Landing



Source: NASA[3]

The wind tunnels are normally generic but often custom made for certain types of testing. As such, they are of different sizes, from a few inches square to the size of a large aircraft. Often, it is not desirable to have too many sensors on the test object because of possible airflow interference. In such cases, wind tunnels may be equipped with lasers for Doppler means to measure velocities using light beams. There are tunnels where one can vary the density too. Also, nowadays, there are tunnels that have hypersonic airflow. The very high speed wind is normally generated for very short periods, sometimes as little as a few seconds.

Wind Tunnels Evolve

In 1897, Konstantin Tsiolkovsky was known to have built an open-section wind tunnel to determine the drag coefficients of various shapes. Osborne Reynolds was the first to use a scale model to determine airflow patterns, and he also evolved the 'Reynolds number'. Modern wind tunnels evolved by the end of the 19th century, just around the time when heavier-than-air flying machines were being experimented with. The Wright Brothers also used a wind tunnel in 1901 for their Wright Flyer. Engineer Gustave Eiffel used a two metre diameter open-return wind tunnel in 1909 to test airflow effects on the Eiffel tower. The U.S. Navy built a 3.4 metre diameter wind tunnel in 1916. In 1931 the National Advisory Committee for Aeronautics (NACA) built a 30-foot-by-60-foot wind tunnel for full-size testing. More sophisticated ones were made as newer and faster planes were evolving. Very large wind tunnels came up during World War II (WWII). By the end of WWII, Germany had a few supersonic wind tunnels capable of Mach 4.4. In the 1960s, even cars designs were being tested in wind tunnels to reduce drag and make them possible to be driven at faster speeds even with less powerful engines. Dedicated automotive-test wind tunnels also had roller belts under the wheels to simulate more realistic conditions. Nowadays, there are supersonic and hypersonic tunnels. Wind tunnels are also used to test the effect of wind on tall buildings, windmill blades, flight characteristics of golf balls, and race car helmets to evaluate the strain on the driver's neck. Meanwhile, high speed computing, advanced algorithms, combined with a huge database, and Computational Fluid Dynamics (CFD) modelling have reduced the demand for wind tunnel testing. The experimental Burt Rutan designed 'SpaceShipOne' that made its first flight in 2003 was built without any wind tunnel testing.

Figure 3: SpaceShipOne

Source: Scaled Composites, LLC

Science and Mechanism of Wind Tunnel

All flight and motion in fluids are based on Bernoulli's principle,[4] first published in 1738. The theorem talks about the conservation of energy. It states that any change in kinetic energy results in a corresponding or equivalent change in potential energy. Therefore, the scale model should not only be of geometric similarity but also weight and other balancing must be accurately done. A key term for that is the 'Reynolds number'[5] which is the ratio of inertial forces to viscous forces. This parameter must be maintained. As the object moves through a fluid, the changes in velocity and pressure create lift and drag. These can be measured in a wind tunnel using specially placed pressure sensors on the surface of the model. As in the actual aircraft, a miniature pitot-tube can be used to measure both dynamic and static pressures. Nowadays, there are pressure sensitive paints for such measurements, or even flexi-strips with embedded miniature pressure sensors. Also, the movements and complex behaviour of the model can be ascertained.

In India, wind tunnels traditionally were a part of the National Aeronautics Laboratory (NAL) under CSIR, which has been supporting the aircraft development industry.

How the Wind Tunnel Works

The air is blown or sucked through a duct using powerful fans or suction devices. The model under test is either suspended or mounted on a pedestal rod and kept near the diametric centre. The model is instrumented and has viewing windows. The airflow has to be made turbulence free and stabilised into the laminar flow using vanes. A circular tunnel is often better for achieving this. The tunnel's inner surface must be as smooth as possible to avoid airflow disturbance from protrusions, including having embedded lighting. Inside the tunnel, temperature variations are avoided lest they generate turbulence. Despite all this, the airflow smoothness is measured and applied to the test results to avoid result distortions. The most basic type of instrument is to mount the test subject on a force balance. Force balance directly measures the aerodynamic forces and moments on the model. Normal clean air cannot be seen. Therefore, for flow visualisation, through test inspection windows, or for video imaging, different methods are used. These could be using smoke, applying some oil, special paints such as pressure sensitive paints, or sublimate material on the model to see the movement of air over the model. High speed cameras and lasers are used for better observations.

Wind Tunnel Classifications

The wind tunnels are graded based on their size and wind speeds. They are also classified by the orientation of the wind tunnel, being horizontal, vertical or circular etc. The lower-speed ones would be subsonic, and the higher-speed ones are transonic. The supersonic tunnel will typically cover M1.2 to M5. Beyond M5.0 will be hypersonic tunnels. PHEDRA High enthalpy low density wind tunnel uses plasma to simulate very low pressure flight conditions such as those in the upper layer of the planetary atmospheres. Typically, the vertical ones are required for V/STOL aircraft, helicopters, drones, spin trials or parachute testing. There are dedicated vehicle testing wind tunnels where various operations of the vehicle gets tested. Also, there are wind tunnels to test various fans used for domestic use or industrial applications.

There is a greater use of unmanned systems as platforms for the authentication of ground tests in the air. These tests could be for an engine, external store, or even an airframe.

There are wind tunnels that factor in the Reynolds number change that takes place in a scaled model. This can be done by increasing pressure to increase the Reynolds number. There are also tunnels that use specialist gases or cryogenics to do the same. Pressure in the tunnel could be reduced to simulate very high altitude. There are tunnels to check out acoustics and suppression systems. Many wind tunnels can also create climatic conditions.

Major Wind Tunnels

One of the largest wind tunnels is at NASA Ames National Full Scale Aerodynamic Complex (operated by the US Air Force) measuring 24.38 m × 37 m. Central Aero Hydrodynamic Institute (TsAGI) at Zhukovsky, near Moscow, Russia has one with internal dimensions are 24 m × 14 m. Most countries have very small wind tunnels, some less than half a meter. China's FL-64 wind tunnel of the state-owned Aviation Industry Corp of China (AVIC) has a one metre diameter and can test hypersonic weapons and glide vehicles[7]. China's JF-22 wind tunnel under construction will simulate up to Mach 30 (it is claimed) and is likely to be ready by the end of 2022. In India, wind tunnels traditionally were a part of the National Aeronautics Laboratory[8] (NAL) under CSIR, which has been supporting the aircraft development industry. HAL and ISRO have their own wind tunnels. Many IITs and other institutes of technology in India also have wind tunnels. An advanced Hypersonic Wind Tunnel (HWT) test facility has been built at the DRDO's Dr. APJ Abdul Kalam Missile Complex in Hyderabad.[9] The state-of-the-art HWT test facility uses a pressure vacuum free jet and has a nozzle exit diameter of one metre. It can simulate Mach 5 to 12 speeds.

Figure 4: ISRO's Advanced Hypersonic Wind Tunnel

Source: ISRO[10]

The Way Ahead

There is a need to build adequate and effective counter-defence against these hypersonic weapons and match the pace by developing indigenous capabilities

The future will be unmanned. A large number of drones are evolving. They bring in a mix of vertical and horizontal flight. They also fly in swarms where the airflow from one affects the other. Boom Technology is developing a M1.7, 55-passenger supersonic airliner with 7,870 km range named “Overture”[11] -targeted to be inducted in 2029. It will require special wind tunnel testing.[12] Hypersonic is also where the action is. There are dedicated companies that specialise in and provide wind tunnel test facilities for testing samples of various applications. They also support them with software solutions. New pressure scanners are evolving. They help the customer evolve an appropriate scale model, advice on instrumentation, among other things. As the world is working towards greener and quieter operations, there are wind tunnels for testing these aspects. Some objects require environmental exposure, and wind tunnels use humidity, pressure, temperature, vibration, and exposure to ultraviolet light (UV) and other climatic variables for tests. Some of the weather instruments require wind tunnel testing. Every country is going for high speed railways and other means of road transport that require aerodynamic testing. Wind turbines are increasingly being used for cleaner energy. There is a greater use of unmanned systems as platforms for the authentication of ground tests in the air. These tests could be for an engine, external store, or even an airframe. Scaled UAS can test new configurations and technologies, reducing the risks and costs.

Changing research requirements and improved integration with CFD software will need wind tunnels for aircraft development for at least the next few decades. “Let’s not write the history of wind tunnel testing too early. We don’t know what is around the corner, and once we get rid of them, we are well and truly in the world of numbers”,[13] said, Professor Chris Atkin, from the Department of Mechanical Engineering and Aeronautics at City University of London.

Notes:

[1] “What Are Wind Tunnels?”, NASA, April 5, 2017, https://www.nasa.gov/audience/forstudents/k-4/stories/nasa-knows/what-are-wind-tunnels-k4.html. Accessed on 11 January, 2022.

[2] Aerodynamic Force Model, https://www.grc.nasa.gov/www/k-12/airplane/tunmodel.html. Accessed on 14 January, 2022.

[3] DC Agle, Grey Hautaluoma, Alana Johnson, "NASA's Perseverance Rover 22 Days From Mars Landing, NASA", January 27, 2021, https://www.nasa.gov/feature/jpl/nasa-s-perseverance-rover-22-days-from-mars-landing. Accessed on 14 January, 2022.

[4] James Prager; Karen King; Denise W. Carlson, Bernoulli's Principle, teachengineering.org, Regents of the University of Colorado, January 5, 2022, https://www.teachengineering.org/lessons/view/cub_bernoulli_lesson01. Accessed on 14 January, 2022.

[5] Kara Rogers, Reynolds number, britannica.com, Last Updated October 18, 2019 https://www.britannica.com/science/Reynolds-number. Accessed on 14 January, 2022.

[6] Force Balance, NASA, https://www.grc.nasa.gov/www/k-12/airplane/tunbal.html. Accessed on 14 January, 2022.

[7] David Rogers, "China announces completion of hypersonic wind tunnel", *Global Construction Review*, November 26, 2021, https://www.globalconstructionreview.com/china-announces-completion-of-hypersonic-wind-tunnel/. Accessed on 13 January 2022.

[8] National Aeronautics Laboratory, https://www.nal.res.in/en/facilities. Accessed on 14 January 2022.

[9] "Hypersonic Wind Tunnel test facility inaugurated at DRDO", *The Hindu*, December 20, 2020, https://www.thehindu.com/news/cities/Hyderabad/hypersonic-wind-tunnel-test-facility-inaugurated-at-drdo/article33375408.ece. Accessed on 14 January 2020.

[10] Doug Messier, "ISRO Commissions Advanced Hypersonic Wind Tunnel", *Parabolic Arc*, April 19, 2017, http://www.parabolicarc.com/2017/04/19/isro-commissions-advanced-hypersonic-wind-tunnel/. Accessed on 14 January 2022.

[11] Overture, Boom Technologies, https://boomsupersonic.com/overture. Accessed on 14 January, 2022.

[12] Boom, "What Is Wind Tunnel Testing?", *Boom Supersonic,* August 10, 2021, https://boomsupersonic.com/flyby/post/what-is-wind-tunnel-testing. Accessed on 14 January, 2022.

[13] Ben Sampson, "The future role of wind tunnels in test and development", *Aerospace Testing International,* March 15, 2018. https://www.aerospacetestinginternational.com/features/the-future-role-of-wind-tunnels-in-test-and-development.html. Accessed on 14 January, 2022.

Centre for Air Power Studies

The Centre for Air Power Studies (CAPS) is an independent, non-profit think tank that undertakes and promotes policy related research, study and discussion on defence and military issues, trends, and development in air power and space for civil and military purposes, as also related issues of national security. The Centre is headed by Air Marshal Anil Chopra PVSM AVSM VM VSM (Retd).

Centre for Air Power Studies
P-284, Arjan Path, Subroto Park, New Delhi 110010
Tel: +91 11 25699130/32, Fax: +91 11 25682533

Editor: Dr Shalini Chawla e-mail: shaluchawla@yahoo.com
Formatting and Assistance: Mr Shantanu Roy Chaudhury, Mr Mohit Sharma and Mr Rohit Singh