# Wind Tunnels

In experimental aerodynamics, forces, moments, heat transfer rates etc. are to be measured on small scale models under conditions simulating the actual flight conditions. The most important condition to be simulated is the relative motion between the model, say glider, aircraft, bullet, rocket or satellite and the fluid.

$$\left.\begin{array}{l} \textit{The flow around a body} \\ \textit{moving in a stationary fluid} \end{array}\right\} \equiv \begin{array}{l} \textit{The flow of fluid around} \\ \textit{a stationary body} \end{array}$$

This fact is the basis of most of the experimental aerodynamic work, where invariably fluid flows past a stationary body at the same relative velocity as the actual flight condition.

- From the energy point of view, less energy is required for a model to fly in a stationary fluid compared to the uniform flow past a stationary model.
- But from the measurement and data collection point of view, a moving body is much more difficult to instrument than a stationary model. This is the main reason of making measurement on a stationary body in fluid flow.
- In principle, the boundaries of uniform fluid flow should extend to infinity but this will result in enormous amount of power requirement. Instead, an area of flow which may be 10-50 times the frontal are of the model is provided. This finiteness and bounded-ness of the fluid flow introduces error in measurements, for which corrections are to be made, and these will be discussed later.

Despite the above general practice, there are situations when it is desirable to reproduce the condition of moving body in a stationary fluid. Examples are:

- A ship model towing tank
- Rocket sled for hypersonic speeds (as long as 7 miles): at hypersonic speeds, the power economy considerations outweigh any other consideration
- Flight testing and measurements on 'on board' mounted models on aircraft
- A whirling arm to move the model in a stationary fluid. Earlier wind tunnels were of this type
- Spinning tunnel

In most other situations, the model is held stationary and the fluid flows past it. This uniform flow is obtained in a Wind Tunnel, which is one of the principal apparatus for carrying out testing, development, and research work in aerospace engineering.

Considering the increased complexity and size of modern aircraft, the large economic investment they represent, the cost of flight testing, and the ever increasing demand for flight safety, a great deal of importance is placed on the conduct of first-rate wind-tunnel testing programs in the process of designing and development of aircraft.

# Classification of Wind Tunnel

## Based on speed

**Low Speed Tunnels** (M<0.3)

Low speed low turbulence tunnel
An average tunnel is likely to have a turbulence level of approximately 1%.
A low turbulence wind tunnel is likely to have turbulence level less than1%. It could be as low as 0.05%. The two principal features of low turbulence wind tunnels are:

- large contraction ratio (C.R.)

$$C.R. = \frac{Area\,of\;settling\;chamber}{area\,of\;T.S.} \geq 10$$

- Presence of several fine mesh wire screens in the settling chamber to damp out unsteadiness and turbulence.

**High Speed Tunnels**

- Subsonic, $0.3 \leq M \leq 1$; This can be further subdivided as low subsonic and high subsonic.
- Transonic : 07 < M < 1.3
- Supersonic : 1.3 < M < 4
- Hypersonic : M > 4

## Based on Density

- <u>Constant density or incompressible flow wind tunnels</u> - most of the low speed wind tunnels are of this type, unless it is a special tunnel for stratification studies.
- <u>Variable density wind tunnels</u> - all the high speed wind tunnels are of this type. Further, some low-speed tunnels can also be variable density type to permit larger variation in Reynolds numbers. A major fabrication consideration in variable density tunnels is the desired absence of leakage.
- <u>Low density wind tunnels</u> - These tunnels simulate the condition for outer space where free molecular flow can exist. These are also sometimes called rarefied gas wind tunnels. In general, such wind tunnels operate in hypersonic speed range. Their fabrications depend very much on the knowledge of vacuum technology.

## Based on medium or fluid type

- Air - This is used most often in the entire Reynolds number range.
- Water - used mainly in low speed applications for flow visualizations and capitation studies.
- Glycerin - has high viscosity and is used at low speed studies of flow near the walls.
- Smoke Tunnel - Smoke is injected in filament form in air flow. These are mostly low speed tunnels with maximum speed of 20 m/s, and are used for flow visualization studies.
- Helium Tunnel- In some hypersonic tunnels, helium is used as a working medium because of two important characteristic features:
    1. Helium has lower critical temperature, i.e. it condenses to liquid phase at a much lower temperature.
    2. It is a monatomic gas, and therefore, it is lighter; this means less power requirement to obtain hypersonic speed.

## Based on Geometry or Layout and the mode of operation

**Mode of Operation**

- Continuous tunnels - Almost all low-speed tunnels are continuous tunnels.
- Intermittent tunnels - tunnels which run for a short duration of the order of a minute or less. These are, in general, high speed tunnels. Power economy consideration is the major factor. They can be of either Blow-down or Induction type. The induction type intermittent tunnels are limited to low supersonic Mach numbers.

**Layout**

- Open circuit type
- Closed circuit type

Intermittent tunnels are invariably open circuit type. Higher subsonic continuous tunnels are in general closed type and have the advantage of better control of medium conditions, less unsteadiness, and less noise.

**Test Section Layout**

- Closed jet
- Open jet

  Power requirement for open jet tunnel is slightly more than the closed jet tunnel.

**Special Purpose Tunnels**

- Cascade Tunnels - mainly used in the flow studies of turbo-machinery cascades. Their important feature is the absence of diffuser after the test section so as to permit free turning of the flow by cascades. Cascade tunnels can be low speed as well as high speed.
- Shock tubes – intermittent type and used for studies on high enthalpy supersonic/hypersonic flows to study the phenomenon of ionization and dissociation.
- Shock tunnel - intermittent type, used for hypersonic flows.
- Ballistic ranges - for experiments on magneto gas dynamics.
- Spinning tunnel - this is a vertical wind tunnel with the air drawn upward by a propeller near the top of the tunnel. The spin tunnel uses an annular return with turning vanes. The dynamically similar model is inserted into the tunnel in a spinning attitude to obtain the spin characteristics of an airplane model after it has stalled.
- Boundary layer tunnel - a low speed tunnel with an extra long test section to have thick boundary layers.
- Industrial Aerodynamic Tunnel - are large test section low-speed tunnels, mostly of the open circuit type.
- Free Flight Tunnels - no balances are used. Dynamically and geometrically similar models fly under the influence of gravitational, aerodynamic and inertia forces and motion pictures are made of their flight. The model controls are remotely movable.
- Stability Tunnels - designed for dynamic stability work. Its most important feature is its ability to subject the models to curving airstreams that simulate those actually encountered when an airplane rolls, pitches or yaws.
- Ice tunnels - Icing condition, the formation and method of removal of ice are studied. A large cooler just before the settling chamber and water spray nozzles are used to generate clouds.

## General layout and major components of a low speed W.T.

**Low speed Wind Tunnel**

The layout is basically decided by the fact whether the tunnel is open circuit or closed circuit.

- Closed Circuit (or return circuit) type Wind Tunnel

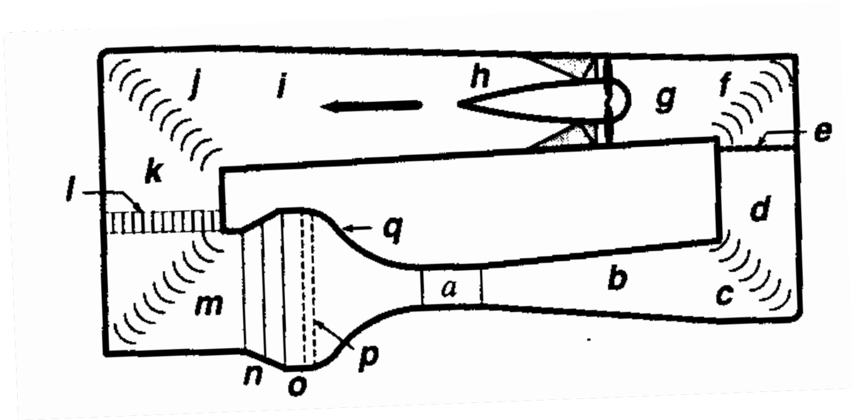


**Figure 1:** Layout of closed circuit wind tunnel

Static pressure in the T.S. is less than the atmospheric (entire return passage is above atmospheric pressure, and some air may leak out. In turn the loss of air would drop the jet pressure below atmospheric unless it were replenished. The breather at the downstream end of the test section could be placed to maintain atmospheric pressure at the test section).

<u>Major Components</u>:

a) *The test section, which may be closed, open, partially open or convertible.* Test section length (L) is typically 2 times the equivalent diameter of the test section. For some special purpose wind tunnel this could be even more.

*b) A diffuser of at least three or four test-section lengths.* Typical divergence angle for a diffuser is about $3.5^o$. The area ratio between inlet and outlet is generally maintained at 2 to 3.

*c) "First corner" incorporating turning vanes.*

*d) Second leg that may continue the diffuser or may be constant area.*

*e) Safety screen to prevent parts of failed models or other unintended flying objects from reaching the fan.* This screen is usually just ahead of the second-corner turning vanes.

*f) "Second corner" incorporating turning vanes.*

g) *Transition from rectangular to circular cross-section to take flow into the fan.*

h) *Fan and straightener section.*

i) *Return or second diffuser.* This will commonly incorporate a transition back to rectangular from the circular cross-section at the fan.

j) *"Third corner" incorporating turning vanes.*

k) *Third leg that may be constant area.*

l) *Heat exchanger.* Some wind tunnels have this element in the tunnel to control the test section air temperature.

m) *"Fourth corner" incorporating turning vanes.*

n) *Wide-angle diffuser with separation control screens.*

o) *Settling chamber*

p) *Flow conditioners typically including flow straighteners (honeycomb) and turbulence control screens.*

q) *Contraction or nozzle.* Typical area ratio of the contraction cone is about , although higher and lower values are not uncommon.

The design of low-speed wind tunnel involves the design of these components.

2. Open Circuit Tunnel

A typical layout of an open circuit tunnel is given in figure 2. This type of wind tunnel is widely used for instructional purposes and for investigation of fundamental flow phenomena. Static pressure in the test section is less than the atmosphere.

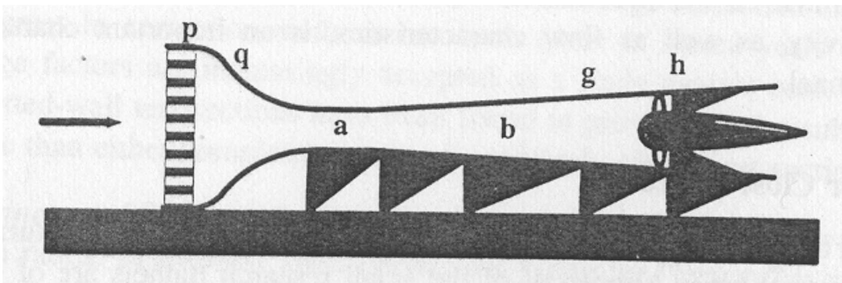


**Figure 2:** Elevation cross section of a typical small open circuit wind tunnel.