Wind tunnels

Types of application of wind tunnel measurements:

realisation of a flow corresponding to prescribed boundary (and in rare cases initial) conditions in a given test volume.

There are two freqent problems: modelling of

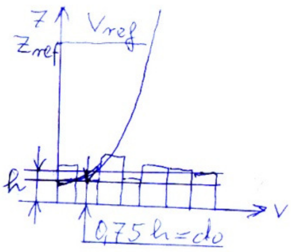
a) **flow past solid objects** (e.g. vehicles) moving relative to fluid or gas at rest with constant velocity along straight pathline,

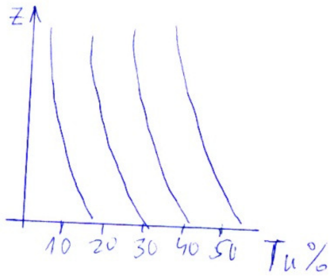
b) **atmospheric boundary layer**.

In case

a) flow velocity (modeling the relative velocity) in the test volume should be theoretically constant and the turbulence intensity is zero. The moving road should be modeled by moving belt to.

b) velocity is zero close to the lover flat boundary of the test value and increases upwards according to the velocity distribution in the atmosphere, and the vertical distribution of turbulence intensity (and also that of size of vortices) is prescribed. These characteristics are mainly influenced by roughness of the ground.





$$\frac{u(z)}{u_{ref}} = \left(\frac{z - d_0}{z_{ref} - d_0}\right)^{\alpha}$$

Exponent $0{,}08 \le \alpha \le 0{,}4$,
Depending on ground roughness
Profile displacement $d_0 = 0{,}75$ h
Mean height of buildings etc.

Types of wind tunnels classifications occurs according

- to wind velocity v [m/s],

  a) low speed $Ma = \frac{v}{a} \le 0{,}3$ where $a = \sqrt{\kappa RT}$ sound speed

  b) high speed (transsonic) $Ma \approx 1$

  c) supersonic $Ma \ge 1$

  d) hypersonic $Ma \ge 5$

- to arrangements:

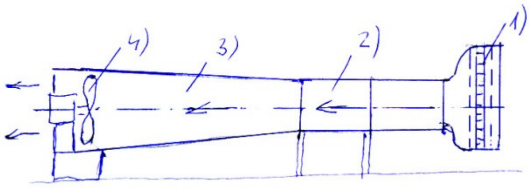
  a) path of air: closed circuit
  open circuit

  b) pressure in test section in comparison to ambient pressure: pressurized
  evacuated
  ambient pressure

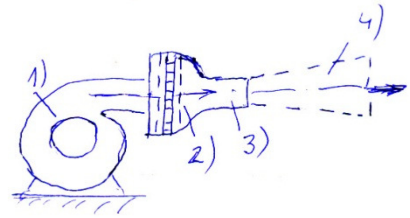
  c) relation of test section and environment open test section
  closed test section

Types of **open circuit** wind tunnels:
a) **evacuating arrangement**: 1) settling chamber, 2) closed test section, 3) diffuser, 4) axial fan
b) **pressurized arrangement**, 1) radial fan, 2) settling chamber, 3) open or closed test section connected to discharge cross section of fan, and in case of closed test section, 4) diffuser. At both arrangements diffuser is used to reduce the power consumption

Evacuating arrangement

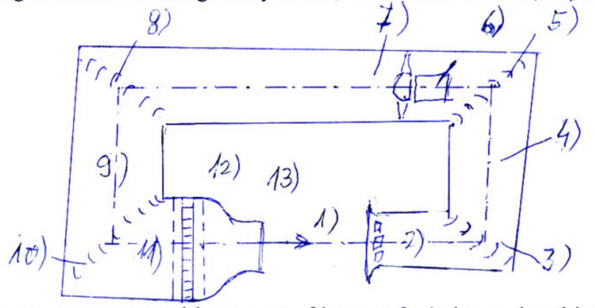


Pressurized arrangement



In case of open circuit arrangement a part of flow circulation is non-controlled, so the environment influences the flow quality in test section: vortices enters in case a) the settling chamber, in case b) the inlet of radial fan. Arrangement a) is more sensitive in terms of returning vortices then arrangement b). This problem can be solved by using closed circuit where the effect of environment can be reduced or exclude. (The reduction of fuel consumption is not significant.) Larger wind tunnels are of closed circuit arrangement.

Elements of **close circuit** wind tunnels:
1) test section, 2) diffuser (cone angle is about 5^0), 3) corner vanes in corner chamber, 4) diffuser, 5) corner vanes, 6) axial fan, 7) diffuser, 8) corner vanes, 9) diffuser, 10) corner wanes, 11) diffuser, 12) settling chamber including honeycombs, woven wire screens, 13) confuser.



Losses in corner vanes total large part of losses of wind tunnel and influence very much the losses of diffuser, too. Honeycomb: tubes of diameter d and of 5 - 6 d length, it reduce the velocity component perpendicular to axis of tubes. Honeycomb can reduce the uniformity of velocity distribution if there is velocity component perpendicular to tube axis. Upstream and downstream of honeycomb screens woven wire screens improve the uniformity of velocity distributions, and reduce the velocity components parallel to the plane of screen. The screens cut up vortices and promote in this way their dissipation. Confusers reduce effectively the change of velocity component parallel to its axis. The ratio of cross sections, the rounding up radii play important role in their effectiveness. Sufficient distance should be secured between woven wire screens and rounding up of confuser. At small distance the screen can decrease the uniformity of velocity distribution.

The cross section of test section is either circular or rectangular. 1: 2 ratio of vertical and horizontal sizes. There are open and closed test sections.

a) **open test section**:
- easy access,
- majority of wind tunnel corrections are unnecessary,
- at sides of test section shear layer, entrainment,
- increased turbulence,
- pressure higher than the ambient and increases in wind direction,
- at the end of confuser deviation of velocity from axial direction.

b) **closed test section**:
- pressure decreases, because thickening of boundary layer velocity increases downstream (compensation increasing cross section, BL suction)
- area blockage ratio is much smaller than that of open test section.
- wind tunnel corrections should be made (pressure decrease, increased velocity beside the body investigated, at the periphery of test section the wall is flat, although the stream-surface would be curved. Slotted walls are frequently used.

Flow similarity:

Low speed wind tunnels $Re_m = \frac{v_m l_m \rho_m}{\mu_m} = \frac{v_m l_m p_m}{\mu_m (T) R T_m} = \frac{v l \rho}{\mu} = \frac{v l p}{\mu(T) R T} = Re$

Since $l \gg l_m$ and velocity cannot be increased, because $Ma_m = Ma$ cannot be ensure, $Re_m = Re$ can be kept by increasing p_m pressure and decreasing T temperature.

At $Ma \geq 1$ $Ma_m = Ma$, i.e. $\frac{v}{\sqrt{\kappa R T}} = \frac{v_m}{\sqrt{\kappa_m R_m T_m}}$ can be assured by changing the temperature at measurement of model.

Wind tunnels in ground vehicle aerodynamics

Scale: 1 : 3 – 1 : 5.

Incompressibility can be neglected if:

$$\Delta\rho/\rho \approx \Delta p/p \leq 0{,}05 \rightarrow \Delta p \leq 5000\,\text{Pa} \rightarrow v \leq \sqrt{\frac{2}{\rho}\Delta p} = \sqrt{\frac{2}{1{,}2}5000} = 91\,\text{m/s}$$

(At experiments in low speed wind tunnels ($v \leq 100\,\text{m/s}$) incompressibility can be neglected.)

At rounded edges if $Re_{em} \ll Re$ turbulence generator e.g. roughness of surface or thin wire along the edge upstream of rounding.

Measurements of:
- 3 force and 3 moment components
- pressure distributions
- mud deposition