Chapter 2: Introduction of Low-Speed Wind Tunnel

Low speed is referred to the air flow speed lower than 100 m/s, for which the incompressible flow condition is satisfied.

Wind tunnel is referred to a facility which provides a controllable flow field for testing aerodynamic models and studying flow phenomena.

*Types of wind tunnels*

- Closed-type wind tunnel
- Open-type wind tunnel
- Aerodynamic wind tunnel; Environmental wind tunnel
- Low turbulence level wind tunnel
How to describe a wind tunnel?

For instance, a 3m by 4m closed-return type wind tunnel is referred to the wind tunnel whose cross section of the test section is 3m by 4m.

The geometrical shape of test section:
- rectangular (general purpose)
- circular (axisymmetric model)
- elliptical (aircraft model)
A layout of a closed-return type wind tunnel
Example: the ABRI wind tunnel in the Kuei-Ren Campus, NCKU

Miau, J. J., Chou, J. H., Cheng, C. M., Chu, C. R., Woo, K. C., Ren, S. K.,
Wind Tunnel. The Fourth Indonesia –Taiwan Workshop on Aeronautical
(Also, presented at The International Wind Engineering Symposium,
IWES 2003, November 17-18, 2003, Tamsui, Taipei County, Taiwan).
Elements of a wind tunnel

Fan drive: provide a pressure increase of flow, to overcome the pressure loss in the tunnel circuit.

Test section: provide desirable flow condition and space for model testing or experiment, where the instrumentation are situated. *(Reynolds number is of the major concern. How to manage the issue of dynamic similarity?)*

Diffuser: a device to lower the air flow speed, consequently reduce the pressure loss due to friction

Guide vanes: to guide the flow through the turning duct, and reduce the extent of secondary flows.

Transition duct: the device to connect the upstream and downstream components of different cross-sectional shapes.

Settling chamber: a large space to lower the air flow speed, and to manage the flow in uniform distribution and lower turbulence intensity.

Nozzle: to accelerate the flow speed to reach the desirable level in the test section, meanwhile reduce the turbulence intensity.
Characteristics of a fan drive: volume flow rate and pressure rise

Volume flow rate is determined by the desirable speed in the test section and the cross-sectional area of the test section.

Pressure rise is intended to overcome (balance) the pressure loss of air flow through the tunnel circuit.

Pressure loss in the tunnel circuit is due to the following factors:
- friction loss due to flow through the tunnel circuit
- pressure drop due to flow through screens, honeycomb
- pressure loss due to flow separation in the diffuser or guide vanes

Fan selection is based on the volume flow rate and pressure rise. In addition, the size (diameter) of the fan has to be fitted into the circuit. Note that fan power (energy loss of flow in the tunnel) is proportional to the cube of the air speed.
Open type wind tunnel: flow through the tunnel circuit, which is drawn from the upstream ambient air, is discharged into the ambient air downstream,

blow-down type: the fan situated upstream of the test section

\[ P_1 > P_{\text{atm}} \]
\[ P_s < P_{\text{atm}} \]
suction type: the fan situated downstream of the test section

\[ P_{\text{atm}} \text{ (stagnation pressure)} \]

\[ P_s < P_i < P_{\text{atm}} \]
Comparison of the blow-down and suction types of wind tunnels

- Pressure in the test section
- Flow quality in the test section

Comparison of the open and closed types of wind tunnels

- Cost of construction
- Cost of operation
- Flow quality in the test section
- Space and environment required
Calibration of wind tunnel is to gain better understandings of flow quality in the test section.

Uniformity of mean flow
Free stream turbulence intensity
Angularity of flow
Steadiness of flow speed and air temperature with run time
Longitudinal pressure gradient
Vibration of wind tunnel structure
Energy ratio

Efforts to improve the flow quality of the wind tunnel are worthwhile to be made after wind tunnel calibration.
Energy ratio: the power obtained in the test section versus the power input; jet energy versus circuit losses

\[
ER_t = \frac{\text{jet energy}}{\sum \text{circuit losses}} = \frac{1}{2} \rho A_0 V_0^3 \frac{1}{\sum_i K_0 \frac{1}{2} \rho A_0 V_0^3} = \frac{1}{\sum_i K_0_i}
\]

\(K_0_i\): pressure loss coefficient of \(i\) component


Comparison of the energy ratios of closed-return type and open type wind tunnels

\[
ER_t > 1 \quad (\text{closed-return W.T.})
\]

\[
< 1 \quad (\text{open type W.T.})
\]
Introduction of water tunnel or water channel

The working principles of a water tunnel or water channel are the same as those of a low-speed wind tunnel.

The water tunnel or water channel for aerodynamics use are usually at low speed, for instance, low than 1m/s. The facilities are mainly for the purpose of conducting flow visualization to gain insights into the complex flow characteristics. *(How to manage the Issue that the Reynolds number of the experiment would be much lower that that of the real situation?)*

For naval research, high speed water tunnel, whose flow velocity in the test section can be up to several tens of meter per second, is indispensable. Moreover, It can be pressurized to simulate the underwater flow condition.


Considerations of dynamic similarity

Dynamic similarity: If the two flows are dynamic similar, the dynamic equations describing the two flows are identical. This implies that the non-dimensionalized equations of the two flows are the same. The coefficients of each term in the two equations are the same. Note that the coefficients represent the non-dimensional parameters, for instance, the non-dimensional parameter of the viscous term of the momentum equation is the Reynolds number. See the references:

Fox, R. W., McDonald A. T., and Pritchard P. J., Introduction to Fluid Mechanics, the Sixth ed., John and Wiley, 2002, Chapter 7,
If the dynamic similarity is not guaranteed between the experimental and flight (real) conditions, would the experimental data be relevant to those of the flight condition?

For instance, cases are

- Drag of a circular cylinder
- Vortex flows produced by a delta wing at an angle-of-attack
speed $V$, and the sphere diameter $D$, we could compute a value for $\frac{\mu V D}{\rho}$, then read the corresponding value for $C_\mu$ and finally compute the drag force $F$.

In Section 7-3 we introduce the Buckingham Pi theorem, a formalized procedure for deducing the dimensionless groups appropriate for a given fluid mechanics or other engineering problem. The theorem may at first seem a little abstract, but as subsequent sections illustrate, it is a very practical and useful approach.

The Buckingham Pi theorem is a statement of the relation between a function expressed in terms of dimensional parameters and a related function expressed in terms of nondimensional parameters. The Buckingham Pi theorem allows us to develop the important nondimensional parameters quickly and easily.

**7-3 Buckingham Pi Theorem**

Given a physical problem in which the dependent parameter is a function of $n - 1$ independent parameters, we may express the relationship among the variables in functional form as

$$q_1 = f(q_2, q_3, \ldots, q_n)$$

where $q_1$ is the dependent parameter, and $q_2, q_3, \ldots, q_n$ are the $n - 1$ independent parameters. Mathematically, we can express the functional relationship in the equivalent form

$$g(q_1, q_2, \ldots, q_n) = 0$$

where $g$ is an unspecified function, different from $f$. For the drag on a sphere we wrote the symbolic equation

$$F = f(D, V, \rho, \mu)$$

We could just as well have written

$$g(F, D, V, \rho, \mu) = 0$$

The Buckingham Pi theorem [5] states that: Given a relation among $n$ parameters of the form

$$g(F, D, V, \rho, \mu) = 0$$

in $C_\mu$ at values of $R$ above $3.5 \times 10^4$, but no effect at all at lower values. This is in contrast to the marked effect at subcritical Reynolds numbers observed in an earlier investigation (Roshko 1955). Evidence of a decrease is more obvious in figure 3, which clearly shows a decrease in $-C_\mu$ at $R > 3.5 \times 10^4$. (iii) There is no significant effect on the pressure distribution, other than that related to changes in the base pressure; the distributions are all similar to the example given in figure 4.

Unfortunately, it was not possible to go to Reynolds numbers as high as in the experiments without the splitter plate, because at the higher dynamic pressures severe flutter developed at the trailing edge of the splitter plate. The reason for this flutter is not clear; apparently it was not connected with vortex shedding off the cylinder, since this was suppressed by the plate. Possibly shedding off the trailing edge of the splitter plate itself had an effect.

5. Ideas about the flow

It was not possible in these experiments to make a detailed investigation of the wake structure, but from the results obtained we tentatively propose the following picture of the wake development.

(a) Transitions and characteristic ranges

The lower, or critical, transition at $2 \times 10^8 < R < 5 \times 10^8$, from high to low values of $C_\mu$, is followed by another (upper) transition, at $10^9 < R < 3.5 \times 10^9$, to a new plateau on which the coefficients have the following mean values: $C_\mu = 0.70$, $C_D = 0.65$. For $R > 3.5 \times 10^9$, the values of $C_\mu$ are small, and most of the drag is due to the pressure on the splitter plate, which is very large.
90. Vortices above an inclined triangular wing. Lines of colored fluid in water show the symmetrical pair of vortices behind a thin wing of 15° semi-vertex angle at 20° angle of attack. The Reynolds number is 20,000 based on chord. Although the Mach number is very low, the flow field is practically conical over most of the wing, quantities being constant along rays from the apex. ONERA photograph, Werlé 1963.

91. Cross section of vortices on a triangular wing. Tiny air bubbles in water show the vortex pair for the flow above in a section at the trailing edge of the wing. ONERA photograph, Werlé 1963.
A glance of some wind tunnel facilities in the world

- NASA wind tunnels
- CARDC
- ETW
- Aerodynamic testing facilities (Fluidyne, USA)