Flow Similarity

Consider two different flow fields over two different bodies. By definition, such flows are dynamically similar if

1. The streamline patterns are geometrically similar.

2. The ratios of flow quantities $V/V_\infty, p/p_\infty, T/T_\infty$, etc. throughout the flow field are the same when plotted against common nondimensionless coordinates.

3. The force coefficients are the same.

What are the conditions under which two flows are similar?

Two flows of different fluids are similar if

1. The two bodies are geometrically similar.

2. The flows have identical initial flow directions.

3. The nondimensionless similarity parameters are the same for both flows.

In aerodynamics, there are only three independent dimensions, mass (M), length (L) and time (T). Thus, $k = 3$. The physical variables are the density ($\rho$), the velocity ($V$), the body length ($\ell$, or $c$), the viscosity ($\mu$) and the speed of sound ($c_0$). Thus, $n = 5$. Dimensionless dependent variables, therefore, can be expressed in terms of only 2 dimensionless variables. The two dimensionless variables are

the Reynolds number : $Re = \frac{\rho V \ell}{\mu}$

and

the Mach number : $M = \frac{V}{c_0}$

The quantities used to define these variables are usually evaluated at upstream conditions denoted with the subscript $\infty$.

The lift, drag, normal and axial forces are nondimensionalized with respect to the dynamic head, $q_\infty = \frac{1}{2}\rho_\infty V_{\infty}^2$, times the area $S$. Hence, the lift and drag coefficients, for example, can be expressed as functions of $Re$ and $M$

$$C_L = F(Re, M)$$

$$C_D = G(Re, M)$$

For flows which may be considered incompressible, $M < .3$, $C_L$ and $C_D$ depend only on the Reynolds number.

$$C_L = F(Re)$$

$$C_D = G(Re)$$