

Basic Applications of Elementary Flows

1 Nonlifting flow over a cylinder

If we combine a uniform flow with a doublet, we get the stream function

$$\psi = V_{\infty} r \sin \theta - \frac{\kappa \sin \theta}{2\pi r} = V_{\infty} r \sin \theta \left(1 - \frac{\kappa}{2\pi V_{\infty} r^2}\right) = V_{\infty} r \sin \theta \left(1 - \frac{R^2}{r^2}\right), \quad (1.1)$$

where $R^2 = \frac{\kappa}{2\pi V_{\infty}}$. This is also the stream function for a flow over a cylinder/circle with radius

$$R = \sqrt{\frac{\kappa}{2\pi V_{\infty}}}. \quad (1.2)$$

The velocity field can be found by using the stream function, and is given by

$$V_r = V_{\infty} \cos \theta \left(1 - \frac{R^2}{r^2}\right), \quad V_{\theta} = -V_{\infty} \sin \theta \left(1 + \frac{R^2}{r^2}\right). \quad (1.3)$$

Note that if $r = R$, then $V_r = 0$, satisfying the wall boundary condition. At the wall also $V_{\theta} = -2V_{\infty} \sin \theta$. This means that the pressure coefficient over the cylinder is given by

$$C_p = 1 - \left(\frac{V}{V_{\infty}}\right)^2 = 1 - 4 \sin^2 \theta. \quad (1.4)$$

2 Nonlifting flow over a sphere

Let's combine a uniform 3-dimensional flow with a 3-dimensional doublet. Let's define R as

$$R = \sqrt[3]{\frac{\mu}{2\pi V_{\infty}}}. \quad (2.1)$$

Using the combined stream function, it can be shown that the velocity field is given by

$$V_r = -V_{\infty} \cos \theta \left(1 - \frac{R^3}{r^3}\right), \quad V_{\theta} = V_{\infty} \sin \theta \left(1 + \frac{R^3}{r^3}\right), \quad V_{\phi} = 0. \quad (2.2)$$

At the wall, the velocity is $V_{\theta} = \frac{2}{3}V_{\infty} \sin \theta$. This means that the pressure coefficient over the sphere is given by

$$C_p = 1 - \left(\frac{V}{V_{\infty}}\right)^2 = 1 - \frac{9}{4} \sin^2 \theta. \quad (2.3)$$

3 Lifting flow over a cylinder

Let's combine a nonlifting flow over a cylinder with a vortex of strength Γ . This results in a lifting flow over a cylinder. The resulting stream function is

$$\psi = (V_{\infty} r \sin \theta) \left(1 - \frac{R^2}{r^2}\right) + \frac{\Gamma}{2\pi} \ln \frac{r}{R}. \quad (3.1)$$

From the stream function we can derive the velocity field, which is given by

$$V_r = V_{\infty} \cos \theta \left(1 - \frac{R^2}{r^2}\right), \quad V_{\theta} = -V_{\infty} \sin \theta \left(1 + \frac{R^2}{r^2}\right) - \frac{\Gamma}{2\pi r}. \quad (3.2)$$

Elementary Basic With Applications

Lei Huang



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