

## TEP4156 Formula sheet

$$\sigma'_{ij} \frac{\partial u_i}{\partial x_j} \geq 0$$

**Velocity derivative**

$$\frac{\partial u_i}{\partial x_j} = \dot{\epsilon}_{ij} + \dot{\Omega}_{ij}$$

$$q_k = -k \frac{\partial T}{\partial x_k}$$

**2D Shear angle rate**

$$\dot{\epsilon}_{ij} = \frac{1}{2} \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right)$$

**Deformation law for newtonian fluids**

$$\sigma'_{ij} = \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3} \delta_{ij} \frac{\partial u_k}{\partial x_k} \right) + \mu_B \delta_{ij} \frac{\partial u_k}{\partial x_k}$$

**2D Rotation angle rate**

$$\dot{\Omega}_{ij} = \frac{1}{2} \left( \frac{\partial u_i}{\partial x_j} - \frac{\partial u_j}{\partial x_i} \right)$$

**Creeping flow**

$$\text{Re} \rightarrow 0 : \quad \vec{\nabla} p = \mu \vec{\nabla}^2 \vec{u}$$

**3D Rotation angle rate**

$$(\dot{\vec{\Omega}})_k = \frac{1}{2} \epsilon_{ijk} \dot{\Omega}_{ij}$$

**Boundary layer equation**

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = U \frac{dU}{dx} + \nu \frac{\partial^2 u}{\partial y^2}$$

$$\dot{\vec{\Omega}} = \frac{1}{2} \vec{\nabla} \times \vec{u}$$

$$u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \frac{k}{\rho c_p} \frac{\partial^2 T}{\partial y^2}$$

**Mass conservation**

$$\frac{D\rho}{Dt} + \rho \vec{\nabla} \cdot \vec{u} = 0$$

**Displacement thickness**

$$\delta^* = \int_0^\infty \left( 1 - \frac{u}{U} \right) dy$$

**Momentum conservation**

$$\rho \frac{Du_i}{Dt} = \frac{\partial \sigma_{ij}}{\partial x_j} + \rho f_i$$

**Momentum thickness**

$$\theta = \int_0^\infty \frac{u}{U} \left( 1 - \frac{u}{U} \right) dy$$

**Energy conservtion**

$$\rho \frac{DE}{Dt} = \frac{\partial}{\partial x_j} (\sigma_{ij} u_i) + \rho f_i u_i - \frac{\partial q_k}{\partial x_k}$$

$$\psi(x, y) = \sqrt{\frac{2}{m+1}} \nu x U f(\eta)$$

**Total energy**

$$E = e + \frac{1}{2} u_i u_i$$

$$\eta = y \sqrt{\frac{m+1}{2} \frac{U}{\nu x}}$$

**Deformation**

$$\sigma_{ij} = -p \delta_{ij} + \sigma'_{ij}$$

$$f''' + f f'' + \frac{2m}{m+1} (1 - f'^2) = 0$$

**Energy equation**

$$\rho \frac{De}{Dt} + p \frac{\partial u_k}{\partial x_k} = \sigma'_{ij} \frac{\partial u_i}{\partial x_j} - \frac{\partial q_k}{\partial x_k}$$

$$\frac{d\theta}{dx} + \left( 2 + \frac{\delta^*}{\theta} \right) \frac{\theta}{U} \frac{dU}{dx} = \frac{C_f}{2}$$

**Enthalpy equation**

$$\rho \frac{Dh}{Dt} - \frac{Dp}{Dt} = \sigma'_{ij} \frac{\partial u_i}{\partial x_j} - \frac{\partial q_k}{\partial x_k}$$

## Additional formulas

**Bulk viscosity**

$$\mu_B = \lambda + \frac{2}{3}\mu$$

**Dynamic viscosity**

$$\nu = \frac{\mu}{\rho}$$

**Mechanical pressure**

$$\bar{P} = P - \mu_B \frac{\partial u_k}{\partial x_k}$$

**Navier-Stokes equation**

$$\frac{\partial \vec{u}}{\partial t} + (\vec{u} \cdot \vec{\nabla}) \vec{u} = -\frac{1}{\rho} \vec{\nabla} P + \nu \vec{\nabla}^2 \vec{u} + \vec{g}$$

**Skin friction coefficient**

$$C_f = \frac{\tau_w}{\frac{1}{2}\rho U^2}$$

**Drag coefficient (flat plate)**

$$C_D = \frac{1}{L} \int_0^L C_f dx, \quad C_f = 2 \frac{\partial \theta}{\partial x}$$

**Shape factor**

$$H = \frac{\delta^*}{\theta}$$

**Laminar boundary layer**

$$\delta \ll L,$$

$$\text{Re} \gg 1$$

## Advanced formulas

**Kármán integral relation**

$$\frac{1}{2}C_f = \frac{\partial \theta}{\partial x} + (2 + H) \frac{\theta}{U} \frac{\partial U}{\partial x}$$

**Orr-Sommerfeld equation**

$$(U - c)(v'' - \alpha v) - U''v + \frac{i\nu}{\alpha}(v'''' - 2\alpha^2 v'' + \alpha^4 v) = 0$$

**Inviscid Orr-Sommerfeld equation**

$$(U - c)(v'' - \alpha^2 v) - U''v = 0 \quad (\alpha^2 ?)$$

TODO: Add Einstein notation, kronecker delta, levi civita,  $\sigma'$ , Couette flow?, Bessel functions