Exercise 14.

- Compressible flow!
  - Density variations in the flow (at $\mathrm{Ma} > 0.3$)
- Mach number:

$$\mathrm{Ma} = \frac{V}{a}$$

$$a = \sqrt{\gamma R T} \quad \text{Eq. (9.16), speed of sound}$$

$$\begin{cases} \mathrm{Ma} < 1 \rightarrow \mathrm{Subsonic} \\ \mathrm{Ma} = 1 \rightarrow \mathrm{Sonic} \\ \mathrm{Ma} > 1 \rightarrow \mathrm{Supersonic} \end{cases}$$

Exercise 14.

- Perfect gas
  - Most gases at moderate pressure and temperature (not steam!)
  - $C_\mathrm{v} = \mathrm{Const.}$, and $C_\mathrm{p} = \mathrm{Const.}$
  - Perfect gas law holds $p = \rho R T$
  - Changes in internal energy $\hat{u}$ and enthalpy h with constant specific heat as:

$$\begin{cases} \mathrm{d}\hat{u} = C_\mathrm{v}\mathrm{d}T \Leftrightarrow \int_{\hat{u}_1}^{\hat{u}_2} \mathrm{d}\hat{u} = \int_{T_1}^{T_2} C_\mathrm{v}\mathrm{d}T \Rightarrow \Delta\hat{u} = C_\mathrm{v}\Delta T & (\text{internal energy}) \\ \mathrm{d}h = C_\mathrm{p}\mathrm{d}T \Leftrightarrow \int_{h_1}^{h_2} \mathrm{d}h = \int_{T_1}^{T_2} C_\mathrm{p}\mathrm{d}T \Rightarrow \Delta h = C_\mathrm{p}\Delta T & (\text{enthalpy}) \end{cases} \quad \text{Eq. (9.5)}$$

- Common assumptions:
  - **Adiabatic process:** No heat transfer
  - **Isentropic process:** No losses (no entropy changes $\Delta s = 0$)

$$\rightarrow \frac{p_2}{p_1} = \left(\frac{T_2}{T_1}\right)^{\gamma/(\gamma-1)} = \left(\frac{\rho_2}{\rho_1}\right)^{\gamma} \quad \text{Eq. (9.9)}$$

Exercise 16.

- Total/stagnation properties
  - Isentropic (imaginary) retardation of the flow velocity

$$\begin{cases} p_0 = p + \frac{\rho V^2}{2} & \\ h_0 = h + \frac{V^2}{2} & \text{Eq. (9.22)} \\ T_0 = T + \frac{V^2}{2C_\mathrm{p}} & \text{Eq. (9.23)} \end{cases}$$

- Can rewrite the total properties to (isentropic) Mach number relations

$\frac{T_0}{T} = 1 + \frac{1}{2}(\gamma - 1)\mathrm{Ma}^2$ Eq. (9.26), with

$\frac{p_0}{p} = \left(\frac{T_0}{T}\right)^{\gamma/(\gamma-1)}$ Eq. (9.28a), and $\frac{\rho_0}{\rho} = \left(\frac{T_0}{T}\right)^{1/(\gamma-1)}$ Eq. (9.28b)

$M = 2.04$

$M = 2$

$M = +3$

$M = 25$