Isentropic Nozzles

• Apply equations for isentropic flow with area change to nozzles

• Nozzles
  – increases velocity of fluid (no work)
  – converts thermal energy to KE \( (T \rightarrow u) \)

• For conventional (wall-bounded) nozzles, two types:
  – converging \( M \leq 1 \)
  – converging-diverging (CD) \( 0 < M < \infty \)

Converging Nozzles

• Assume choked

• Solution of VI.17 (\( M \) \( v. \) \( A/A^* \))
  VI.6-8 (\( T/T_o \), \( p/p_o \), \( \rho/\rho_o \) \( v. \) \( M \))

• Large change in pressure and density as approach throat

\[ \gamma = 1.4 \]
Converging Nozzle and Back Pressure

- What determines whether flow gets choked (goes sonic)?
  - Back pressure \( (p_o/p_b) \)
    - pressure is “driving force”,
    - e.g., if \( p_o = p_b \), no flow
- What happens as we lower \( p_b \) (initially = \( p_o \))
- Mach # at exit keeps rising until flow is choked (\( M_e = 1 \))
  - \( p_e = p^* \), max. mass flow rate

Critical Back Pressure

- What is \( p_b/p_o \) required to go sonic?
  - \( p_b/p_o = p^*/p_o \)
  - \( \frac{p_o}{p} = \left(1 + \frac{\gamma-1}{2}M^2\right)^{\gamma-1} \) (from VI.7)
  - \( \frac{p^*}{p_o} = \left(1 + \frac{\gamma-1}{2} \right)^{\gamma-1} \)
  - \( \frac{p^*}{p_o} = \left(\frac{2}{\gamma+1}\right)^{\gamma-1} \) (VI.20)
    \[
    \begin{array}{c|c|c|c}
    \gamma & 5/3 & 1.4 & 1.3 \\
    \hline
    p^*/p_o & 0.487 & 0.528 & 0.546
    \end{array}
    \]
Converging-Diverging Nozzles

- Assume choked
- Solution of VI.17 (M v. A/A*)
  VI.6-8 (T/T₀, p/p₀, ρ/ρ₀ v. M)
- Very large change in pressure and density

CD Nozzle and Back Pressure

- What happens as we lower p_b (initially =p₀)?
- Mₑ keeps rising until flow is choked (M₁=1)
  – still subsonic at exit
- If lower p_b enough, can get isentropic Mₑ>1 solution
- p_b in between, get nonisentropic flow