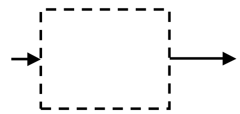
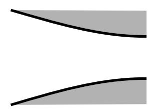
Isentropic Nozzles

- Apply equations for isentropic flow with area change to nozzles
- **Nozzles**
  - increases velocity of fluid (no work)
  - converts thermal energy to KE (T→u)

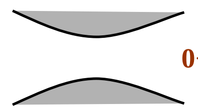


- For conventional (wall-bounded) nozzles, two types:
  - converging



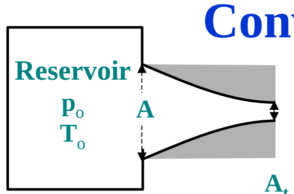
M≤1

  - converging-diverging (CD)

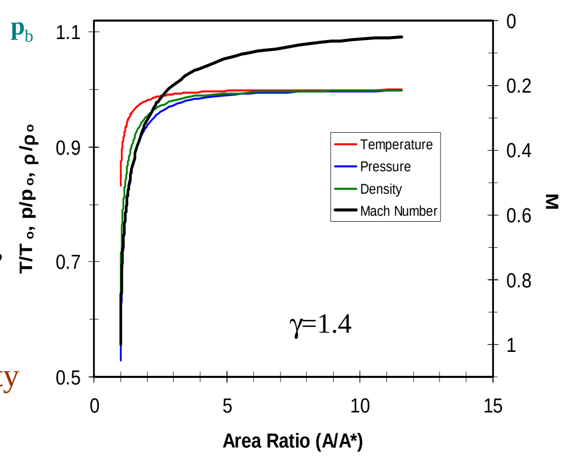


0<M<∞

Converging Nozzles



- Assume choked
- Solution of VI.17 (M v. A/A*) VI.6-8 (T/T_o, p/p_o, ρ/ρ_o v. M)
- Large change in pressure and density as approach throat



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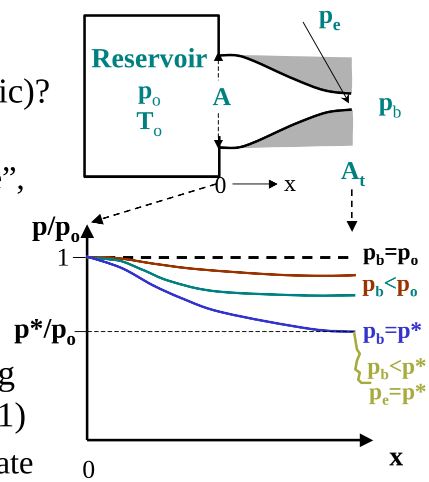
Converging Nozzle and Back Pressure

- What determines whether flow get 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



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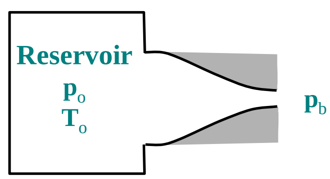
Critical Back Pressure

- What is p_b/p_o required to go sonic?
  – p_b/p_o = $\mathbf{p^*/p_o}$

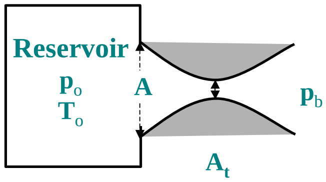


$$\frac{p_o}{p}=\left(1+\frac{\gamma-1}{2}M^2\right)^{\gamma/\gamma-1} \quad \text{(from VI.7)}$$

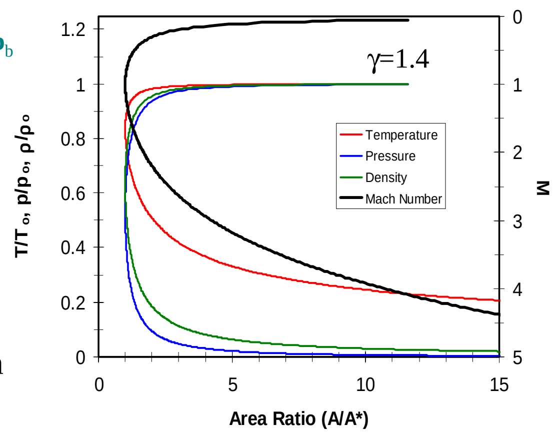
$$\frac{p^*}{p_o}=1\Big/\left(1+\frac{\gamma-1}{2}1^2\right)^{\gamma/\gamma-1}$$

$$\frac{p^*}{p_o}=\left(\frac{2}{\gamma+1}\right)^{\gamma/\gamma-1} \quad \textbf{(VI.20)} \quad =\begin{cases}0.487 & \gamma=5/3\\ 0.528 & \gamma=1.4\\ 0.546 & \gamma=1.3\end{cases}$$

Converging-Diverging Nozzles



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



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CD Nozzle and Back Pressure

- What happens as we lower p_b (initially $=p_o$)?
- M_e keeps rising until flow is choked (M_t=1)
  - **still subsonic at exit**
- If lower p_b enough, can get isentropic M_e>1 solution
- p_b in between, get **nonisentropic flow**