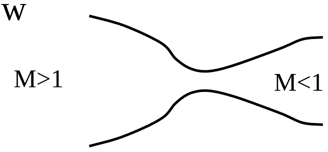
Supersonic (Engine) Inlets

- For air-breathing engines on supersonic vehicles, usually want to slow flow down to subsonic speeds inside engine
  - – need diffuser (M>1→M<1) for engine inlet
  - – exception: supersonic combustion (e.g., SCRAM jets)
- Goal
  - – lowest p_o loss (highest thrust)
    - given flight M
    - mass flow rate requirement (thrust)
    - stable operation (nothing drastic for small changes in flight conditions)

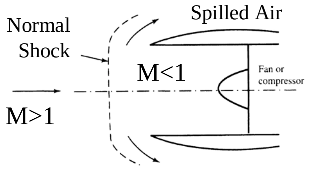
CD Inlet



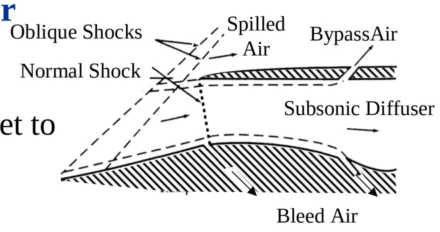
- Can get close to isentropic flow
  - – lowest potential p_o loss
  - – starting problem (like supersonic wind tunnel, have to swallow shock)
  - – most cases requires variable area throat (heavy, complex)
  - – stability problem: if "shock" leaves throat, can exit engine lowering mass flow (higher A_2^*)
- **Not typically used**

Shock Inlets

- **Normal shock diffuser**
  - simple, diverging section preceded by normal shock
  - highest p_o loss (strong shock)



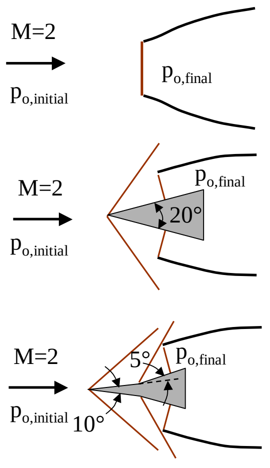
- **Oblique Shock Diffuser**
  - oblique shock(s) followed by normal shock at (or inside) inlet to subsonic diffuser
  - lower p_o loss
  - works for range of M



Example: Normal v. Oblique Diffusers

- **Given:** You need to pick a diffuser for Mach 2 flight conditions. Your choices are a normal shock diffuser and 2 different oblique shock diffusers
- **Find:**

  Stagnation pressure loss for each ($p_{o,final}/p_{o,initial}$)
- **Assume:** air is TPG/CPG with γ=1.4, steady, adiabatic, no work, inviscid except for shock,….



Solution: Normal v. Oblique Diffusers

- **Analysis:**
  - **Normal Shock Diffuser**

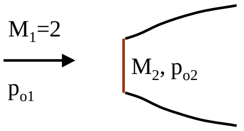
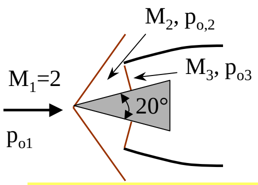


Table B.1 or VII.11,13

$$M_1 = 2 \Rightarrow M_2 = 0.577,\ p_{o2}/p_{o1} = 0.721$$

  - **Single Oblique Shock (+Normal)**



VII.26 or C.1

$$M_1 = 2, \delta = 10^\circ \Rightarrow \theta = 39.3^\circ$$

$$M_{1n} = M_1 \sin\theta = 2\sin 39.3^\circ = 1.267$$

B.1 or VII.11,13 $\Rightarrow M_{2n} = 0.803;\ p_{o2}/p_{o1} = 0.985$

$$M_2 = M_{2n}/\sin(\theta - \delta) = 1.64$$

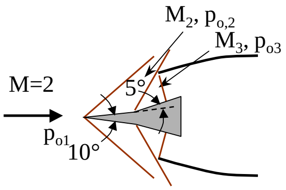
B.1 or VII.11,13 $\Rightarrow M_3 = 0.657; p_{o3}/p_{o2} = 0.880$

$$\frac{p_{o3}}{p_{o1}} = \frac{p_{o3}}{p_{o2}}\frac{p_{o2}}{p_{o1}} = 0.867$$

normal shock inlet - 28% p_o loss
oblique shock inlet - 13.3% p_o !!!

Solution: Normal v. Oblique Diffusers

- **Analysis: (con't)**
  - **Two 5° Turns (+Normal Shock)**



VII.26 or C.1

$$M_1 = 2, \delta_1 = 5^\circ \Rightarrow \theta_1 = 34.3^\circ$$

$$M_{1n} = M_1 \sin\theta_1 = 2\sin 34.3^\circ = 1.127$$

B.1 or VII.11,13 $\Rightarrow M_{2n} = 0.891;\ p_{o2}/p_{o1} = 0.998$

$$M_2 = M_{2n}/\sin(\theta_1 - \delta_1) = 1.82$$

VII.26orC.1 $M_2 = 1.82, \delta_2 = 5^\circ \Rightarrow \theta_2 = 37.9^\circ$

$$M_{2n} = M_2 \sin\theta_2 = 1.82\sin 38.0^\circ = 1.120$$

B.1 or VII.11,13 $\Rightarrow M_{3n} = 0.897;\ p_{o2}/p_{o1} = 0.998$

$$M_3 = M_{3n}/\sin(\theta_2 - \delta_2) = 1.65$$

B.1or VII.11,13 $\Rightarrow M_3 = 0.654; p_{o4}/p_{o3} = 0.8765$

$$\frac{p_{o4}}{p_{o1}} = \frac{p_{o4}}{p_{o3}}\frac{p_{o3}}{p_{o2}}\frac{p_{o2}}{p_{o1}} = 0.873$$

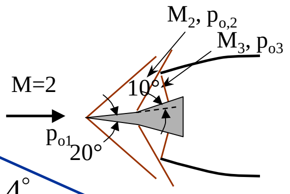
double obl. shock inlet
~ 12.7% p_o loss

Double Oblique Inlet - Advantages

- So for M=2, same total turning angle (10°)
  - two oblique shocks slightly better than one (12.7% v. 13.3% p_o loss)
  - significant improvement over normal shock alone (28% p_o loss)
- Oblique shock diffuser with two 10° turns (total δ of 20°) even better
  - only 4.3% p_o loss (solution shown on next slide)
  - so larger overall deflection can give better p_o
- Stagnation pressure advantages of using multiple oblique shocks increase with higher M

Double Oblique Shock Diffuser

- **Two 10° Turns (+Normal Shock)**



from previous results for 10° turn

$$M_1 = 2, \delta = 10^\circ \Rightarrow \theta_1 = 34.3^\circ$$

$$M_2 = 1.64;\ p_{o2}/p_{o1} = 0.985$$

VII.26 or C.1 $M_2 = 1.64, \delta_2 = 10^\circ \Rightarrow \theta_2 = 49.4^\circ$

$$M_{2n} = M_2 \sin\theta_2 = 1.64 \sin 49.4^\circ = 1.245$$

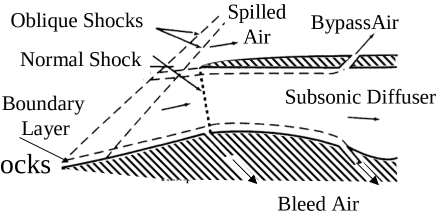
B.1 or VII.11,13 $\Rightarrow M_{3n} = 0.815;\ p_{o2}/p_{o1} = 0.988$

$$M_3 = M_{3n}/\sin(\theta_2 - \delta_2) = 1.28$$

B.1 or VII.11,13 $\Rightarrow M_3 = 0.796;\ p_{o4}/p_{o3} = 0.983$

$$\frac{p_{o4}}{p_{o1}} = \frac{p_{o4}}{p_{o3}}\frac{p_{o3}}{p_{o2}}\frac{p_{o2}}{p_{o1}} = 0.957$$

Double Oblique Inlet - Disadvantages



- **Flow separation**
  - since p increases across oblique shocks, the flow sees adverse p gradient
  - so more or bigger oblique shocks (or longer external ramp), the greater the chance the boundary layer will separate
    - ⇒major change in flowfield, large losses (p_o and mass flowrate)
- **Internal Turn Angle**
  - larger total external turn angle showed less p_o loss
  - larger external flow turning requires larger inlet
  - also requires larger internal flow turning to get flow back to horizontal