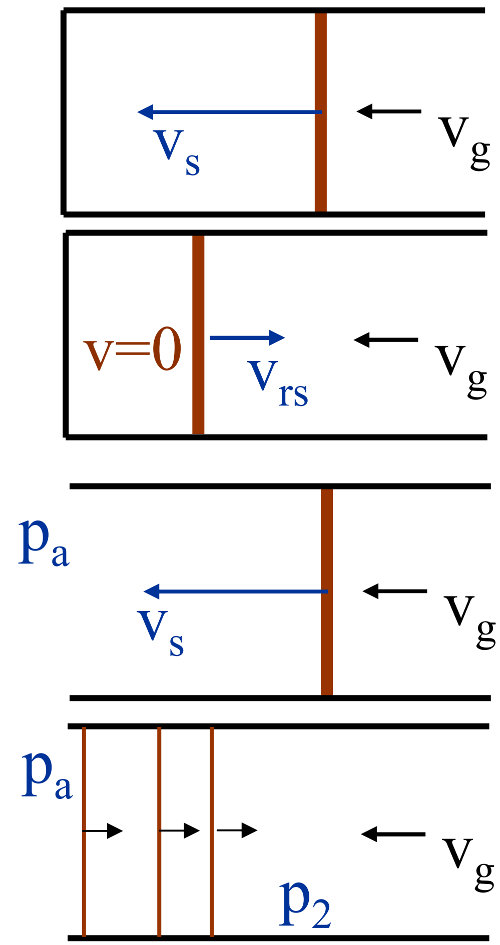
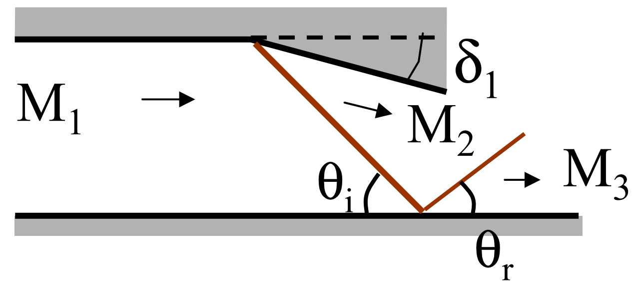
Reflected Waves

- Already examined what happens when normal shock "hits" a boundary
  - if incident shock hits solid wall, get reflected (normal) shock - required to satisfy velocity (**bc**) boundary condition (v=0)
  - if it hits open end, get reflected expansion waves - satisfy pressure bc ($p=p_a<p_2$)
- Wave reflections "impose" bc (pressure or velocity) on flow



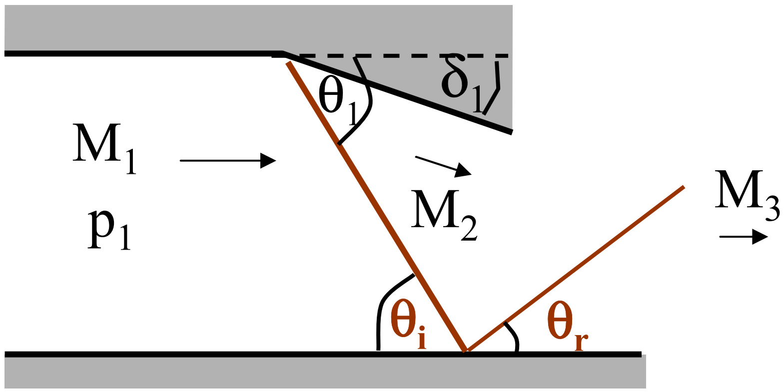
Oblique Shock Reflection From Wall



- Consider "weak" (M_2>1) oblique shock wave impinging on a flat wall
  - incident shock wave turns flow toward the lower wall
  - flow can not pass through boundary, must turn back parallel to lower wall - velocity boundary condition
  - flow turns back on itself ⇒ compression ⇒in this case, **reflected** wave is **oblique shock**

- Reflected shock weaker than incident shock
  - M_2<M_1

Example: Oblique Shock Reflection

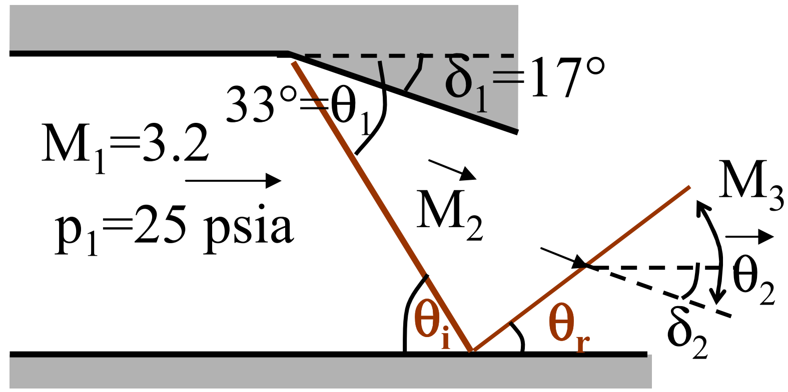


- **Given:** Mach 3.2 flow with static pressure of 25 psia approaching a 17° (δ_1) turn produces oblique shock wave at 33° (θ_1). Oblique shock then "hits" bottom wall, producing reflected oblique shock.
- **Find:**

  θ_i, θ_r, M_2, M_3, p_2, p_3

- **Assume:** TPG/CPG with γ=1.4, steady, adiabatic, no work, inviscid except shocks, ….

Example Oblique Shock Reflection



- **Analysis:**
  - **θ_i** $\quad \theta_i = \theta_1 = 33^\circ$
  - **M_2, p_2**

$$M_{1n} = M_1 \sin\theta_i = 3.2\sin(33^\circ) = 1.742$$

with M_{1n}, B.1 or eqs. $\Rightarrow M_{2n} = 0.630; p_2/p_1 = 3.37$

$$M_2 = M_{2n}/\sin(\theta_i - \delta) = 0.630/\sin(16^\circ) = 2.29 \qquad p_2 = \frac{p_2}{p_1}p_1 = 84.3\,\text{psia}$$

  - **θ_r** $\quad \theta_r = \theta_2 - \delta_2$ **flow must be turned horizontal again, so δ_2=δ_1 =17°**

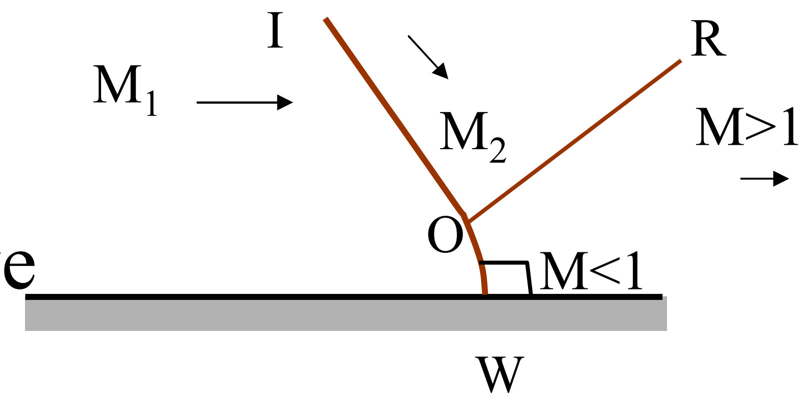
M_2=2.29, C.1 or VII.26 $\Rightarrow \theta_2 = 42.2^\circ; \theta_r = 42.2^\circ - 17^\circ = 25.2^\circ \quad \neq \theta_i$

  - **M_3, p_3** $\quad M_{2n} = M_2 \sin\theta_2 = 2.29\sin(42.2^\circ) = 1.54$

with M_{2n}, B.1 or eqs. $\Rightarrow M_{3n} = 0.688; p_3/p_2 = 2.59$

$$M_3 = 0.688/\sin 25.2^\circ = 1.615 \qquad p_3 = 2.59(84.3\,\text{psia}) = 218\,\text{psia}$$

Mach Reflection

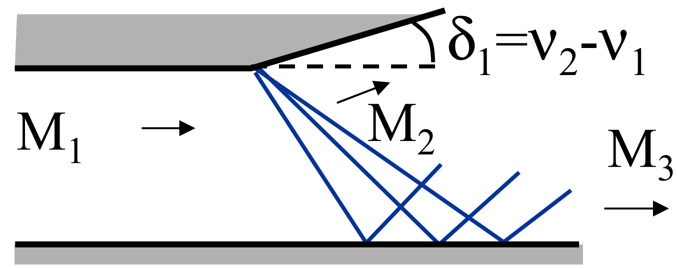


- If M_2 low enough, required turning angle for reflected wave may exceed maximum oblique shock angle
  - no simple reflected wave possible, get something like detached shock
  - IO: incident oblique shock
  - OW: strong curved shock, normal at wall
  - OR: weak oblique shock

Oblique Shock and Pressure BC

- If oblique shock "hits" a pressure boundary condition, reflected wave must adjust flow pressure to match boundary pressure
- Type of reflected wave will depend on whether pressure must drop or rise
  - pressure rise⇒compression: flow will "turn back on itself"
  - pressure drop⇒ expansion: flow will "open up"

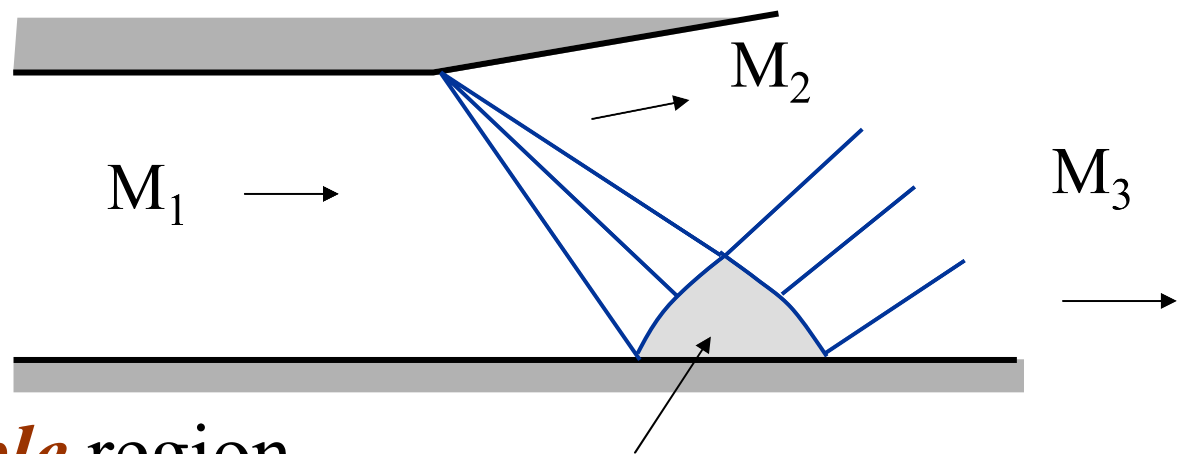
Reflection From Expansion on Wall



- Consider PM fan impinging on a flat wall
  - incident expansion waves tend to turn flow away the lower wall
  - can not create vacuum, flow must be turned back parallel to lower wall - velocity boundary condition
  - flow "opens up"⇒ expansion⇒ in this case, **reflected** waves are **expansions (Mach waves)**
- For case shown above (flow returning to original angle)
  - $\nu_3=\delta_2+\nu_2=\delta_2+(\delta_1+\nu_1)=2\delta+\nu_1$ (use to get M_3)

Non-Simple Region

- In region where incident and reflected waves interact, can not use our simple quasi-1D theory



- In this ***non-simple*** region,
  - get curved waves
  - flow still isentropic
- Outside this region, our quasi-1D methods still valid

Summary of Reflected Waves

- "Reflections" from supersonic waves represent information from a boundary being transmitted into supersonic flow
  - reflections "impose" boundary condition on flow
- Generally, pressure or velocity boundary conditions
- Type of reflected wave will depend on whether compression or expansion is needed to meet boundary conditions