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 \(\Rightarrow\) compression \(\Rightarrow\) 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° ($\delta_1$) turn produces oblique shock wave at 33° ($\theta_1$). Oblique shock then “hits” bottom wall, producing reflected oblique shock.

- **Find:**
  \[ \theta_i, \theta_r, M_2, M_3, p_2, p_3 \]

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

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Reflected Waves -3
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Example Oblique Shock Reflection

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

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

  with $M_{in}$,

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

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

  - $\theta_r \quad \theta_r = \theta_2 - \delta_2$ flow must be turned horizontal again, so $\delta_2 = \delta_1 = 17^\circ$

  $M_2 = 2.29$

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

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

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

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