INTAKES

(Fluid mechanics ⟷ Thermodyn)

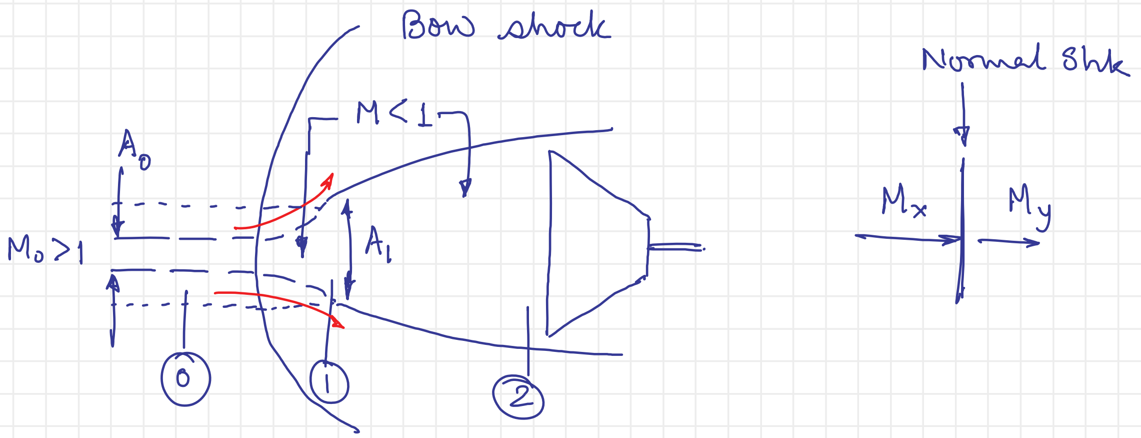
- Function :

  ① Decelerate flow to $M_2 = 0.4 - 0.6$ efficiently
  - ↳ with min losses (max π_d, η_d).
  - ↳ Losses due to wall friction, flow separation and shock waves.

  ② Adequate mass flow rate $\dot{m}_0$
  - ↳ with smallest engine face area (min Drag)
  - ↳ critical for supersonic applications

  ③ Uniform flow at compressor entry
  - ↳ over cross-section and in time

- Normal shock intake :



Supersonic application : $M_0 > 1$

Simplest to analyse $\longrightarrow$ relate gas dyn to Π_d, η_d.

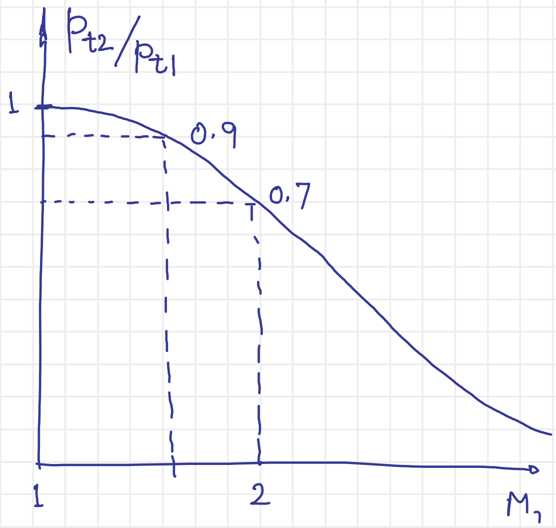
Major loss due to normal shock wave

Normal shock relations :

$$\frac{p_2}{p_1} = 1 + \frac{2\gamma}{\gamma+1}\left(M_1^2 - 1\right)$$

$$M_2^2 = \frac{2 + (\gamma-1) M_1^2}{2\gamma M_1^2 - (\gamma-1)}$$

$$\Rightarrow \frac{p_{t2}}{p_{t1}} = fn\,(M_1)$$



$\rightarrow$ Intake performance :

$$\Pi_d = \frac{p_{t2}}{p_{t0}} \leq \left(\frac{p_{t2}}{p_{t1}}\right)_{N.S.} \quad (\text{friction, etc.})$$

$$\eta_d = \frac{\Pi_d^{\frac{\gamma-1}{\gamma}}\left[1 + \frac{\gamma-1}{2} M_0^2\right] - 1}{\frac{\gamma-1}{2} M_0^2} \quad \text{neglect friction, etc}$$

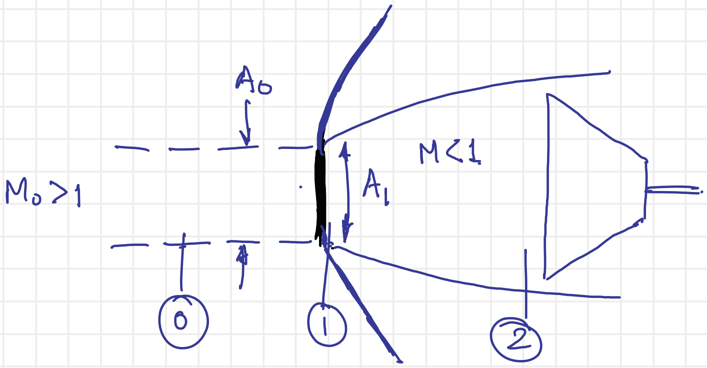
Not preferred beyond $M_0 = 1.6$

$\rightarrow$ Spillage of air $\Rightarrow$ capture area $<$ inlet face area

Only part of the air enters the engine.

Maximum $\dot{m}_0$ when shock at inlet lip.

Minimum A_1 for a required $\dot{m}_0$. $\longrightarrow$ reqd F_{net}.



- <u>External compression inlet</u>:

To reduce tot press loss $\Rightarrow$ increase π_d.

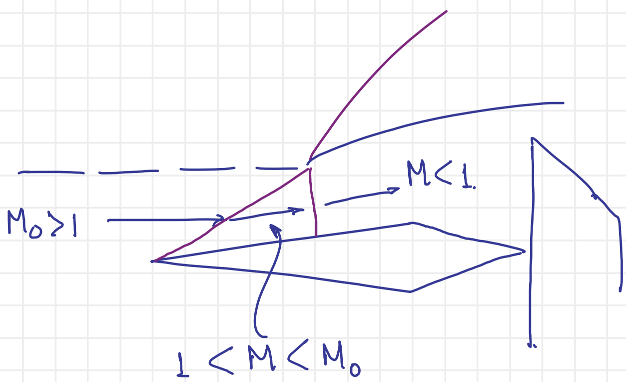
Operate at higher M_0.

Oblq shocks have lower losses than Normal shk.

Introduce (weak) oblique shocks ahead of terminal normal shock.

Reduce strength of normal shock

$M_x \downarrow \;\; \Rightarrow \;\; p_{ty}/p_{tx} \uparrow$



(*)

Back press

$\downarrow$

NS location

$\downarrow$

Effect on π_d

Multiple weak oblique shocks better than a single oblique shock

$\Rightarrow$ Extend idea to infinite number of very weak shock waves

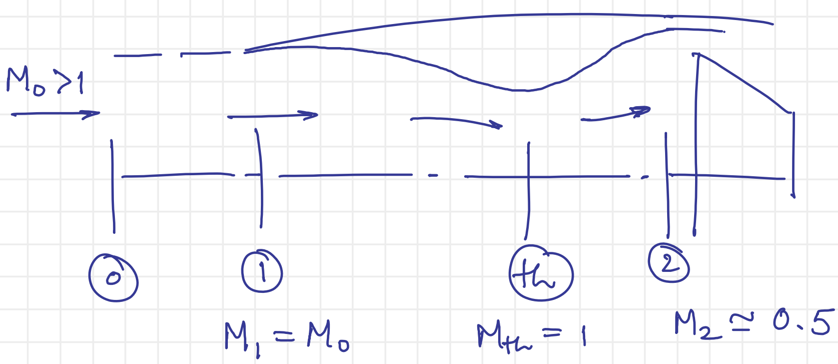
- Isentropic C-D diffuser :

Very gradual turning $\Rightarrow$ weak compression waves (isentropic).

Practically difficult → careful design & fabric.
→ fail at off-design M_0

Good for concepts → throat sizing
→ starting problems
→ off-design operations

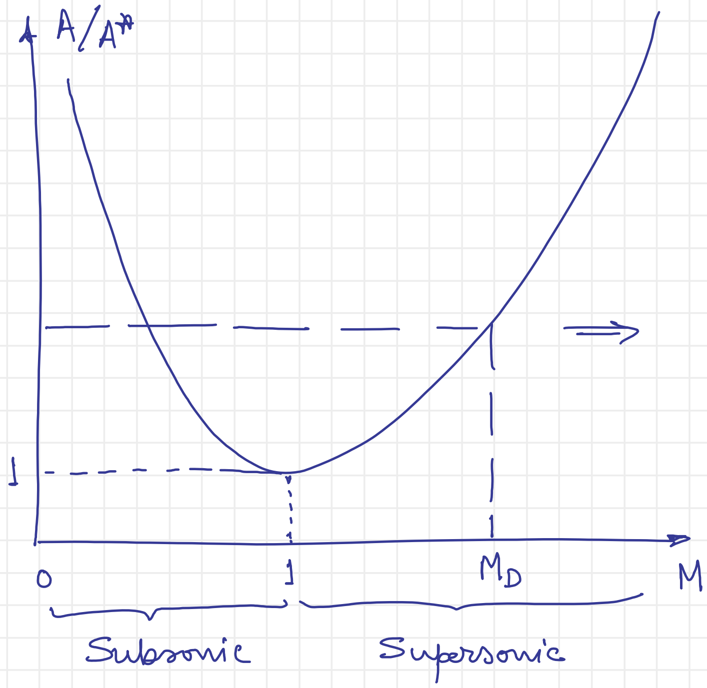
Capture ratio : $A_0/A_1 = 1$.



Assume : Isentropic

$p_t = \text{const}$, $T_t = \text{const}$,

$$\frac{A}{A^*} = \frac{1}{M}\left[\left(\frac{2}{\gamma+1}\right)\left(1+\frac{\gamma-1}{2}M^2\right)\right]^{\frac{\gamma+1}{2(\gamma-1)}}$$



Choosing a design Mach number M_D fixes the area ratio A_1/A_{th}

Knowing the required $\dot{m}_0$ at a given altitude (p_0, T_0, M_0) fixes the inlet face area A_1.

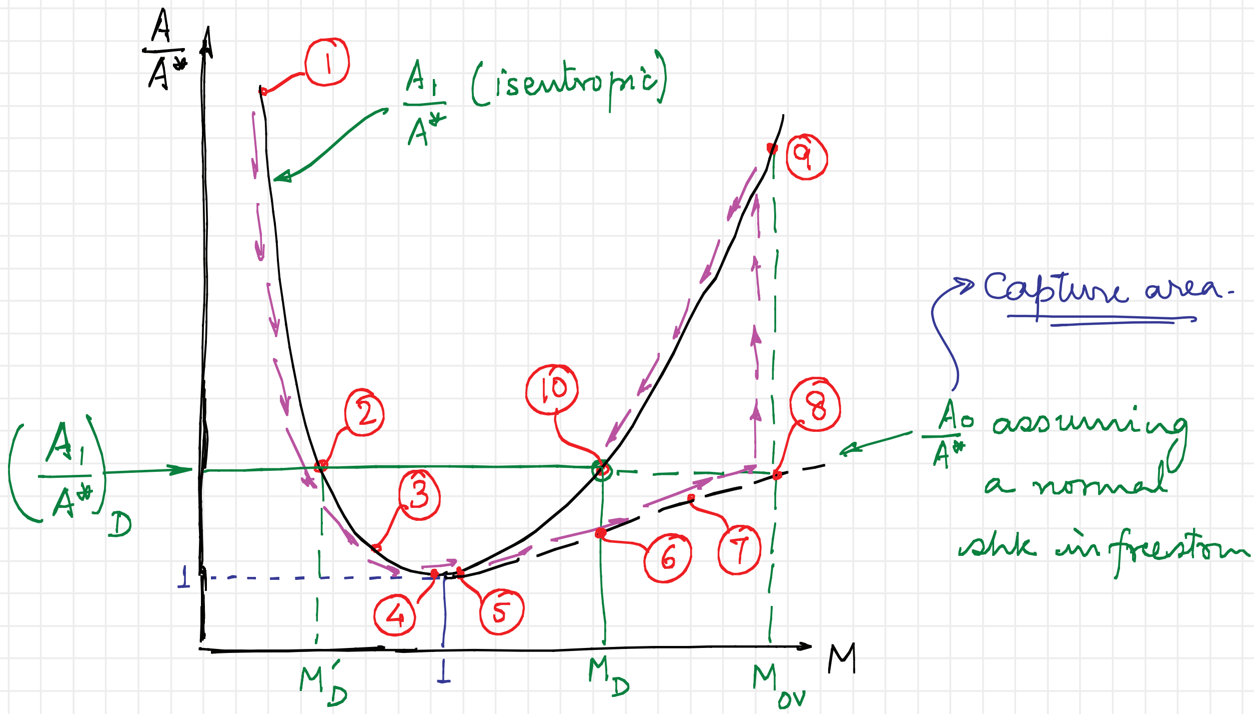
A_{th} can thus be determined, but it will work isentropically for only $M_0 = M_D$ that too once <u>started</u>.

@ $M_0 \neq M_D$: can have shk waves

$\Rightarrow$ unstarted subsonic flow.

Supersonic Intake Starting Problem:

- The intake is designed assuming supersonic flow in convergent part. at $M_0 = M_D$
- Same A_{th} chokes for a subsonic Mach no. also!
  @ $M_0 = M_D'$
- How to establish supersonic flow inside the duct as the vehicle accelerates from 0 to design Mach no.



Dashed curve :

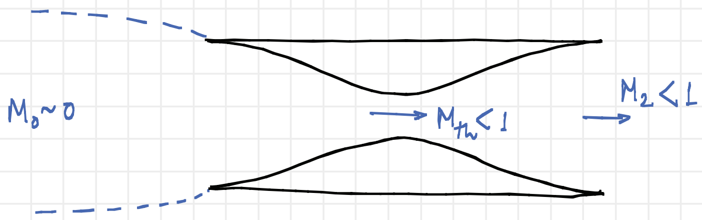
Normal shk $M_2 = fn(M_1)$

Freestrm		Post-shk
5	$\longrightarrow$	4
6	$\longrightarrow$	3
8	$\longrightarrow$	2

Corresponding A/A^*

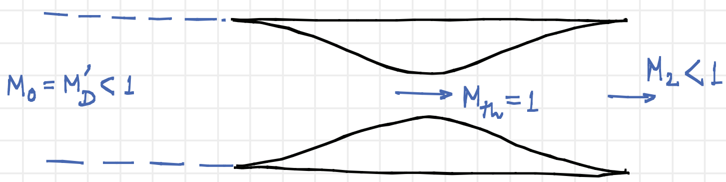
→ Sequence of states :

①



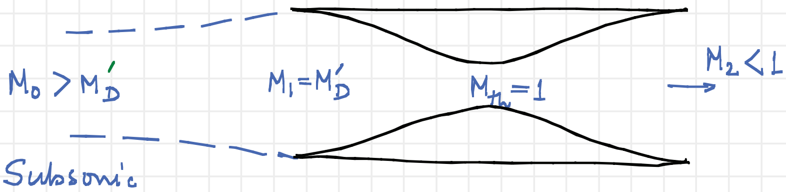
$\frac{A_0}{A_1} > 1$

②



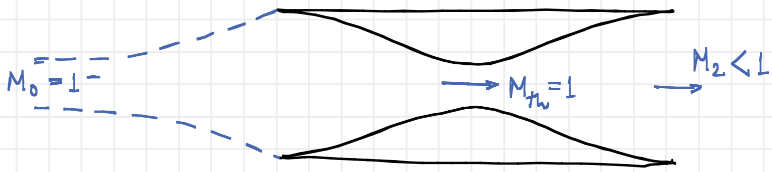
$\frac{A_0}{A_1} = 1$

③



$\frac{A_0}{A_1} < 1$

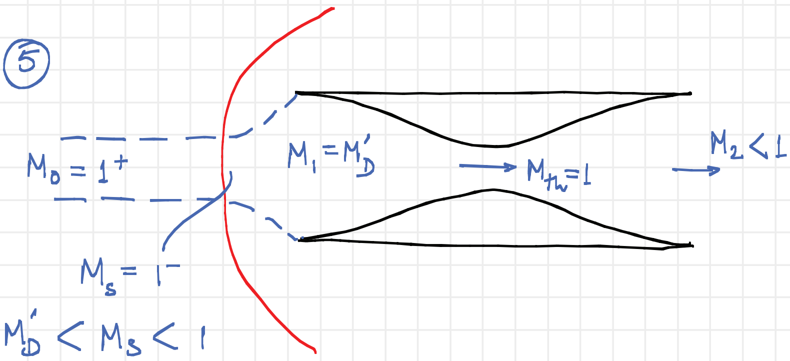
④



$\frac{A_0}{A_1} < 1$

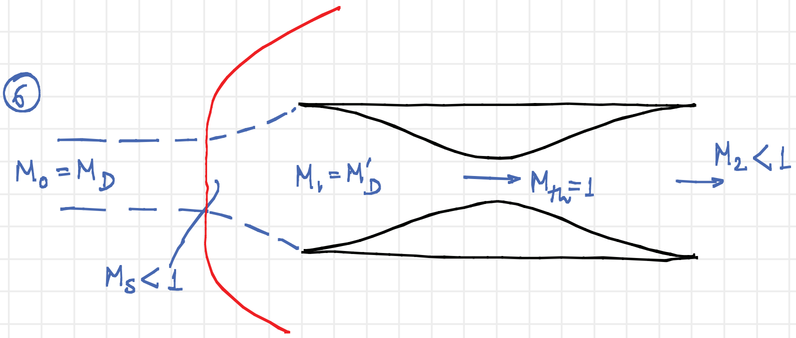
$\frac{A_0}{A_{th}} = 1$

⑤



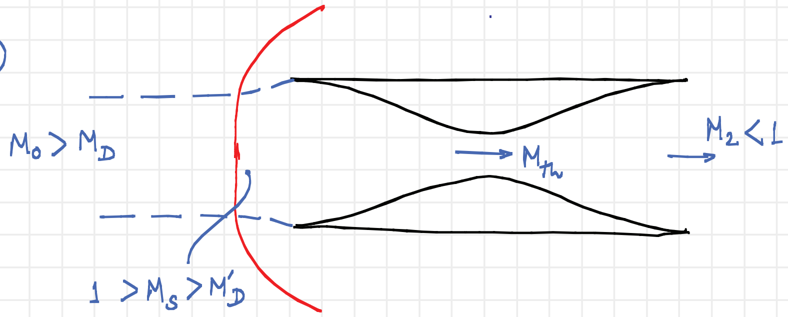
$\frac{A_0}{A_1} = 1^-$

6



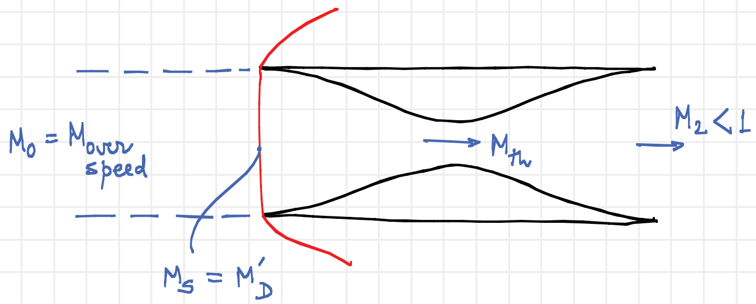
$\frac{A_0}{A_1} < 1$

7



Shock closer to inlet face

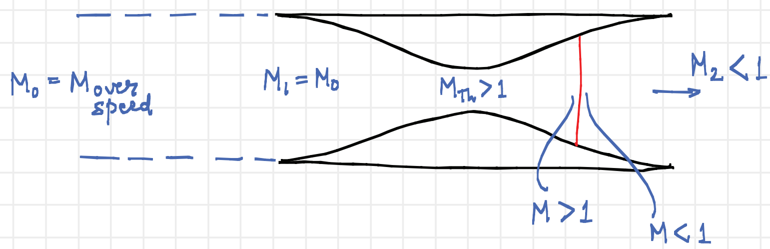
8



$\frac{A_0}{A_1} = 1$

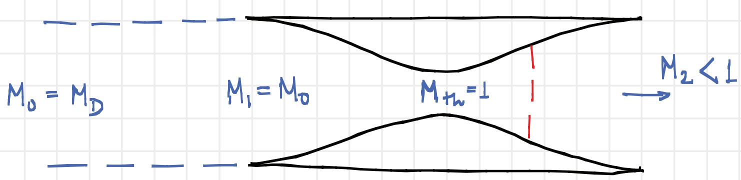
Shock at inlet face.

9



$\frac{A_0}{A_1} = 1$

10

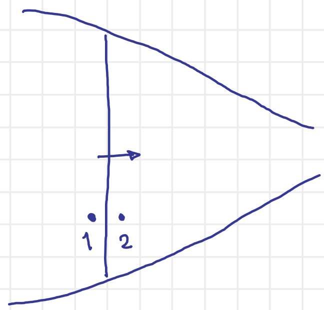


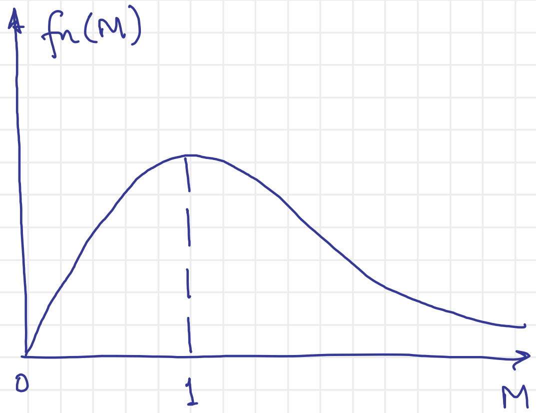
Shock possible depending on back pressure

- Shock unstable in a convergent duct:

$$\dot{m} = \sqrt{\frac{\gamma}{R}}\,\frac{p_t}{\sqrt{T_t}}\,A\,\underbrace{M\left[1+\frac{\gamma-1}{2}M^2\right]^{-\frac{(\gamma+1)}{2(\gamma-1)}}}$$

$$\frac{\dot{m}}{A} = \sqrt{\frac{\gamma}{R}}\,\frac{p_t}{\sqrt{T_t}}\,fn(M)$$





Small displacement of shk towards the throat

$M \downarrow \Rightarrow$ weaker shk $\Rightarrow \Delta p_t \downarrow \Rightarrow p_{t2} \uparrow$

also $fn(M) \uparrow \Rightarrow \frac{\dot{m}}{A} \uparrow$

$\Rightarrow$ Easier for the mass of air to go through throat

$\Rightarrow$ Shock gets sucked towards the throat.
and stands in the <u>divergent</u> part of inlet.

Shock location adjusts to match back pressure

$\longrightarrow$ Optimal location $\rightarrow$ just downstream of throat.

- Engine thrust : $F_{net} \propto \dot{m}_0 \propto \rho_0 A_1 V_1 \propto M_1$.

Less than adequate $\dot{m}_0$ for 1, 2, ... 7.

Only @ 8 : $M_1 = M_D'$ and all of A_0 enters engine

Starting strategies :

1. Overspeeding
2. Variable area : change A_{th}
3. Design CD inlet by assuming a normal shock in div section.

$$\cancel{\frac{p_t}{p_t^*}} \frac{A}{A^*} = \frac{1}{M} \left[\left(\frac{2}{\gamma+1} \right) \left(1 + \frac{\gamma-1}{2} M^2 \right) \right]^{\frac{\gamma+1}{2(\gamma-1)}} \quad 3$$

$$(\;)M^{1/3} = (a + bM^2)$$

$$(\;)t = a + bt^6$$