SESA3029 Aerothermodynamics

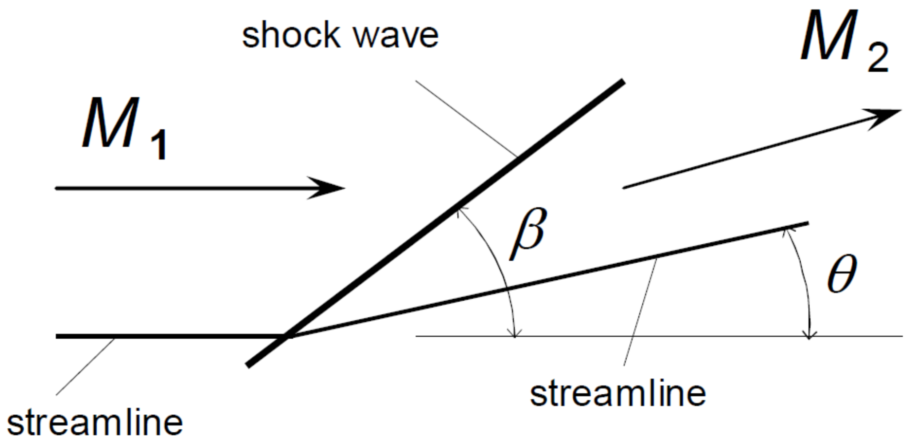
this lecture will explain the slant.

Lecture 2.2

Oblique shock examples, engine intake and detached shocks

APG photo

Oblique shock relation

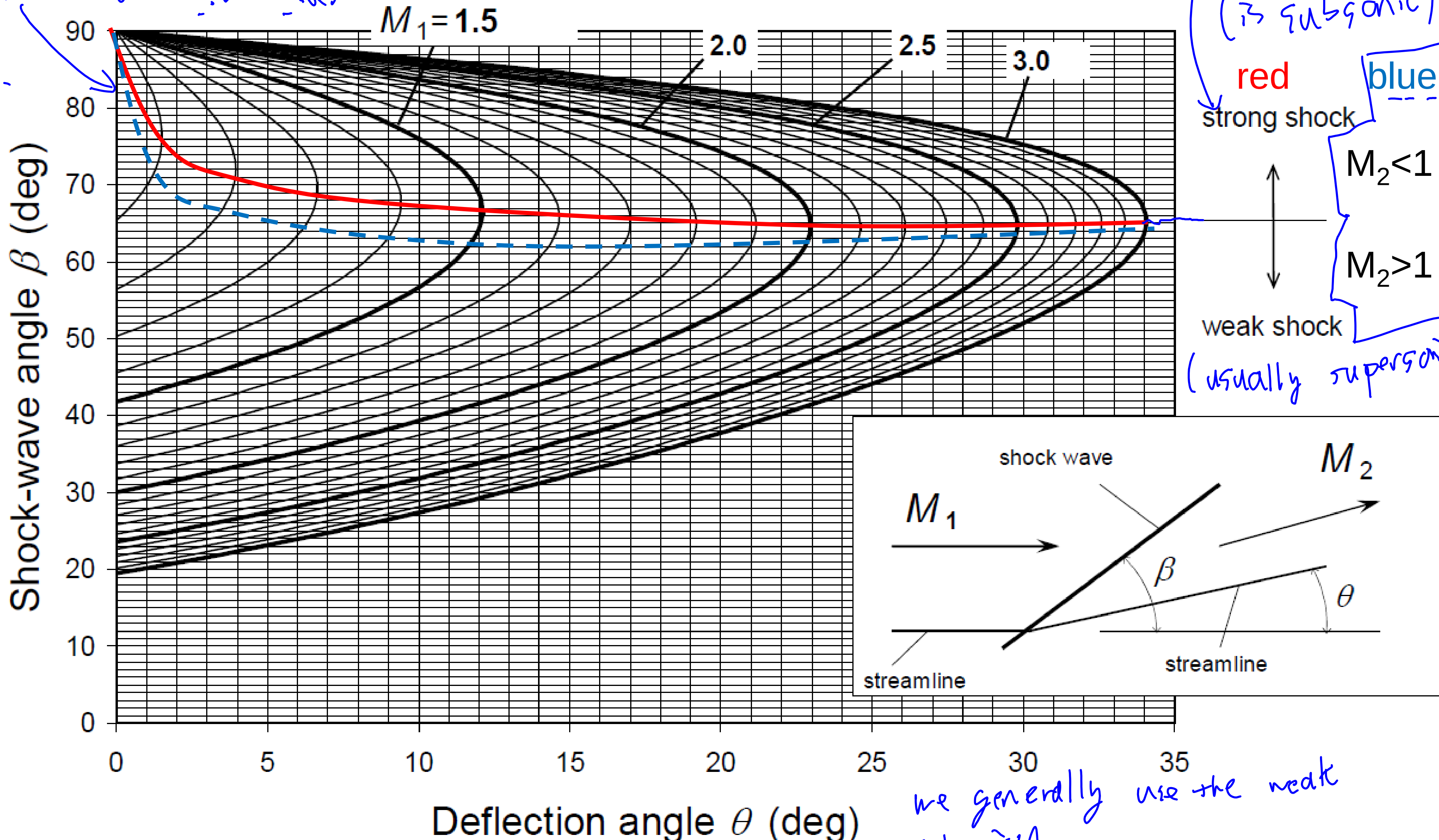


$$\tan\theta = 2\cot\beta\left[\frac{M_1^2\sin^2\beta - 1}{M_1^2\left(\gamma + \cos 2\beta\right) + 2}\right]$$

dot line is where mach number after shock is 1 ∴ below is supersonic ∴ above is subsonic

Oblique-shock chart: $\gamma = 1.4$

in internal flows (compressor/turbine) there can be strong shocks (is subsonic)



(usually supersonic)

we generally use the weak solution.

It is (just) possible to have a weak shock with M_2<1

(barely/rarely)

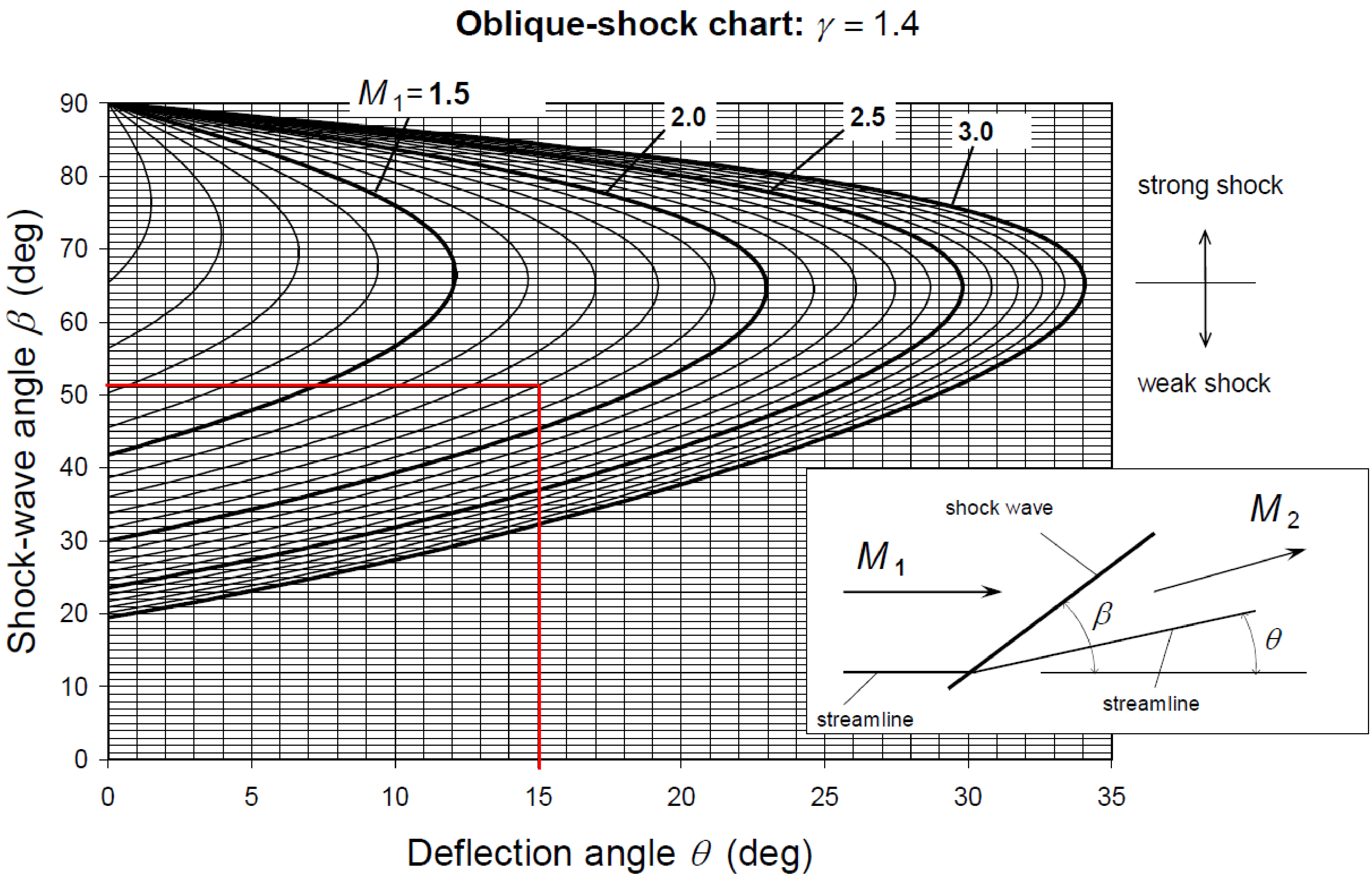
Example

An M_1=1.8 stream is deflected by 15 degrees.

Find

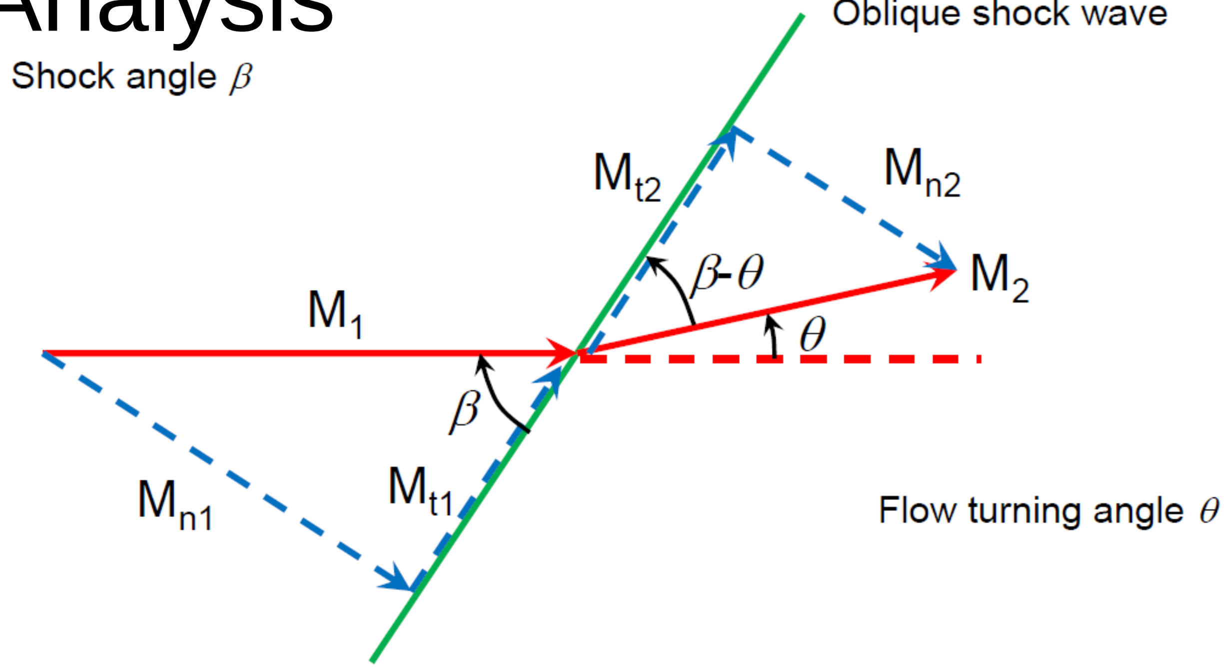
(a) the shock angle (weak solution), and

(b) M_2 (the flow Mach number after the shock)



Shock angle β=51 degrees

Analysis



$$M_{n1} = M_1 \sin \beta$$

$$M_{n2} = M_2 \sin(\beta - \theta)$$

$$M_{n1} = M_1 \sin \beta = 1.8 \sin(51^\circ) = 1.399$$

NST

M_{n1}	M_{n2}	p_2/p_1	ρ_2/ρ_1	T_2/T_1	p_{02}/p_{01}	"p_{02}/p_1"
1.3800	0.7483	2.0551	1.6549	1.2418	0.9630	2.9798
1.4000	0.7397	2.1200	1.6897	1.2547	0.9582	3.0492
1.4200	0.7314	2.1858	1.7243	1.2676	0.9531	3.1198

$$M_2 = \frac{M_{n2}}{\sin(\beta - \theta)} = \frac{0.74}{\sin(51^\circ - 15^\circ)} = 1.259$$

On-line shock calculator gives 51.3° and M_2=1.245

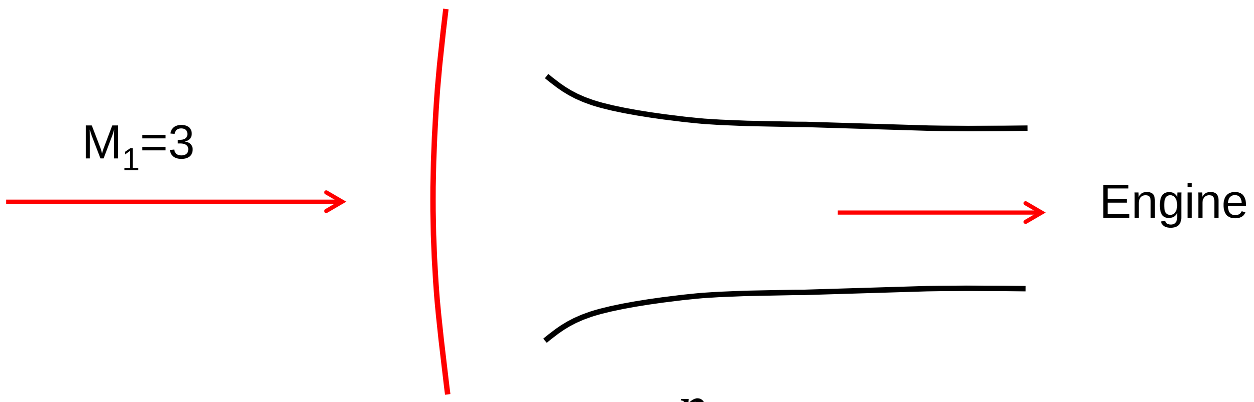
website link on. blackboard

Engine intake design in supersonic flow

We are interested particularly in the reduction ('loss') of stagnation pressure, since this affects the engine performance

(a) Normal shock intake

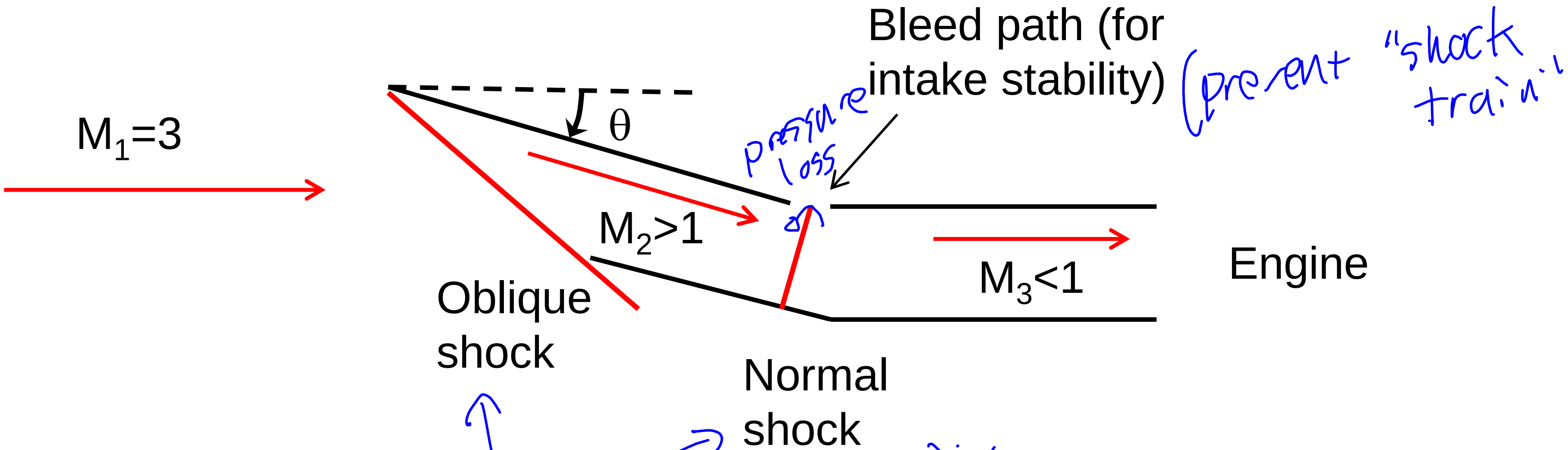
normal shock ∴ entropy



For M_1=3, NST gives $$\frac{p_{02}}{p_{01}} = 0.328$$

i.e. a 67% loss of stagnation pressure

(b) Oblique + normal shock



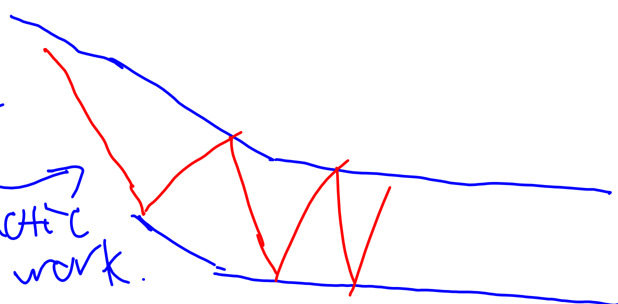
both produce entropy

e.g. take θ=22°

OSC gives β=40°

M_{n1}=3sin40°=1.93

Note that is too chaotic and wouldn't work.



NST gives M_{n2}=0.59, M_2=0.59/sin(40°-22°)=1.91 and p_{02}/p_{01}=0.754

For normal shock NST gives M_3=0.593 and p_{03}/p_{02}=0.762

Total stagnation pressure change

$$\frac{p_{03}}{p_{01}} = 0.754 \times 0.762 = 0.574$$

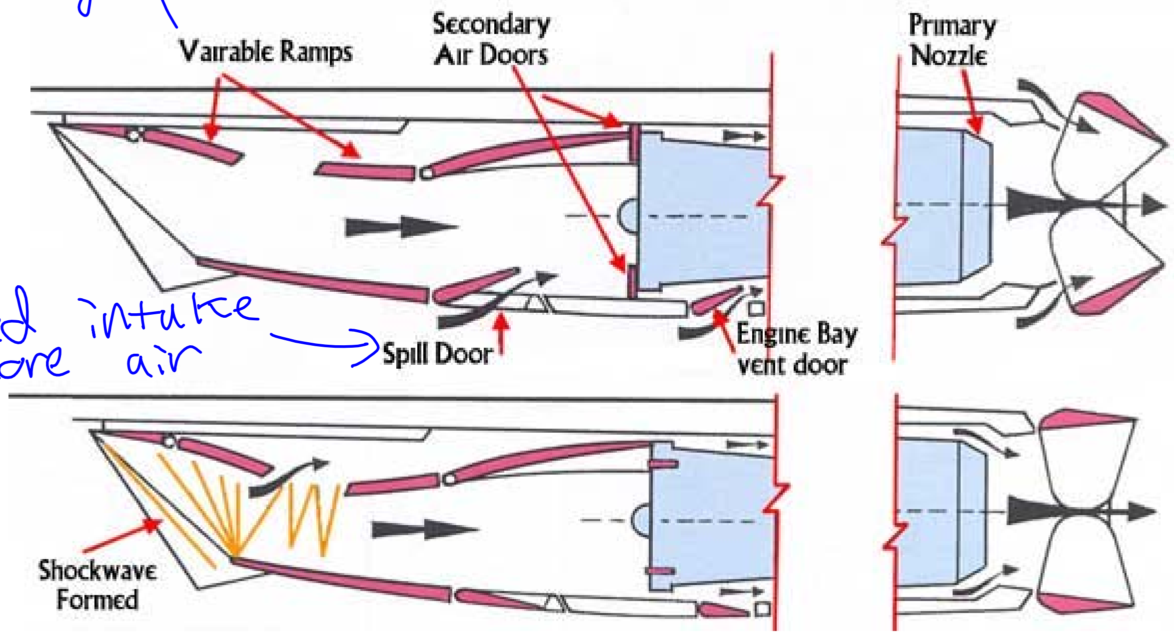
i.e. a 43% loss, compared to 67% for the normal shock intake

We can do better with more oblique shocks: The minimum loss occurs when the stagnation pressure drop across each shock is the same. but more oblique shocks creates new issues

A limiting case is isentropic compression using a curved surface.

Concorde intake

geometry can change



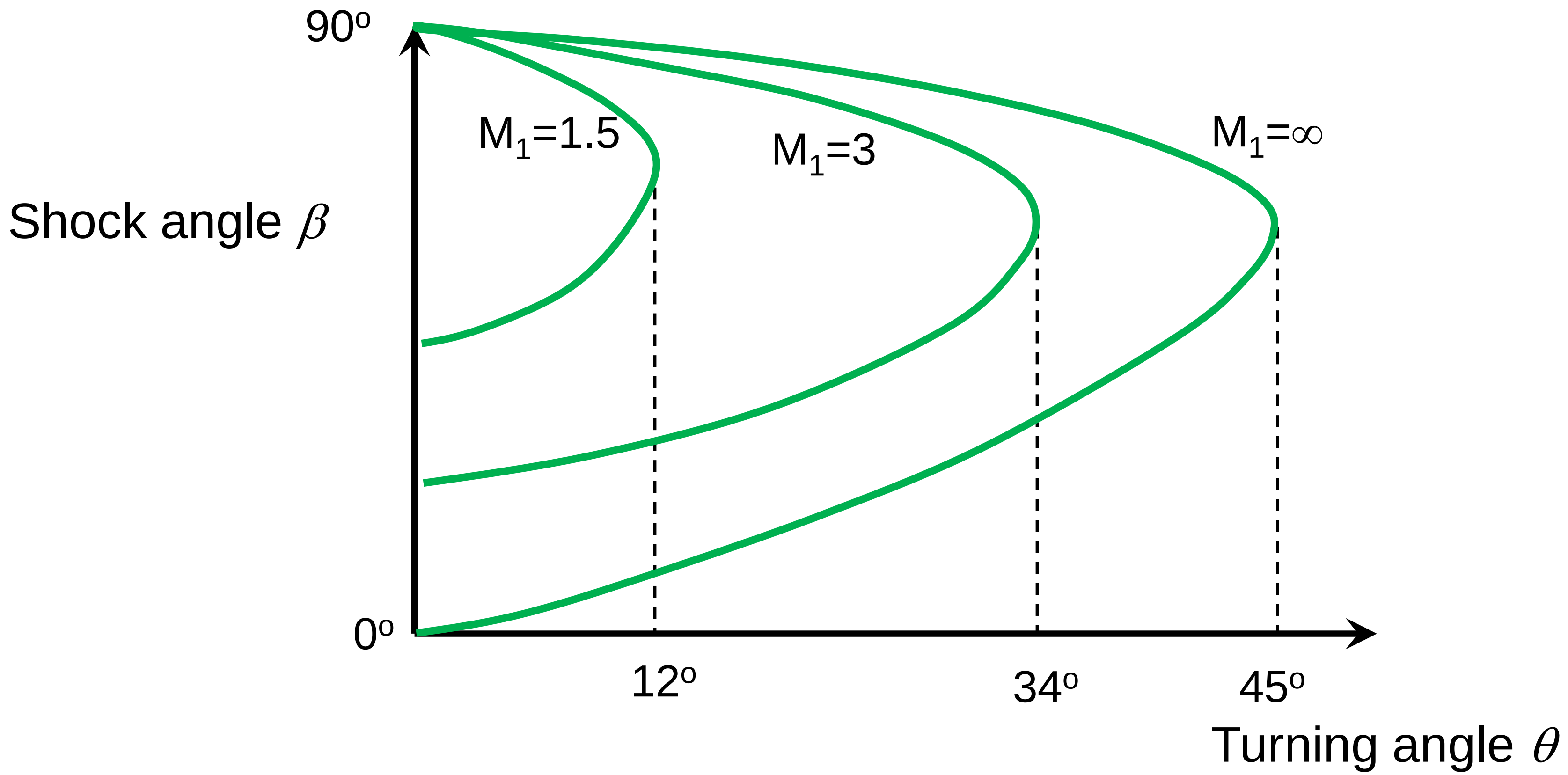
Subsonic operation

increased intake for more air

Supersonic operation

www.concordesst.com

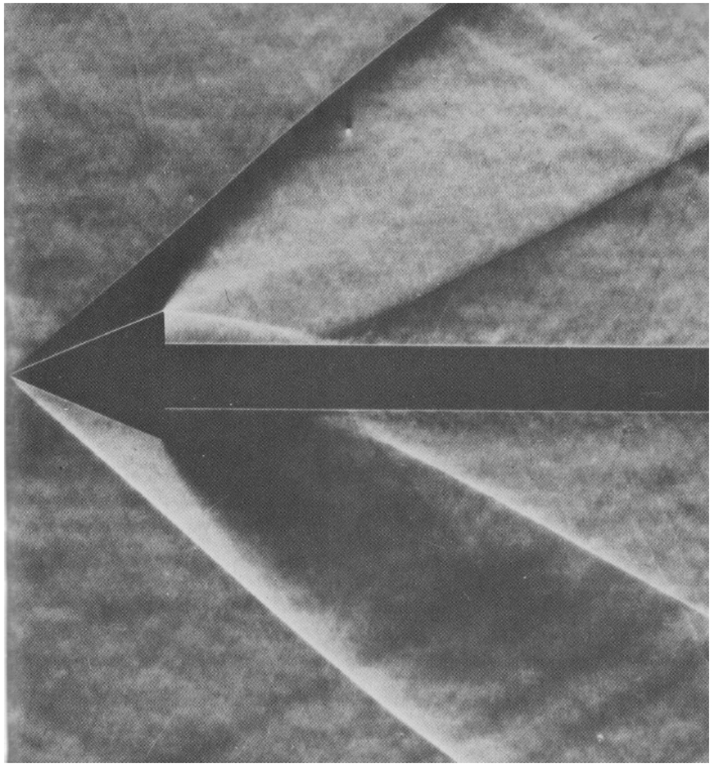
Reminder: Oblique shock chart (γ=1.4, simplified)



- For every M_1 there is a maximum turning angle θ_{max}

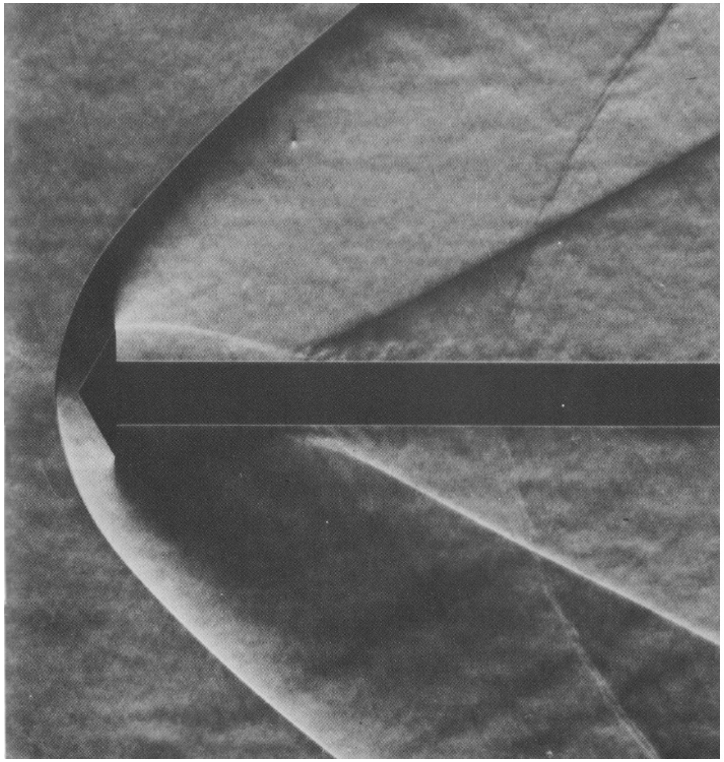
If your turning angle is greater than θ_{max} your shock will detach

M=1.96 flow over a cone



$\theta = 22.5^\circ$

Attached oblique shock

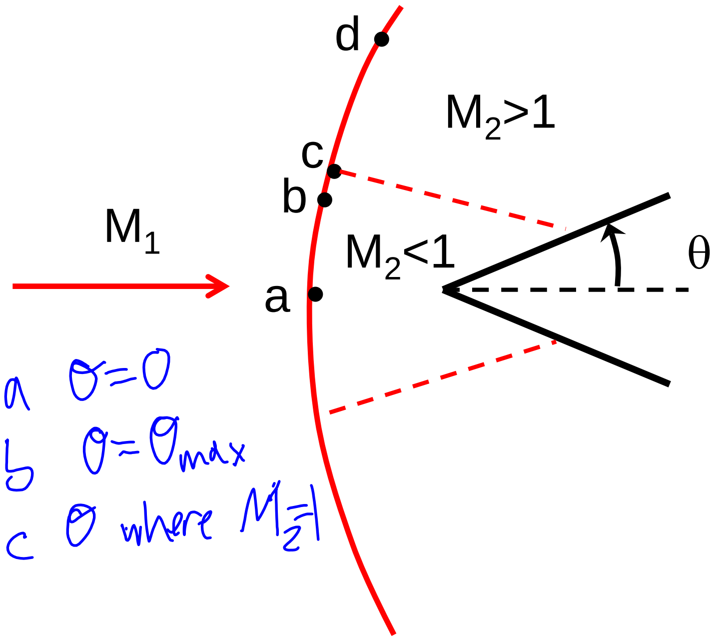


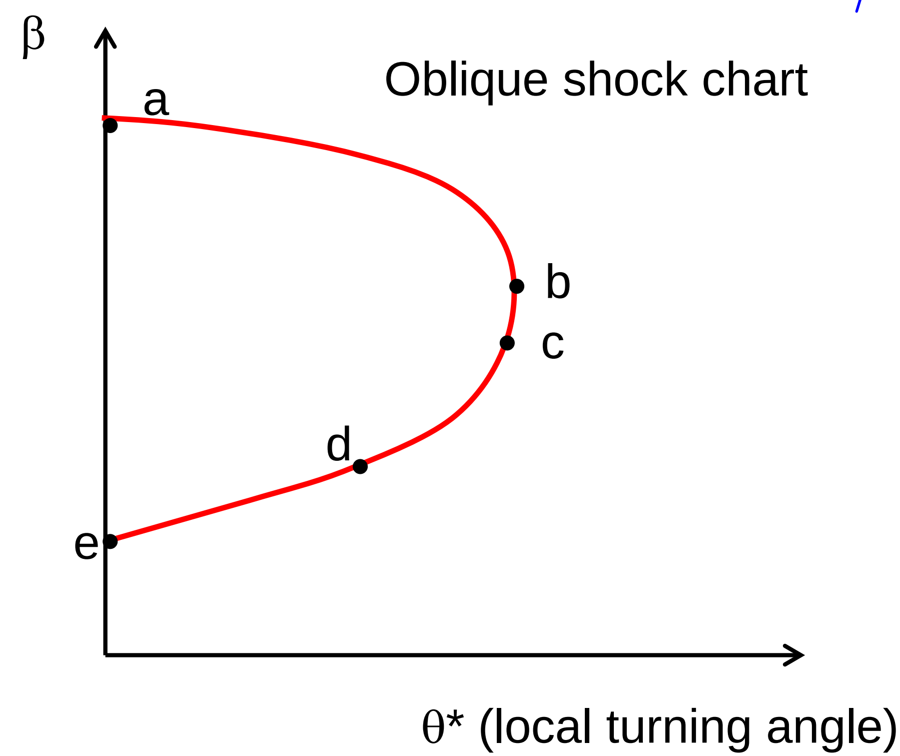
$\theta = 60^\circ$

Detached curved shock

$\theta_{max} \approx 23^\circ$

Flow past a cone or 2D wedge for $\theta > \theta_{max}$ (detached shock)





a: flow through a normal shock wave

b: maximum turning angle

c: limiting case $M_2=1$

d: weak solution

e: Mach wave (far from object)

detached shocks work with many θ solutions hence the curve.