Ramjet/Scramjet/Pulsejet

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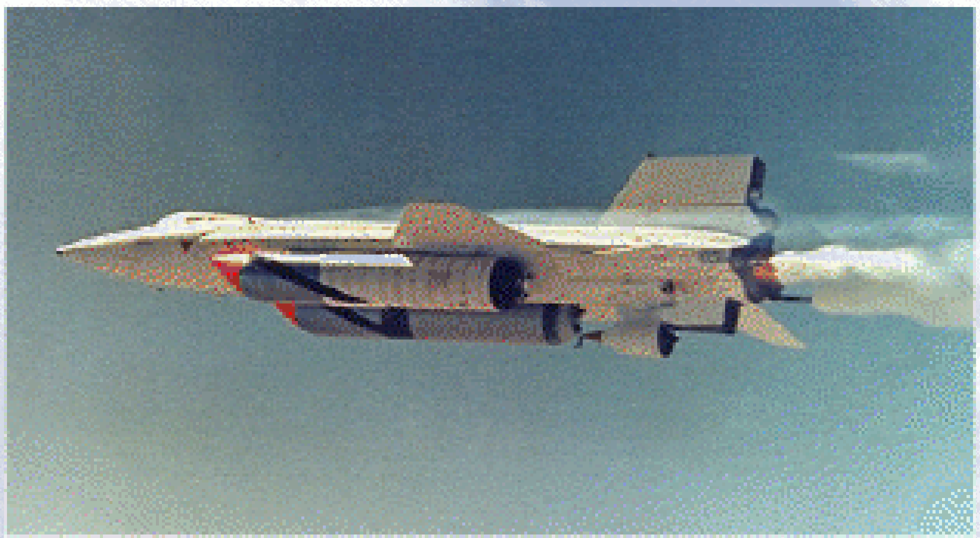
Ramjet Propulsion

Glenn Research Center



X – 15 with ramjet engine

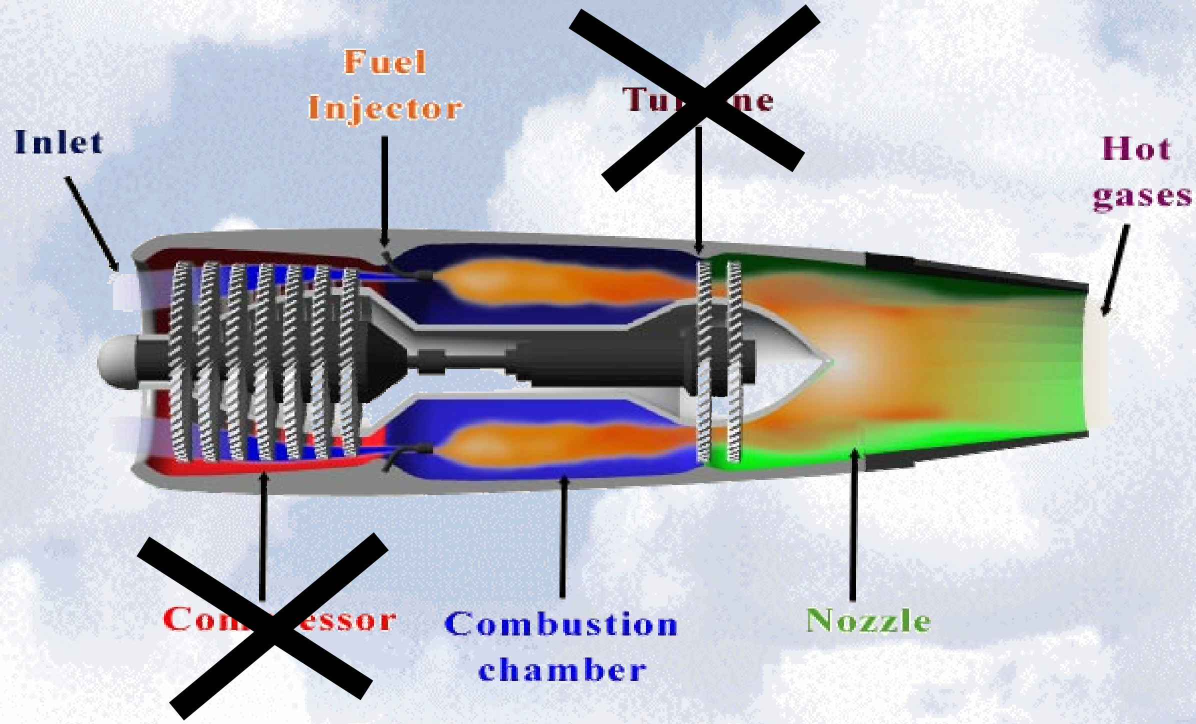
- Uses supersonic diffuser-cone as compressor.

•Basically the same operation as a turbojet

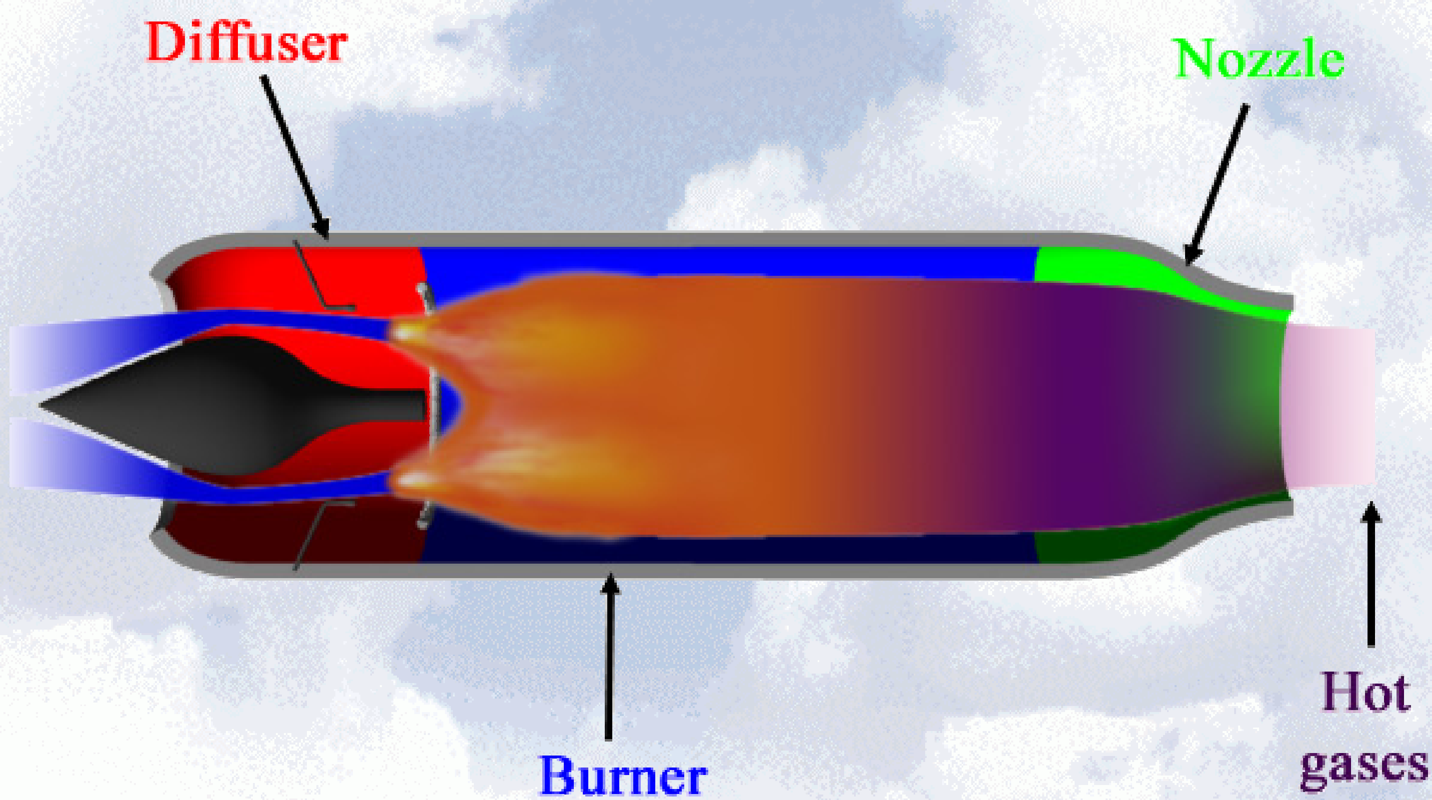
Ramjet test

Working fluid is the surrounding air.

Turbo Jet



Ramjet Components



SCRAMJET

- *"Supersonic Combustion Ramjet"*
- Air in Combustion chamber is still supersonic, rather than subsonic
- Fuel is still injected for ignition, but fuels do not ignite quickly enough
- A workable fuel injection system for the SCRAMJET is still in development.

Pulsejet

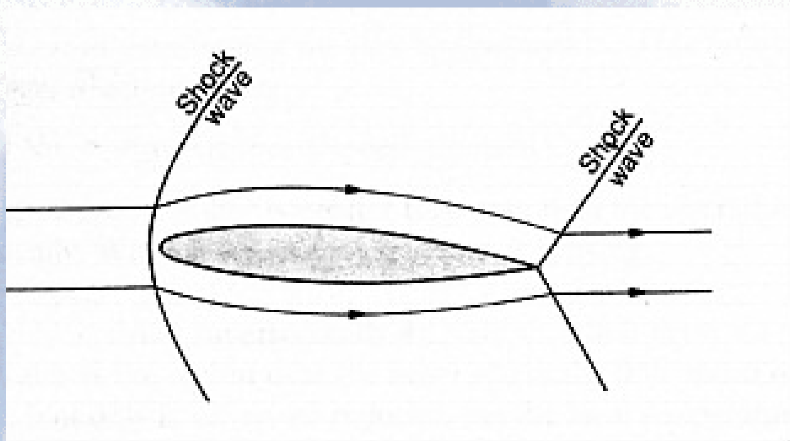
- The pulsejet is basically a pulsating jet.
- Only consist of a combustion chamber and a nozzle.
- Currently used in a lot of RC jet models.

Super-Sonic Characteristics

- Pressure variations are not transmitted upstream
- Shock Waves are formed due to extreme pressure disturbances
- Directly correlates to Mach number

$$M = \frac{V}{\sqrt{\gamma R T}}$$

Super-Sonic Flow Characteristics



(before shock)

-High speed flow is undisturbed

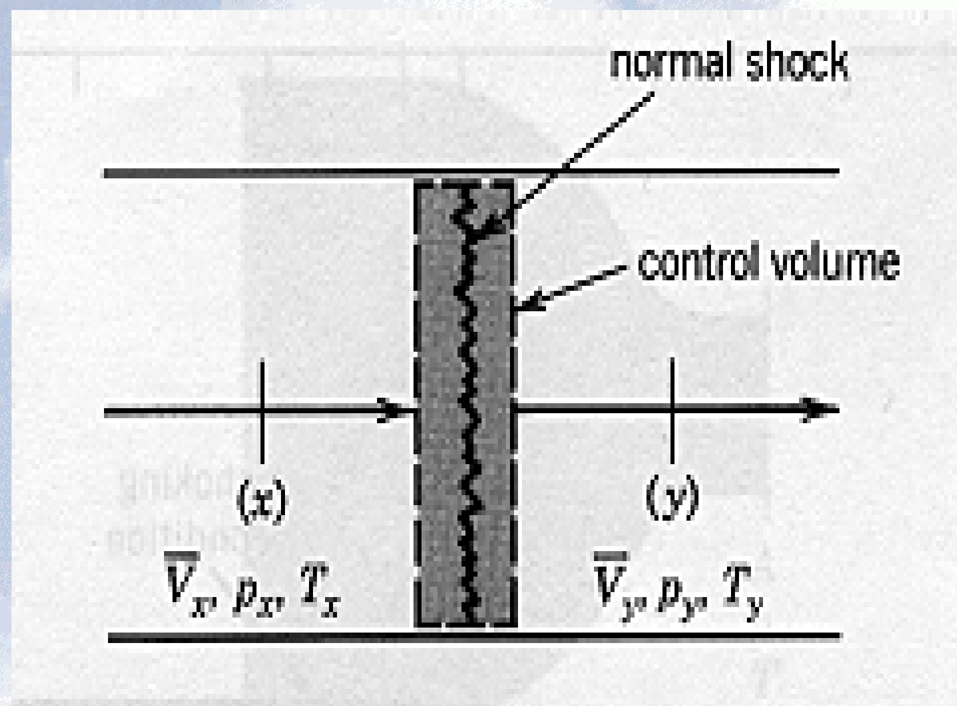
(after shock)

-Velocity Decreases

-Air Pressure, Temperature, and Density Increase

Normal Shock

- Definition: A shock front perpendicular to fluid flow causing a pressure rise and velocity decrease suddenly and irreversibly.



Normal Shock Flow Functions

For flow through a normal shock, with no direction change, area change, or work done, the governing equations are:

Continuity: $$\rho_1 u_1 = \rho_2 u_2$$

u = V = Velocity

Momentum: $$P_1 - P_2 = \rho_1 u_1 (u_2 - u_1)$$

Energy: $$T_{01} = T_{02}$$

Normal Shock Flow Functions

In terms of the initial *(state 1)* and final *(state 2)* Mach numbers, the following parameters can be derived:

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

$$\frac{P_{02}}{P_{01}} = \frac{\left[\dfrac{\frac{\gamma+1}{2} M_1{}^2}{1 + \frac{\gamma-1}{2} M_1{}^2}\right]^{\gamma/(\gamma-1)}}{\left[\frac{2\gamma}{\gamma+1} M_1{}^2 - \frac{\gamma-1}{\gamma+1}\right]^{\frac{1}{\gamma-1}}}$$

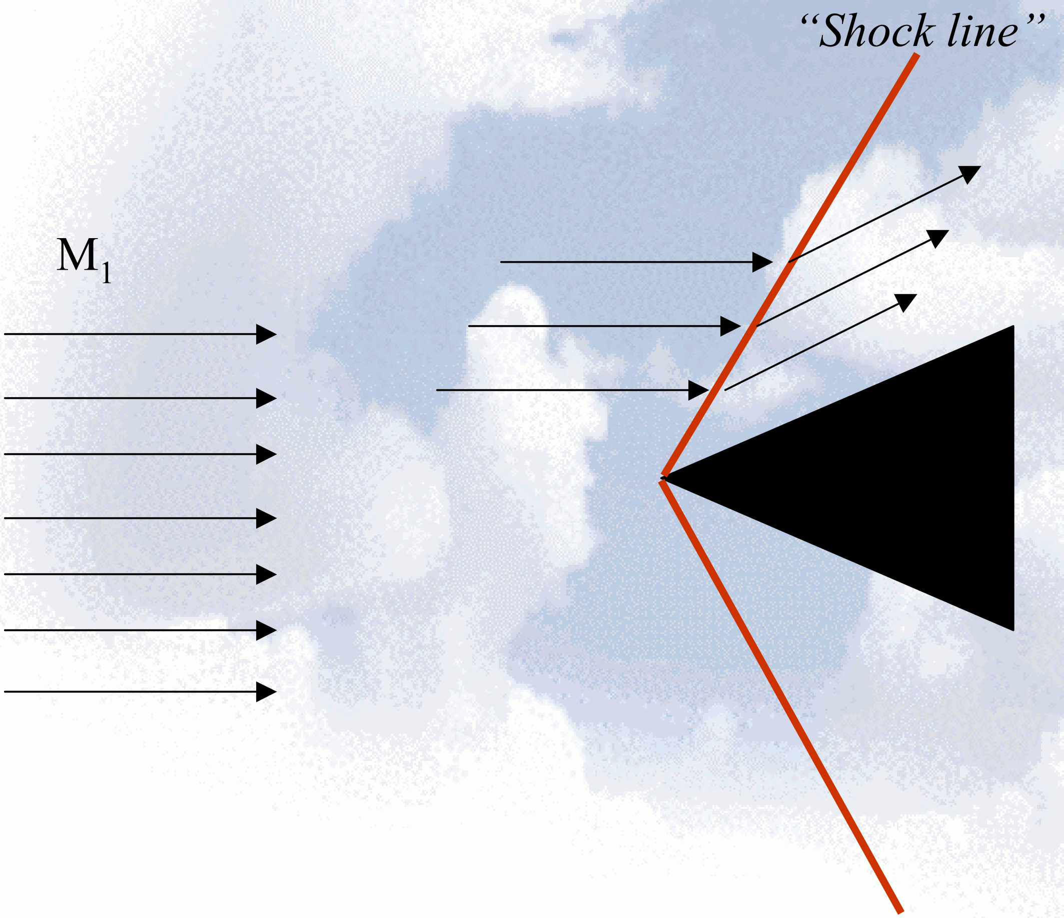
$$\frac{P_2}{P_1} = \frac{2\gamma}{\gamma + 1} M_1^2 - \frac{\gamma - 1}{\gamma + 1}$$

Normal Shock Flow Functions (cont'd)

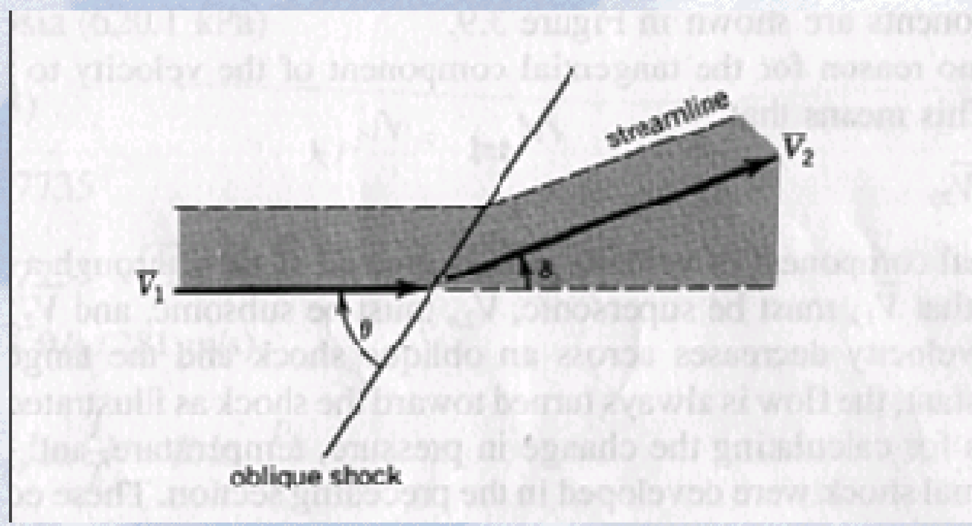
$$\frac{T_2}{T_1} = \frac{1 + \frac{\gamma - 1}{2} M_1{}^2}{1 + \frac{\gamma - 1}{2} M_2^2}$$

$$\frac{\rho_2}{\rho_1} = \frac{V_1}{V_2} = \frac{M_1}{M_2} \left[\frac{1 + \frac{\gamma - 1}{2} M_2^2}{1 + \frac{\gamma - 1}{2} M_1^2} \right]^{1/2}$$

Oblique Shock Theory

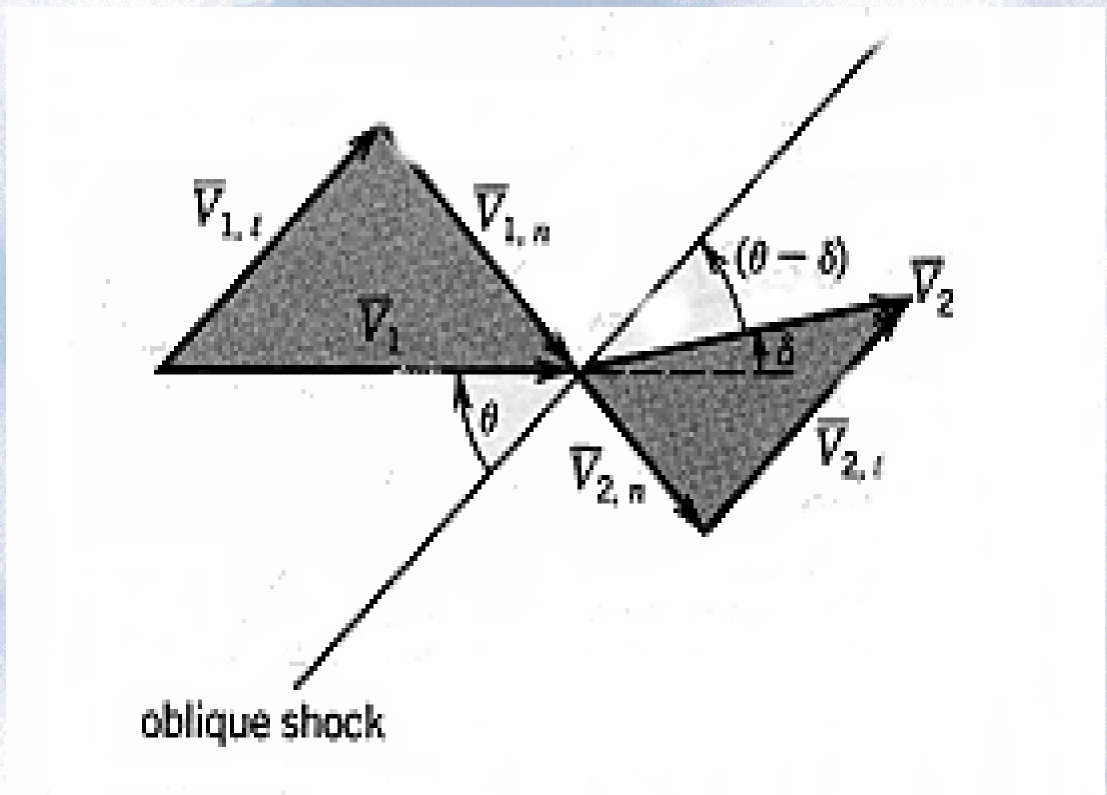


Oblique Shock



Oblique Shock (cont'd)

Figure #1



Oblique Equations

$$M_{1n} = M_1 \sin\theta$$

$$M_{2t} = M_{1t}\sqrt{\frac{T_1}{T_2}}$$

$$M_2 = \sqrt{M_{2t}^{\,2} + M_{2n}^{\,2}}$$

Table E.4 Normal-Shock Flow Functions (one-dimensional flow, ideal gas, $k = 1.4$)

M_1	M_2	p_{0_2}/p_{0_1}	T_2/T_1	p_2/p_1	ρ_2/ρ_1
1.00	1.000	1.000	1.000	1.000	1.000
1.50	0.7011	0.9298	1.320	2.458	1.862
2.00	0.5774	0.7209	1.687	4.500	2.667
2.50	0.5130	0.4990	2.137	7.125	3.333
3.00	0.4752	0.3283	2.679	10.33	3.857
3.50	0.4512	0.2130	3.315	14.13	4.261
4.00	0.4350	0.1388	4.047	18.50	4.571
4.50	0.4236	0.09170	4.875	23.46	4.812
5.00	0.4152	0.06172	5.800	29.00	5.000

Oblique Shock (cont'd)

Wave Angle, θ

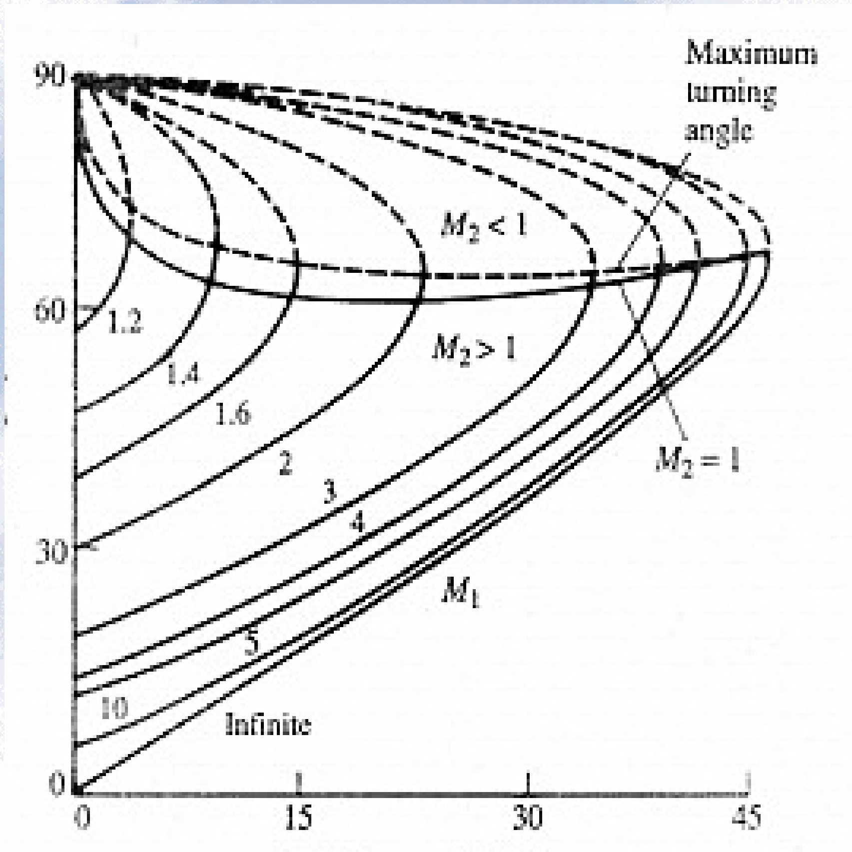
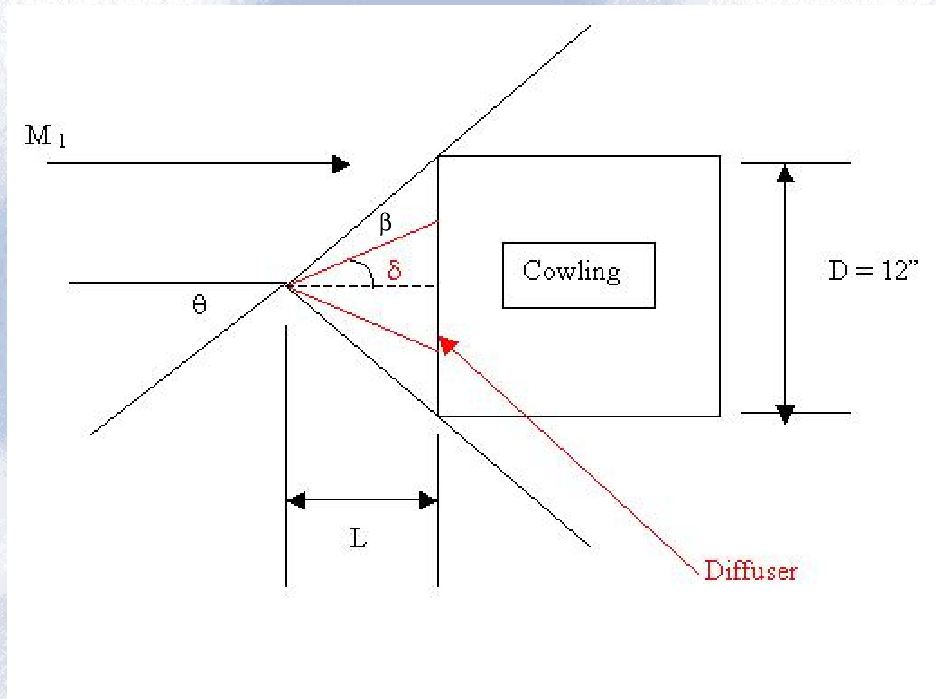


Figure #2

Deflection Angle, δ

Oblique Shock (Example)



Given: M_1=5 and $\theta = 30^0$

Find: Deflection angle *(cone angle)* δ, stagnation pressure ratio *(p_{o2}/p_{01})*, and M_2

Solution:

$$M_{1n} = M_1 \sin\theta = 5\sin 30 = 2.5$$

From Table 3.1 in FGT book:

$T_2/T_1 = 2.1375$
$M_{2n} = 0.51299$
$P_{02}/P_{01} = 0.49901$

$$M_{1t} = M_1 \cos\theta = 5\cos 30 = 4.33$$

$$M_{2t} = M_{1t}\sqrt{\frac{T_1}{T_2}} = 4.33\sqrt{\frac{1}{2.1375}} = 2.96$$

$$M_2 = \sqrt{M_{2t}^{\ 2} + M_{2n}^{\ 2}} = \sqrt{2.96^2 + 0.51299^2} = 3.0$$

$$\beta = \tan^{-1}\left(\frac{M_{2n}}{M_{2t}}\right) = \tan^{-1}\left(\frac{0.51299}{2.96}\right) = 9.83^\circ$$

$$\delta = \theta - \beta = 30 - 9.83 = 20.17^\circ$$

Advantages of Ramjets

- Ram compression increases with flight speed
- No need for a compressor
- Elimination of compressor means that the turbine is unnecessary
- Less weight associated with Ramjet configuration
- No moving parts

Disadvantages of Ramjets

- Inefficient below Mach 3
- Will not work if there is no forward motion
- Some other form of propulsion is required to provide the initial acceleration to high speeds (turbojets, rocket boosters, etc.)

SR-71
“Blackbird”

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