$\Rightarrow \quad p_1 = 1.117 \times 10^3$ Pa.

$T_1 = 226.98$ K.

$\rho = 0.01715$ kg/m³.

$u_1 = 7620$ m/sec.

Assume $\beta = 1.2\theta, = 48^\circ$

~~$u_{n_2} = 0$~~

$u_{n_2} = 0$

$u_{n_1} = u_1 \sin\beta$

$= 5662.76$ m/sec.

$$p_1 + \rho_1 u_{n_1}^2 = p_2 + \rho_2 u_{n_2}^2 \qquad u_{n_2}^2 = 0$$

$$\cancel{1.117 \times 10^3 + 0.01715 \times 7620^2 = p_2}$$

$$1.117 \times 10^3 + 0.01715 \times 5662.76^2 = p_2$$

$$\Rightarrow p_2 = 551063 \text{ Pa}$$

$$= 5.47.$$

$$\cancel{h_1} = h_{01} = c_p T_1 + \frac{u_{n_1}^2}{2} = h_2. \qquad \because u_{n_2} = 0$$

$$h_2 = 16.26 \text{ MJ/kg}$$

From. chart, for h_2 & p_2.

$z = 1.324.$

$T = 6650$ K.

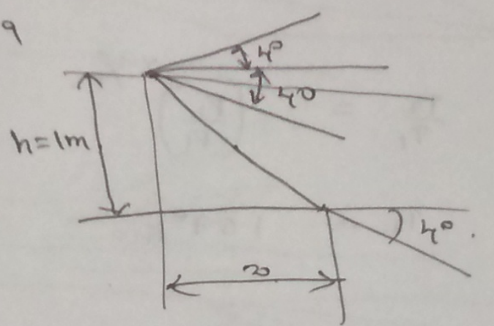
1. Air flows down a wide tunnel at mach number of 9.8 with a pressure of 120 Pa and a temperature of $-45°C$. The upper wall of this channel turns through an angle of $5°$ away from the flow leading to the generation of an expansion wave. Find the pressure, Mach number and temperature behind this expansion wave.

2. Consider the fig below.

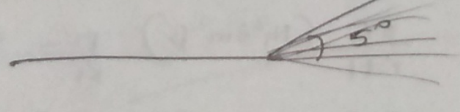
$M_1 = 9$

$P_1 = 60$ pa

$T_1 = -26C$.



Q (1). $M = 9.8$. $P_1 = 120$ pa $T_1 = -45°C$.

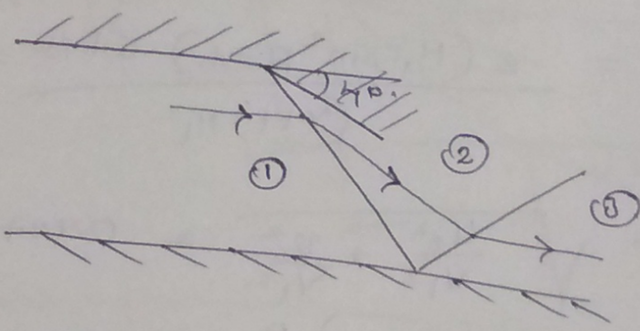


$$\theta = \frac{2}{\gamma - 1}\left[\frac{1}{M_1} - \frac{1}{M_2}\right]$$

$$0.0872 = \frac{2}{0.4}\left[\frac{1}{9.8} - \frac{1}{M_2}\right]$$

$$M_2 = 11.82.$$

(15). Air flowing with a Mach number of 7 with a pressure of 120 pa and a temper of −60°C passes over a wedge which turns the flow through an angle of 4° leading to the generation of an OS wave. The OS wave impinges on a flat wall, which is parallel to the flow upstream of the wedge and is reflected from it. Find the pressure, Mach and velocity behind the reflected shock wave.



$$\frac{\beta}{\theta} = \frac{\gamma+1}{4} + \sqrt{\left(\frac{\gamma+1}{4}\right)^2 + \frac{1}{M_1^2\theta^2}}$$

$$= \frac{2.4}{4} + \sqrt{\left(\frac{2.4}{4}\right)^2 + \frac{1}{7^2 \times 0.0698^2}}$$

$$\frac{\beta}{\theta} = \cancel{1.031}\ 2.732$$

$$\Rightarrow \beta = \overset{0.1907}{\cancel{0.7372}} \text{ rad} = \cancel{19.32}\ 10.929^\circ.$$

$$\frac{P_2}{P_1} = 1 + \frac{2\gamma}{\gamma+1}\left(M_1^2 \sin^2\beta - 1\right).$$

$$= 1 + \frac{2 \times 1.4}{2.4}\left(7^2 \times \sin^2 10.929 - 1\right).$$

1st iteration $\frac{\rho_2}{\rho_5} = 0.1$ Approximal.

$P_5 = 88.8$ atm.

$h_5 = 4.46$ MJ/kg

$Z = 1.009$ $\rho_5 = 9.086$ kg/m^3.

$T = 3420$K.

2nd iteration.

$P_5 = 102.82$.

$h_2 = 5.14$ MJ

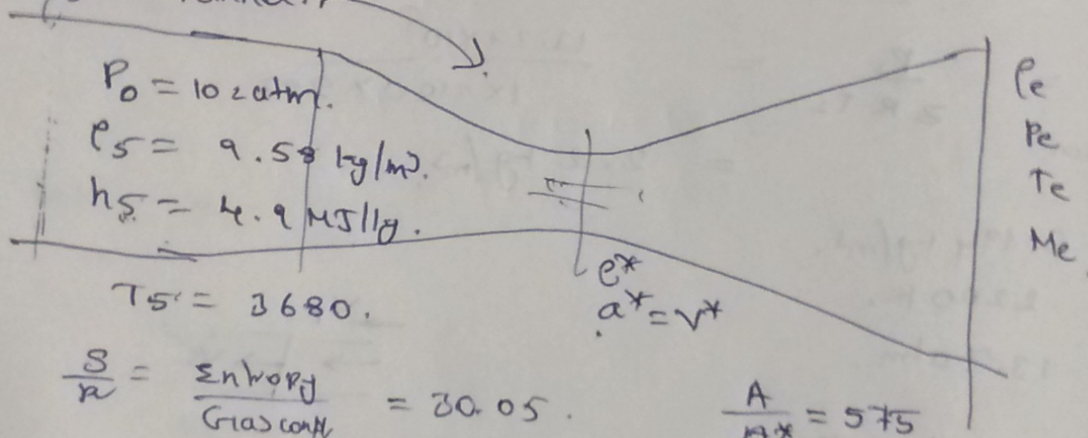
$Z = 1.01$

$T = 3740$k.

$\rho_5 = 9.56$ kg/m^3.

(2) Q.

shock tunnel.



$T_5 = 3680$.

$\frac{S}{R} = \frac{\text{Entropy}}{\text{Gas const}} = 30.05$.

$\frac{A}{A^*} = 575$.

$$T\,ds = dh - v\,dp.$$

For adiabatic flow. $h_0 =$ const.

$$\Rightarrow \quad dh + u\,du = 0$$

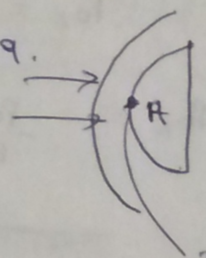
$$dp = -\rho v\,dv$$

$$v\,dx = \frac{-dp}{\rho} = -\nu\,dp.$$

ν → Sp. volume

$$\boxed{P_{02} = 9 \text{ kPa} \quad \text{Answer}}$$

2. Air flows over a blunt body. The air flow in the ~~sd~~ free stream, ahead of the body has a Mach number of 9 and static pressure of 100 pa. find the pressure acting on the front of the body using hypersonic relation and compare it with the solution from exact ~~ka~~ N.S relation. sketch the flow pattern near the nose.



$P_A = P_2 = P_{02}$

It is assumed to be N.S.

$M_1 = 9$. $\quad P_1 = 100 \text{pa}$.

P_{02}

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

$$= 94.5$$

$$\frac{u_2}{V_1} = 1 - \frac{2}{\gamma+1}$$

$$= 0.167$$

$$u_2 = 0.167 V_1$$

$$V_1 = M_1 a_1$$

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

$$= 15.75$$

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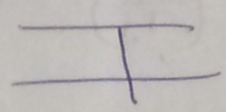
Syllabus up to 18th, A4 sheet of formulae.
29th exam.

1. Air is flowing out of a duct at a velocity of 250 m/s with a temp of 0°C and a pr of 101 kPa. A value at the end of the duct is suddenly closed. Find the pressure acting on the value immediately after the value closure.

$\xrightarrow{V_1}$ | $\leftarrow V_s$ $V_2 = 0$ $V_1 + V_s$ V_s.



$$M_{down} = \sqrt{\frac{T_1}{T_2}}\left[M_{up} - \frac{V_1}{a_1}\right].$$

$$M_1 = \frac{V_1 + V_s}{a_1} \qquad M_2 = \frac{V_s}{a_2}.$$

$$= \frac{V_1}{a_1} + \frac{V_{s}}{a_2} \times \frac{a_2}{a_1}$$

$$M_1 = \frac{V_1}{a_1} + M_2 \cdot \sqrt{\frac{T_2}{T_1}}$$

$$= \frac{250}{331.19} + M_2\sqrt{\frac{T_2}{T_1}}$$

$$M_1 = 0.75485 + \boxed{M_2\sqrt{\frac{T_2}{T_1}}}$$

$C_d \Rightarrow 1$

we have to take projected area

$$Drag = (P - P_0)\,\pi a^2.$$

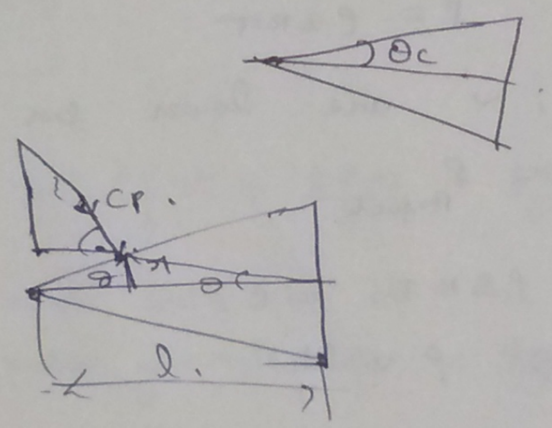
$C_d = 1$

~~$C_d = 26389.$~~

$Drag = \frac{1}{2} \cdot \gamma M^2 \cdot P_1 \times 1 \times$

$$Drag = 26389\ N$$
$$= 26.38\ KN$$

(5) Find the C_D for cone (θ_c) using Newtonian Aproximation.



Assume ~~the~~ $V_e = 2000\ m/sec$.

$h = 2.9\ MJ/kg$.

$P = 10.4\ atm$.

$z = 1$

$\rho_e = 1.47$

$\rho_e V_e = 2949 \neq 9.9$.

$V_e = 3040\ m/sec$.

$h = 3.4\ MJ$ $\qquad \rho_e = 3.41 \times 10^{-3}\ kg/m^3$.

$P_e = 303\ pa$. $\qquad \rho_e V_e = 10.386$.

$\cancel{T = 3011k}$.

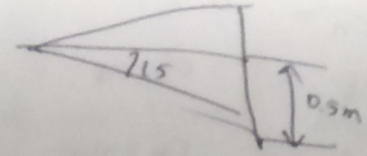
$T_e = 310\ k$.

Page No - 617   J.D Anderson.

Equi Quasi 1D Flow.

$\Rightarrow P_2 = 4112\ Pa.$

Drag = 3890 N



$\sin 15 = \frac{0.5}{l}$

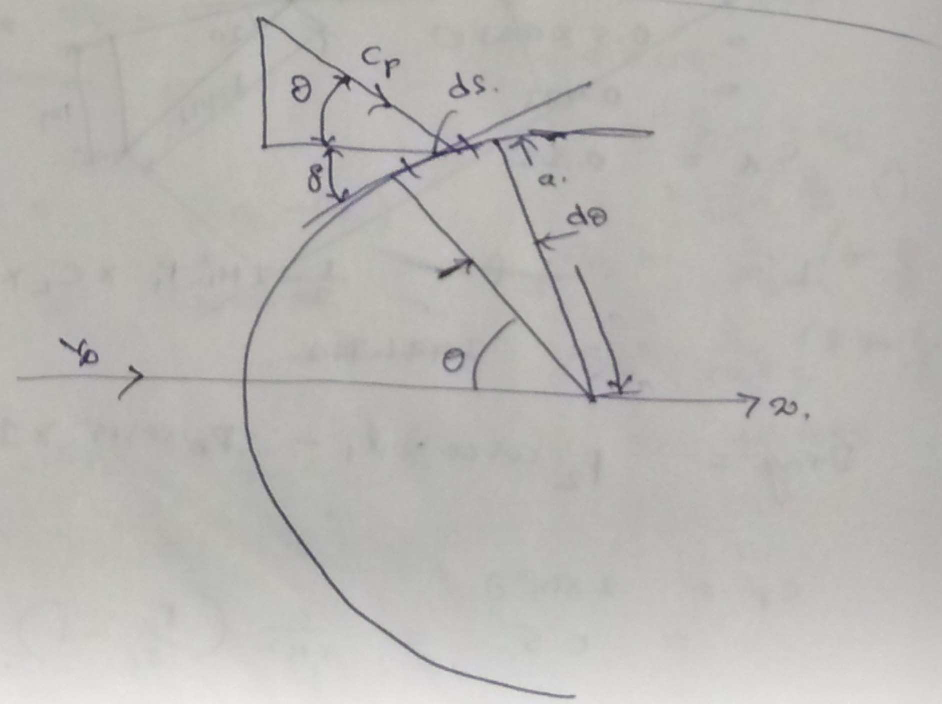
$l = 1.93.$

(3) Find the C_D for circular cylinder using Newtonian Approximation.

(4) Find the C_D for ~~hemi~~sphere using Newtonian approximation and then find the drag for Sphere flying at mach 10, using Newtonian Approximation $T_\infty = 200k$, $P_\infty = 1208a$, Radius = 1m

---

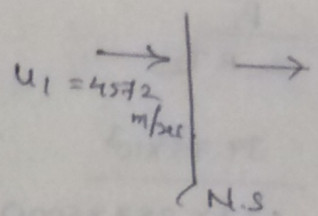
Q(1)



Calculate the flow down stream of a Normal shock wave, when velocity $u_1 = 4572\ m/sec$ at an altitude of 45,720m.

at 45.72km

$\frac{\rho}{\rho_{SL}} = 1.40628$.



$P_1 = 142\ N/m^2$.

$T_1 = 266\ K$ $\quad a_1 = 327\ m/sec$

$M_1 = \frac{u_1}{a_1} = 13.98 \approx 14$

$\rho_1 = 1.895 \times 10^{-3}\ kg/m^3$.

$$u_2 = \rho_1/\rho_2 \cdot u_1$$

$$P_2 = P_1 + \rho_1 u_1^2 - \rho_2 u_2^2$$

$$h_2 = h_1 + \frac{u_1^2}{2} - \frac{u_2^2}{2}$$

$$\frac{T_{01}}{T_1} = 1 + \frac{\gamma - 1}{2} M_1^2.$$

$T_{01} = 10693^\circ K$, Temp is large enough to have dissociation.

$$h_1 = C_p T_1 = 267.33 \times 10^3\ J/kg.$$

$$h_1 + \frac{u_1^2}{2} = h_2 + \cancel{\frac{u_2^2}{2}} \to 0.$$

$u_2 = 0$. assume iteration -

$$267.33 \times 10^3 + \frac{4572^2}{2} = h_{02}.$$

$$h_{02} = 10718.9\ kJ/kg.$$

$$P_2 = 142 + 1.895 \times 10^{-3} \times 4572^2$$

$$= 39.75\ kPa.$$

$$\frac{P_2}{P_1} = 1.89 = 1.91466.$$

$$\frac{\rho_2}{\rho_1} = \frac{(\gamma+1) M_1^2 \sin^2\beta}{(\gamma-1) M_1^2 \sin^2\beta + 2}$$

$$= 1.563.$$

$$\frac{u_2}{V_1} = 0.9866 = 1 - \frac{2\sin^2\beta}{\gamma+1}$$

$$\frac{v_2}{V_1} = \cancel{\times}0.0298 = \frac{\cancel{\sin 2\beta}}{\cancel{\gamma+1}} \quad 0.067 \checkmark$$

$$= \frac{2(M_1^2 \sin^2\beta - 1)\cot\beta}{(\gamma+1) M_1^2}$$

$$\frac{V_2}{V_1} = \sqrt{\frac{u_2^2}{V_1^2} + \frac{v_2^2}{V_1^2}} = 0.987$$

$M_2 = \cancel{6.24}$.

$$\frac{\beta_{2-3}}{\theta} = \cancel{2.97}.$$

compute.

$\frac{P_3}{P_2}$, $\frac{\rho_3}{\rho_2}$, =

$\frac{P_2}{P_1} = 1.8885$, $\frac{\rho_2}{\rho_1} = 1.5632$

$\frac{T_2}{T_1} = \frac{P_2/P_1}{\rho_2/\rho_1} = 1.208.$

$M_2 = 6.3.$ $\beta_2 = 11.8^\circ$

$\frac{P_3}{P_2} = 1.769$, $\frac{\rho_3}{\rho_2} = 1.4953$.

$\frac{T_3}{T_2} = 1.183.$

$T_3 = 304\,K$, $P_3 = 400$ Pa.

$M_3 = 5.688$

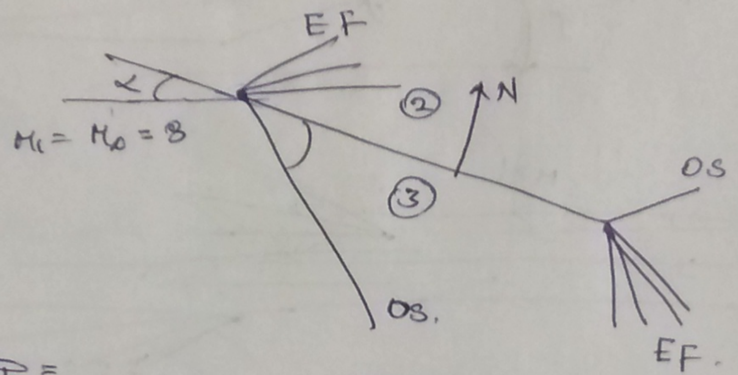
25/1/16

Tutorial - 3

1) Consider an infinitely thin flat plate at angle of attack of 15° in a Mach 8 flow. Assume inviscid flow. Calculate the pressure coeff on the top and bottom surface of the plate, the lift and drag coefficients and the lift to drag ratio using

a) Exact shock wave and expansion wave theory

b) Newtonian theory. Compare results.



1-2 $\cancel{\theta_2}$ =

Expansion Fan

$\frac{P_2}{P_1} = 0.0203$

$P_3/P_1 = 9.443$

$C_n \cancel{\theta} = (C_{P_3} - C_{P_1})$

$= \frac{2}{\gamma M^2}\left(\frac{P_3}{P_1} - 1\right)$

$C_{P_3} = \frac{2}{\gamma M_1^2}\left(\frac{P_3}{P_1} - 1\right)$

$C_l = C_n \cos\alpha,$

$= \frac{2}{\gamma M_1^2}\left(\frac{P_3}{P_1} - 1\right)$

$C_{P_2} = \frac{2}{\gamma M_1^2}\left(\frac{P_2}{P_1} - 1\right)$ $= +0.1888.$

$= -0.02186$

$\Rightarrow \quad dh - \frac{dp}{\rho} = dh - v\,dp = 0$

$\boxed{T\,ds = 0}$ Isentropic flow.

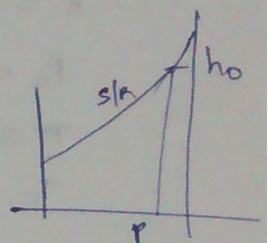
$$\frac{dA}{A} = (M^2 - 1)\frac{dv}{v}.$$

Assume

$v^* = 1200\ m/sec.$

$$h_0 - \frac{(1200)^2}{2} = h_*$$

$$\boxed{h_0 = h_5 = 49\ MJ/kg.}$$



$h^* = 48.28\ MJ/kg.$

From charts, ho & s/R. $T^* = 3270K,\ Z = 1$

$$\gamma^* = \frac{h}{e} = \frac{\gamma D}{\gamma D - \gamma + 1} \quad (\gamma = 1.4)$$

$\gamma^* = 1.28.$

$$D = \frac{h}{Z C_p T}$$

$C_p = 1005\ J/kg$

$$a^* = \sqrt{\gamma^* P/\rho} = \sqrt{\gamma^* Z R T^*} = 1099\ m/s.$$

iterate till $a^* = v^*$.

After many iterations,

$T^* = 3310k.$

$p^* = 4.96\ bar.$

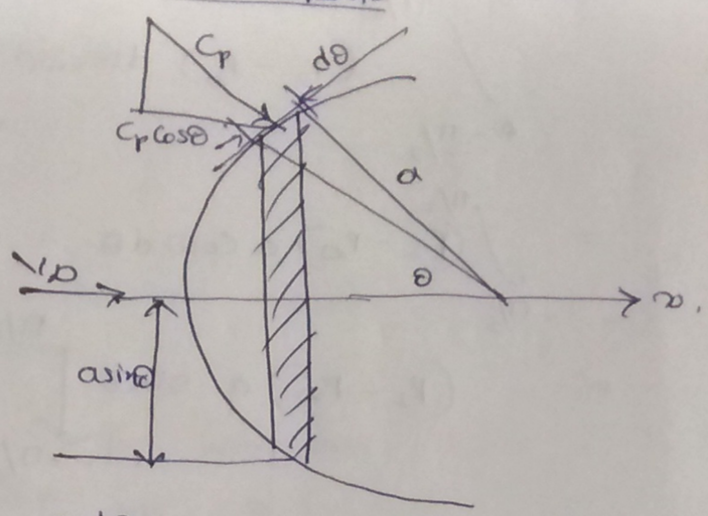
$\rho^* = 5.22\ kg/m^3.$

$A^* v^* \rho^* = \rho_e V_e A_e.$

$$\boxed{\rho_e V_e = 9.99.}$$

Q (4).

~~Sphere~~ Full sphere. ~~Hemisphere~~ (Area integration)



$ds = a\,d\theta$.

(dA). Area of strip $= ds \times 2\pi a\sin\theta$

$$\text{Drag} = \int_{-\pi/2}^{\pi/2} (P_2 - P_\infty)\cos\theta\,(dA)$$

$$= \int_{-\pi/2}^{\pi/2} (P - P_\infty)\cos\theta \times [a \times d\theta \times (2\pi a\sin\theta)]$$

$$= \int_{-\pi/2}^{\pi/2} (P - P_\infty)\, 2\pi a^2 \sin\theta\cos\theta\, d\theta$$

$$= \int_{0}^{\pi/2} (P - P_\infty)\cdot \pi a^2 \sin 2\theta\, d\theta$$

$$= (P - P_\infty)\pi a^2 \left[-\frac{\cos 2\theta}{2}\right]_0^{\pi/2}$$

$$= -\frac{(P - P_\infty)}{2}\pi a^2 [-1 + 1].$$

$M_{up} > M_{down} = (M_{up} - 0.259)\sqrt{\frac{T_2}{T_5}}$

Iterative procedure to solve

M_{up}	$\frac{T_5}{T_2}$	M_{down}	$(M_{up} - 0.259)\sqrt{\frac{T_2}{T_5}}$
1.7747	1.235	0.75	1
1.2	1.128	0.9422	0.886
1.166	1.106	0.865	0.861
1.17	$\boxed{1.109}$	0.865	0.865

$\frac{T_5}{T_2} = 1.109$ $\frac{P_5}{P_2} = 1.43$

$T_5 = 362 K$ $P_5 = 207.35\ Pa$

$\rho_5 = \frac{P_5}{RT_5} = 1.995 \times 10^{-3}\ kg/m^3$

AC

$\frac{P_2}{P}$

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

$$\cancel{15.75} = \cancel{\frac{1+0.2\times 9^2}{1+0.2\times M_2^2}}$$

$$\cancel{M_2 = 0.678.}$$

$$\cancel{\frac{P_{02}}{P_2}} = \cancel{\left(1+0.2\times 0.678^2\right)^{3.5}}$$

$$P_{02} = 1.86\, P_2$$

$$P_{02} = \frac{P_{02}}{P_2} \times \frac{P_2}{P_1} \times P_1$$

$$\cancel{= 12.952}$$

$$\frac{U_2}{V_1} = \frac{V_2}{V_1} = 1 - \frac{2}{\gamma+1} = 0.167.$$

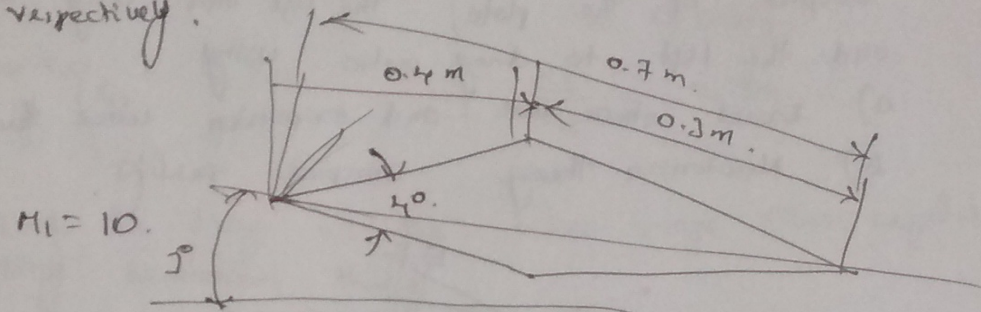
$$\frac{M_2}{M_1} = \frac{V_2}{V_1}\sqrt{\frac{T_1}{T_2}}$$

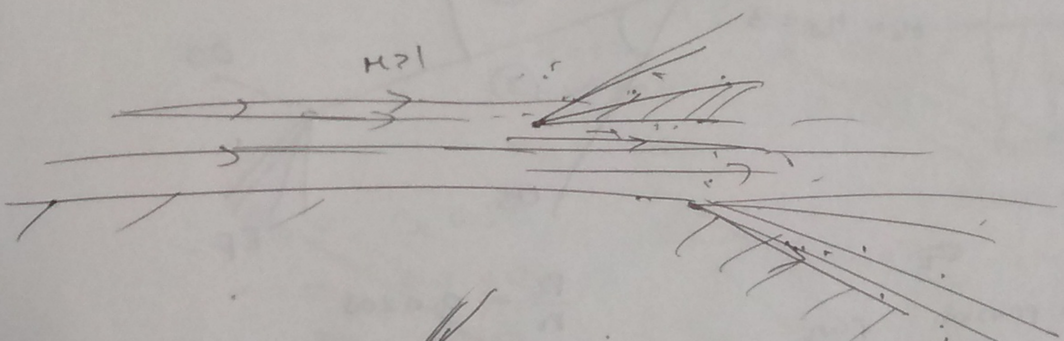
$$M_2 = 0.388$$

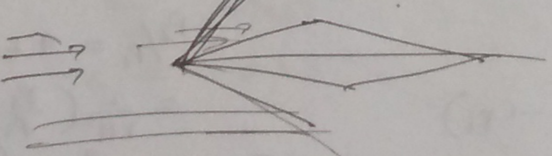
$$\frac{P_{02}}{P_2} = \left(1+\frac{\gamma-1}{2}M_2^2\right)^{\gamma/\gamma-1}$$

$$= 1.109$$

Q.
(3). Find the lift per meter span for the wedge shaped airfoil shown in fig. Also sketch the flow pattern about the airfoil. The mach number and the pressure and the pressure ahead of the airfoil are 10.6 and 400pa, respectively.







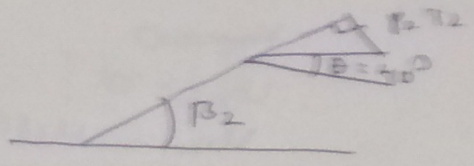
$$u_{n_1} = V_1 \sin\beta$$

$$\rho_1 u_{n_1} = \rho_2 u_{n_2}$$

$$\tan(\beta-\theta) = \frac{v_{n_2}}{v_{n_1}} \tan\beta$$

$$\boxed{\theta = 0^\circ}$$

Problems:-



$V_\infty = 25000 \text{ ft/sec}$

at alt $= 100{,}000$ ft

$= 30.48$ km.

$V_\infty = 7620$ m/sec.

$$\left(\frac{\rho}{\rho_{SL}}\right)_{30.48} = 1.1813 - \frac{(1.1813 - 1.0177)}{1} \times 0.48$$

$$= 1.10277 \times 10^{-2}$$

$$T = 226.5 + \frac{(227.5 - 226.509)}{1} \times 0.48$$

$$= 226.98^\circ K$$

$$\frac{\rho}{\rho_{SL}} = 1.5029 - \frac{(1.5029 - 1.2891) \times 0.48}{1}$$

$$= 1.4 \times 10^{-2}$$

$$a = 301.71 + (302.37 - 301.71) \times 0.48$$

$$= 302 \text{ m/sec}$$

$P_2 = \rho_2 Z R T_2$

$551063 = \rho_2 \times 1.324 \times 287 \times 6650$

$\rho_2 = 0.218\ kg/m^3$

$\rho_1 u_{n_1} = \rho_2 u_{n_2}$

$u_{n_2} = 445.48\ m/sec.$

0.6

$$\tan(\beta - \theta) = \frac{u_{n_2}}{u_{n_1}} [\tan\beta]$$

$\beta = 44.43 \ / 85.6$

~~β~~ ~~ts~~ ~~ks~~

$$\boxed{\beta = 44.43^\circ}$$

2nd Iteration

$u_{n_1} = 5334.28\ m/sec.$ $u_{n_2} = 445.329\ m/sec$

$1.117 \times 10^3 + 0.01715 \times 5334.28^2 = P_2 + 0.218 \times 445$

$P_2 = 4.45 \times 10^5\ Pa$

$P_2 / P_a = 4.4$ ✓

~~$h_2 = h_{01} =$~~

~~$h_2 + \frac{\rho_2 u_{n_2}^2}{2}$~~

$$h_2 + \frac{445.329^2}{2} = 1.005 \times 10^3 \times 226.98 + \frac{5334.28^2}{2}$$

$h_2 = 14.35\ MJ/kg$

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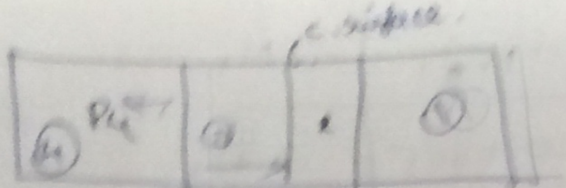


$u_3 = u_2$
$p_3 = p_2$

$P_4 =$ ~~4442000000~~

For $M = 3$

$P_1 = 1$ atm.

$P_2 = 10.33$ atm

$M_2 =$

$\frac{T_2}{T_1} = 2.679$.

$T_2 = 803.7$ K.

$a_2 = 568.27$ m/sec.

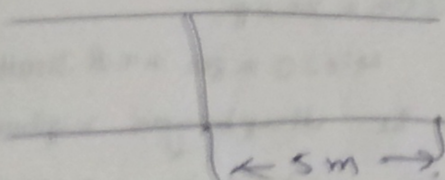
$M_2 = M_1 \frac{a_1}{a_2} - \frac{V_2}{a_2}$

$0.4752 = 3 \times \sqrt{\frac{1}{2.679}} - \frac{V_2}{568.27}$

$V_2 = 771.53$ m/sec. $= a_3$

~~$a_3 = 347.2$ m/sec.~~

6



$t = \frac{5}{424.34}$

$= 0.0117$ sec

$\left(\frac{P_4}{P_3}\right)^{\gamma-1/\gamma} = \frac{T_4}{T_3}$

$\Rightarrow \left(\frac{44420}{10.33 \times 1.01325 \times 10^5}\right)^{0.4/1.4} = \frac{300}{T_3}$

$T_3 = 198.78$ K

$a_3 = 282.61$ m/sec.

$C_n = 0.21$

$C_l = 0.208$.

$C_d = C_n \sin\alpha$

$= 0.05435$

$L/D = C_l/C_d = 3.74$.

Newtonian.

$C_{P_2} = 0, \quad C_{P_3} = 2\sin^2\theta$

$= 0.134$.

$C_l = C_n \cos\theta$

$= 0.1294$.

$C_d = C_n \sin\theta$

$= 0.034$.

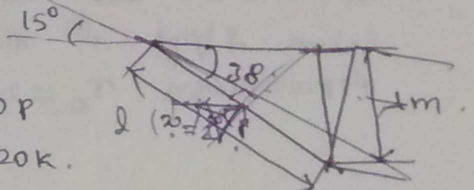
$\frac{C_l}{C_d} = 3.74$

2Q. Find the drag on the below wedge (base height - 1m) using Newtonian theory.

$M = 12$

$P_\infty = 80\ p$

$T_\infty = 120K$.



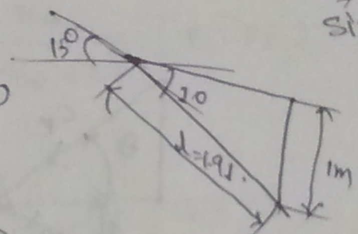
$\sin 30 = \frac{1}{x}$

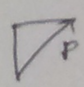
$x =$

$\cancel{C_l = C_n \cos\theta}$

$\cancel{= 0.5 \times \cos 30}$

$\cancel{= 0.433}$.





$C_d = 0.25$

$L = \cancel{\tfrac{1}{2}\rho v} \ \frac{1}{2} \gamma M_1^2 P_1 \times C_L \times 1$

$= \cancel{3491712}$.

$\text{Drag} = P_2 \cos 60 \times l_1 - P_\infty \cos 15 \times 1$

$C_p = 2\sin^2\theta$

$= 0.5 = \frac{2}{\gamma M^2}\left(\frac{P_2}{P_1} - 1\right)$.

From page 28 for h_2 & ρ_2

$Z_2 = 1.23$. $T_2 = 5000k$.

$$\rho_2 = \frac{P_2}{Z_2 R T_2}$$

$$= \frac{39.75 \times 10^3}{1.23 \times 287 \times 5000} = 0.0225 \text{ kg/m}^3.$$

Iteration. 2 $u_2 = \frac{\rho_1}{\rho_2} . u_1$

$u_2 = 385. \text{ m/se}$

$P_2 = 36.418 \text{ KPa}$

$\frac{P_2}{P_0} = 0.3594$

$h_2 = 10718 \times 10^3 - \frac{385^2}{2}$

$= 10.64 \text{ MJ/kg}$.

$T_2 = 4970k$.

$Z_2 = 1.228$.

$\rho_2 = 0.021 \text{ kg/m}^3$

III Iteration $u_2 = 412.6. \text{ m/s}$

$P_2 = 36.17 \text{ KPa}$

$\frac{P_2}{P_0} = 0.357$

$h_2 = 10718 \times 10^3 - \frac{412.6^2}{2}$

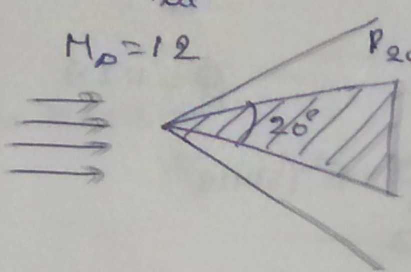
$= 10.63 \text{ MJ}$

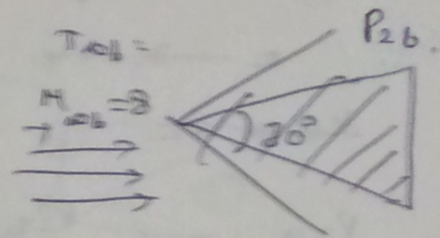
$P_{02} = \frac{P_{02}}{P_2} \times \frac{P_2}{P_1} \times P_1$

$P_{02} = 10.483\,kPa.$

$\Rightarrow \frac{P_{02}}{P_{01}} = 0.00476$

Q(4). P_{2b}, if $\cancel{P}$ $P_{\infty b} = P_{\infty a}/2$ and $T_{\infty a} = T_{\infty b}$.





$\frac{P_2}{P_1} = \cancel{2\times1.4}\ \frac{2\gamma}{\gamma+1} M_1^2 \sin^2\beta.$

Taking $\beta = 1.2\theta$. for case 'a'.

$= 1.2\times10 = 12°.$

$\frac{\rho_{\infty a}}{\rho_{\infty b}} = \frac{P_{\infty a}/R\cancel{T}_{\infty a}}{P_{\infty b}/R\cancel{T}_{\infty b}}$

$\frac{\rho_{\infty a}}{\rho_{\infty b}} = \frac{P_{\infty a}}{P_{\infty b}} = 2.$

$\Rightarrow \frac{P_2}{P_1} = \frac{2\times1.4}{2.4} \times 12^2 \times \sin^2 12$

$= 7.262.$

$P_1 = 688.5\,kPa.$

$\cancel{P_1} =$

$\frac{P_{2a}}{P_{\infty a}} = \frac{2\gamma}{\gamma+1} M_1^2 \sin^2\beta$

$= \frac{2\times1.4}{2.4} \times 12^2 \times \sin^2 12$

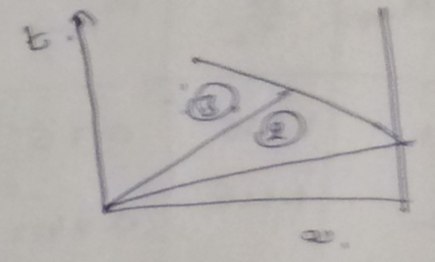
$= 7.26.$

$\Rightarrow P_{\infty a} = 5/7.26 = 0.6887\,kPa$

ACOUSTIC Impedance (Z) – Its relevance to shock propagation.

$z = \rho a$.

for gases ρ = assumed to be constant.



$$R = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2.$$

→ please refer sir ppt for notes ...

→ ~~Aco~~ Z - Determines whether ~~a sho~~ there will be a reflected shock wave or EF.

Q8. A quick valve of a shock tube, filled with He on the driver side and air on the driven side operates opens generating and an incident shock wave of Mach-3. The driver gas was initially at a temp and pr of 300K and 930 kPa. The driven gas initial conditions were 21 kPa pressure & 300 K. Determine the wave system generated at the end of the tube when the waves interact with the contact surface.

$$\text{time} = \frac{\text{Distance}}{V_3 - a_3} = \frac{55}{771.550 - 22.611}$$

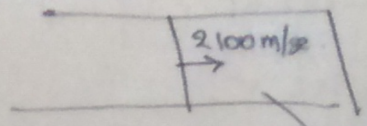
$$= 0.0015 \text{ sec}$$

Q3) To achieve the tailored condition, in which the reflected shock passes through the contact surface unaltered, what should be the velocity of the shock wave.

Driven gas: helium, driven gas: air $T_4 = T_1 = 300K$, $P_1 = 1atm$).

Tutorial.

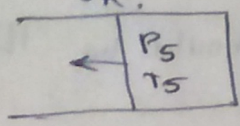
shock tube



$P_1 = 0.3$ atm.

$T_1 = 300k$.

Find, $P_5 = ?$, $T_5 = ?$ (Conditions behind reflected sh



$$\rho_1 V_s = \rho_2 (V_s - V_p)$$

$$\cancel{P_1 + \rho_1 u} \quad P_1 + \rho_1 V_s^2 = P_2 + \rho_2 (V_s - V_p)^2$$

$$h_1 + \frac{V_s^2}{2} = h_2 + \frac{(V_s - V_p)^2}{2}$$

Let $\frac{\rho_2}{\rho_1} = 6$. (For hypersonic Flow).

$$V_s - V_p = \frac{\rho_1}{\rho_2} \cdot V_s$$

$$P_2 = P_1 + \rho_1 V_s^2 \left[1 - \frac{\rho_1}{\rho_2}\right]$$

$$V_s - V_p = \frac{V_s}{6}.$$

$$0.833\, V_s = V_p.$$

$$V_s = 1.2\, V_p.$$

$$\Rightarrow V_p = 1750\ m/sec$$

From chart for. P_2 & h_2

$Z = 1.285$

$T = 6280\,k.$

$P_2 = \rho_2 Z R T_2$

$\rho_2 = 0.192\ kg/m^3.$

$\cancel{P_1 + \rho_1 u_{n1}^2} = \cancel{P_2 + \rho_2 u_{n2}^2}$

$\rho_1 u_{n1} = \rho_2 u_{n2}.$

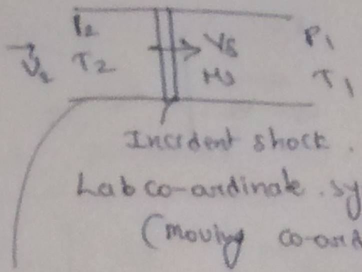
$u_{n2} = 476\ m/sec.$

$\beta = 45.06 / 84.9.$

III rd iteration

$\beta = 45.0423.$	$\rho_2 = 0.194\ kg/m^3$
$T_2 = 6350\,k$	$u_{n2} = 475.118 m/sec$
$Z = 1.288.$	$P_2 = 4.49\ atm$
	$V_2 = 5408.2 m/sec.$

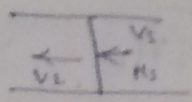
Find V_2 using $\boxed{\beta, \theta}$ u_{n2}.



Incident shock.

Lab co-ordinate system.

(Moving co-ordinate system).



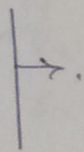
shock co-ordinate system.

→ Normal shock relations can be used.

→ Please read from book → Dont rely on class.

A Normal shock across which pr ratio is 1.45 moves down a duct into still air at pr of 100kPa and Temp of 28C. If the end of the duct is suddenly closed. find the pressure acting at the end of the duct behind reflected shock.

(2) (1).



$$\frac{P_2}{P_1} = 1.45.$$

$$M_1 = \frac{V_1}{a_1}$$

$$M_2 = \frac{V_1 - V_b}{a_2}.$$

From tables.

$M_s = 1.1772.$ $M_2 = 0.8567.$

$\frac{T_2}{T_1} = 1.1137.$ $\Rightarrow T_2 = 326.3k,$

$a_2 = 362$ m/sec.

$a_1 = 341.11$ m/sec.

$$M_2 = \frac{V_s - V_2}{a_2}.$$

P_2

$\xleftarrow{\;\;} \; V_s - V_2 \;|\; \xleftarrow{\;\;} \; V_s$

$$V_s = a_1 \times M_1$$
$$= 403.9 \text{ m/s}$$

$$0.8567 = \frac{403.9 - V_2}{362}.$$

$$\boxed{V_2 = 93.77 \text{ m/sec}}$$

$P_2 = 145$ pa.

Reflected shock

$V_2 \rightarrow \;\; \xleftarrow{\;} V_R \;|\; \;\; V_5 = 0.$

up | down

$\xrightarrow{\;\;}$ $V_2 + V_R$, $P_2\ T_2$ | $\xrightarrow{\;\;} V_R$, $P_5\ T_5$

$$M_{up} = \frac{V_2 + V_R}{a_2}, = \frac{V_R}{a_2} + \frac{V_R}{a_2} \cdot \frac{a_5}{a_5}$$

$$M_{down} = \frac{V_R}{a_5} \qquad = \frac{V_R}{a_2} + M_{down} \cdot \sqrt{\frac{T_5}{T_2}}.$$

$$M_{up} = \frac{93.78}{362} + \frac{V_R}{a_2}.$$

$$= 0.259 + M_{down}\sqrt{\frac{T_5}{T_2}} \qquad \text{— (1).}$$

$P_2 = 0.3 \times 1.01325 \times 10^5 + 0.353 \times V_s^2 \left[1 - \frac{1}{6}\right]$

$P_2 = 30397.5 + 0.2941 \times 2100^2$

$P_2 = 13.27$ bar.

$h_2 = h_1 + \frac{V_s^2}{2}\left[1 - \left(\frac{\rho_1}{\rho_2}\right)^2\right]$

$= 1005 \times 300 + \frac{2100^2}{2}\left[1 - \left(\frac{1}{6}\right)^2\right]$

$= 2.44$ MJ/kg.

From charts. for P_2 & h_2. (chart are not provided for $\frac{P_2}{P_{atm}} > 10$.

$P_2/P_{atm} = 13$. $Z = 1$ $T_2 = 2100$ K

$\rho_2 = \frac{P_2}{ZRT_2} = \frac{13.27 \times 10^5}{1 \times 2100 \times 287}$.

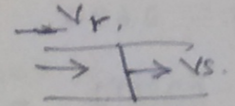
$= 2.2$ kg/m³.

From 2nd iteration.

$\rho_2 = 2.194$ kg/m³.

$T_2 = 2200$ K.

$P_2 = 13.7$ atm.



~~$P_5 = P_2 + \rho_2$ [~~

$[V_{sr} + V_p]\rho_2 = V_{sr} \times \rho_5$

$P_5 = P_2 + \rho_2 (V_{sr} + V_p)^2 \left[1 - \frac{\rho_2}{\rho_5}\right]$

$h_5 = h_2 + \frac{(V_{sr} + V_p)^2}{2}\left[1 - \left(\frac{\rho_2}{\rho_5}\right)^2\right]$

$V_{sr} = \frac{V_p}{\left[\frac{\rho_5}{\rho_2} - 1\right]}$.

$$\frac{p_2}{p_1} = \left[1 - \left(\frac{\gamma - 1}{2}\right) \ldots\right]^{2\gamma/(\gamma+1)}$$

$M_c = M_1\theta$ ✓

$$\frac{p_2}{120} = \left[1 - 0.2 \times 9.8 \times 0.0872\right]^{\frac{2.8}{0.4}}$$

$p_2 = 32.3\ \text{Pa}.$

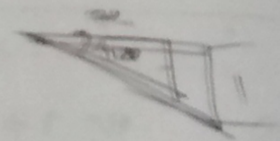
$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\gamma-1/\gamma}.$$

$T_2 = 1157° K.$

Q2.

Os $M_1 = 9$

$\theta = 0.0698 = 4°$



$\cancel{\beta = 1.2\theta}$

$= \cancel{0.08372}$ $= \cancel{4.8°}$

$\tan 4.8 = \frac{1}{x}$

$$\cancel{\frac{p_2}{p_1} = \frac{2\gamma}{\gamma+1}\left(M_1^2 \sin^2\beta\right)} \quad \frac{p_2}{p_1} = 8.25$$

$$\cancel{= \frac{2.8}{2.4} \times 9^2 \times (\sin 4.8)^2} \quad 0.16$$

$\beta = 9.2°$

$$\frac{\beta}{\theta} = \frac{\gamma+1}{4} + \sqrt{\left(\frac{\gamma+1}{4}\right)^2 + \frac{1}{M_1^2\theta^2}}$$

$\Rightarrow \beta = 9.2°.$

$$x = \frac{1}{\tan\beta}$$

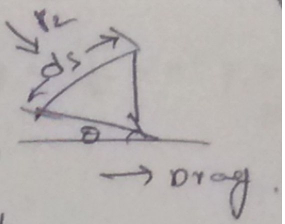
$= 6.17\ \text{m}$

$p_2 = \cancel{144.93\ \text{Pa}}$ ✓

$= 134.93\ \text{Pa}$ ✓

$C_p =$ $\quad ds = a\,d\theta$, $\quad \delta = 90 - \theta$

Drag force $= \displaystyle\int_{-\pi/2}^{\pi/2} (P_2 - P_\infty)\, ds \cos\theta$



$= \displaystyle\int_{-\pi/2}^{\pi/2} (P_2 - P_\infty)\, a \cos\theta\, d\theta$

$= (P_2 - P_\infty)\, a \sin\theta \Big|_{-\pi/2}^{\pi/2}$

Drag $= 2a\,(P_2 - P_\infty)$

$= C_D \times q_\infty \times 2a$

$\cancel{C_D = \dfrac{2a}{q_\infty \times 2a}(P_2 - P_\infty)}$

$C_D = \displaystyle\int_0^{\pi/2} \left(\frac{P - P_\infty}{q_\infty}\right) \cos\theta\, d\theta$

$C_p = 2\sin^2\delta$ $\quad \delta = 90 - \theta$

$= 2\cos^2\theta$

$= \displaystyle\int_0^{\pi/2} 2\cos^3\theta\, d\theta$

$= 4/3$ ✓

M_1	$\sqrt{T_2/T_1}$	M_2	M_1
1.02.	1.0064	0.9805	1.73.
1.2.	1.06.	0.8422.	1.64.
1.4.	1.12.	0.7397.	1.58
1.5.	1.1489	0.7011	1.56
1.54	1.16	0.6874	1.55
1.56	1.167	0.6809	1.55

Ans. $M_1 = 1.55$, get $P_2/P_1 \Rightarrow P_2 = 26.5 P_1$

2. In a shock tube. (driver gas - air and driven gas air)
After the diaphragm ruptures, the shock moves into the driven section with a mach number of 3. pressure and temp of driven gas are 1 atm 300 K resp.
Press. and temp of driver gas 4420 kPa and 300K.
Calculate the driven gas temp after the diaphragm ruptured.
Assuming the driven section is open and driven section is very long. calculate the time for the tail of EF from the driver section to reach the open end of the driven section.
Length of the driven section = 5m.

→ N & OS → 2 cl... tutorial.

→ ~~...~~ Non newtonian → tutorial.

1. Air is expanded from a large reservoir in which the pressure and temp are 1 Mpa and 35°C through the variable area duct. A normal shock occurs at a point in the duct where the Mach number is 8. Find the pressure and temperature in the flow just downstream of the shock wave. Downstream of the shock wave, the flow is brought to rest in another large reservoir. Find the pressure and temp in the reservoir. Assume that flow is one-dimensional and isentropic everywhere except through the shock wave.

$P_0 = 1 MPa$, $T_1 = 35°C = 308 K$.

$M = 8$. $P_2 = ?$ $T_2 = ?$.

$$\frac{P_2}{P_1} = \frac{2\gamma}{\gamma+1}\left(M_1^2 \sin^2\beta\right)$$

for N.S. $\beta = 90°$

$\because M_1 \to \infty$.

$$= \frac{2 \times 1.4}{1.4+1} \times 8^2$$

$P_2 = 74.67 MPa$.

$\frac{P_{01}}{P_1} = \left(1 + 0.2 \times 8^2\right)^{1.4/(...)}$

$P_1 = 10.2 Pa$.

$P_2 = 7648 Pa$

$$\frac{T_2}{T_1} = \frac{2\gamma(\gamma-1)}{(\gamma+1)^2} M_1^2 \sin^2\beta$$

$$= \frac{2 \times 1.4 \times 0.4}{(2.4)^2} \times 8^2$$

$T_2 = 3832 K$.

$$\frac{P_{02}}{P_2} = \frac{1}{1 + \frac{\gamma-1}{2} M_2^2}$$

$$\frac{u_2}{v_1} = 1 - \frac{2\sin^2\beta}{(\gamma+1)}$$

$$= 1 - \frac{2}{2.4}$$

$$u_2 = 0.1667\, v_1$$

$$v_1 = M_1 a_1$$

$$= 8 \times \sqrt{1.4 \times 287 \times 303}$$

$$= 2814.3 \text{ m/sec}$$

$$u_2 = 469.14 \text{ m/sec}$$

$$M_2 = \frac{u_2}{a_2} = \frac{469.14}{\sqrt{1.4 \times 287 \times 3832}}$$

$$\boxed{M_2 = 0.378}$$

$$\cancel{\frac{P_{02}}{P_2}} =$$

$$T_{02} = T_2 + \frac{u_2^2}{2C_p}$$

$$= \cancel{5885.5\,k} \cdot 3941\, k.$$

$$\frac{P_{02}}{P_2} = \left(\frac{T_{02}}{T_2}\right)^{\gamma/\gamma-1}$$

(or)

Using hypersonic similarity parameter

$(K) = M\theta$.

$\Rightarrow$ Taking $M_1\theta_1 = M_2\theta_2 = K$.

$\therefore \frac{P_2}{P_1}$ depends on only K.

$K_1 = 12 \times \frac{10}{1} \times \frac{\pi}{180}$, $8 \times 20 \times \frac{\pi}{180}$

$= 2.094$

$K_1 = K_2$

$\frac{P_{2a}}{P_{\infty a}} = \frac{P_{2b}}{P_{\infty b}}$.

$7.262 = \frac{P_{2b}}{P_{\infty b}}$.

$\frac{P_{2b}}{P_{\infty b}} = \frac{2 \times 1.4}{2.4} \times 8^2 (\sin 18)^2$

$\theta = 1.2\theta$

$= 1.2 \times 15 = 18^\circ$

$= 7.13$.

$P_{2b} = P_{\infty b} \times 7.13$.

$P_{\infty b} = \frac{P_{\infty a}}{2} = \frac{0.6887}{2} = 0.3443$

$P_{2b} = 0.3443 \times 7.13$

$= 2.455 kPa$.

$P_{2b} = \frac{P_{1b}}{P_{1a}} \times P_{2a} = \frac{\rho_{\infty b} R T_{\infty b}}{\rho_{\infty a} R T_{\infty a}} \times P_{2a}$

$= 2500 Pa$.

iv) For $M = 3$, $\frac{T_2}{T_1} = 2.679$. get $a_2 = ?$

$T_2 = 803.7$ $a_2 = 568.27$ m/sec. $e_2 =$

2) Find a_3.

Find P_2/P_1 for $M = 3$, get P_2. Across contact surface $P_2 = P_3$.

ii) Analyse the driver side: Driver gas encountered an EF.
Any expansion (hyper (supersonic)) is isentropic.

$$\frac{P_4}{P_3} = \left(\frac{T_4}{T_3}\right)^{\gamma/\gamma-1} \qquad \gamma = 1.667$$

$$\frac{P_2}{P_1} = 10.333 \Rightarrow P_2 = 21 \times 100333$$

$P_2 = 2166.9933$ kPa.

$$\frac{\cancel{P_4}}{216.93} = \frac{T_4}{T_3} \qquad T_4 = 300 K$$

$$\frac{930}{216.933} = \left(\frac{300}{T_3}\right)^{\frac{1.667}{0.667}} \qquad R = \cancel{4157}\ 2078.5\ J/kg°K$$

$\boxed{T_3 = 167.5K}$ ~~$a_3 = 1077.37$~~.

$a_3 = \sqrt{\gamma R T_3} = 762$ m/sec.

~~e_2~~ $a_2 =$ $a_2 < a_3$, $\therefore$ There will be EF ✓.

01/02/

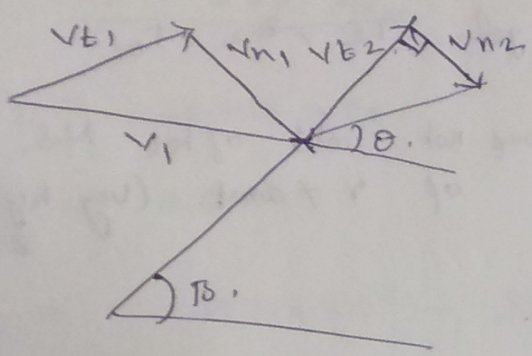
Tutorial

→ θ - β - M relations with $\gamma = 1.4$ not valid for real gas with varying γ.

→ solving problems with varying 'γ' value.

θ - β - V - relation.

$\theta = \checkmark$



$V_{t_2} = V_{t_1}$

$$\tan(\beta - \theta) = \frac{V_{n_2}}{V_{t_2}} = \frac{V_{n_2}}{V_{t_1}} = \frac{V_{n_2}}{V_{n_1}} \tan\beta.$$

$$\tan(\beta - \theta) = \frac{V_{n_2}}{V_{n_1}} \tan\beta..$$

$$p_1 + \rho_1 u_{n_1}^2 = p_2 + \rho_2 u_{n_2}^2$$

$$h_1 + \frac{u_{n_1}^2}{2} = h_2 + \frac{u_{n_2}^2}{2}$$

$$p = \rho z R T$$

For total quantities

$h_{01} = h_{02}$ for equillibrium flows.

1) Correspond h_2, P_2 get $\frac{s_2}{R}$ from charts.

$$\frac{P_{01}}{P_1} = \left(\frac{T_{01}}{T}\right)^{\gamma/\gamma-1}$$

2) get h_{01} from previous cal.
~~mach~~ match. $h_{02} = h_{01}$ and get P_{02}

3) From P_{02} & h_{02} get ~~T_2, Z_2~~ T_{02}.

Isentropic relations does not hold after N.S.
use only charts as $\gamma \neq$ const. (Very high!
$Z >$ 1

4) $$C_p = \frac{P_{02} - P_1}{\frac{\gamma}{2} P_1 M_1^2}$$

8th quez.