2024-2025 Spring
AE306 PH-1

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11.04.2025

P1- Air in a freestream flow has a temperature of 37 °C and density of 0.83 kg/m^3. Mach number for this flow is given as 3.4. Treating the air as a calorically perfect gas, find the following properties:

a) Internal energy per unit mass, e. (Ans. 222 425 J/kg.K)
b) Enthalpy per unit mass, h. (Ans. 311 395 J/kg.K)
c) Air speed, V. (Ans. 1200 m/s)
d) Total (stagnation) temperature, T_o. (Ans. 1026.77 K)
e) Ratio of kinetic energy to internal energy. (Ans. 3.237)

Take specific heat ratio of the air as 1.4.

P2- Imagine you are flying through the Martian atmosphere in a spacecraft with an indicated airspeed of 538 m/s. If a normal shock is expected to form in front of your spacecraft, calculate the following using the given atmospheric conditions on Mars.

a) Upstream static and stagnation properties.

b) Downstream static and stagnation properties.

On 10.04.2025, at the equator of Mars and 1000 m of altitude, following atmospheric properties are shared [1] :

Temperature (C): -58

Pressure (Pa): 542.96

Molecular weight for Mars atmosphere, $\mathscr{M}$ (g/mol): 43.51

Air heat capacity, Cp (J / kg.K) : 766.202

$M_1 = ?\ (Ans.\ 2.3)$	$M_2 = ?\ (Ans.\ 0.5225)$
$p_1 = 542.96$ Pa	$p_2 = ?\ (Ans.\ 3204.1$ Pa$)$
$\rho_1 = ?\ (Ans.\ 0.0132\ kg/m^3)$	$\rho_2 = ?\ (Ans.\ 0.0434\ kg/m^3)$
$T_1 = -58\ C$	$T_2 = ?\ (Ans.\ 113.43\ C)$
$p_{o,1} = ?\ (Ans.\ 6807.34\ Pa)$	$p_{o,2} = ?\ (Ans.\ 3827.9\ Pa)$
$\rho_{o,1} = ?\ (Ans.\ 0.0882\ kg/m^3)$	$\rho_{o,2} = ?\ (Ans.\ 0.0496\ kg/m^3)$
$T_{o,1} = ?\ (Ans.\ 130.8\ C)$	$T_{o,2} = ?\ (Ans.\ 130.8\ C)$

[1] Based on the Mars Climate Database Calculations: https://www-mars.lmd.jussieu.fr/mcd_python/

P2- On 10.04.2025, at the equator of Mars and 1000 m of altitude, following atmospheric properties are shared :

Temperature (C): -58
Pressure (Pa): 542.96
R:Molecular weight of Mars atmosphere (g/mol): 43.51
Air heat capacity Cp (J / kg.K) : 766.202

Question: Are the equations we derived for the calorically perfect gasses still valid in Mars atmosphere?

$$\frac{T_0}{T} = 1 + \frac{\gamma - 1}{2} M^2$$

$$\frac{p_0}{p} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\gamma/(\gamma-1)}$$

$$\frac{\rho_0}{\rho} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{1/(\gamma-1)}$$

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

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

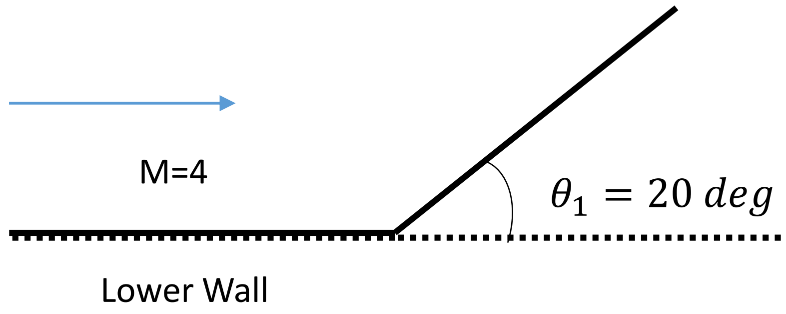
$$\frac{\rho_2}{\rho_1} = \frac{u_1}{u_2} = \frac{(\gamma + 1) M_1^2}{2 + (\gamma - 1) M_1^2}$$

$$\frac{T_2}{T_1} = \frac{h_2}{h_1} = \left[1 + \frac{2\gamma}{\gamma + 1}(M_1^2 - 1)\right] \frac{2 + (\gamma - 1) M_1^2}{(\gamma + 1) M_1^2}$$

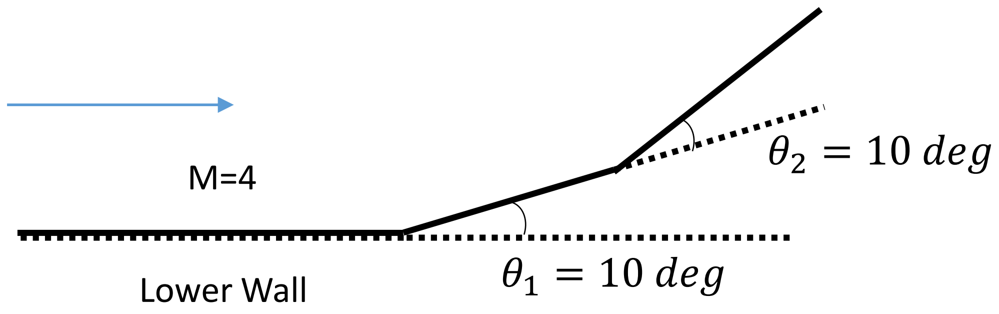
P3- An experimental aircraft with its Pitot Tube located at the nose is performing a flight test for the calibration purposes. Based on the information provided from the flight computer:

a) Find the expected pitot reading if M=0.48 at a freestream pressure of 1 atm. (Ans. 1.1708 atm)
b) Find the expected pitot reading if M=2.33 at a freestream pressure of 0.76 atm. (Ans. 5.6787 atm)
c) Compare the dynamic pressures for these two readings with the dynamic pressures that would be erroneously obtained using incompressible flow assumptions (i.e., Bernoulli's equation).
(Ans. @M=0.48 $q_{\infty,comp} = 16341.7\ Pa$ and $q_{\infty,incomp} = 17306.31\ Pa$ with 5.9% of error.
Ans. @M=2.33 $q_{\infty,comp} = 292644\ Pa$ and $q_{\infty,incomp} = 498389\ Pa$ with 70% of error.)

P4- Two different cases of corner flow are desired to be investigated. In the first case, airflow turns a sharp corner with a 20^o deflection angle as shown in Figure 1a. In the second case, there are two 10^o corners to provide a gradual turn for the flow as it is shown in Figure 1b. For a freestream Mach number of 4 and a pressure value of 0.75 atm, compare the loss in total pressure at the vicinity of the downstream wall for two cases. Neglect shock interactions and assume an inviscid flow.
(Ans. $\Delta p_o = 39.731\ atm$ for case 1 and $\Delta p_o = 11.84\ atm$ for case 2. Case 2 is more efficient.)

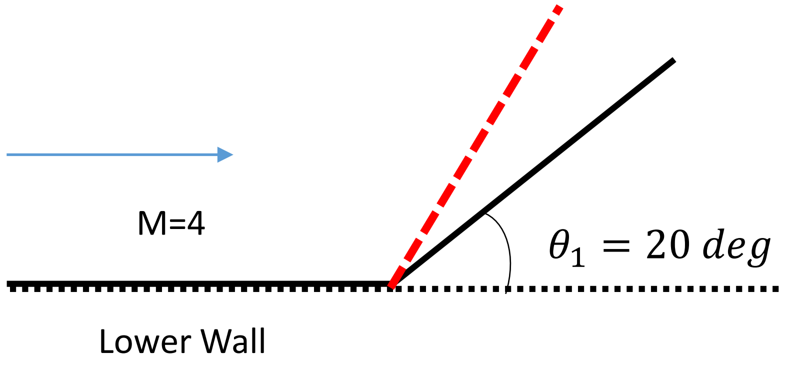


a) Case 1

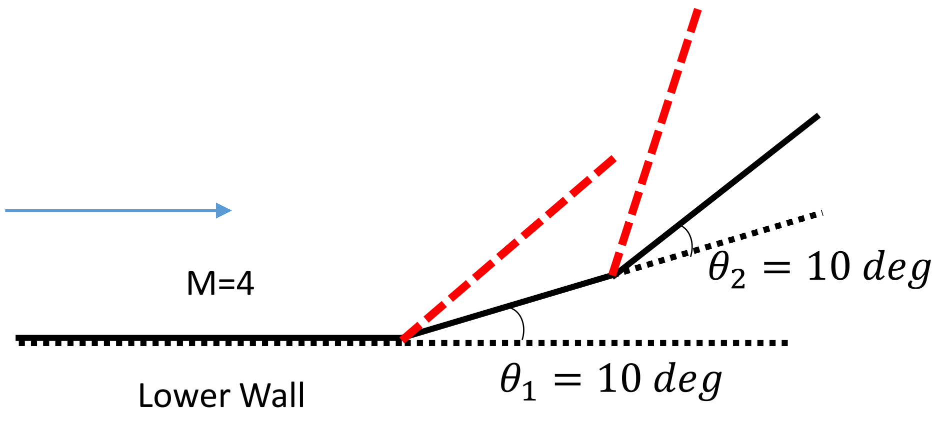


b) Case 2

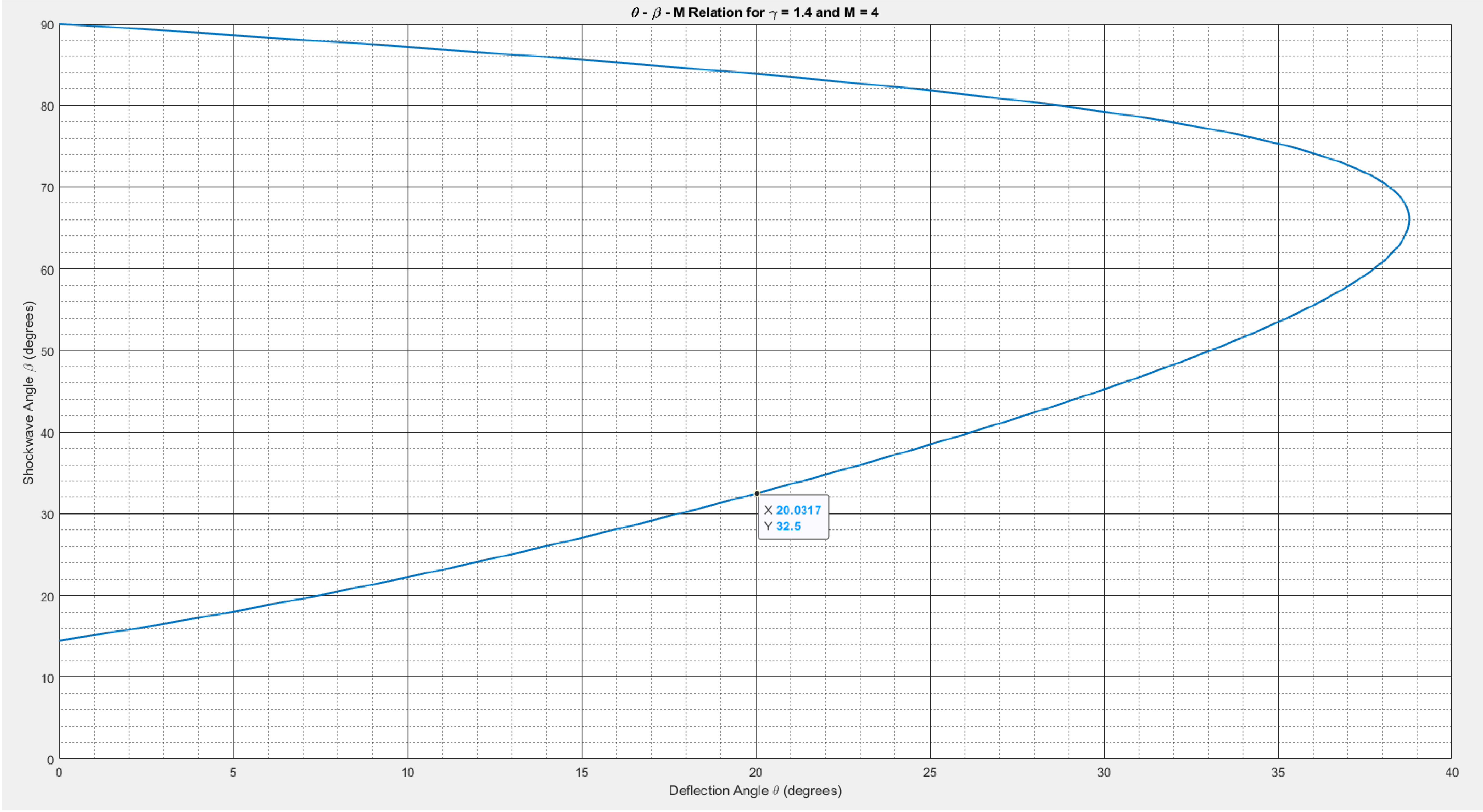
P4-

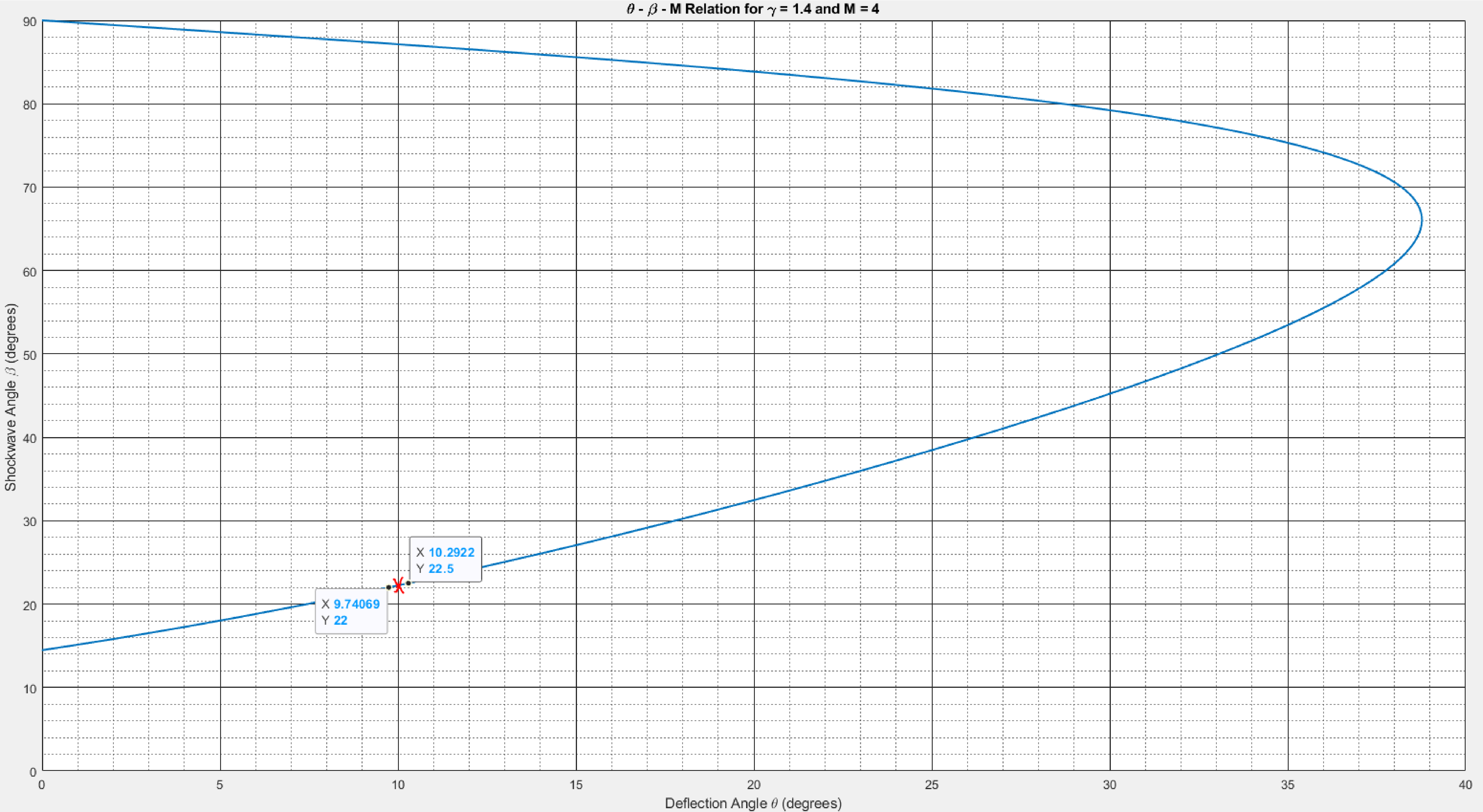


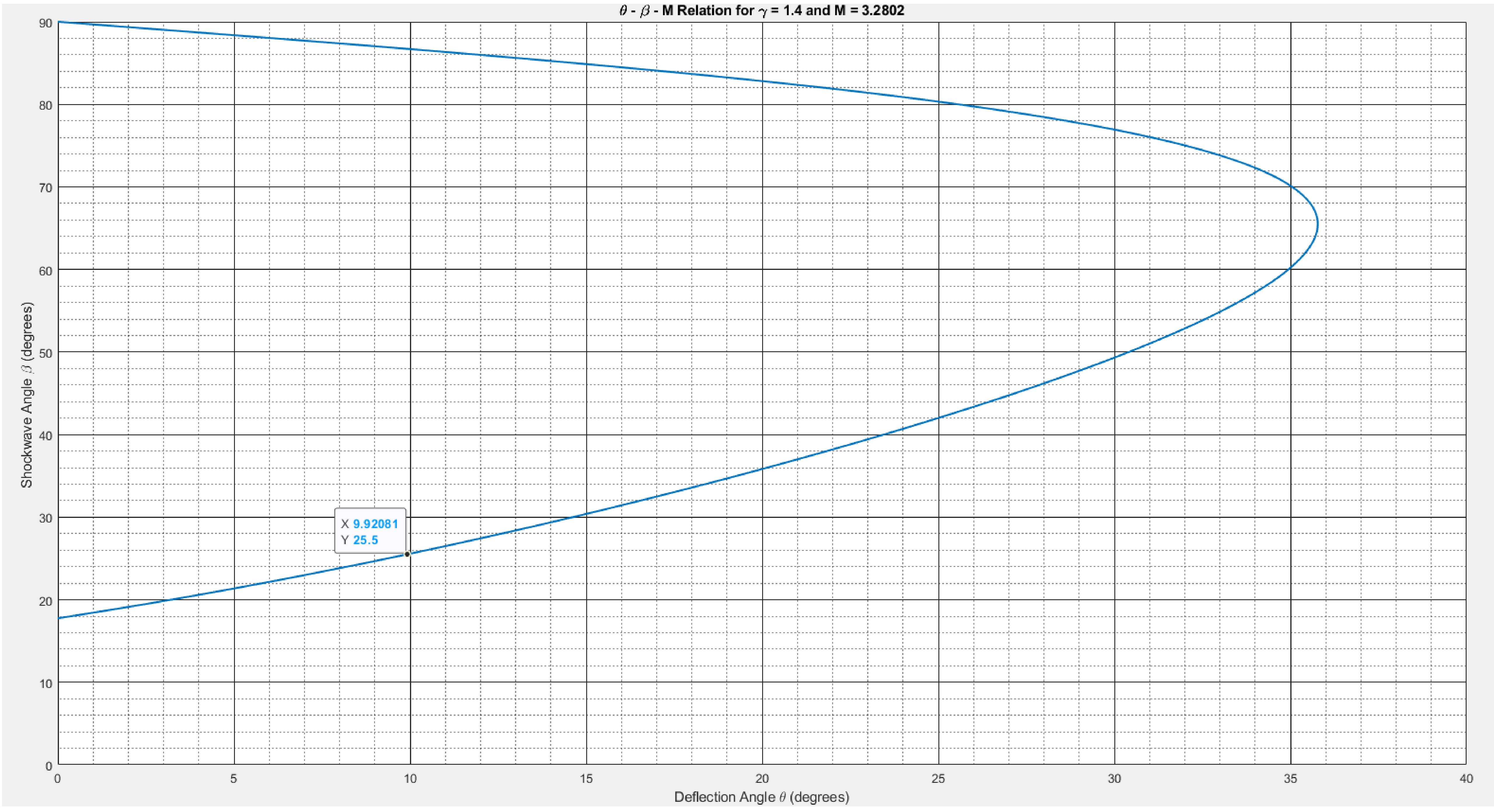
a) Case 1



b) Case 2


θ - β - M Relation for γ = 1.4 and M = 4
Shockwave Angle β (degrees)
Deflection Angle θ (degrees)
X 20.0317
Y 32.5
0
10
20
30
40
50
60
70
80
90
0
5
10
15
20
25
30
35
40


θ - β - M Relation for γ = 1.4 and M = 4
Shockwave Angle β (degrees)
Deflection Angle θ (degrees)
X 10.2922
Y 22.5
X 9.74069
Y 22
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
80
90

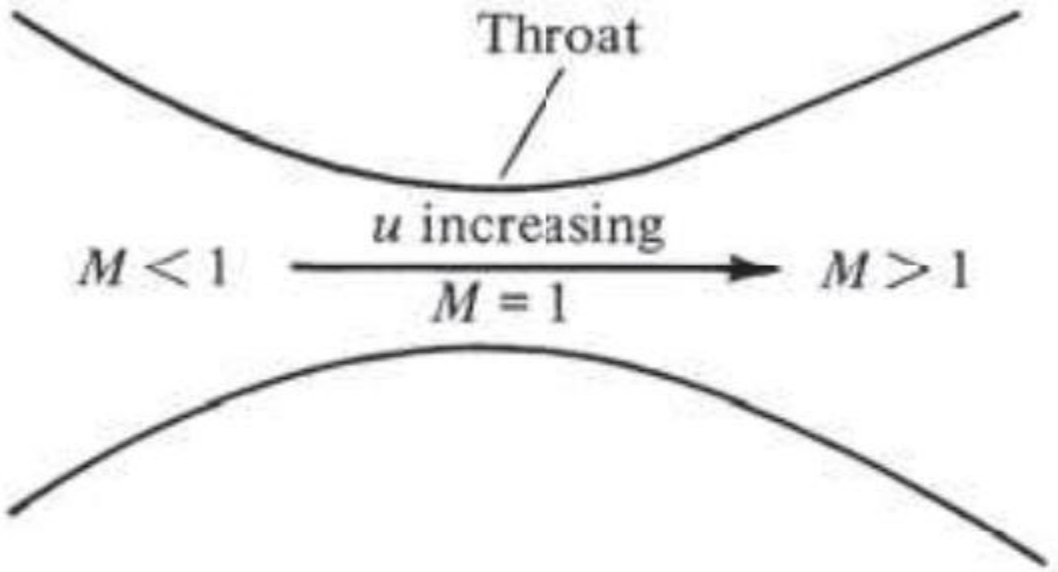


θ - β - M Relation for γ = 1.4 and M = 3.2802
Shockwave Angle β (degrees)
Deflection Angle θ (degrees)
X 9.92081
Y 25.5
0
10
20
30
40
50
60
70
80
90
0
5
10
15
20
25
30
35
40

P5- A thin plate is travelling with a freestream Mach value of 3.2 at 3° of angle of attack. Find the lift and drag coefficients for this plate using Shock-Expansion Theory. (Ans. $C_l = 0.09$ $C_d = 0.0046$)

P6- Consider the isentropic expansion of air in a nozzle flow. Throat area of the nozzle is given as 2.12 m2. If the measured density and temperature at the throat are given as 0.372 kg/m3 and 254 K, respectively, find;

a) The area of the point where M=0.3 (Ans. 4.3143 m2)
b) The area of the point where M=3.4 (Ans. 13.11 m2)
c) Mass flow per second through the nozzle (HW). (Ans. 252.02 kg/s)



Thanks for listening.

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or by visiting my office: HUBF/Room 105