AS6060 - Shockwave Dynamics

Assignments

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AE21B108
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- 1.] Solve the RR and MR using two-shock and three-shock theory using Mach number relations.

- The flow properties have been found using two-shock and three-shock theory. The following shows the code results.
- For an RR: $M_0 = 3, \theta_1 = 20°$.

```
revadhillon@Revas-MacBook-Air Semester5 % python3 Assignment_1.py
Mach number:3
Turn angle should be lesser than or equal to: 34.073439775606 degrees.
Turn angle:20
Pressure:100
Temperature:100
Density:10


M1:1.9941316655645582
P1:377.12574630826623
T1:155.9617301620383
p1:24.180659314079612

M2:1.2037175733083607
P2:1071.612355236284
T2:217.09007513876827
p2:49.362567798241756
revadhillon@Revas-MacBook-Air Semester5 %
```

- For an MR: $M_0 = 3, \theta_1 = 30°$.

```
revadhillon@Revas-MacBook-Air Semester5 % python3 Assignment_1.py
Mach number:3
Turn angle should be lesser than or equal to: 34.073439775606 degrees.
Turn angle:30
Pressure:100
Temperature:100
Density:10


M1:1.405933969110253
P1:635.5884169515928
T1:200.66936634093736
p1:31.67341525720112

M2:1.046063213418639
P2:1010.0392485670454
T2:229.7248066340997
p2:43.96735656745213
θ_2:8.610303534043519

M3:0.5507760342327158
P3:1010.0392485295183
T3:263.98387448286445
p3:38.26139950813857
θ_3:21.38969646595648
revadhillon@Revas-MacBook-Air Semester5 %
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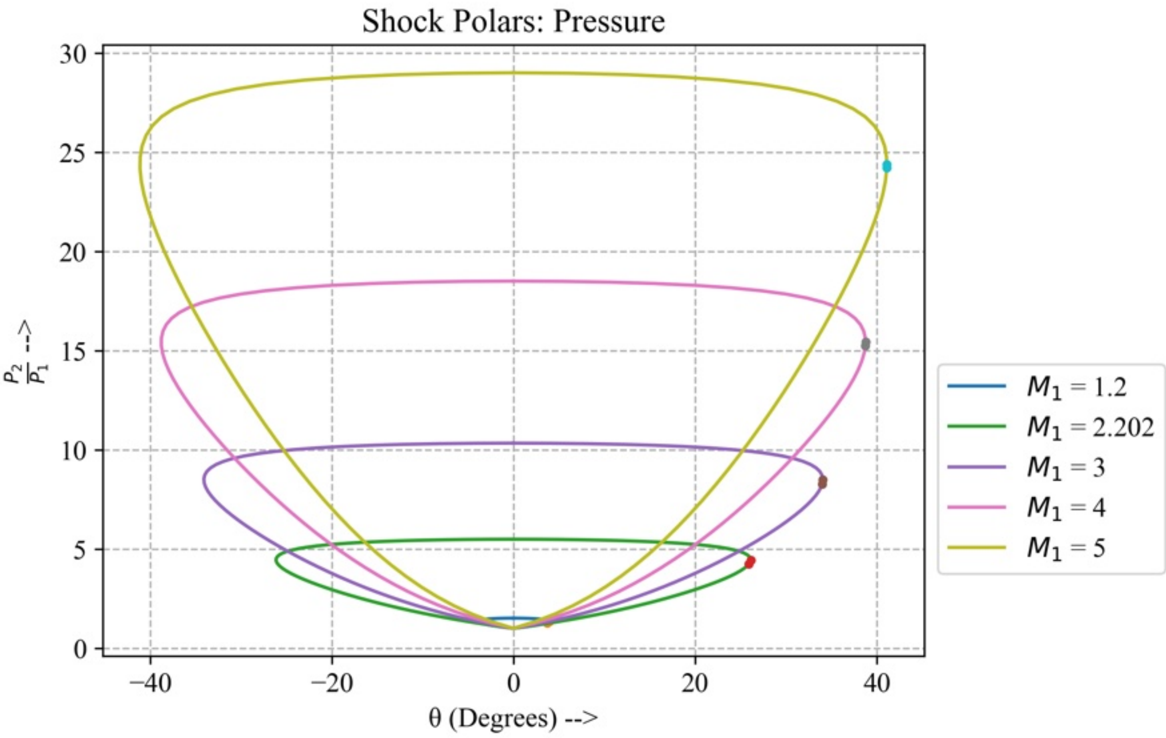
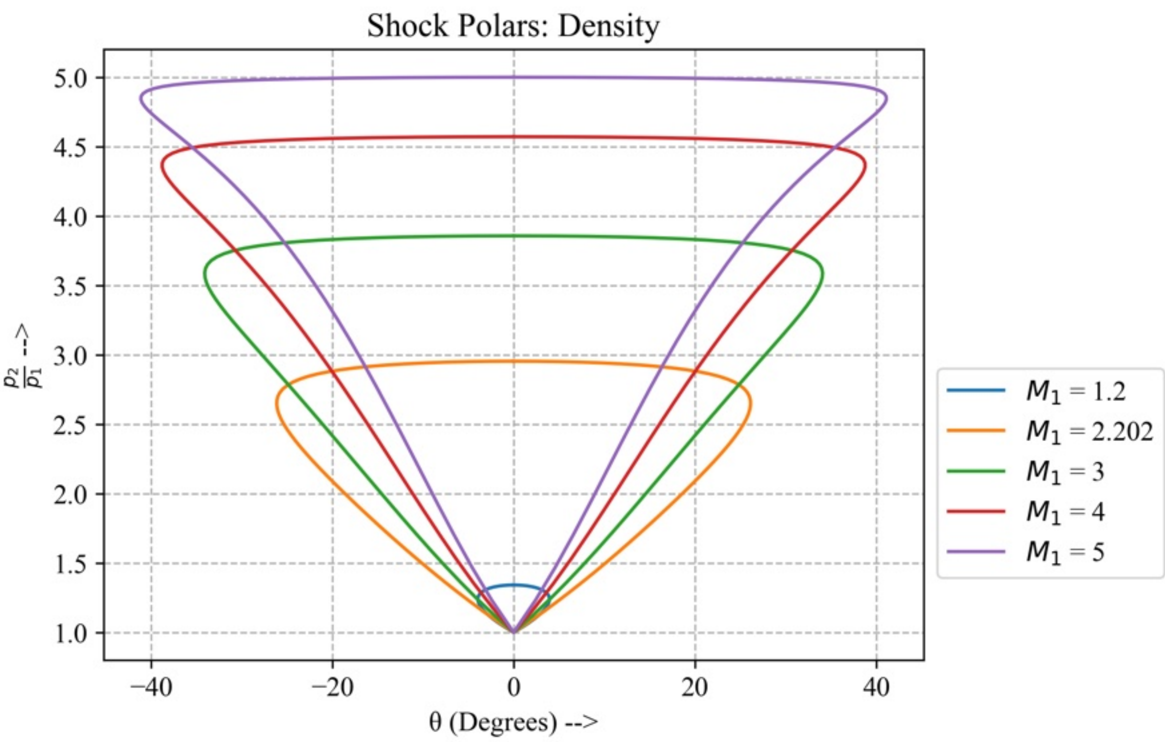
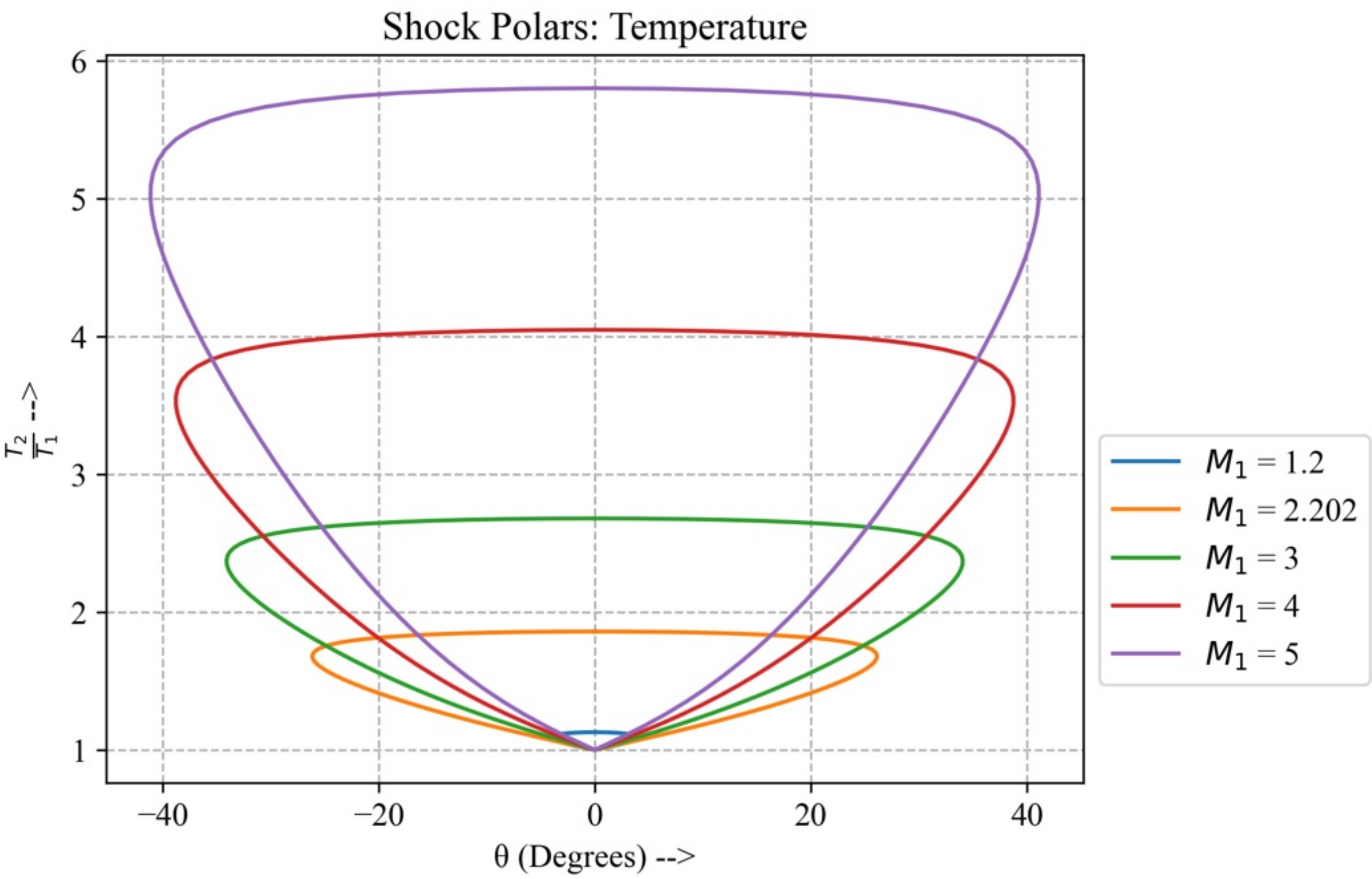
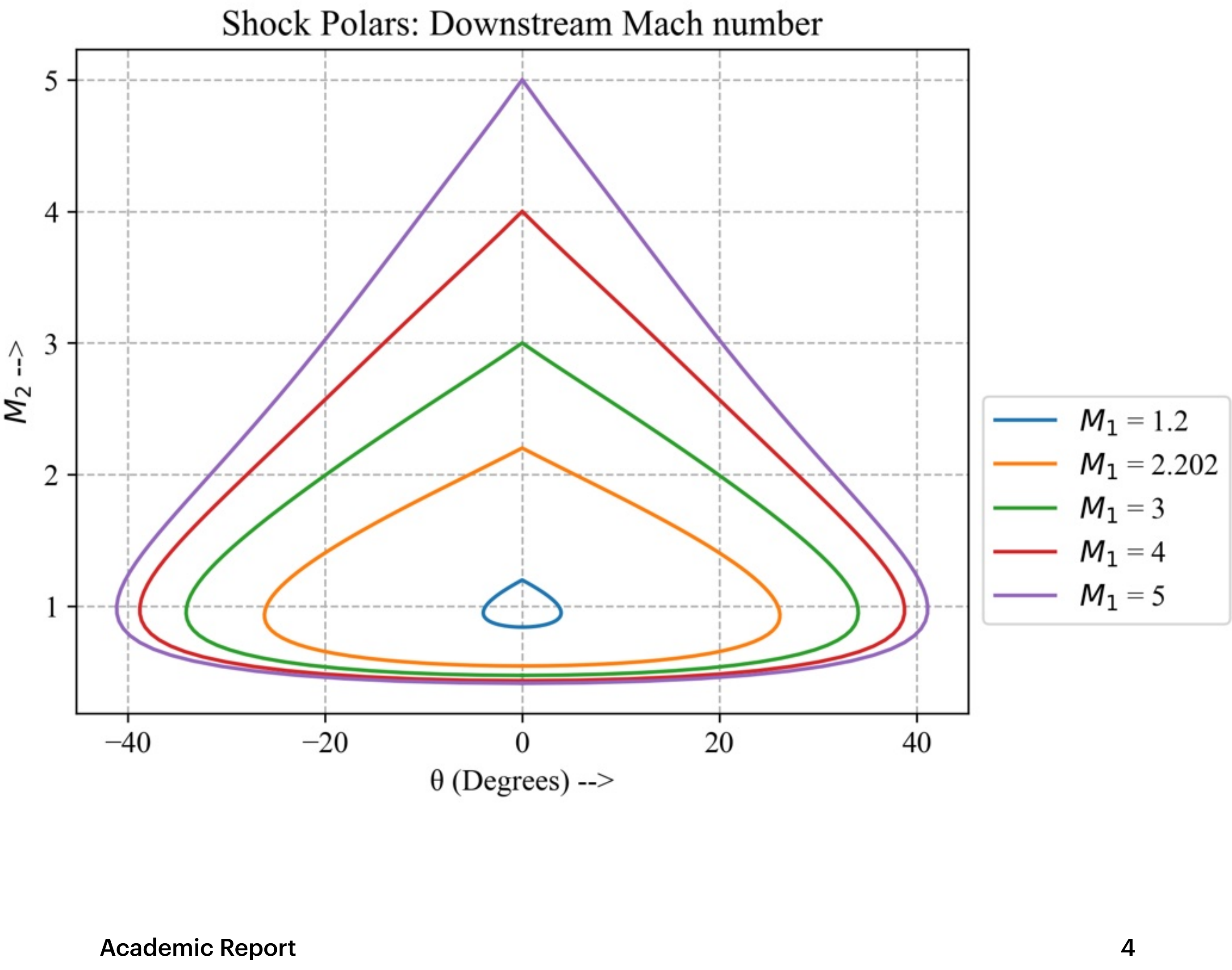
○ 2.] Draw shock polars (pressure, density, temperature, downstream Mach number) for various Mach numbers.



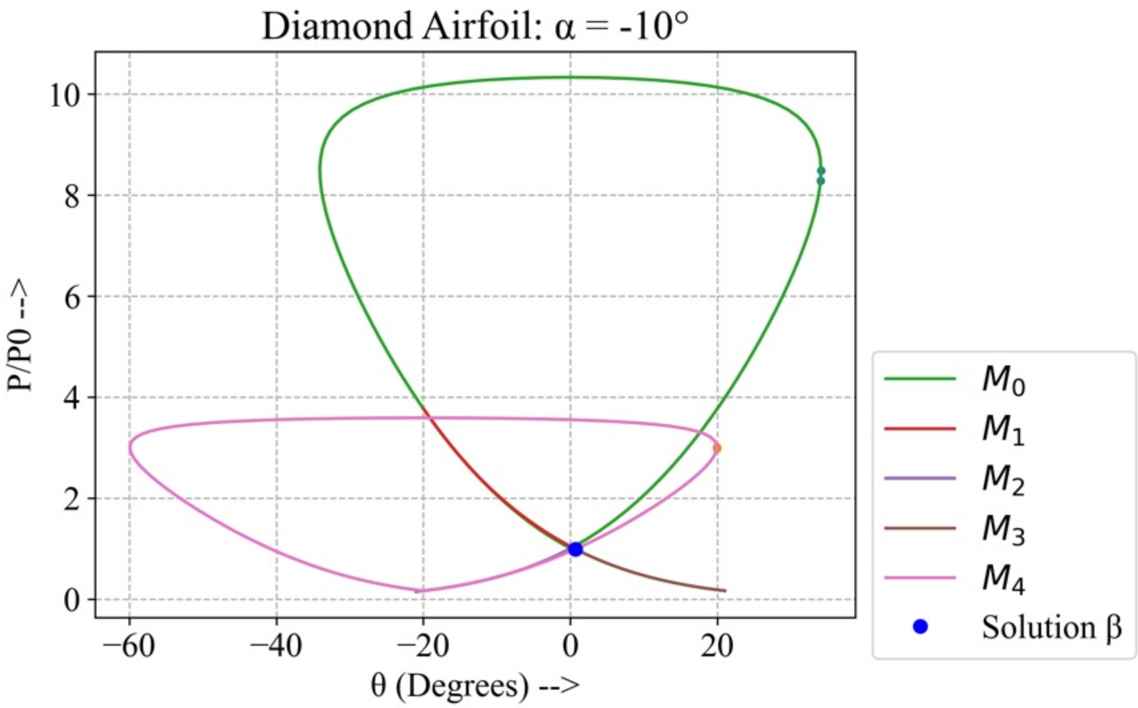



Shock Polars: Temperature
$\frac{T_2}{T_1}$ -->
θ (Degrees) -->
M_1 = 1.2
M_1 = 2.202
M_1 = 3
M_1 = 4
M_1 = 5

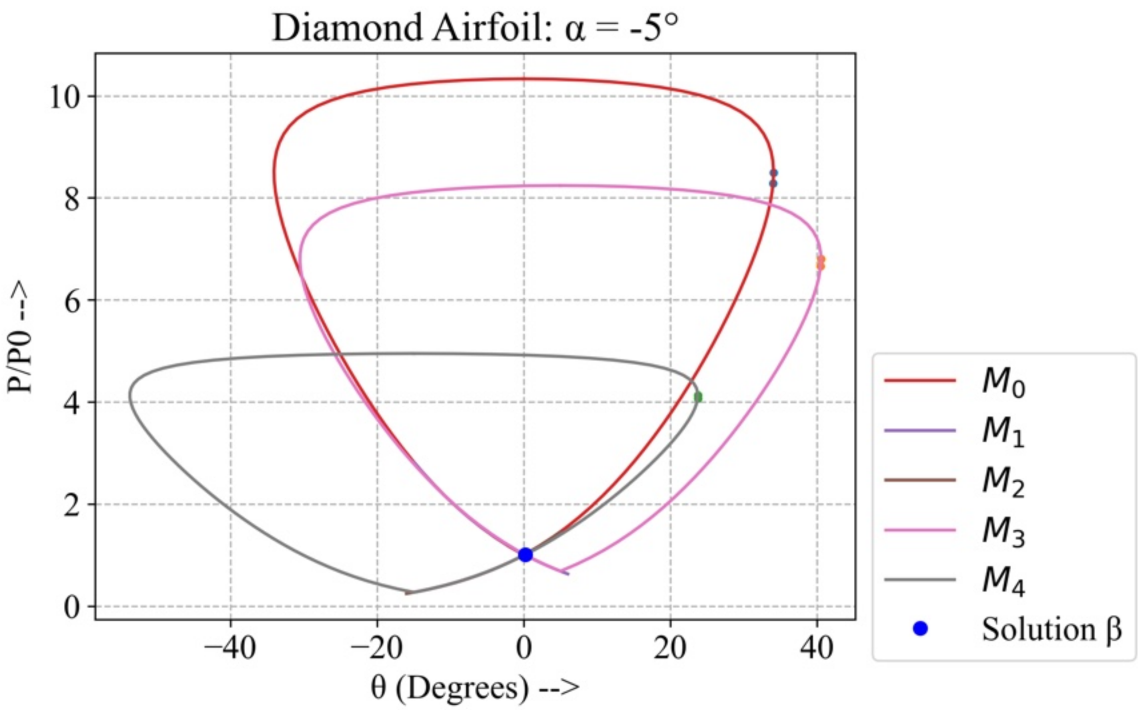

Shock Polars: Downstream Mach number
M_2 -->
θ (Degrees) -->
M_1 = 1.2
M_1 = 2.202
M_1 = 3
M_1 = 4
M_1 = 5

○ 3.] Using shock polar solutions, find the flow deflection angle β at the trailing edge of a symmetric diamond airfoil for angles of attack (0, 5, 10, -5, -10). $\theta = 10°$. The flow deflection angle β has been taken positive clockwise.

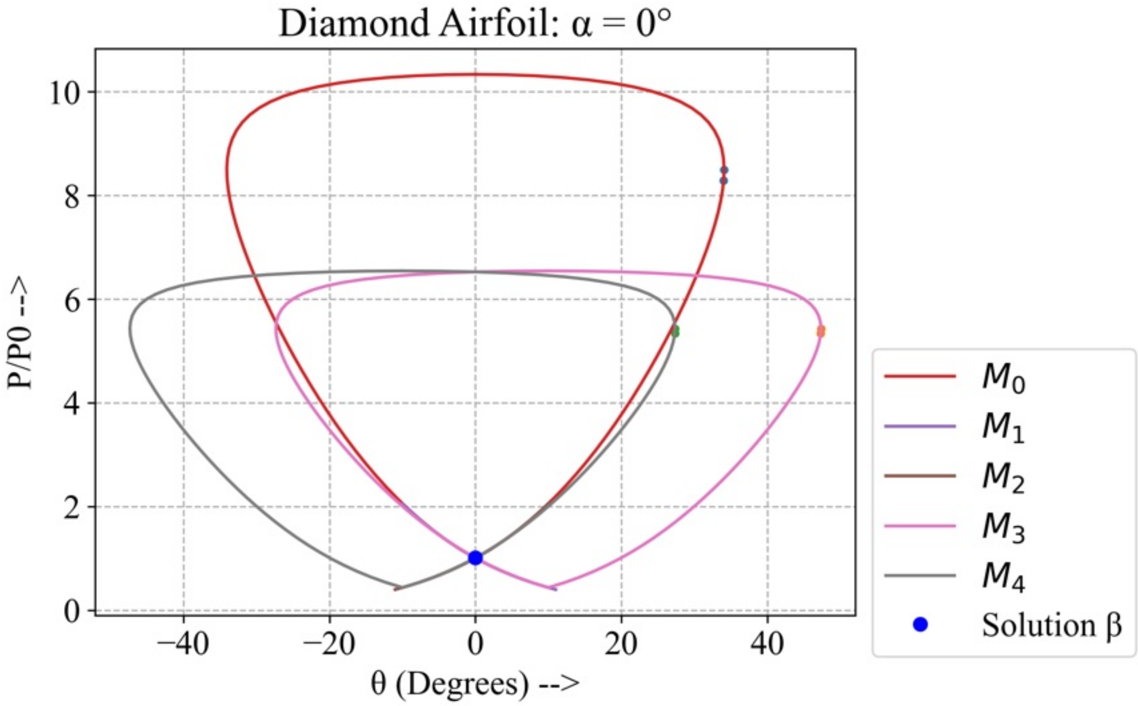
- $\alpha = -10°, \beta = 0.6965°$:



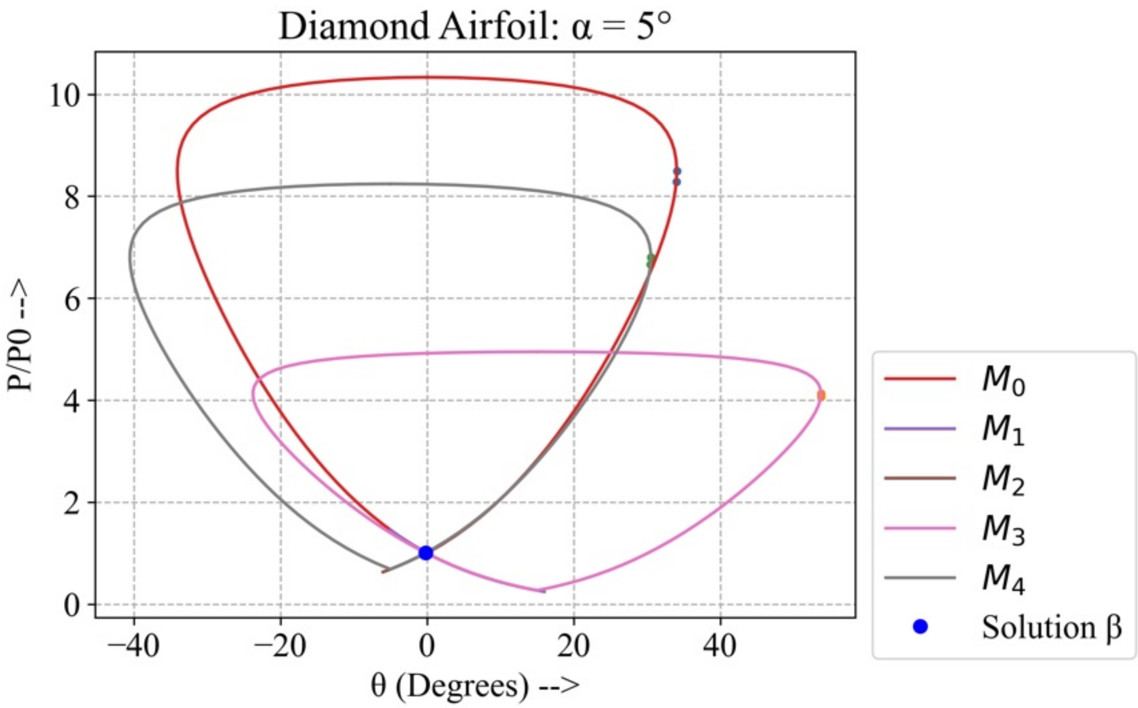
- $\alpha = -5°, \beta = 0.1933°$:



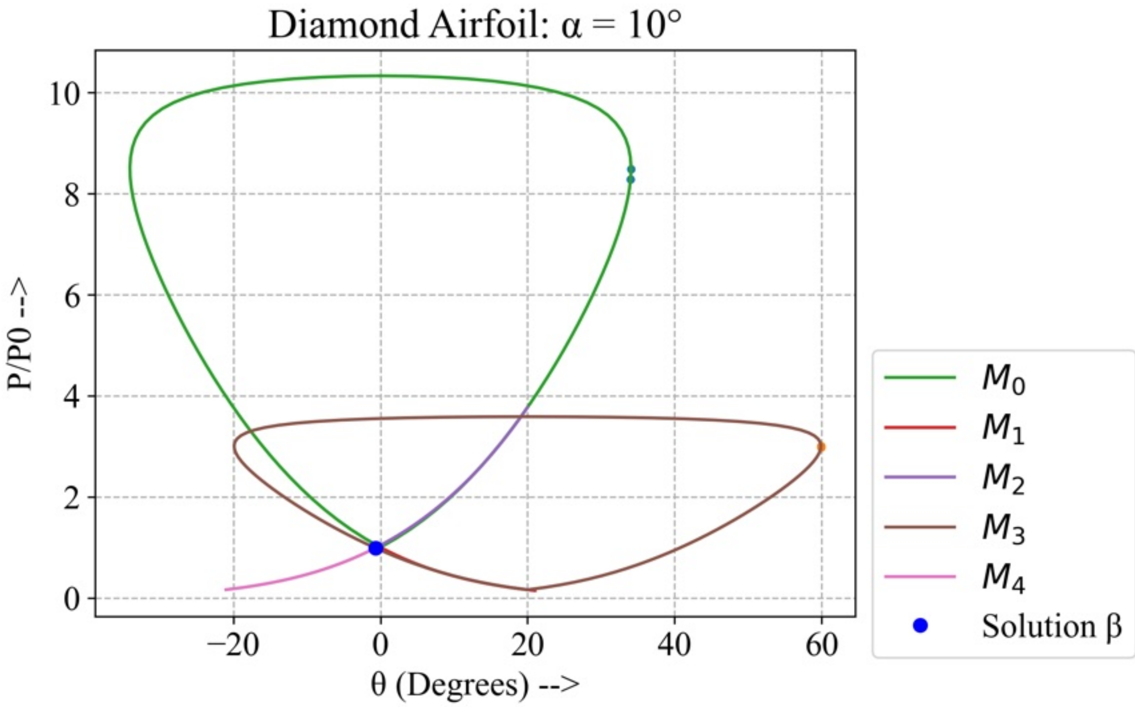
- $\alpha = 0°, \beta = 0°$:



- $\alpha = 5°, \beta = -0.1933°$:

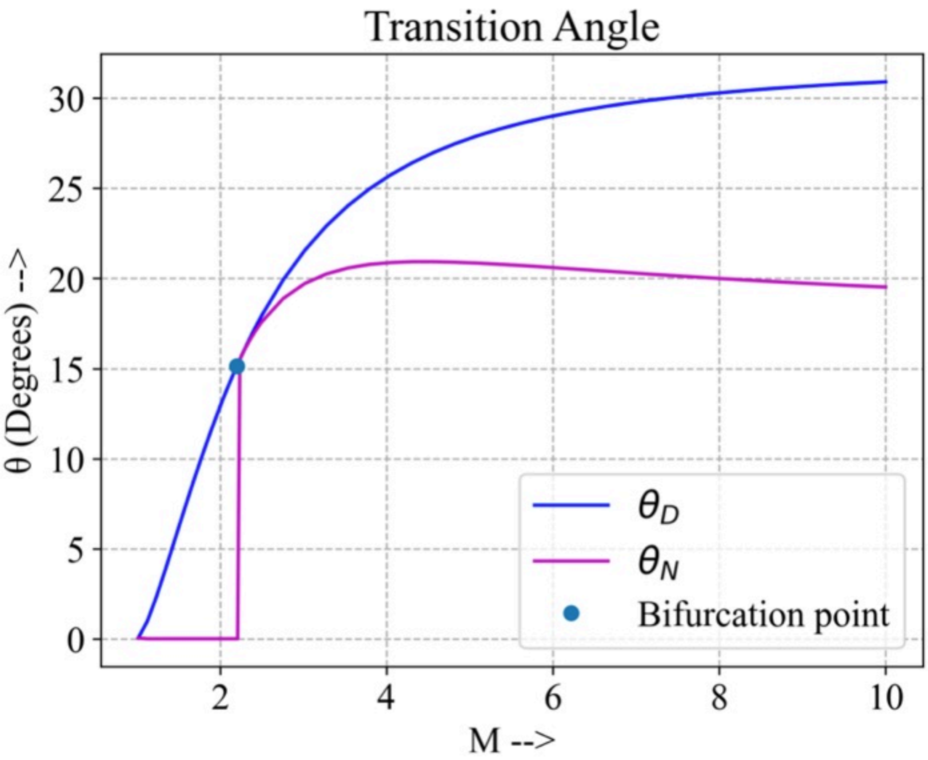


- $\alpha = 10°, \beta = -0.6965°$:



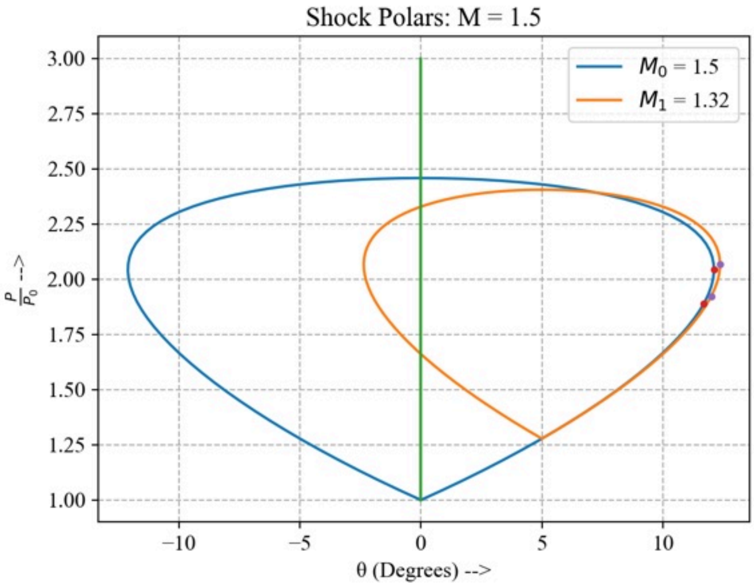
- 4.] Plot the dual solution domain for steady symmetric wedge angle variation induced RR-MR and MR-RR transitions – identify the Mach number where the curves bifurcate. Why is von Neumann condition not existing below this Mach number? Prove with the help of shock polars.

- The following graph shows that the bifurcation point is at M = 2.202.
- Below this Mach number, the von Neumann condition does not exist. We see $\theta_N = 0°$ due to variable initialisation in the code.

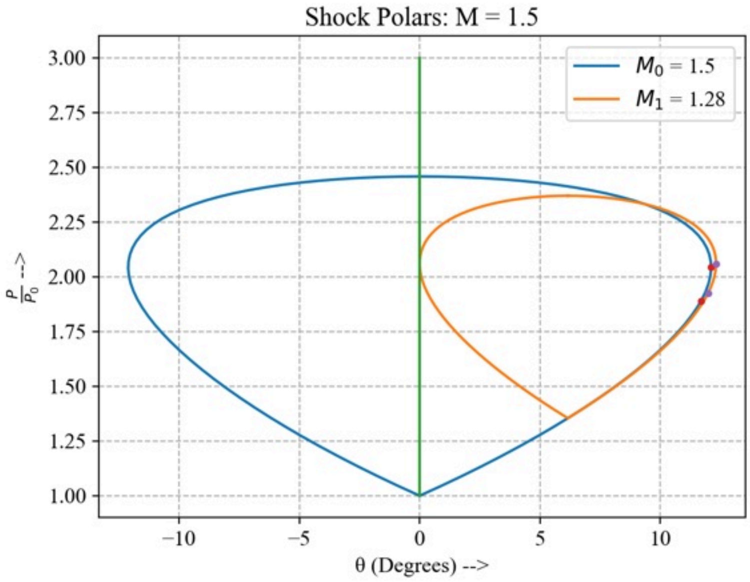


- Reason: For von Neumann condition to exist, there must be a turning angle such that the point of intersection of the incident and reflected polars coincides with the normal shock solution of the incident polar. For M < 2.202, this is not possible.

- Consider the shock polars for Mach 1.5. It can be observed that as the turning angle is varied, the reflected polar satisfies the detachment criterion. However, the von Neumann condition is not possible as the reflected polar never coincides with the normal shock solution of the incident polar.

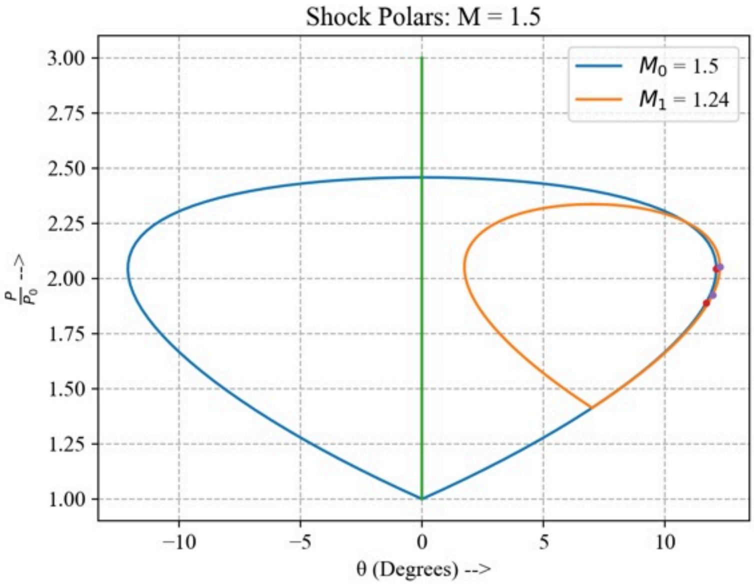


$\theta = 5^{\circ}$



Detachment criterion

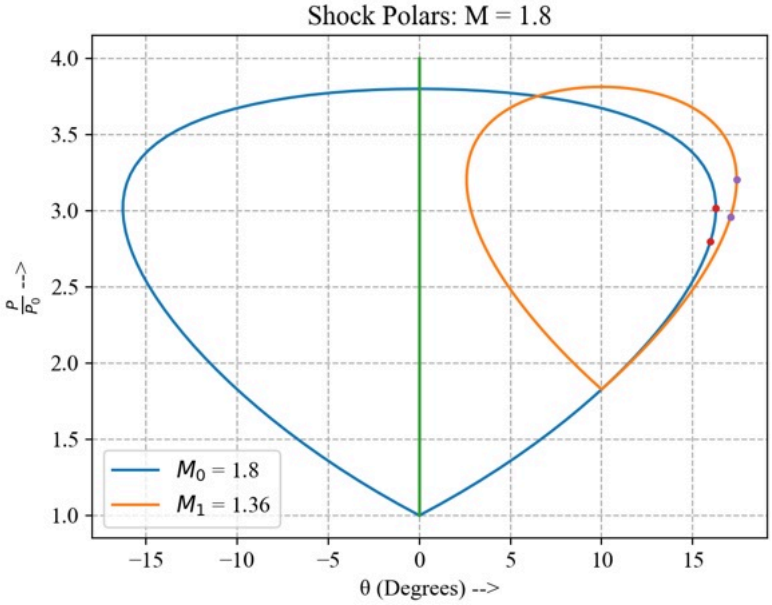
$\theta = 6.159^{\circ}$



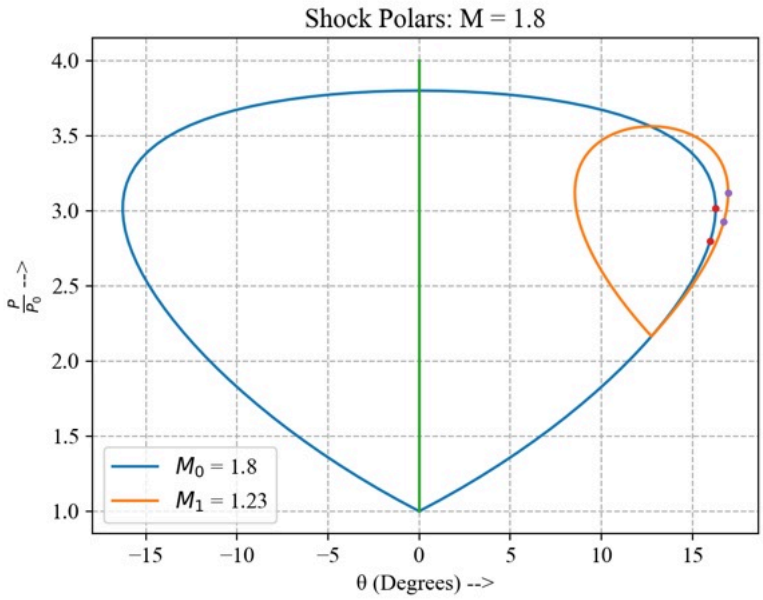
$\theta = 7^{\circ}$

○ 5.] Draw the shock polar solutions for various reflections in Weak Mach Reflection domain.

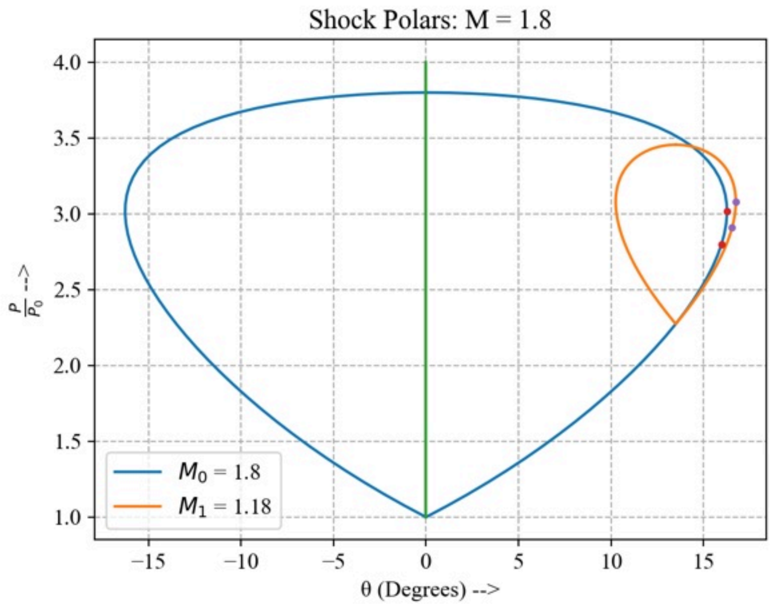
- Simple MR = SMR:



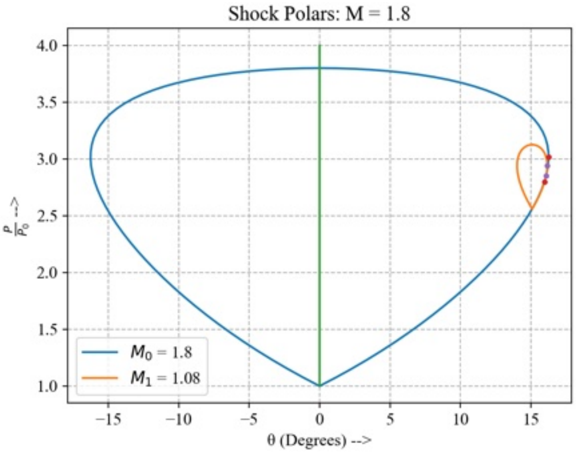
- SMR ⇌ vNR:

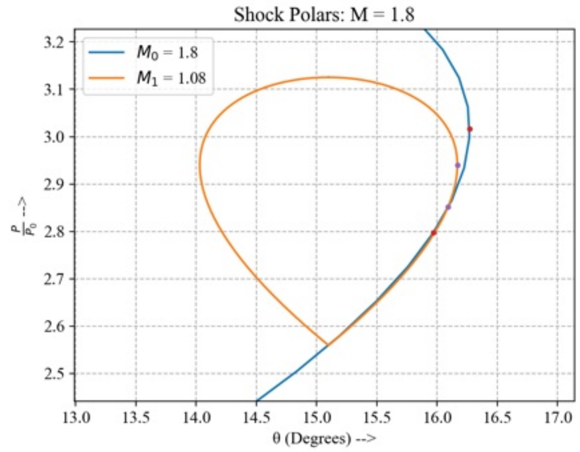


- vNR:

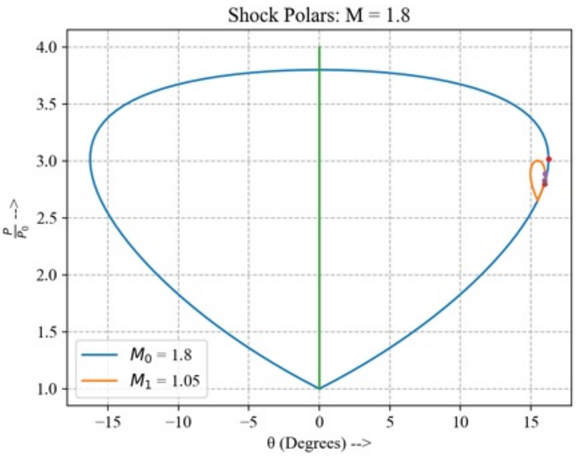


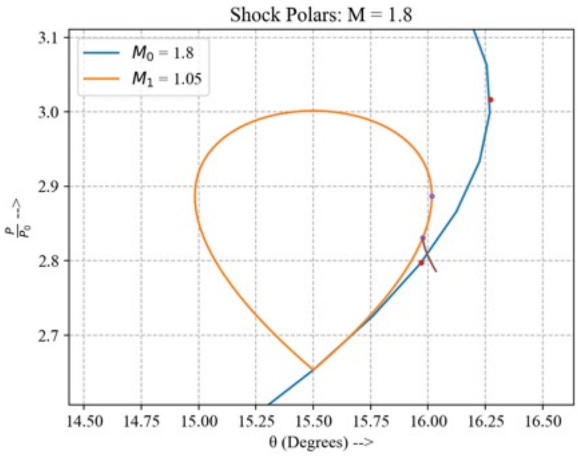
- vNR ⇌ VR:



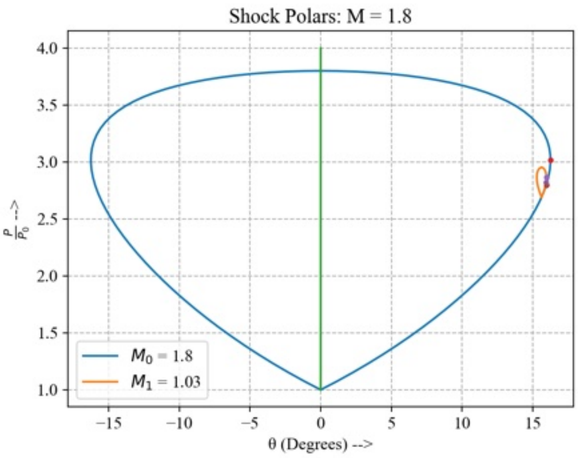


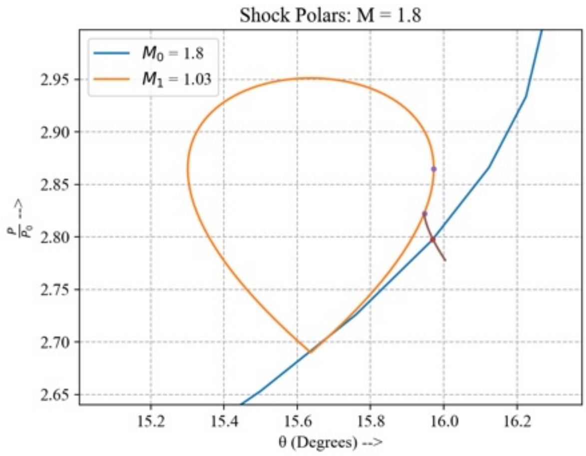
- VR:



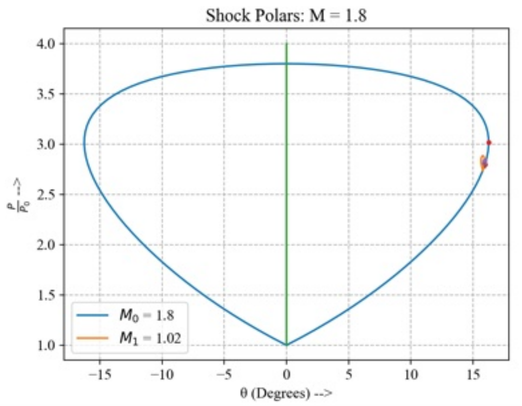


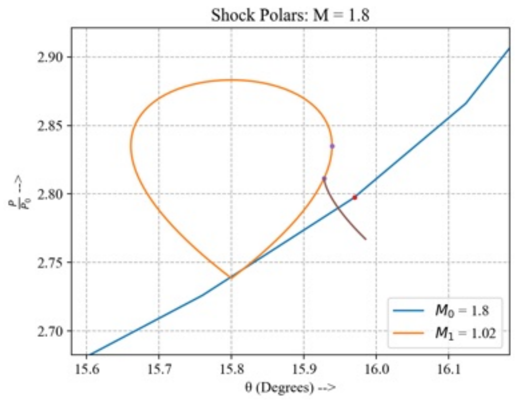
- VR ⇌ GR:





- GR:

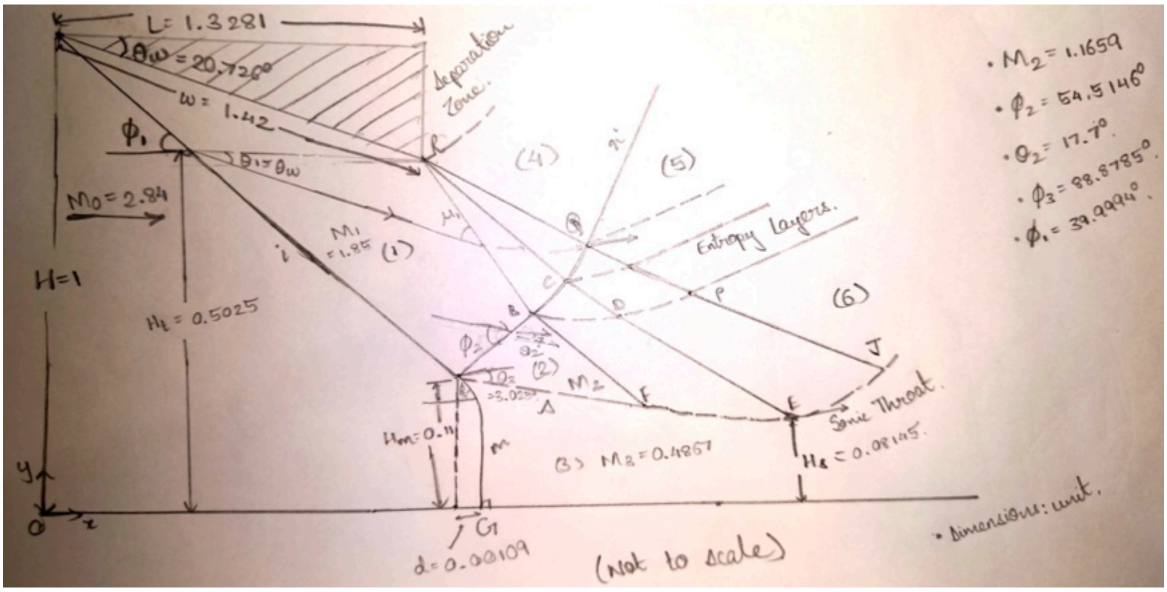

Shock Polars: M = 1.8
M_0 = 1.8
M_1 = 1.02
θ (Degrees) -->
$\frac{p}{p_0}$ -->


Shock Polars: M = 1.8
M_0 = 1.8
M_1 = 1.02
θ (Degrees) -->
$\frac{p}{p_0}$ -->

- 6.] Calculate the Mach stem size using Li & Bendor's method & Mouton and Hornung Methods for any arbitrary value of M, θ_w. The solution should contain dimensioned schematic and shock polar. For any arbitrary Mach number, Vary the θ_w and predict the von-Neumann condition with Mach stem size (Mach stem size becomes zero) draw the corresponding shock polar also for which Mach stem height shrinks to zero.

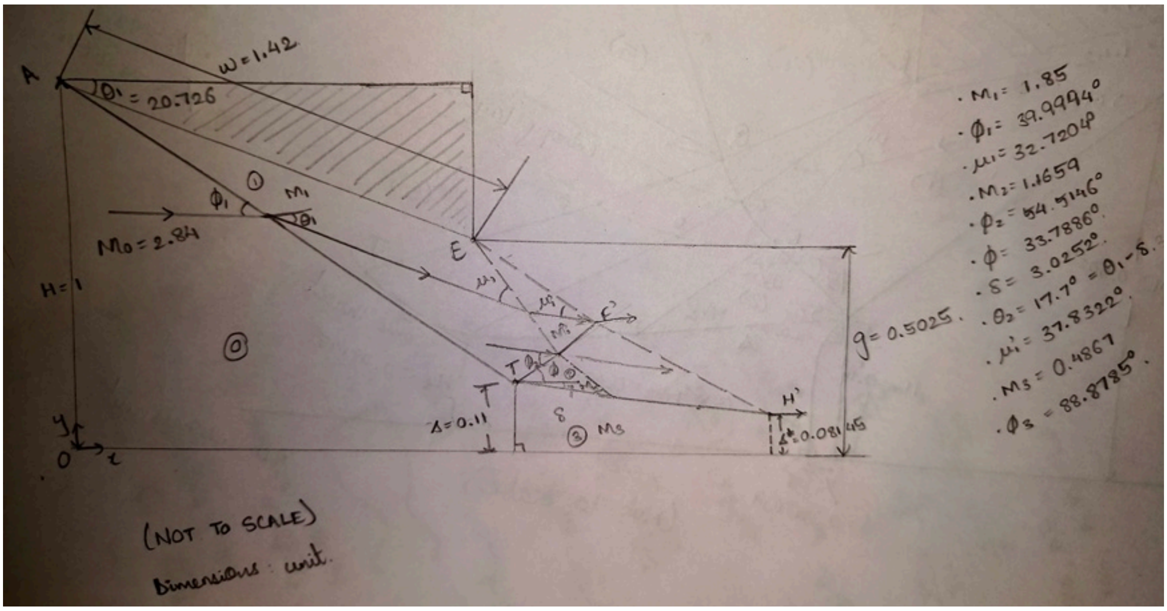
- The shock polar solution is obtained from three-shock theory. Hence, the shock polars are the same for both methods.
- Li and Bendor's method:

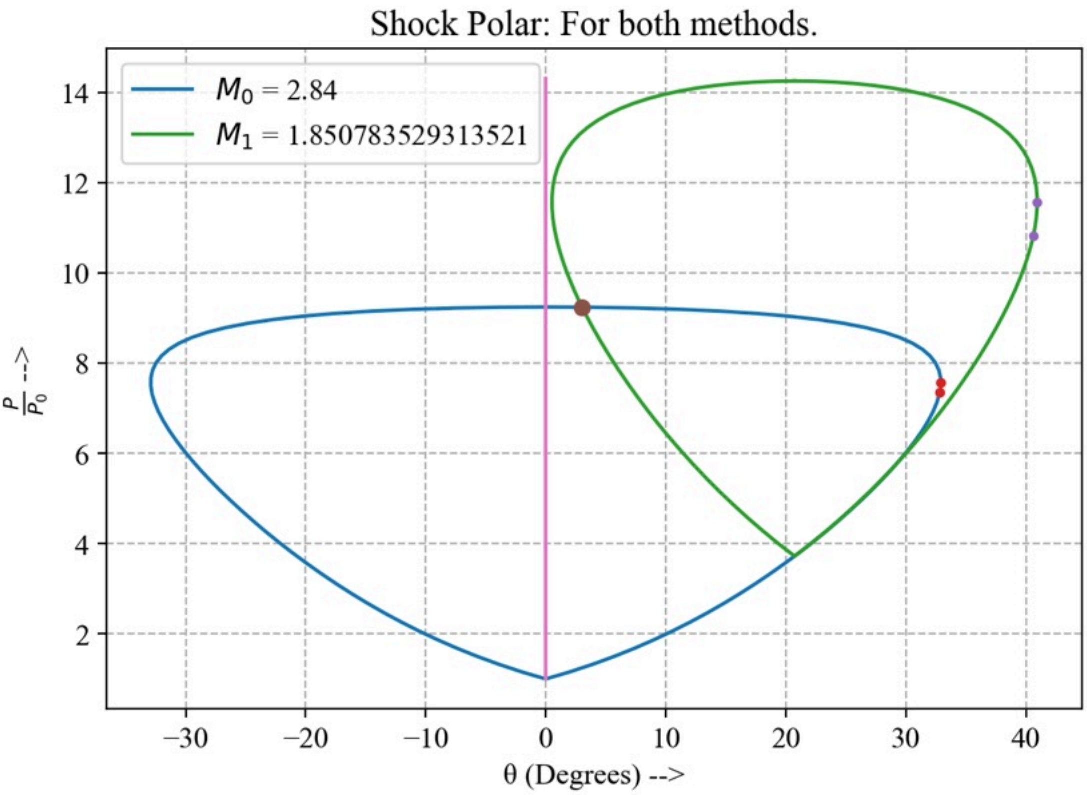
```
revadhillon@Revas-MacBook-Air Semester5 % python3 Assignment_6_LiBendor.py
Enter wedge angle in degrees:20.726
Enter inlet Mach number:2.84
Enter length of the hypotenuse of the wedge w/H:1.42
The Mach stem height Hm/H = 0.11
revadhillon@Revas-MacBook-Air Semester5 %
```



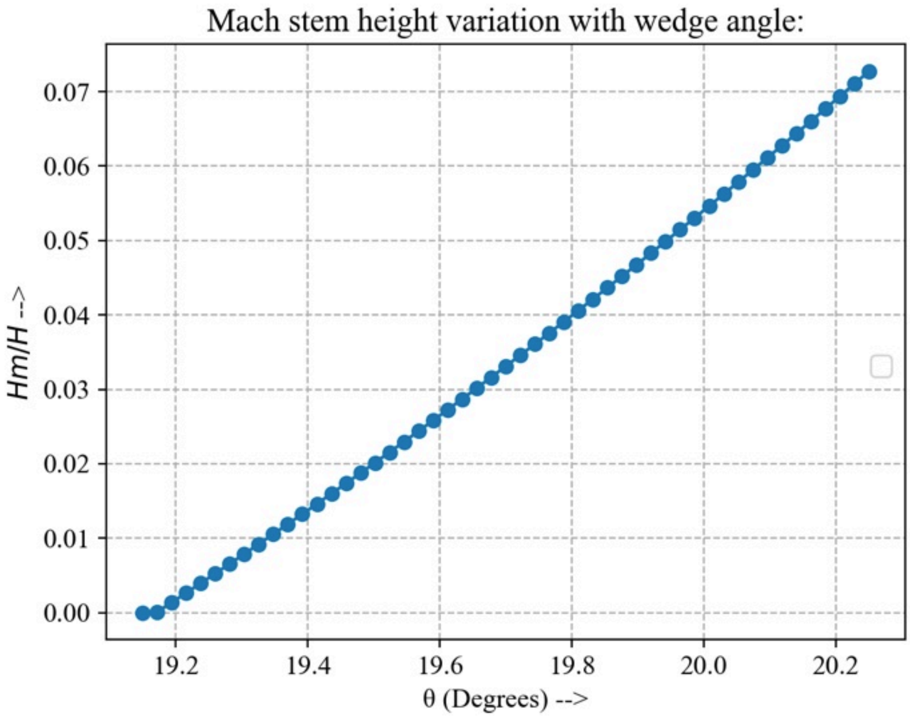
- Mouton and Hornung method:

```
revadhillon@Revas-MacBook-Air Semester5 % python3 Assignment_6_MoutonHornung.py
Enter wedge angle in degrees:20.726
Enter inlet Mach number:2.84
Enter length of the hypotenuse of the wedge w/H:1.42
The Mach stem height Hm/H = 0.11
revadhillon@Revas-MacBook-Air Semester5 %
```

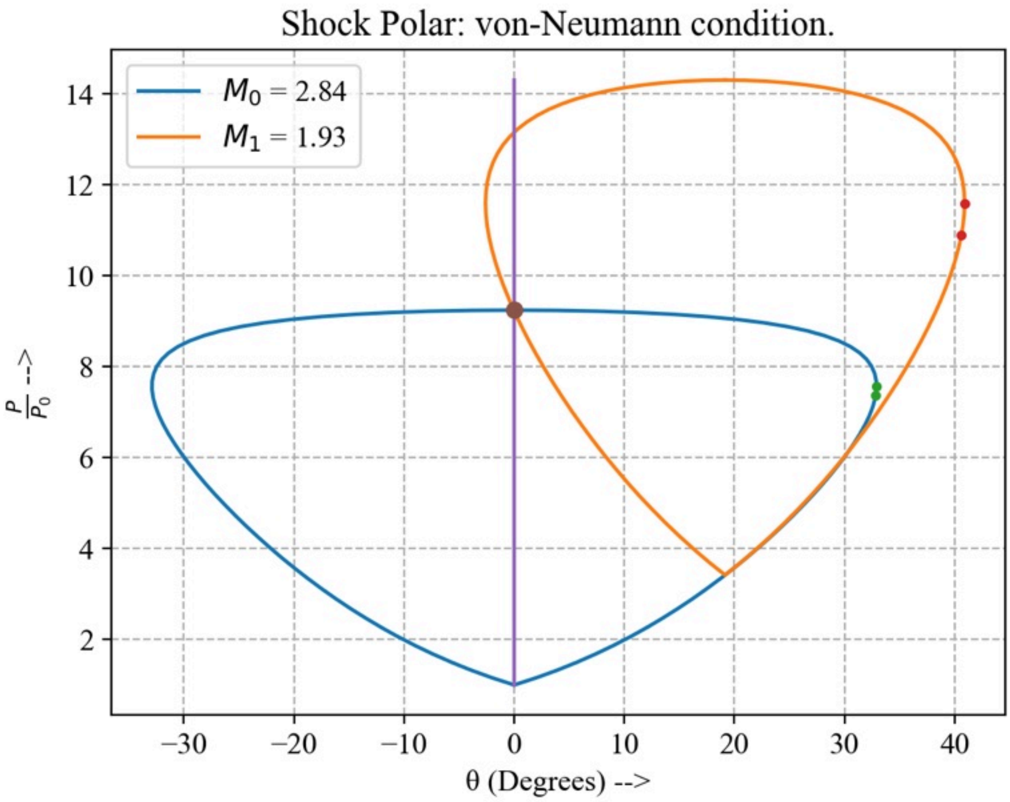




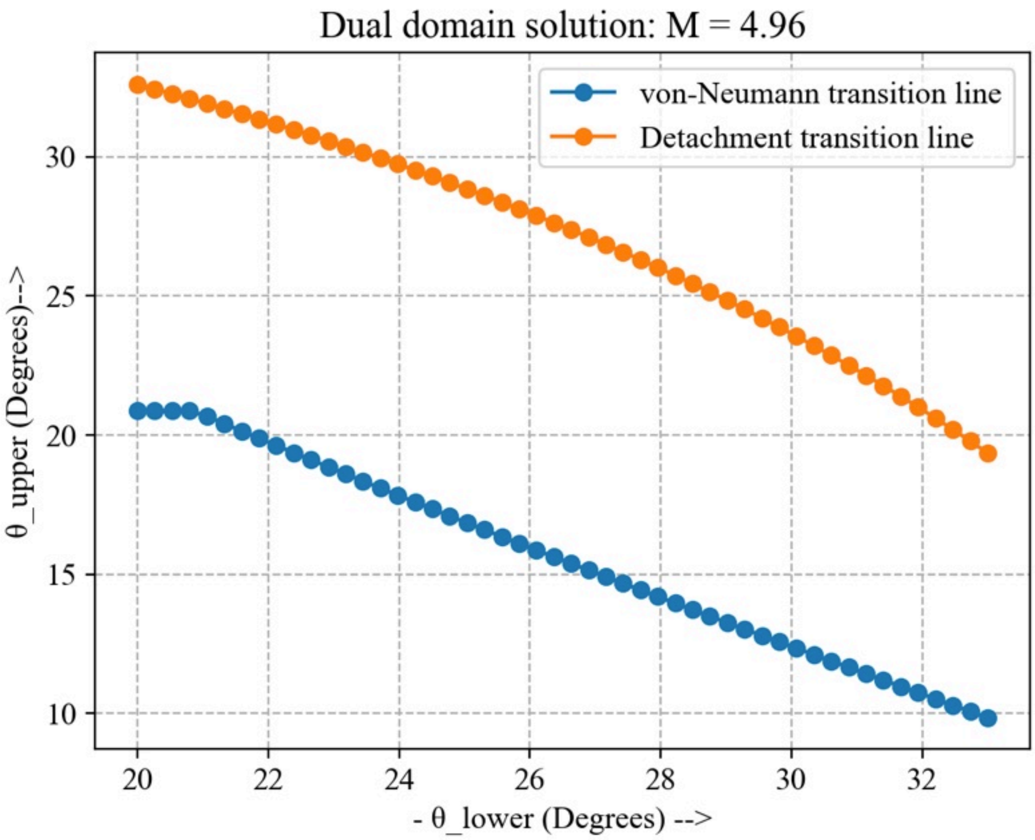
- For Mach number = 2.84, the following figure shows the Mach stem height variation with wedge angle.
- Predicted von-Neumann condition: $\theta_w = 19.15°$.



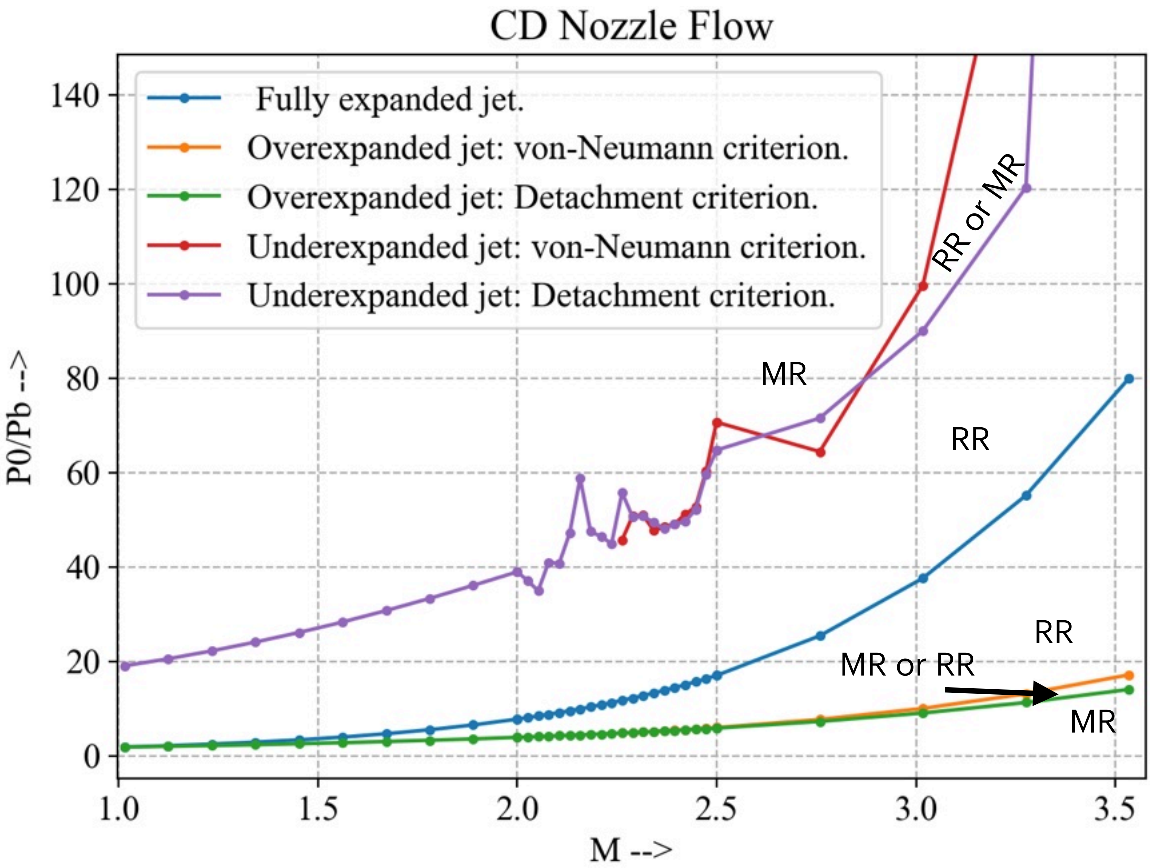
- The corresponding shock polar is as plotted below:



○ 7.] Plot the dual solution domain for steady asymmetric wedge angle variation induced RR-MR and MR-RR transitions.

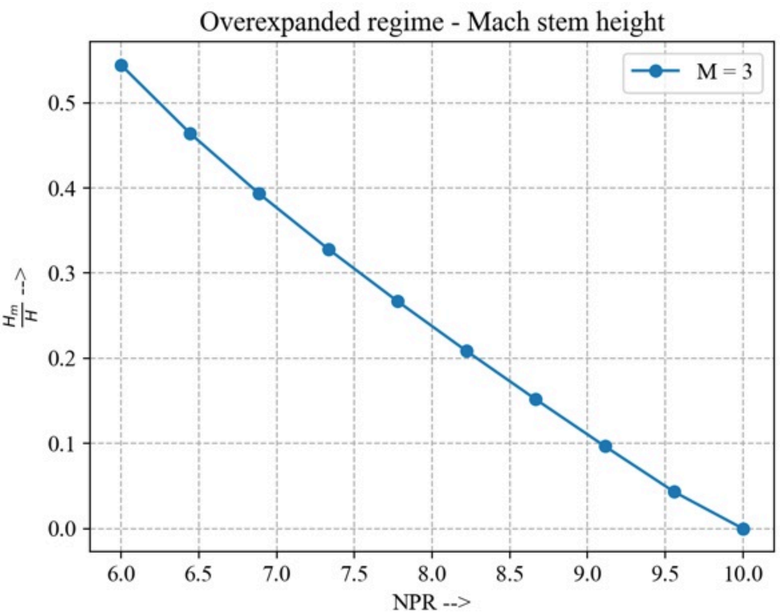


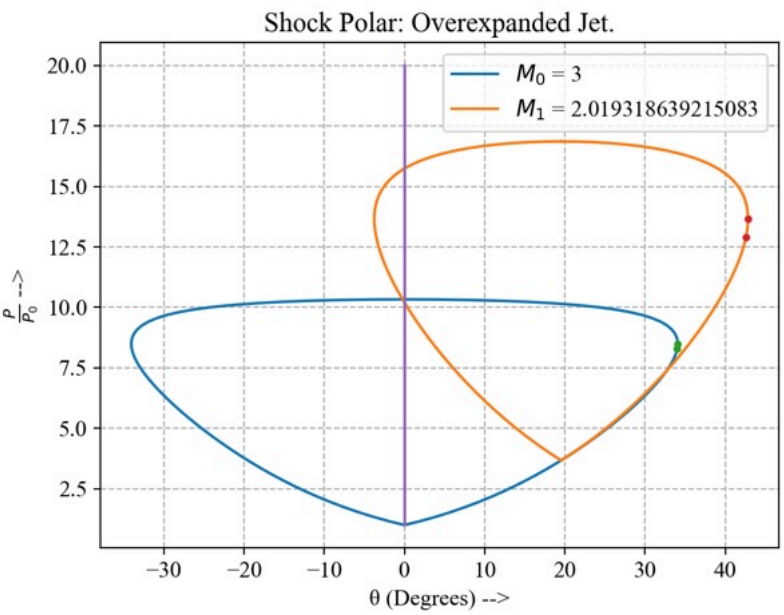
- 8.] Mark the regimes (sonic pressure ratio, MR, RR, properly expanded, RR, MR) in a plot Po/Pb Vs exit Mach number for any area ratio for an inviscid flow through a CD nozzle.

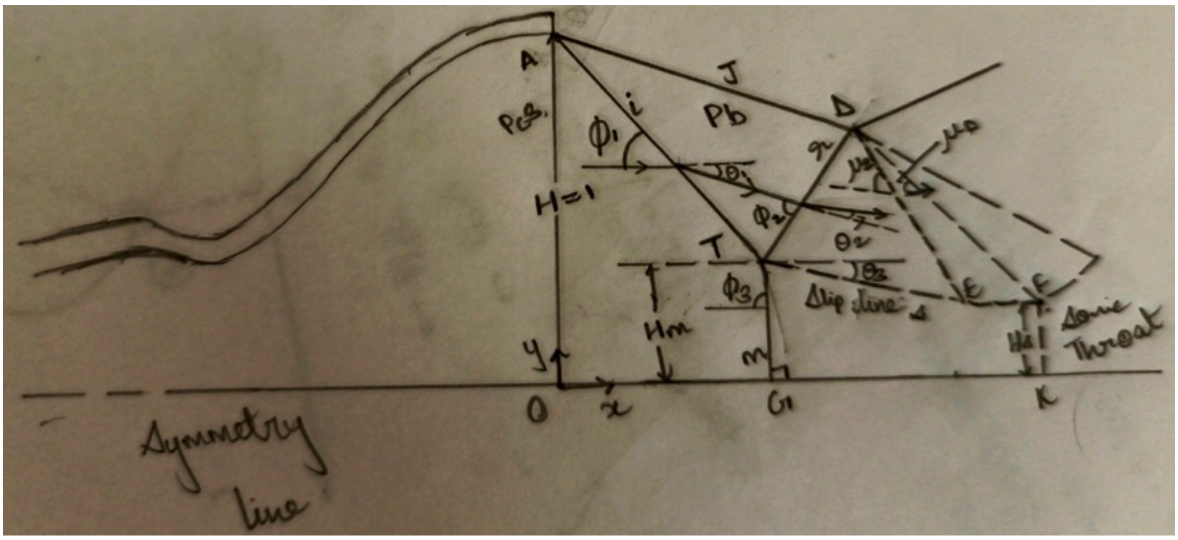


- 9.] Predict the Mach stem size in over expanded regimes for various pressure ratios using Li & Bendor method or Mouton & Hornung method. or your own method. The solutions should contain dimensioned schematic and shock polar.
(a) Check whether Mach stem size is going to zero at von-Neumann condition as predicted in question 1.
(b) Get the value of theta3 from shock polar. Make a correlation between theta3 and Mach stem height for various area ratios.

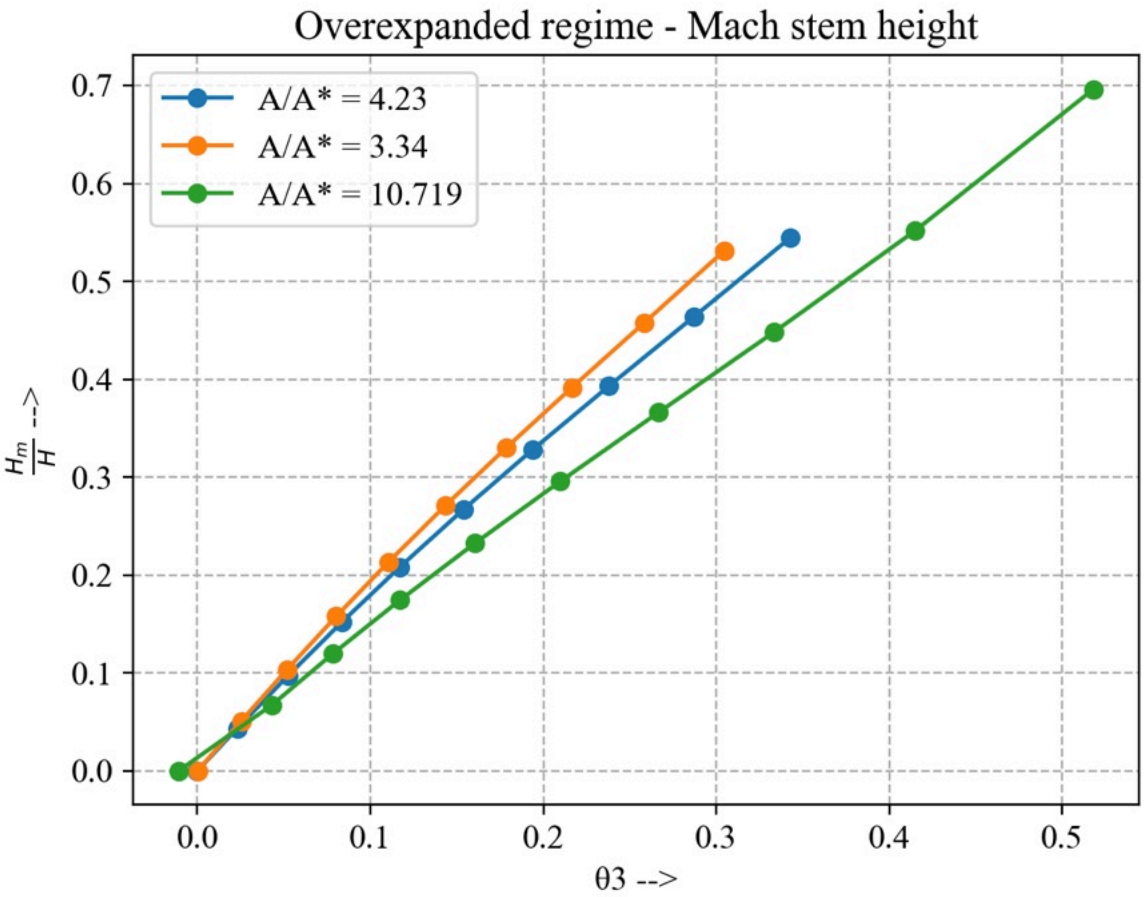
- Method used: Mouton & Hornung method.
- (a) Mach stem height goes to 0 at NPR = 10. The corresponding wedge angle is θ_w = 19.528°. The von-Neumann condition is satisfied as can be seen from the shock polar.



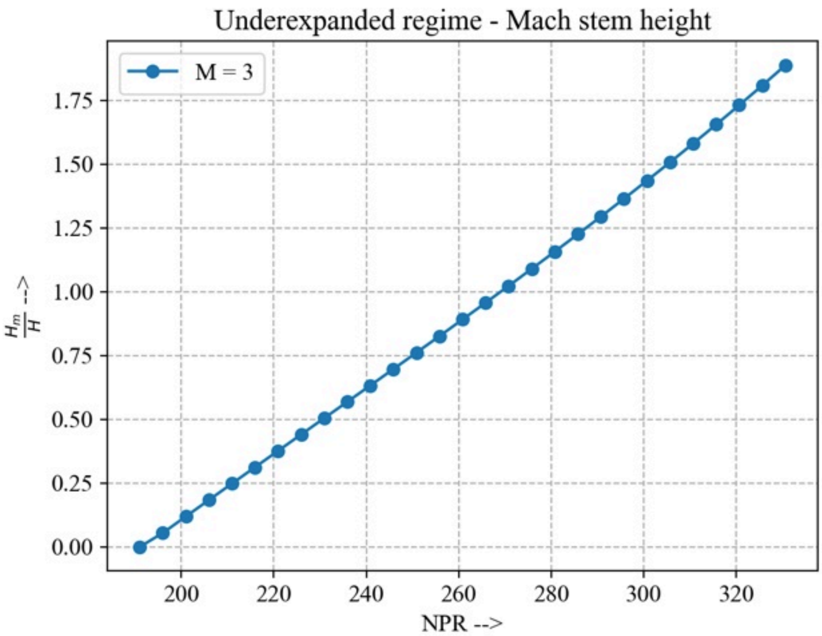


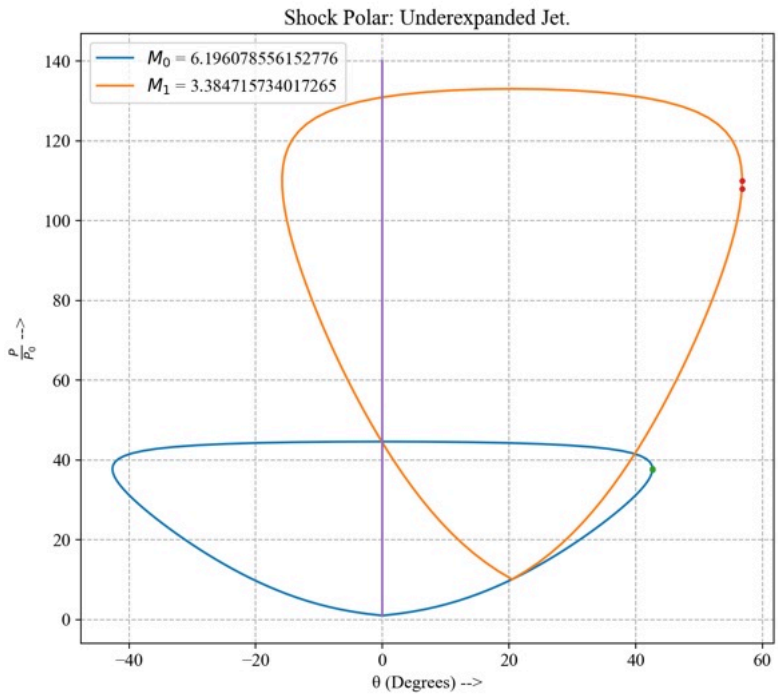


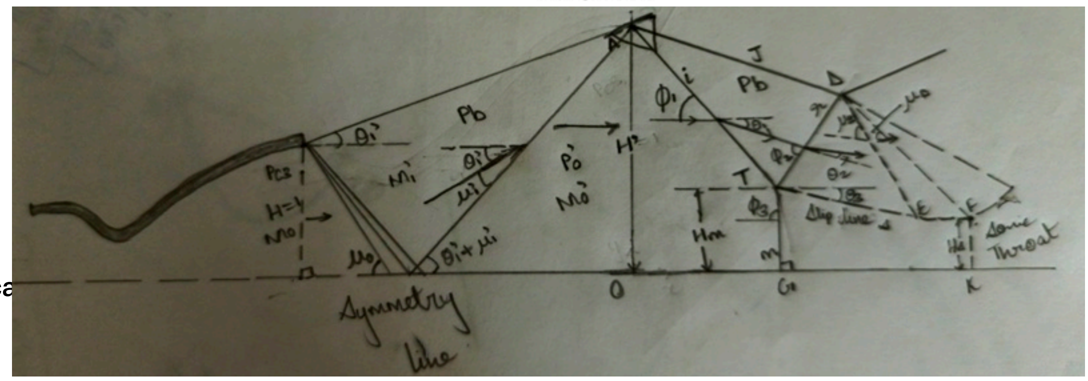
- (b) The following plot shows the relation between theta3 and Mach stem height for various area ratios. An almost linear variation is observed. Slope of the line decreases with increase in area ratio.



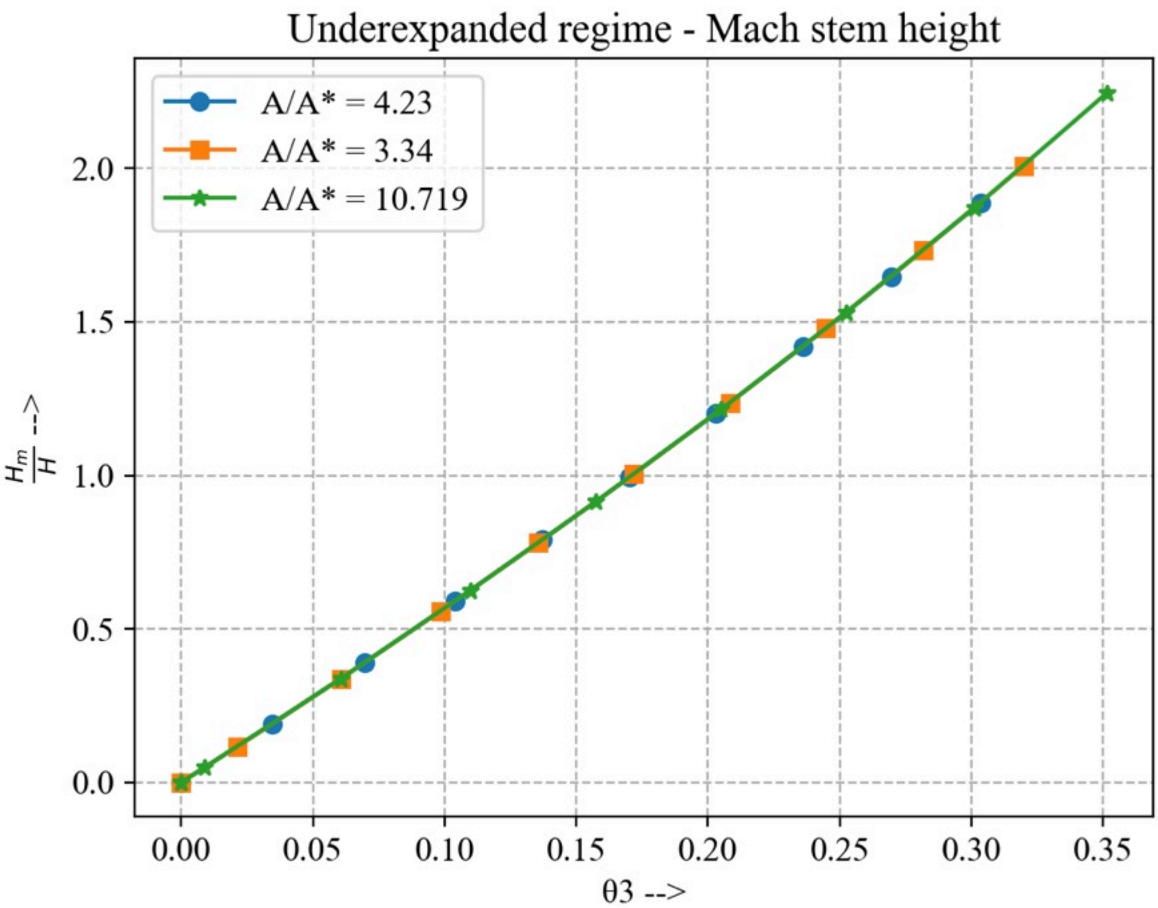
- 10.] Repeat question no.9 for under expanded regime also.
  - Method used: Mouton & Hornung method.
  - (a) Mach stem height goes to 0 at NPR = 191.00. The corresponding wedge angle is $\theta_w = 20.47°$.
  - The von-Neumann condition is satisfied as can be seen from the shock polar.





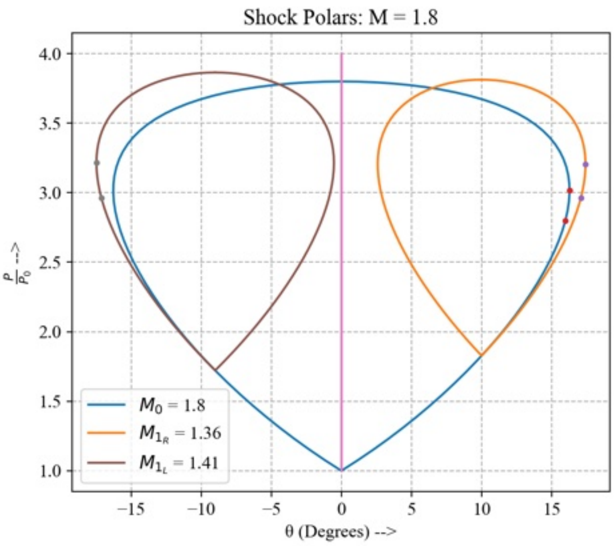


- The following plot shows the relation between theta3 and Mach stem height for various area ratios. An almost linear variation is observed. The lines for the different area ratios overlap.

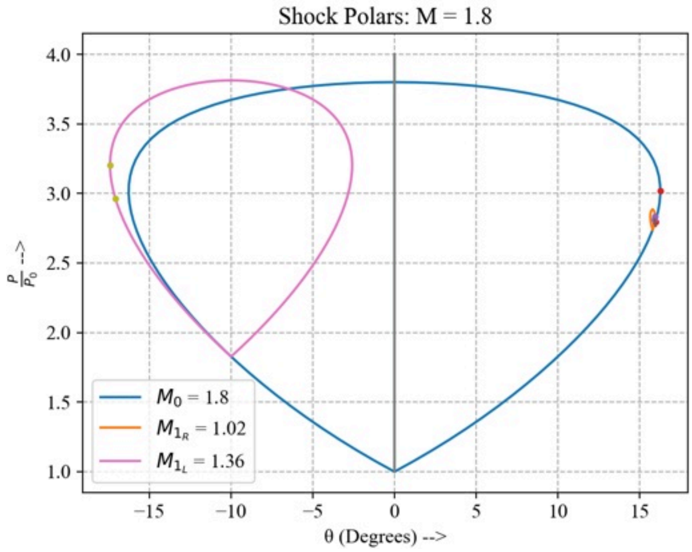


- 11.] Draw the shock polar solutions for asymmetric weak reflections (M_0<2.2).

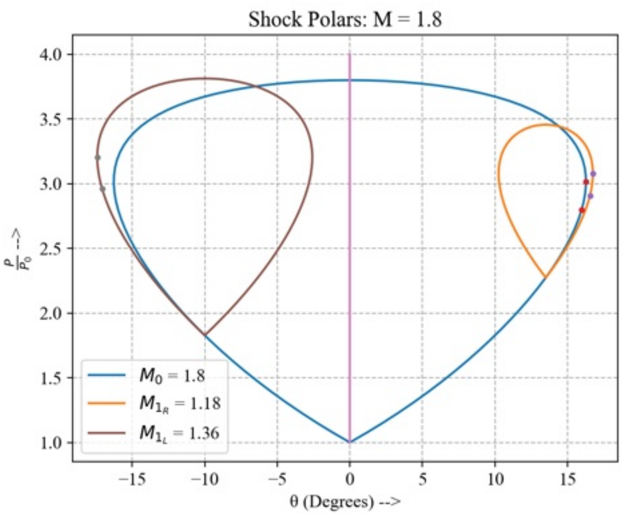
- SMR - SMR:



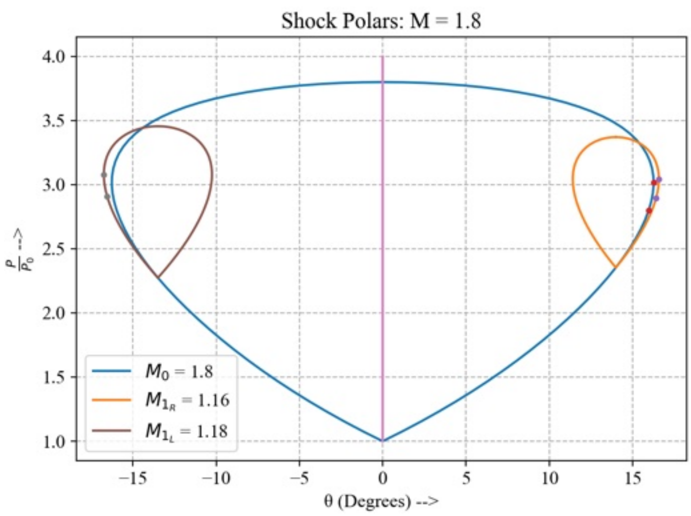
- SMR - GR:



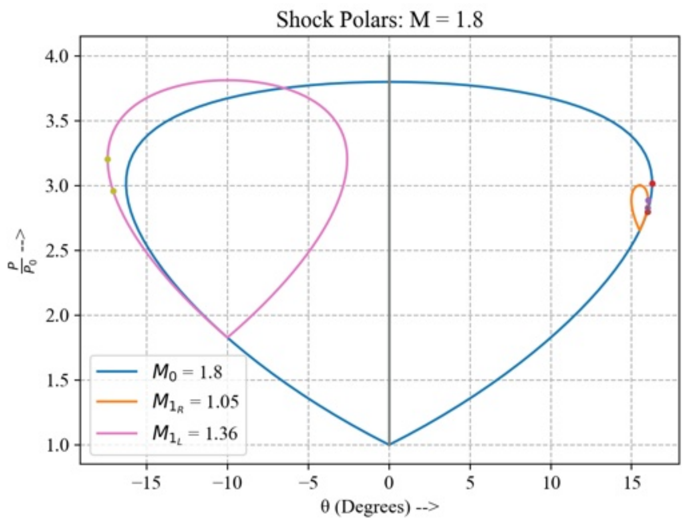
- SMR - vNR:



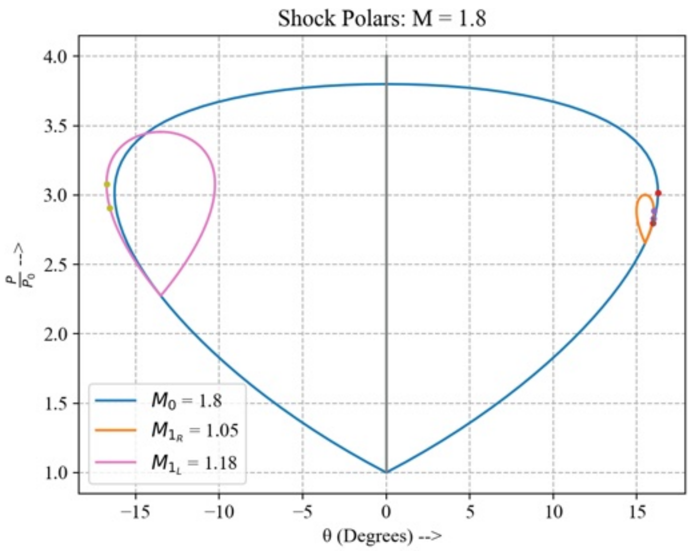
- vNR - vNR:



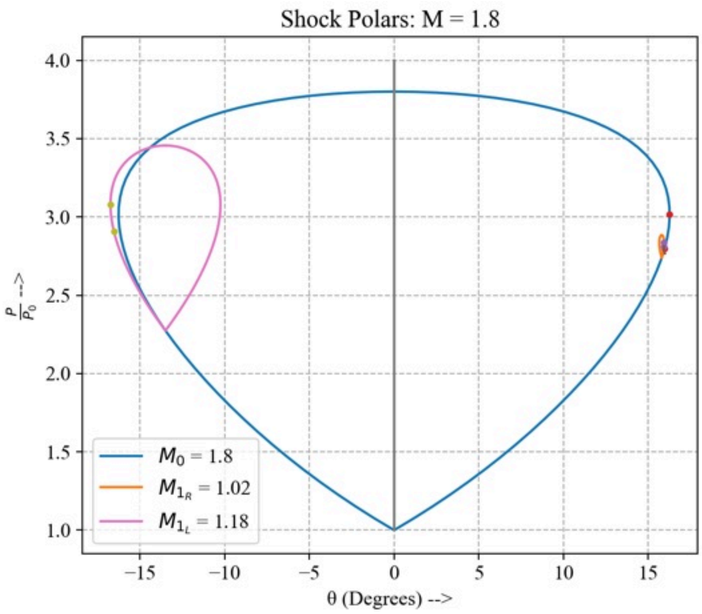
- SMR - VR:



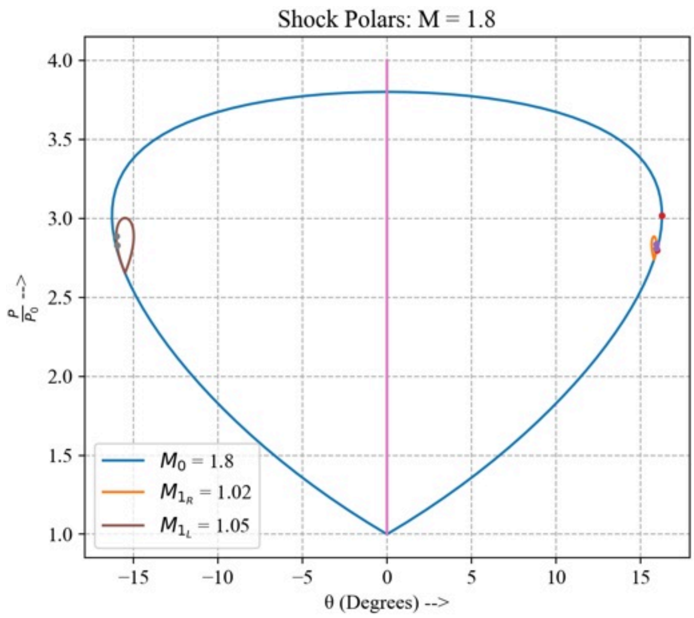
- vNR - VR:



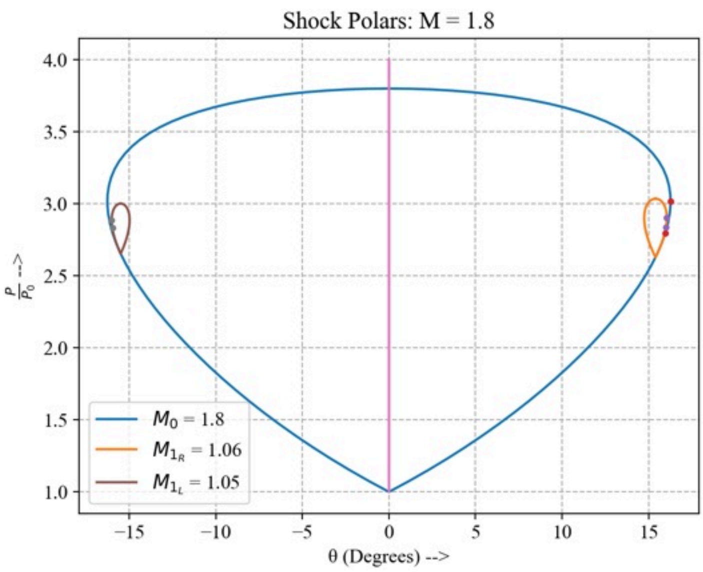
- vNR - GR:



- VR - GR:



- VR - VR:



- GR - GR: