AE 622 - Computing of high speed flows
Assignment 5: Report
Simulation of 2D scramjet intake

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Introduction

A 2D inlet for a scramjet is simulated with Mach number 5.5 and angle of attack -3^o and compared with inviscid theory results as well as with design geometry (i.e. at Mach 6.5 and zero angle of attack). 3000 iterations were performed and residue was plotted. Total Pressure ratios, Temperature ratios and overall total pressure ratios across the shocks were compared.

Plots

M = 6.5, aoa = 0

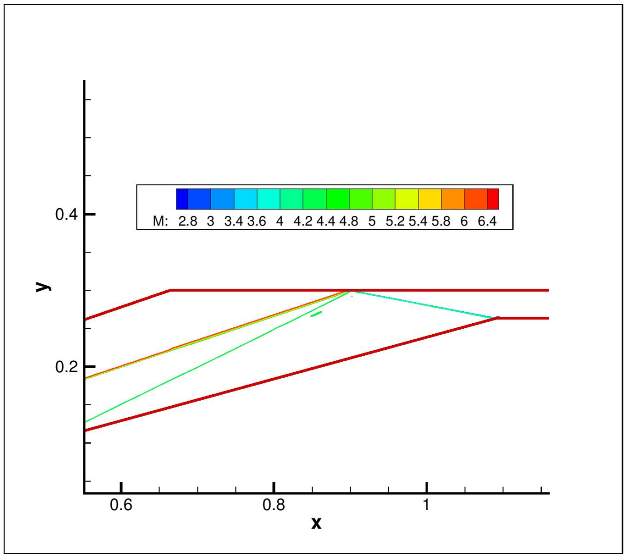

Figure 1: Mach number Contour Plot

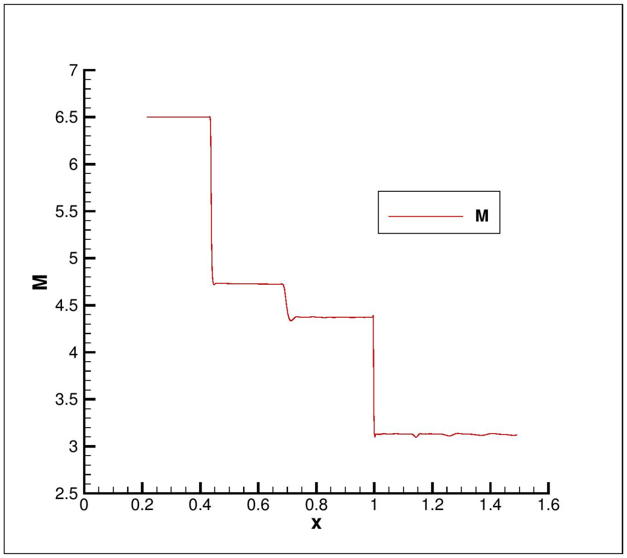

Figure 2: Mach Number jumps across the shocks.

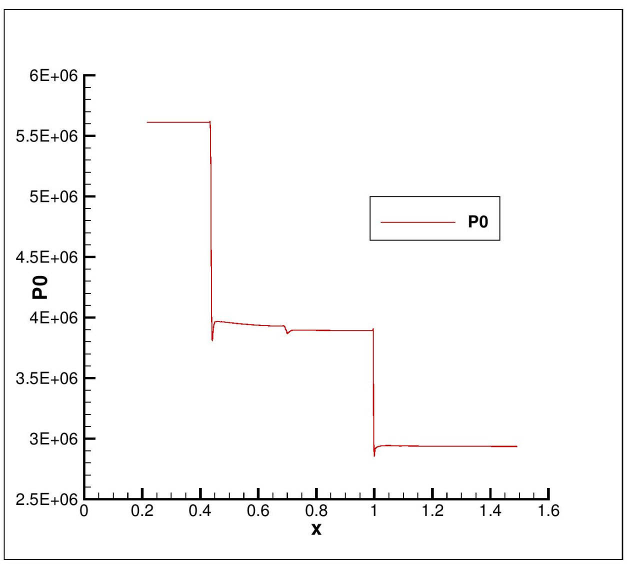

Figure 3: Total Pressure jumps across the shocks.

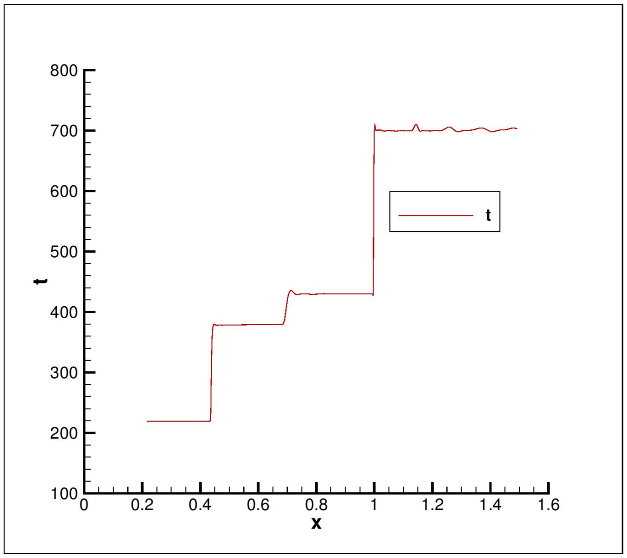

Figure 4: Temperature jumps across the shocks.

M = 5.5, aoa = -3^o

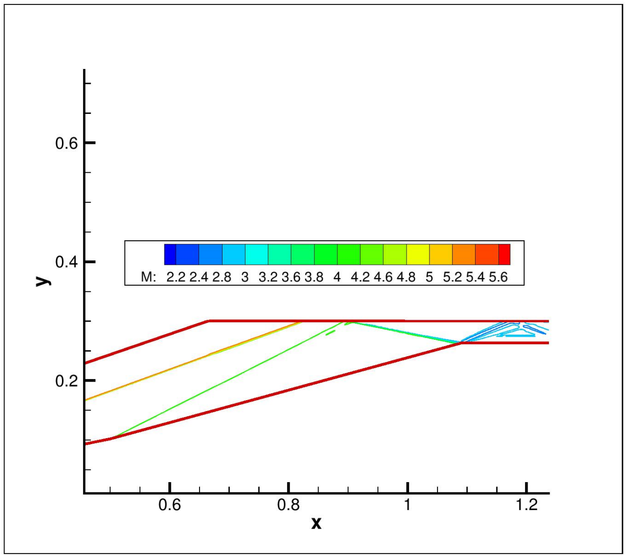

Figure 5: Mach number Contour Plot

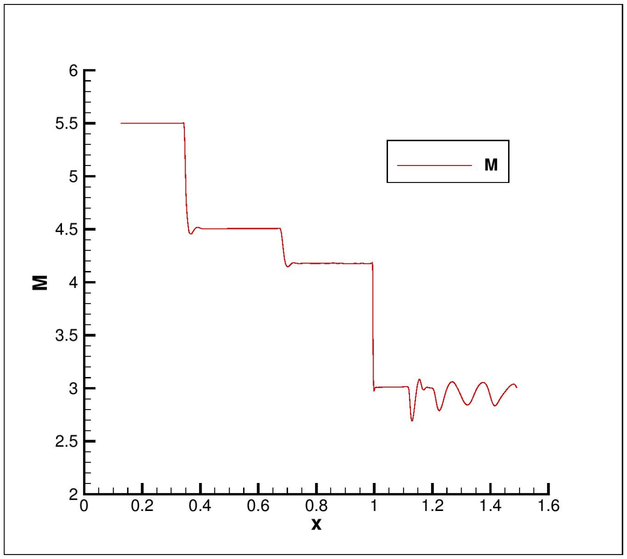

Figure 6: Mach Number jumps across the shocks.

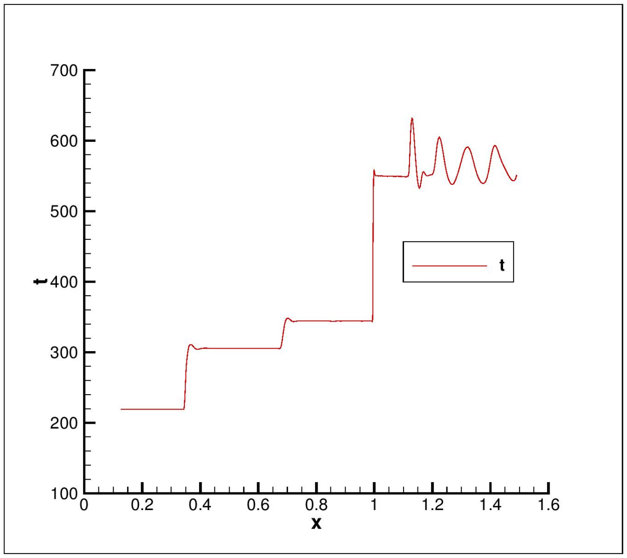

Figure 7: Temperature jumps across the shocks.

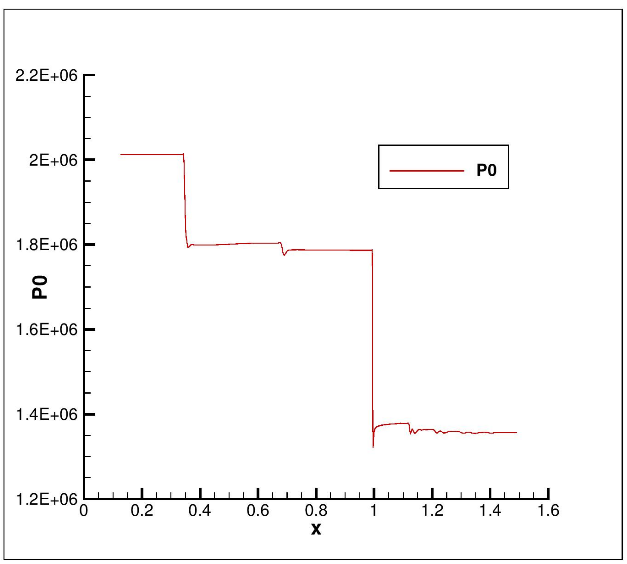

Figure 8: Total Pressure jumps across the shocks.

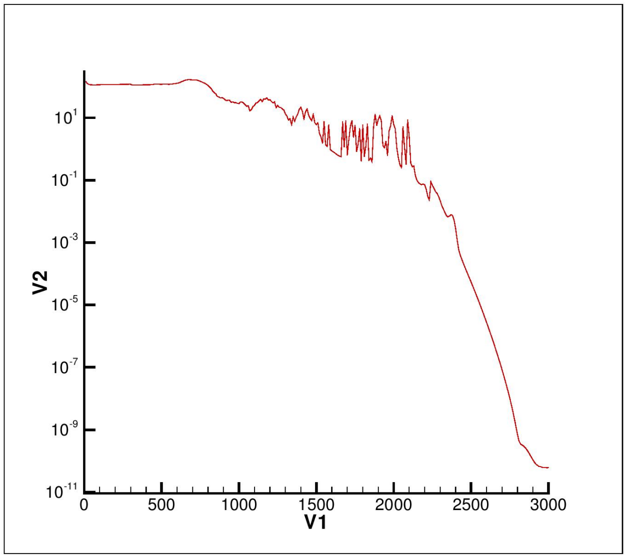

Figure 9: Residue Plot for convergence.

Comparison of Numerical Results with Inviscid Theory Results

M = 6.5, aoa = 0

$\theta 1 = 15.292, \theta 2 = 11.518$

Table 1:

Flow Properties	Numerical	Theoretical
$M1$	6.5	6.5
$M2$	4.718	4.7185
$M3$	4.366	4.3668
$M4$	3.120	3.1271
P_{o2}/P_{o1}	0.7082	0.69498
P_{o3}/P_{o2}	0.9971	0.9920
P_{o4}/P_{o3}	0.7720	0.75516
T_4/T_1	3.182	3.21
Total Pressure loss	47.65	47.938

M = 5.5, aoa = -3^o

$\theta 1 = 12.292, \theta 2 = 8.518$

Table 2:

Flow Properties	Numerical	Theoretical
$M1$	5.5	5.5
$M2$	4.508	4.5028
$M3$	4.177	4.2753
$M4$	3.0112	3.242
P_{o2}/P_{o1}	0.8950	0.8916
P_{o3}/P_{o2}	0.9532	0.9920
P_{o4}/P_{o3}	0.8628	0.0.7611
T_4/T_1	2.506	2.2222
Total Pressure loss	32.6%	23.61%

Observations

Different domain sizes and grid sizes were tried and the following observations were made -

1. It can be seen from the plots above, that the flow is decelerated and compressed in the inlet region, thus, mach number decreases, temperature increases, total pressure decreases (converted in the form of heat) and density increases.

2. From the mach number contour plot, it is clear that two shock wave emerging from the two ramps do not intersect on the cowl. This happens when free stream mach number is less than design mach number. (design mach number in this case is 6.5).

3. From figure 9, it can be seen that residue is high till 2200 iterations after which there is a steep decrease in residue to around 10^{-9} after 3000 iterations.

4. Static temperature gain is lower in case of Mach number 5.5, $aoa = -3^o$ than Mach number 6.5, $aoa = 0^o$ while, overall total pressure loss is greater for the design condition.

5. In case of mach number 5.5, $aoa = -3^o$, the number of mach waves are more than design condition, therefore, compression region of scramjet engine is higher. This also led to fluctuations in pressure and temperature plots as can be seen in figure 6 and 7.

6. Such fluctutations (or mach waves) do not occur in design condition because the reflected shock from the cowl tip exactly cancels these mach waves.

7. Numerical results for our case maches closely with the inviscid theory results, except in region 4, where the difference in mach number, pressure, and temperature is higher than rest of the regions. This happened because we didn't take into account the mach waves that will emerge after the 3rd shock while using inviscid theory.