AE339
PROJECT REPORT

GAS TABLE CALCULTOR

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ABSTRACT :

- The aim of this project is to use the concepts of Isentropic Flows, Normal Shocks and Oblique Shocks learnt in class and apply them in order to develop a working Gas Table Calculator.

OBJECTIVES :

- To develop equations to find various parameters with a single given parameter in isentropic flow, normal shock and oblique shock
- To write a code for the above equations and make a working calculator

ISENTROPIC FLOW EQUATIONS :

- Mach Number is denoted as M and specific heat ratio is γ
- Mach Angle (μ):

$$\mu = \sin^{-1}\left(\frac{1}{M}\right)$$

- Prandtl-Meyer Angle (ν):

$$\nu(M) = \sqrt{\frac{\gamma+1}{\gamma-1}}\tan^{-1}\left(\sqrt{\frac{\gamma-1}{\gamma+1}(M^2-1)}\right) - \tan^{-1}\left(\sqrt{M^2-1}\right)$$

- Static pressure to Stagnation pressure (p/p0):

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

- Static density to Stagnation density (ρ/ρ0):

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

- Static temperature to Stagnation temperature (T/T0):

$$\frac{T}{T_0} = \left(1+\frac{\gamma-1}{2}M^2\right)^{-1}$$

- Pressure Ratio at Critical Mach Number (p/p*):

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

- Density Ratio at Critical Mach Number (ρ/ρ*):

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

- Temperature Ratio at Critical Mach Number (p/p*):

$$\frac{T}{T^*} = \left(\frac{1 + \frac{\gamma-1}{2} M^2}{\frac{\gamma+1}{2}} \right)^{-1}$$

- Area Ratio at Critical Mach Number (A/A*):

$$\frac{A}{A^*} = \frac{1}{M} \left(\frac{2}{\gamma+1} \left(1 + \frac{\gamma-1}{2} M^2 \right) \right)^{\frac{\gamma+1}{2(\gamma-1)}}$$

NORMAL SHOCK EQUATIONS :

- Upstream Mach Number is denoted as M1 and specific heat ratio is γ
- Downstream Mach Number (M2):

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

- Total Pressure Ratio (p02/p01):

$$\frac{p_{02}}{p_{01}} = \left(\frac{(\gamma+1)M^2}{2 + (\gamma-1)M^2} \right)^{\frac{\gamma}{\gamma-1}} \left(\frac{2\gamma M^2 - (\gamma-1)}{\gamma+1} \right)^{\frac{1}{\gamma-1}}$$

- Static Pressure Ratio (p1/p02):

$$\frac{p_1}{p_{02}} = \frac{\left(1 + \frac{2\gamma}{\gamma+1}(M^2-1)\right)^{-1}}{\left(1 + 0.5(\gamma-1)\left(\sqrt{\frac{2+(\gamma-1)M^2}{2\gamma M^2-(\gamma-1)}}\right)^2\right)^{\frac{\gamma}{\gamma-1}}}$$

- Static Pressure Ratio (p2/p1):

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

- Density Ratio (ρ2/ρ1):

$$\frac{\rho_2}{\rho_1} = \frac{p_2}{p_1} \cdot \frac{T_1}{T_2} = \frac{(\gamma+1)M_1^2}{2 + (\gamma-1)M_1^2}$$

- Temperature Ratio (T2/T1):

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

OBLIQUE SHOCK EQUATIONS :

- Upstream Mach Number is denoted as M1, specific heat ratio is γ, Turn Angle is θ and Wave Angle is β.
- Turn Angle (θ) with respect to wave angle (β) :

$$\tan\theta = \frac{2\cot\beta\left(M_1^2\sin^2\beta - 1\right)}{M_1^2(\gamma + \cos 2\beta) + 2}$$

- Normal Mach Number Upstream (Mn1):

$$M_{n1} = M \cdot \sin(\beta)$$

- Downstream Mach Number (M2):

$$M_2 = \sqrt{\frac{2 + (\gamma - 1)M_{n1}^2}{2\gamma M_{n1}^2 - (\gamma - 1)}} \cdot \frac{1}{\sin(\beta - \theta)}$$

- Normal Mach Number Downstream (Mn2):

$$M_{n2} = M_2 \cdot \sin(\beta - \theta)$$

- Static Pressure Ratio (p2/p1):

$$\frac{p_2}{p_1} = 1 + \frac{2\gamma}{\gamma + 1} \cdot (M_{n1}^2 - 1)$$

- Density Ratio (ρ2/ρ1):

$$\frac{\rho_2}{\rho_1} = \frac{M_{n1}^2(\gamma + 1)}{2 + (\gamma - 1)M_{n1}^2}$$

- Temperature Ratio (T2/T1):

$$\frac{T_2}{T_1} = \frac{1 + \frac{2\gamma}{\gamma+1}(M_{n1}^2 - 1)}{\frac{M_{n1}^2(\gamma+1)}{2+(\gamma-1)M_{n1}^2}}$$

- Stagnation Pressure Ratio (p02/p01):

$$\frac{p_{02}}{p_{01}} = \frac{p_2}{p_1} \cdot \left(\frac{1 + \frac{\gamma-1}{2}M_{n2}^2}{1 + \frac{\gamma-1}{2}M_{n1}^2}\right)^{\frac{\gamma}{\gamma-1}}$$

LIBRARIES USED :

- **math library :** The math library in Python provides access to a collection of basic mathematical functions and constants.
- In the gas table, we sometimes have different parameters instead of the normal ones and we do not hav direct equations for them.
- Hence, we have to use the function **fsolve** from **scipy.optimize**. It is used to calculate the roots of non-linear equations. It uses the hybrid **Powell method**, which combines **Newton-Raphson** and other techniques for robust performance.
- We also use the function **bisect** from **scipy.optimize**. It uses numerical root-finding method that uses the **bisection method**.