Important Boundary Layer Equations for Hypersonic Flow Formulas PDF

Formulas
Examples
with Units

List of 20
Important Boundary Layer Equations for Hypersonic Flow Formulas

1) Dimensionless Quantities Formulas

1.1) Nusselt's Number with Reynolds Number, Stanton Number and Prandtl Number Formula

Evaluate Formula

Formula

$$N_u = Re \cdot St \cdot Pr$$

Example

$$1400 = 5000 \cdot 0.4 \cdot 0.7$$

1.2) Prandtl Number with Reynolds Number, Nusselt's Number, and Stanton Number Formula

Evaluate Formula

Formula

$$Pr = \frac{N_u}{St \cdot Re}$$

Example

$$0.7 = \frac{1400}{0.4 \cdot 5000}$$

1.3) Reynolds Number for given Nusselt's Number, Stanton Number and Prandtl Number Formula

Evaluate Formula

Formula

$$Re = \frac{N_u}{St \cdot Pr}$$

Example

$$5000 = \frac{1400}{0.4 \cdot 0.7}$$

1.4) Stanton Number with Reynolds Number, Nusselt's Number, Stanton Number and Prandtl Number Formula

Evaluate Formula

Formula

$$St = \frac{N_u}{Re \cdot Pr}$$

Example

$$0.4 = \frac{1400}{5000 \cdot 0.7}$$

2) Hypersonic Flow Parameters Formulas

2.1) Dynamic Viscosity around Wall Formula

Evaluate Formula

Formula

$$\mu_{viscosity} = \mu e \cdot \left(\frac{Tw}{T_{static}} \right)^{n}$$

Example with Units

$$11.1648\,\text{P} = 11.2\,\text{P} \cdot \left(\frac{15\,\text{K}}{350\,\text{K}} \right)^{0.001}$$

2.2) Local Shear Stress at Wall Formula

Evaluate Formula

Formula

$$\tau = 0.5 \cdot C_f \cdot \rho_e \cdot \mu e^{2}$$

Example with Units

$$0.9408\,\text{Pa} = 0.5 \cdot 0.00125 \cdot 1200\,\text{kg/m}^3 \cdot 11.2\,\text{P}^{2}$$

2.3) Local Skin-Friction Coefficient Formula

Evaluate Formula

Formula

$$C_f = \frac{2 \cdot \tau}{\rho_e \cdot u_e^{2}}$$

Example with Units

$$0.0013 = \frac{2 \cdot 61\,\text{Pa}}{1200\,\text{kg/m}^3 \cdot 8.8\,\text{m/s}^{2}}$$

2.4) Skin Friction Coefficient for Incompressible Flow Formula

Evaluate Formula

Formula

$$c_f = \frac{0.664}{\sqrt{Re}}$$

Example

$$0.0094 = \frac{0.664}{\sqrt{5000}}$$

2.5) Static Density Equation using Skin Friction Coefficient Formula

Evaluate Formula

Formula

$$\rho_e = \frac{2 \cdot \tau}{C_f \cdot u_e^{2}}$$

Example with Units

$$1260.3306\,\text{kg/m}^3 = \frac{2 \cdot 61\,\text{Pa}}{0.00125 \cdot 8.8\,\text{m/s}^{2}}$$

2.6) Static Velocity Equation using Skin Friction Coefficient Formula

Evaluate Formula

Formula

$$u_e = \sqrt{\frac{2 \cdot \tau}{C_f \cdot \rho_e}}$$

Example with Units

$$9.0185\,\text{m/s} = \sqrt{\frac{2 \cdot 61\,\text{Pa}}{0.00125 \cdot 1200\,\text{kg/m}^3}}$$

2.7) Static Viscosity Relation using Temperature of Wall Formula

Evaluate Formula

Formula

$$\mu e = \frac{\mu_{viscosity}}{\left(\frac{Tw}{T_{static}} \right)^{n}}$$

Example with Units

$$10.2322\,\text{P} = \frac{10.2\,\text{P}}{\left(\frac{15\,\text{K}}{350\,\text{K}} \right)^{0.001}}$$

3) Local Heat Transfer for Hypersonic Flow Formulas

3.1) Adiabatic Wall Enthalpy using Stanton Number Formula

Evaluate Formula

Formula

$$h_{aw} = \frac{q_w}{\rho_e \cdot u_e \cdot St} + h_w$$

Example with Units

$$102.0409\,\text{J/kg} = \frac{12000\,\text{W/m}^2}{1200\,\text{kg/m}^3 \cdot 8.8\,\text{m/s} \cdot 0.4} + 99.2\,\text{J/kg}$$

3.2) Enthalpy of Wall using Stanton Number Formula

Evaluate Formula

Formula

$$h_w = h_{aw} - \frac{q_w}{\rho_e \cdot u_e \cdot St}$$

Example with Units

$$99.1591\,\text{J/kg} = 102\,\text{J/kg} - \frac{12000\,\text{W/m}^2}{1200\,\text{kg/m}^3 \cdot 8.8\,\text{m/s} \cdot 0.4}$$

3.3) Local Heat Transfer Rate Calculation using Stanton Number Formula

Evaluate Formula

Formula

$$q_w = St \cdot \rho_e \cdot u_e \cdot \left(h_{aw} - h_w \right)$$

Example with Units

$$11827.2\,\text{W/m}^2 = 0.4 \cdot 1200\,\text{kg/m}^3 \cdot 8.8\,\text{m/s} \cdot \left(102\,\text{J/kg} - 99.2\,\text{J/kg} \right)$$

3.4) Local Heat Transfer Rate using Nusselt's Number Formula

Evaluate Formula

Formula

$$q_w = \frac{N_u \cdot k \cdot \left(T_{wall} - Tw \right)}{x_d}$$

Example with Units

$$16041.6667\,\text{W/m}^2 = \frac{1400 \cdot 0.125\,\text{W/(m*K)} \cdot \left(125\,\text{K} - 15\,\text{K} \right)}{1.2\,\text{m}}$$

3.5) Nusselt Number for Hypersonic Vehicle Formula

Evaluate Formula

Formula

$$N_u = \frac{q_w \cdot x_d}{k \cdot \left(T_{wall} - Tw \right)}$$

Example with Units

$$1047.2727 = \frac{12000\,\text{W/m}^2 \cdot 1.2\,\text{m}}{0.125\,\text{W/(m*K)} \cdot \left(125\,\text{K} - 15\,\text{K} \right)}$$

3.6) Stanton Number for Hypersonic Vehicle Formula

Evaluate Formula

Formula

$$St = \frac{q_w}{\rho_e \cdot u_e \cdot \left(h_{aw} - h_w \right)}$$

Example with Units

$$0.4058 = \frac{12000\,\text{W/m}^2}{1200\,\text{kg/m}^3 \cdot 8.8\,\text{m/s} \cdot \left(102\,\text{J/kg} - 99.2\,\text{J/kg} \right)}$$

3.7) Static Density Equation using Stanton Number Formula

Evaluate Formula

Formula

$$\rho_e = \frac{q_w}{St \cdot u_e \cdot \left(h_{aw} - h_w \right)}$$

Example with Units

$$1217.5325\,\text{kg/m}^3 = \frac{12000\,\text{W/m}^2}{0.4 \cdot 8.8\,\text{m/s} \cdot \left(102\,\text{J/kg} - 99.2\,\text{J/kg} \right)}$$

3.8) Static Velocity using Stanton Number Formula

Evaluate Formula

Formula

$$u_e = \frac{q_w}{St \cdot \rho_e \cdot \left(h_{aw} - h_w \right)}$$

Example with Units

$$8.9286\,\text{m/s} = \frac{12000\,\text{W/m}^2}{0.4 \cdot 1200\,\text{kg/m}^3 \cdot \left(102\,\text{J/kg} - 99.2\,\text{J/kg} \right)}$$

3.9) Thermal Conductivity at Edge of Boundary Layer Equation using Nusselt's Number Formula

Evaluate Formula

Formula

$$k = \frac{q_w \cdot x_d}{N_u \cdot \left(T_{wall} - Tw \right)}$$

Example with Units

$$0.0935\,\text{W/(m*K)} = \frac{12000\,\text{W/m}^2 \cdot 1.2\,\text{m}}{1400 \cdot \left(125\,\text{K} - 15\,\text{K} \right)}$$

Variables used in list of Boundary Layer Equations for Hypersonic Flow Formulas above

- c_f Skin friction coefficient
- C_f Local Skin-Friction Coefficient
- h_{aw} Adiabatic Wall Enthalpy *(Joule per Kilogram)*
- h_w Wall Enthalpy *(Joule per Kilogram)*
- **k** Thermal Conductivity *(Watt per Meter per K)*
- **n** Constant n
- N_u Nusselt Number
- **Pr** Prandtl Number
- q_w Local Heat Transfer Rate *(Watt per Square Meter)*
- **Re** Reynolds Number
- **St** Stanton Number
- T_{static} Static Temperature *(Kelvin)*
- T_{wall} Adiabatic Wall Temperature *(Kelvin)*
- **Tw** Wall Temperature *(Kelvin)*
- u_e Static Velocity *(Meter per Second)*
- x_d Distance from Nose Tip to Required Base Diameter *(Meter)*
- $\mu_{viscosity}$ Dynamic Viscosity *(Poise)*
- **μe** Static Viscosity *(Poise)*
- ρ_e Static Density *(Kilogram per Cubic Meter)*
- τ Shear Stress *(Pascal)*

Constants, Functions, Measurements used in list of Boundary Layer Equations for Hypersonic Flow Formulas above

- Functions: **sqrt**, sqrt(Number)
  A square root function is a function that takes a non-negative number as an input and returns the square root of the given input number.
- Measurement: **Length** in Meter (m)
  Length Unit Conversion
- Measurement: **Temperature** in Kelvin (K)
  Temperature Unit Conversion
- Measurement: **Speed** in Meter per Second (m/s)
  Speed Unit Conversion
- Measurement: **Thermal Conductivity** in Watt per Meter per K (W/(m*K))
  Thermal Conductivity Unit Conversion
- Measurement: **Heat Flux Density** in Watt per Square Meter (W/m²)
  Heat Flux Density Unit Conversion
- Measurement: **Dynamic Viscosity** in Poise (P)
  Dynamic Viscosity Unit Conversion
- Measurement: **Density** in Kilogram per Cubic Meter (kg/m³)
  Density Unit Conversion
- Measurement: **Specific Energy** in Joule per Kilogram (J/kg)
  Specific Energy Unit Conversion
- Measurement: **Stress** in Pascal (Pa)
  Stress Unit Conversion

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