1 Introduction

The main objective of this report is compute the thermodynamics cycle of a combustion engine and the corresponding output power generated. Secondary objective : torque profile $T(RPM)$, efficiency η, fuel consumption profile according to the engine RPM.

2 Engine power

1. compute pressure and power with thermodynamic cycle

   Study the combustion to estimate its efficiency:

$$\eta_{\text{combustion}} = \frac{q_{\text{out}}}{q_{\text{in}}} \tag{1}$$

   q : energy $[J/kg]$
   The results is per [kg] $\rightarrow$ J/kg, W/kg, ...

2. choose the mass flow $\dot{m}$, the displacement, and size of combustion chamber.
-> we can compute power in W and pressure in Pa
V_{min} is the volume when the piston is at TDC
V_{max} is the volume when the piston is at BDC
3. Establish the thrust force, along the y-axis R_1 : main Referential, centered on the crankshaft :

- x to the right
- y to the top
- z perpendicular to the plan formed by x and y .
- The piston head is moving in the y direction.

$$F_{\text{thrust}} = p \cdot S_p = p \cdot \pi \cdot \left(\frac{D}{2}\right)^2 \tag{2}$$

$$\vec{F}_{\text{piston}} = \begin{bmatrix} 0 \\ -1 \\ 0 \end{bmatrix}_{R_1} \tag{3}$$

F_{thrust} : thrust force $[N]$
p : pressure inside the combustion chamber $[Pa]$
D : piston diameter, bore $[m]$
S_p : piston head section $\left[m^2\right]$
4. subtract the power lost because of friction between piston head and cylinder:

$$F_{\text{thrust } 2} = F_{\text{thrust}} - F_{\text{frictionpiston-cyclinder}} \tag{4}$$

5. the thrust fore in the connecting rod referential

$$\vec{F}_{\text{thrust}}^{R_{cc}} = F_{\text{thrust }2} \cdot \begin{bmatrix} \cos(\theta_{cc}) \\ \sin(\theta_{cc}) \\ 0 \end{bmatrix}_{R_{cc}} \tag{5}$$

θ_{cc} : angle between connecting rod and the y axis

6. subtract the power/energy lost because of between the crankshaft and oil

$$\vec{F}_{\text{thrust}}^{\text{total}} = \vec{F}_{\text{thrust}}^{R_{cc}} + \vec{F}_{\text{oilfriction}} \tag{6}$$

Here, we can also add the energy consumed by the running gears : water pump, oil pump, alternator,

7. Torque is the vector product of this force with the position of the connecting rod, from the center of the crankshaft. It should be oriented in the Z-direction.

$$\vec{T}_{\text{piston}} = \vec{F}_{\text{thrust}}^{\text{total}} \times \text{ position }_{cc} = \vec{F}_{\text{thrust}}^{\text{total}} \times \begin{bmatrix} \cos(\alpha_{cc}) \\ \sin(\alpha_{cc}) \\ 0 \end{bmatrix}_{R_1} \tag{7}$$

α_{cc} : connecting rod angle according to R_1

8. Power output is the scalar product of the torque with crankshaft angular speed

$$\text{Power } = \vec{T}_{\text{piston}} \cdot \text{ ome } \vec{e}ga \tag{8}$$

9. Engine mechanical efficiency: quotient of output power by the inputheat power (fuel power).

$$\eta_m = \frac{\text{Power}}{\dot{Q}_{\text{in}}} \tag{9}$$

10. link cycle phases with 4 strokes with crankshaft angle.

11. then follow steps defined in Notion

2.0.1 Friction

different frictions, which increase the mechanical loses

- Piston friction : cylinder, piston pin,

$$\overrightarrow{BC}_{R_1} = \begin{bmatrix} \overline{BC}_{x_1} \\ \overline{BC}_{y_1} \\ 0 \end{bmatrix}_{R_1} \tag{10}$$

2.1 Engine thrust

Theorem of the preservation of linear momentum:

$$\iint_{\Sigma} [P \cdot \vec{n} + \rho \cdot \vec{V}(\vec{V} \cdot \vec{n})] = 0 \tag{11}$$

The term $\vec{V} \cdot \vec{n}$ is equal to zero when the velocity is perpendicular to the normal vector, which is the case on the lateral surface. What remain are the terms corresponding to the surfaces A_0 and A_{10}, which are perpendicular to the axis of the jet engine. The thrust:

$$\begin{aligned} F &= \left(P_{10} + \rho_{10} \cdot V_{10}^2\right) A_{10} - \left(P_0 + \rho_0 \cdot V_0^2\right) A_0 \\ &= P_{10} \cdot A_{10} + \rho_{10} \cdot V_{10}^2 \cdot A_{10} - P_0 \cdot A_0 - \rho_0 \cdot V_0^2 \cdot A_0 \end{aligned} \tag{12}$$

mass flow:

$$\dot{m} = D = \rho \cdot V \cdot A \tag{13}$$

$$\begin{aligned} F &= P_{10} \cdot A_{10} + D_{10} \cdot V_{10} - P_0 \cdot A_0 - D_0 \cdot V_0 \\ &= D_{10} \cdot V_{10} - D_0 \cdot V_0 + P_{10} \cdot A_{10} - P_0 \cdot A_0 \end{aligned} \tag{14}$$

By using the simple trick of adding $P_0 \cdot A_{10} - P_0 \cdot A_{10} = 0$

$$\begin{aligned} F &= D_{10} \cdot V_{10} - D_0 \cdot V_0 + P_{10} \cdot A_{10} - P_0 \cdot A_0 + P_0 \cdot A_{10} - P_0 \cdot A_{10} \\ &= D_{10} \cdot V_{10} - D_0 \cdot V_0 + (P_{10} - P_0) A_{10} + P_0 (A_{10} - A_0) \end{aligned} \tag{15}$$

It is useful to add the drag due to the engine housing:

$$X_c = -\iint P_c \cdot dA \vec{n} \vec{x} - > X_c = P_c (A_{10} - A_0) \tag{16}$$

Where the P_c is the pressure at the surface of the housing. Historically, the first jet fighter, the Me-262, was equipped with two Junkers Jumo 004 B turbine engines with housings. So, these housings will produce each a drag force. Since then, engines were housed inside the body of the jet fighter. In this case, this term is equal to 0 .