Recruitment Project - 2nd Semester 2024/25

BLUE

Team Leader of Design
Diogo Martins

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Dear Design recruits,

This recruitment project aims to give you the necessary knowledge to operate within the Design team, consisting of several tasks that will address the fundamental aspects of developing jet engine components.

In each task, you will receive data and arrive at results that must be used in the next task. In other words, you will have a real experience of how the Design team operates and will observe the interconnection of each engine component.

This will be a multidisciplinary project, and you will make use of elements with which you are probably not yet familiar. By the end of the project, we hope that will no longer be the case.

The tasks presented aim to work on the following areas: **Thermodynamic Cycles**, **Compressor**: *impeller* and *diffuser*, **Turbine**.

Because this is a recruitment project, autonomy, dedication to the project, and meeting deadlines are expected. However, you should not hesitate to ask any questions that arise during the course of the project. The main goal is for you to learn.

I wish you good work,

Diogo Martins - Design Team Leader

1 Thermodynamic Cycles

Deadline: 13/04

Objective: To consolidate and apply the main concepts of thermodynamic cycle operation.

The Blue intends to develop an engine with the following characteristics:

- Pressure ratio (PR) = 3
- *Mass Flow Rate* ($\dot{m_{ar}}$) = 2.0 kg/s → constant throughout the engine
- Turbine inlet temperature (T_3) = 990ºC
- $\frac{\dot{m_{fuel}}}{\dot{m_{air}}} = 71.3$

It is known that for engine start, an air injector will be used in which the air exits at a speed of 540 km/h, causing changes in the air properties before reaching the compressor. In addition, the atmospheric temperature is 25ºC and the atmospheric pressure is 1 bar.

Also assume:

- Compressor efficiency (η_c) = 0.75
- Turbine efficiency (η_t) = 0.85
- Gamma (γ) = 1.4 (cold) = 1.333 (hot)

From this data, it is intended to calculate:

1. The static temperature and jet velocity at the nozzle exit: T_5 and C_5.
2. The inlet and outlet areas of the engine.
3. The *Thrust*: F.
4. The *Thrust-specific fuel consumption*: TSFC.

Compare now the value obtained for the *Thrust* with the expected design value of 250 N. What is the reason for this difference?

All calculations must be presented in SI units.

Tips: Ideal conditions in the nozzle, diffuser, and combustion chamber can be assumed. Potential energy variations along the engine should be neglected, and stagnation values should be used to avoid taking kinetic energy variations into account. As an approximation, the effect of choking in the nozzle can be ignored.

2 Compressor - *Impeller* and *diffuser*

Deadline: 11/05

Objective: To consolidate and apply the main design concepts of an *impeller* and a *diffuser*.

Blue now intends to develop a compressor for the previously mentioned engine. This compressor will be radial and composed of an *impeller* and a *diffuser*.

2.1 Impeller

The *impeller* has straight blades, meaning the blades follow a radial direction. It has the following characteristics:

- Pressure ratio (PR) = 3
- Mass Flow Rate = 2.0 kg/s
- Revolutions per Minute (RPM) = 1000
- Number of Blades (z) = 50
- Initial Blade Height (b1) = 10 cm;
- Inner Radius = 10 cm
- Outer Radius = 50 cm
- Compressor efficiency (η_c) = 0.75

The air has these characteristics:

- Gamma (γ) = 1.4 (cold)
- $T_{initial}$ = 309.34 K
- Initial air density = 1.28 kg/m^3
- Perfect gas constant for air (R) = 287
- Initial stagnation pressure = 1.0×10^5 Pa

Imagining an *impeller* with the mentioned characteristics, for **n = 100** points in the *impeller*, using *MATLAB*, calculate:

1. Enthalpy (h), Temperature (T), Pressure (p), and Density (ρ).
2. Blade height (b_n).
3. Tangential velocity (C_W).
4. Total velocity (C).
5. One chosen angle in the velocity triangle.
6. For each of the above items, create a *plot* [a graph in *MATLAB*] of each property as a function of the value of n.

2.2 Diffuser

The *diffuser* to be developed will have 3 parts: radial blades, a blade-free curvature space, and axial blades.

It is intended that the air passing through the *diffuser* has a radial velocity equal to 30 m/s immediately before the curvature.

Considering only the axial blade section of the *diffuser*, calculate for $\mathbf{n = 50}$ equally spaced points, using *MATLAB*, the following parameters:

1. Temperature, Pressure, and Density.
2. Surface area.
3. Tangential velocity.
4. Total velocity.
5. One chosen angle in the velocity triangle.
6. For each of the above items, create a *plot* [a graph in MatLab] of each property as a function of n.

Simplifications:

- Assume there is a linear variation of enthalpy along the *impeller*.
- Throughout the *impeller* and the *diffuser*, consider the compressor efficiency $(\eta_c) = 0.75$ as constant.
- Assume that the stagnation temperature and stagnation pressure are constant in the *diffuser*.
- Assume that the pressure ratio (PR) refers only to the *impeller*.

Note: Iterative processes will have to be used during this task.

Formulary

For your support, below is a set of formulas that you will need:

Formulas to be used in Task 1:

Energy balance for a control volume:

$$\frac{dE}{dt} = \dot{Q} + \dot{W} + \dot{m}[(h_{in} - h_{out}) + \frac{1}{2}(v_{in}^2 - v_{out}^2) + g(z_{in} - z_{out})]$$

Perfect/Ideal Gas Equation:

$$pv = RT \Leftrightarrow p = \rho RT$$

Relations with c_p:

$$dh = c_p(T)dT$$
$$c_p = c_v + R$$
$$k = \frac{c_p}{c_v}$$
$$\text{If } c_p = \text{const} \implies \Delta h = c_p \Delta T$$

$$c_p = \frac{kR}{k-1}$$

Relations between P and T in an isentropic process:

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}}$$

Isentropic efficiency (Compressor and Turbine):

$$\eta_c = \frac{\Delta h_S}{\Delta h_R} \qquad \eta_t = \frac{\Delta h_R}{\Delta h_S},\ h_r \equiv \textit{real enthalpy and } h_s \equiv \textit{isentropic enthalpy}$$

Other important formulas:

$$\text{Thrust} = \dot{m}(v_{out} - v_{in})$$
$$TSFC = \frac{\dot{m}_{fuel}}{Thrust}$$
$$\text{Air-fuel ratio} = \frac{\dot{m}_{air}}{\dot{m}_{fuel}} \qquad \text{(For stoichiometric proportion)}$$

Additional formulas to use in Task 2:

***Slip factor*:**

$$\text{Slip Factor: } \sigma = 1 - \frac{0.63\pi}{z},\ \textit{z is the number of blades in the compressor}$$

Enthalpy:

$$h = T \times c_p$$

***Mass flow rate*:**

$$\dot{m} = V_{normal} \times \rho \times A$$

Dynamic pressure and temperature from static pressure and static temperature

$$p = p0 \times \left(\frac{T_1}{T0_1}\right)^{\frac{k}{k-1}}$$

$$T_1 = T0_1 - \frac{C_1^2}{2c_p}$$

Conservation of angular momentum in the diffuser:

$$C_{W_2} \times D_2 = C_{W_1} \times D_1$$

Additional formulas to use in Task 3:

Calculation of psi (ψ)

$$\psi_1 = \frac{\dot{m}}{A \times \rho_1 \times U}$$

Formula for the tangential velocity at the point between the *rotor* and the *stator*

$$C_{W_2} = c_p \times \frac{T0_1 - T0_3}{U}$$

Note: In addition to these formulas, the relationships of the velocity triangle and the geometry of the components as presented in the Aerodynamics workshop should also be considered.