Task 6 - OLVHN

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1 Overview

This report contains the results and summary of the 12 step process described in Dr. Cizmas notes for computing the Operating Line. Also included in this report is the engine performance vartiatio with wheel speed, altitude and aircraft speed.

2 Methodology for Computing the Operating Line

As we determine the Operating Line of our engine, we first define our operating parameters:

$$\dot{m}_{air} = 1.64089 \left[\frac{kg}{s}\right] \tag{1}$$

$$w_{c_n} = 283.91025 \left[\frac{kJ}{kg}\right] \tag{2}$$

$$\eta_{compressor_n} = 0.90 \tag{3}$$

$$\sigma_{comb} = 0.90 \tag{4}$$

$$\eta_{turbine} = 0.94 \tag{5}$$

$$\pi_{c_n} = 9.2 \tag{6}$$

$$\lambda = 2.85377 \tag{7}$$

$$T^*_{1_n} = 288.16[K] \tag{8}$$

$$T^*_{3_n} = 1410[K] \tag{9}$$

$$p^*_{1_n} = 1.01325[bar] \tag{10}$$

$$p^*_{3_n} = 9.042243[bar] \tag{11}$$

$$h^*_{3_n} = 1574.3477 \left[\frac{kJ}{kg}\right] \tag{12}$$

$$N_n = 52612.464822[rpm] \tag{13}$$

$$\pi_D = 0.93 \tag{14}$$

$$\gamma_g = 1.304286 \tag{15}$$

$$\frac{A_{3.5}}{A_5} = 1.2 \tag{16}$$

1. Calculate the compressor work w_c, given an angular speed calculated in Task2, as a function of nominal compressor work and nominal angular speed.

$$w_c = w_{c_n}\left(\frac{N}{N_n}\right)^x \tag{17}$$

Usually $x \in [1.9, 2.1]$, for convience we will start with $x = 2$.

Note:

$$N = 1.1N_r \tag{18}$$

Recall when at nominal conditions:

$$N_r = \frac{N_n}{1.05} \tag{19}$$

N	w_c
55117.82029 rpm	313.0460185$\frac{kJ}{kg}$

2. Estimate the compressor efficiency η_c, given an angular speed calculated in Task2, as a function of nominal compressor efficiency and nominal angular speed. We start by calculated the pressure ratio π^*_c

$$\pi^*_c = \left[\left(\pi_{c_n}^{\frac{\gamma-1}{\gamma}}\right)\frac{\eta_c}{\eta_{c_n}}\left(\frac{N}{N_n}\right)^x + 1\right]^{\frac{\gamma}{\gamma-1}} \tag{20}$$

To begin the caluation we can start by assuming $\eta_c = \eta_{c_n}$. Once the pressure ratio is calculated, read that π^*_c from the compressor map, and find the corresponding $\dot{m}\frac{\sqrt{T^*_1}}{p^*_1}$. Once you have that, find the corresponding η_c from the compressor map. If $\eta_c \neq \eta_{c_n}$ then iterate until the change is less than a allowed tolerance. For our engine, we allowed a tolerance of 0.01.

π_c^*	η_c
10.4001622	0.878213

3. Calculate the T_3^* from:

$$\pi_c^* = \frac{1+f}{\sigma_{comb}}\left(\frac{p_3^*}{\dot{m}\sqrt{T_3^*}}\right)_n \sqrt{\frac{T_3^*}{T_1^*}}\frac{\dot{m}\sqrt{T_1^*}}{p_1^*} \tag{21}$$

Where:

$$\frac{1+f}{\sigma_{comb}}\left(\frac{p_3^*}{\dot{m}\sqrt{T_3^*}}\right)_n = constant \tag{22}$$

From here, calculate h_3^* from:

$$h_3^* = \left(\frac{1+minL}{1+\lambda minL}\right)h_{\lambda=1} + \left(\frac{(\lambda-1)minL}{1+\lambda minL}\right)h_{air} \tag{23}$$

Where:

- h_λ - enthalpy of the combustion products for λ excess air
- $h_{\lambda=1}$ - enthalpy of the combustion products for stoichiometric combustion
- h_{air} - enthalpy of the air

Check to see if the ratio $\frac{w_c}{h_3^*}$ is equal to the nominal ratio $\frac{w_{c_n}}{h_{3_n}^*}$. If not, iterate x until it is, within a reasonable tolerance of about 1%.

After iterating x, we arrived to $x = 1.4$.

T_3^*	h_3^*
1552.103717 [K]	1753.74986 $\frac{kJ}{kg}$

4. We are now to find the critical conditions by:

$$\pi_{c_{cr}}^* = \frac{1}{\sigma_{comb}\pi_D}\left[\frac{\frac{\gamma_g+1}{2}}{1-\frac{w_c}{h_3^*}\frac{1}{\eta_{turbine}}}\right]^{\frac{\gamma_g}{\gamma_g-1}} \tag{24}$$

$$N_{cr} = N_n\sqrt{\frac{\eta_{c_n}}{\eta_{c_{cr}}}\frac{\pi_{c_{cr}}^{\frac{\gamma-1}{\gamma}}-1}{\pi_{c_n}^{\frac{\gamma-1}{\gamma}}-1}} \tag{25}$$

We are to then repeat steps (1)-(3) for three values of angular speed larger than the critical angular speed.

$\pi^*_{c_{cr}}$	N_{cr}	$\eta_{c_{cr}}$
5.462985	44711.24058 rpm	0.879

$\frac{w_c}{h_3^*}$	$\left(\frac{w_c}{h_3^*}\right)_n$	% diff
0.1785009519	0.180335162	1.0171116 %

5. Once we have reached the critical value, our ratio $\frac{w_c}{h_3^*}$ is no longer constant. If the flow isn't critical, then the variation of $\frac{w_c}{h_3^*}$ is given by:

$$\frac{w_c}{h_3^*} = \eta_{turbine}\left[1 - \left(\frac{p_H}{p_3^*}\right)^{\frac{\gamma_g - 1}{\gamma_g}} - K\left(\frac{A_{3.5}}{A_5}\right)^2\left(\frac{p_3^*}{p_H}\right)^{\frac{2}{\gamma_g}}\right] \tag{26}$$

Where:

$$K = \left(\frac{A_5}{A_{3.5}}\right)^2\left(\frac{p_H}{p_3^*}\right)^{\frac{2}{\gamma_g}}\left[1 - \left(\frac{p_H}{p_3^*}\right)^{\frac{\gamma_g - 1}{\gamma_g}}\frac{w_c}{h_3^*}\frac{1}{\eta_{turbine}}\right] \tag{27}$$

$$\frac{p_H}{p_3^*} = \frac{1}{\sigma^*_{combustion}\pi_c^*\pi_D} \tag{28}$$

Recall that π_D is given by:

$$\pi_D = \frac{p_1^*}{p_H} \tag{29}$$

When performing this step be sure to choose a π_c^* that is less than the critical value $\pi^*_{c_{cr}}$.

K	$\frac{p_H}{p_3^*}$	$\frac{w_c}{h_3^*}$
0.007177101	0.23020826	0.180335162

6. Now we are to choose an N value smaller than the critical value N_{cr}, and calculate w_c using equation (16) We chose a N value that was 1% less than the critical value.

$$N < N_{cr} \tag{30}$$

Now we use equation (16) to calculate w_c.

N	w_c
44500 rpm	199.73351054474077 $\frac{kJ}{kg}$

7. Now calculate h_3^* from equation (26) and $w_c = 171.430154 \frac{kJ}{kg}$.

$$h_3^* = w_{c_n} \left(\frac{w_c}{h_3^*} \right)^{-1} \tag{31}$$

h_3^*
1107.56831 $\frac{kJ}{kg}$

8. Calculate T_3^* using the stoichiometric and air gas tables.

T_3^*
1028.878066 K

9. For known value of π_c^* and N read from the the compressor map the value of the corrected mass flow rate

$$\pi_c{}^* = 5.18983611172067 \tag{32}$$

Yields a corrected mass flow rate of:

$m_a \frac{\sqrt{T_1^*}}{p_1^*}$
$(0.63)(1.6087157)\frac{\sqrt{288}}{101325}$

10. Now determine T_3^* using equation (21).

11. Compare the values of T_3^* from step 8 to T_3^* from step 10, if they differ by more than 10 degrees K, then iterate until with different N value.

T_3^*
1033.097120243129 K

12. Now choose another value of π_c^* and go back to step 5 and repeat the process to get other points on the operating line at $\frac{p_H}{p_3^*}$