AE630

Homework Assignment – 1

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PROBLEM STATEMENT :

The objective is to write a computer program to implement numerical solution to the combined blade-element/ momentum theory (BEMT) discussed in class and to plot the graph for variation of thrust versus blade pitch angle and variation of power versus blade pitch angle (varying it from 0 to 16 degrees).

INFORMATION GIVEN:

(rotor geometry)	(*value)*
Blade radius, R	0.355 m
Blade chord, c	0.032 m
Number of blades, N_b	2
RPM	1500
Density of air, ρ	1.125 kg/m^3
Lift curve slope, Cl_α	5.73
Drag coefficient, Cd_o	0.01

Power = Profile power + k x Induced power,
(where k=1.15)

SOLUTION:

The formulae of power and thrust that I will be using are:

Power = $C_P \rho A(\Omega R)^3$

Thrust = $C_T \rho A(\Omega R)^2$

where C_P = Power Coefficient = C_Q (Torque Coefficient)
C_T = Thrust Coefficient
A = Area of the blade
Ω = Angular velocity in rad/sec
R = Blade radius

And C_Q is calculated as below:

$$C_Q = \int_0^1 \lambda dC_T + \int_0^1 \frac{1}{2}\sigma C_d r^3 dr$$

here, induced power is calculated using the first term and profile power is calculated using the second one.

And C_T is calculated as below:

$$C_T = \frac{1}{2}\int_0^1 \sigma C_{l_\alpha}(\theta r^2 - \lambda r)dr$$

λ is calculated as below:

$$\lambda(r) = \frac{\sigma C_{l_\alpha}}{16}\left(\sqrt{1 + \frac{32\theta r}{\sigma C_{l_\alpha}}} - 1\right)$$

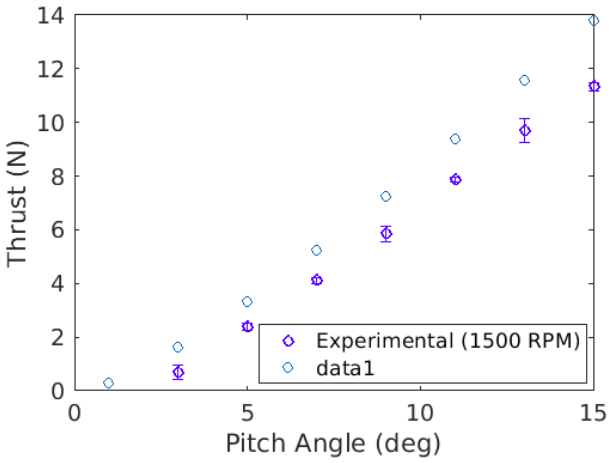
σ(solidity) is calculated as below:

$$\sigma = \frac{N_b c}{\pi R}$$

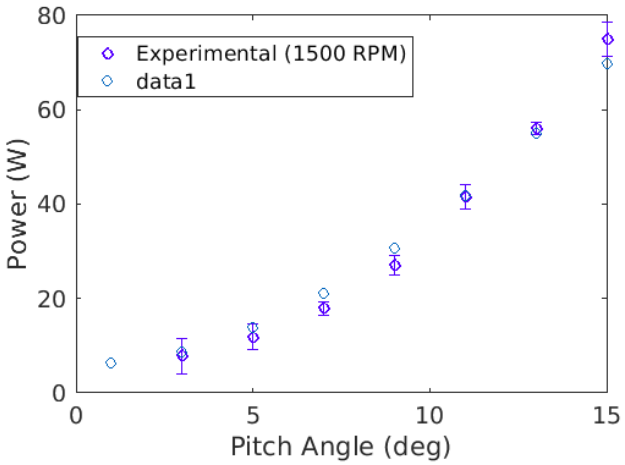
METHOD OF INTEGRATION:
Out of six-point Gaussian Quadrature and simple rectangular/ trapezoidal rule based numerical integration, I have used the latter one in my calculations.

FILES INCLUDED:
BEMT.m : This contains the required code.
BEMT_plot.mlx : This contains the script file in which I call the function BEMT for different values of pitch angle and also plot the graphs. In this file, I comment the part that plots the thrust when I want to plot the power and vice versa.
Graphs: The two graphs have been put in this pdf as well.

GRAPHS:



1) Thrust vs blade pitch angle.



2) Power vs blade pitch angle

COMPARISON & COMMENTS:
The obtained values differ a bit from the experimental measurements given in the fig files due to the following reasons:
I) I did not include the losses due to tip vortex which could be included using Prandtl's Tip Loss Factor.
II) I took Cl_α as a constant but it varies with angle of attack.

NOTE:
The power calculation due to BEMT will come out to be less than the experimental one due to the extra drag and to compensate it we used the factor of k=1.15 in induced power.
If we would have used k=1 then the graph of power versus pitch angle would have been like the following one: