AE 667: Assignment 1

Weightage: 20% of the total grades

Suggested due date: 27th Sept. 2023 (Sunday)
(Try your best to finish work by this day. The next assignment will get posted by then and extending work beyond this point will lead to less time for the next assignment)

Absolute deadline: 3rd Sept. 2023 (Sunday) 11:59 PM
(Submissions after this deadline will attract 5% penalty for each 30 minutes delay. For example, 15% will be deducted from the assignment grades if the submission happens at 1:30 AM)

A note on plagiarism:

This is an individual assignment. While discussion is encouraged, simply copying someone else's work will attract zero marks for all involved.

Background

You have created a drone startup, and you have won a project on developing a reconnaissance drone that meets Indian Navy's requirements. The drone is supposed to carry a surveillance payload containing passive sonar weighing. The drone should be able to take-off and land vertically from a ship deck and also be able to dive in the water to install the sonar strategically on the ocean floor. A sample mission profile provided by the navy is as follows:

1. Take-off from ship deck carrying the sonar
2. Travel 5 km (on a calm day) over the sea
3. Dive inside the water to a depth of about 500 meters
4. Search the ocean bed and leave the payload at an appropriate location.
5. Rise back to the surface
6. Return to the ship and land.

Relevant payload specifications:

- Weight = 5 kg
- Volume = 0.0025 m^3
- Water proof (until 1000m depth)

Goal:

Design the amphibian drone's rotor in full detail considering the stated requirements, using a self-developed tool.

Tasks

1. **Do the initial sizing** of your vehicle rotor using Momentum Theory to decide on tentative rotor dimensions and power requirement in hover. Also check the rotor's estimated power requirement under water.
2. **Make computational tools** to implement **BE Theory** and **BEM Theory** with the Prandtl Tip Loss model (will require iterative solving). The program will be used for design purpose;

hence it should be flexible enough to allow setting linear twist, linear taper, and root cut-outs, and non-zero climb velocity.

3. **Benchmark your tools** by comparing your results from BE Theory and BEM Theory against the experimental results from a paper by Knight and Hefner [1]. We want to see if the developed codes are good enough for designing your rotor. [Note that the definition of C_T and C_P used in the paper are a bit different from the modern definition. Hence, make the necessary modification to the available data before comparison.]

   Details on rotor geometry and airfoil from the paper are provided in the following table:

Rotor	
Radius	0.762 m
Root Cut-out	0.125 m
Number of blades	2/3/4/5 (choose any one for your analysis)
Chord length	0.0508 m
Airfoil	
C_l	$= a_o\ \alpha$ $= 5.75\ \alpha$
C_d	$= C_{d(min)} + \varepsilon\ \alpha^2$ $= 0.0113 + 1.25\ \alpha^2$

4. **Understand design variables:** Study the effect of variation in (a) Solidity (b) Taper (c) Twist on Thrust and Power coefficients.
5. **Finalize your rotor to meet the requirements** by setting rotor design parameters: (a) Airfoil, (b) Radius, (c)Number of Blades, (d)Chord Length Variation, (e)Twist Variation. Come up with at least three feasible designs that give the desired hover performance in air as well as water. Assume that it is possible to change rotor speed and collective pitch angle of the blades while transitioning between air and water operation as necessary. Pick the best of the three rotor designs for your drone. Check how far is your rotor's performance from the ideal one from momentum theory.
6. **Determine your rotor's performance** by plotting Thrust and Power vs Collective Pitch (θ_{root}) in air and water up to the airfoil stall limit.

Report Structure

1. Starting Assumptions & Data

State all assumptions / data on environment, vehicle, physics, flight condition, etc. utilized while doing the assignment. [5]

2. Initial Sizing

Mention the following with sufficient explanation/justification/supporting calculations.

2.1. Rotor Diameter [1]

2.2. Ideal Power in Air [2]

2.3. Ideal Power in Water [2]

3. The Computational Tool

3.1. Working/Algorithm/Logic Flow Diagram of the B.E Theory part of your code [7]

3.2. Working/Algorithm/Logic Flow Diagram of the B.E.M Theory part of your code [7]

4. Benchmarking the Tools

4.1. <u>C_T vs θ_0 plots</u>: B.E.T, B.E.M.T, experimental results on the same chart for comparison [3]

4.2. <u>C_Q vs θ_0 plots</u>: B.E.T, B.E.M.T, experimental results on the same chart for comparison [3]

4.3. Observations, comments, conclusions from the above plots [4]

5. Design Variable Variations

5.1. C_T vs σ & C_P vs σ plots and observations [4]

5.2. C_T vs taper ratio & C_P vs taper ratio plots and observation (Taper ratio = c_{tip}/c_{root}) [4]

5.3. C_T vs twist & C_P vs twist plots and observation (twist = $\theta_{root} - \theta_{tip}$) [4]

6. Rotor Design & Performance

6.1. Describe 3 feasible designs and their performance by filling out the following table.

(Here feasibility refers to thrust demand being met and power required being within the capability limits of your assumed power plant.)

Design Parameter				
	Design 1	**Design 2**	**Design 3**	
Airfoil				[1.5]
Rotor Radius				[1.5]
Number of Blades				[1.5]
Chord Length Variation				[1.5]
Twist Variation				[1.5]
Root Cutout				[1.5]
Operating Condition				
Rotor Speed in Air				[1.5]
Rotor Speed in Water				[1.5]
Collective Pitch in Air				[1.5]
Collective Pitch in Water				[1.5]
Steady Hover Performance Estimates				
Thrust in Air				[1.5]
Power in Air				[1.5]
Ideal Power in Air				[1.5]
Thrust in Water				[1.5]
Ideal Power in Water				[1.5]
Power in Water				[1.5]
Performance Limits (RPM constant, varying only collective pitch)				
Stall Collective Pitch Angle in Air				[1.5]

Maximum Thrust Before Stall in Air				[1.5]
Power at Max Thrust in Air				[1.5]
Stall Collective Pitch Angle in Water				[1.5]
Maximum Thrust Before Stall in Water				[1.5]
Power at Max Thrust in Water				[1.5]

6.2. Describe briefly how did you estimate the stall collective pitch angles. [1]

7. Acknowledgement

Mandatory to acknowledge people you discussed with or took help for any part of the assignment

8. References

List all references (books, paper, websites, etc.) used while doing the assignment

9. Code/Tool

As a separate zip file, along with its user manual [20]

Guidance on the computer program:

1. **Programming language**: Use only freely available ones. (-5% for MATLAB, etc.)
2. **Thoroughly commented** and user friendly (- 5% if not done)
3. **User Manual**: Clear guide to tell the user how to run the program and use it. (-5% if not done)
4. **In case the program is not working by the time of the submission**:
    a. Describe the logic flow in section 3 in good detail.
    b. Use someone else's program who is using the same algorithm as you were trying to implement. Do not forget to acknowledge the creator of the code, otherwise you will be caught for plagiarism.
    c. Generate results using the code for doing the later parts of the assignment.
    d. You may still want to get your code ready at some point for modifying it for the next assignment.
    e. Obviously, there are marks for a working tool!
5. **Naming convention**: (- 5% if not done right)
    a. All files & functions of the program (including user manual, excluding report) to be packed in a .zip file named after your roll number eg. "193010100.zip"
    b. The main file of the program to be named after your roll number. Eg. "193010100.py"
    c. The report in PDF format also to be named after your roll number. Rg. ""193010100.pdf""

References

[1] Knight, M., & Hefner, R. A. (1937). Static thrust analysis of the lifting airscrew.

Through this assignment, we are aiming at gaining and/or practicing our ability to:

1. Develop a tool to analyse or design rotors based on BEM Theory
2. Make sense out of prediction results
3. Use a prediction tool to design rotors/propellers
4. Do some basic programming