AE 667: Assignment 1

Weightage: 20% of the total grades

Suggested due date: 24th Aug. (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: 31st Sept. (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)

Work Share:

1. **Team**: Coding part of the assignment (rotor performance estimator and mission planner development)
2. **Individual**: Helicopter design and analysis using the developed codes

A note on plagiarism:

The coding aspects of the assignment are to be done in a team, and the design aspects are to be done individually. While discussion across teams is encouraged, simply copying someone else's work will attract zero marks for all involved.

Background

You are hired at HAL's helicopter division and your team has been given the tasks of developing a futuristic compound helicopter and a mission planner specifically built for it. The program manager has suggested the team to develop the tools necessary for design first, and then asked the individual team members to do their best in designing the compound helicopter, hoping to get more than one good designs. The requirements the design tools and the compound helicopter are as follows:

Performance Estimator Tool:

1. Should be able to model a helicopter consisting of main rotor, tail rotor, fuselage, skid, horizontal stabilizer and vertical stabilizer.
2. It should have the flexibility to accommodate change in helicopter design parameters.
3. It must account for:
    - Pilot inputs (collective pitch, cyclic pitch, tail rotor collective, etc.)
    - Flight conditions (hover, climb, forward flight)
    - Atmospheric conditions (variation in temperature, pressure, density, etc)
4. The performance estimator tool will serve as the backend for the mission planner tool and will also be used for helicopter design.

Mission Planner Tool:

1. Must calculate how much fuel will be needed for a given mission profile consisting of take-off, climb, cruise, loiter, cruise, and landing, with a preset fraction of reserve fuel

2. Must give a warning if the mission is not possible for any reason such as insufficient fuel capacity, insufficient engine power, blade stall, etc. in any of the flight segments
3. Must account for the head/tail winds for the cruise segments
4. Must account for any loading or unloading of the payload in the middle of a mission

Compound Helicopter:

1. Max take off altitude: 3500 m altitude (with all passengers and a full fuel tank)
2. Desired top speed: 400 km/s
3. Service ceiling: 5000 m
4. Range: 500 km
5. Payload: 2 pilots + 8 passengers, assume 70kg/person

Goals of Assignment 1:

1. Initiating the development of performance estimator tool and mission planner, with physics of hover and climb modes, and provision for future inclusion of other flight modes. (**team effort**)
2. First-cut design of helicopter rotor(s) necessary for hover and climb modes using the developed tools. (**individual effort**)

Group Tasks

1. **Make performance estimator tool** to implement **Blade Element Momentum Theory (BEMT)** with the Prandtl Tip Loss model (will require iterative solving). The program should be flexible enough to allow setting linear twist, linear taper, and root cut-outs, and non-zero climb velocity, etc.
2. **Benchmark the tool** by comparing your results from BEMT 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 rotors.
[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	$= a_0\ \alpha$ $= 5.75\ \alpha$
C_d	$= C_{d(min)} + \varepsilon\ \alpha^2$ $= 0.0113 + 1.25\ \alpha^2$

3. **Understand Design Variables** Study the effect of variation in (a) Solidity (b) Taper (c) Twist on Thrust and Power individually for the benchmark rotor.
4. **Make mission planner tool** with hover and vertical climb modes, taking in further information about the helicopter (such as vehicle weight, tail rotor power fraction, engine losses, specific fuel consumption of the engine, etc.) and utilizing the power estimator code. The mission planner tool must be able to estimate vehicle weight each minute

Individual Tasks

5. **Define details** of own compound helicopter.
6. **Finalize the rotor(s)** by setting rotor design parameters: (a) Airfoil, (b) Radius, (c)Rotor Speed, (d)Number of Blades, (e)Chord Length Variation, (f)Twist Variation.
7. **Determine your rotor's performance** by plotting Thrust and Power vs Collective Pitch (θ_0) up to the stall limits.
8. **Check the hover endurance** of your helicopter at 2000 m altitude.

Program Structure

Flight Simulator Program

The performance estimator tool must have the following functions for modularity. Additional functions or sub-functions may be created as necessary.

1. User Inputs: Allow users to specify geometric, aerodynamic, structural, and functional details of the helicopter rotors, fuselage, engine, etc.
2. Blade Geometry: Takes in bladed geometry parameters and returns chord length and pitch angle of the blade section at a given radial location
3. Atmosphere: Calculates temperature, pressure, density, speed of sound, etc. at a given altitude for specified weather condition (ISA temperature offsets)
4. Airfoil: Gives C_l , C_d, C_m of the airfoil at a given angle of attack
5. Inflow: Computes inflow consisting of vehicle velocity, wind velocity, and induced velocity for each blade section
6. Instantaneous integrator: integrates instantaneous forces and moments on individual blades. It relies on all of the above functions in addition to the knowledge of instantaneous blade location to give answers.
7. Cycle integrator: integrates forces and moments about one complete rotation for performance computations (thrust, power, moments, etc.)
8. Vertical and horizontal stabilizers: Computes forces on the horizontal and vertical stabilizers based on stabilizer geometry and placement.

Mission Planner Program

The Mission Planner program must have the following functions for modularity. Additional functions or sub-functions may be created as necessary.

1. Mission Inputs: Allows users to specify mission data, such as take-off weight, take-off altitude, fuel weight, details about each flight segment.
2. Flight Segments: Calculates power required for the flight segment (based on flight simulator program), power available from the engine, and fuel burn rate. Updates vehicle and fuel weight frequently and warns if the flight segment is infeasible due to any reason (insufficient engine power, potential stall, insufficient fuel). The flight segments of interest are:
    a. Hover and vertical climb
    b. Forward and steady climb
    c. Payload pickup/drop
    d. Loiter

Team Report Slides (70%)

0. Team Member Contribution [Mandatory]

[Note: Contribution level marked against each team member will be used as a scaling factor while assigning marks for the team tasks]

Sr. No	Roll Number	Name	Contribution Level (0 to 5)	Specifics of Contribution
1				
2				
3				
4				
5				

<u>Contribution Level Rubrics</u>:

- **0**: Was completely unresponsive and did not put any effort.
- **1**: Responded, but didn't do the promised tasks, and didn't try to learn to do it either.
- **2**: Did the promised/assigned tasks only partially/incorrectly and didn't try to learn to do it completely/correctly.
- **3**: Did the promised/assigned tasks only partially/incorrectly but put some effort to learn to do it right.
- **4**: Did the promised/assigned tasks to just acceptable quality with or without guidance from the other team members.
- **5**: Did the promised/assigned tasks completely with or without guidance from other team members.

1. Starting Assumptions & Data

State all assumptions / data utilized while programming and designing vehicle
(for eg. Airfoil data taken from tables, fuselage assumed to be drag-less, etc.)

1.1. Physics Assumptions/Data [1]
1.2. Environmental Assumptions/Data [1]
1.3. Vehicle Assumptions/Data [1]
1.4. Flight Condition Assumptions/Data [1]

2. Algorithm/Logic Flow Diagrams

2.1. Working/Algorithm/Logic Flow Diagram of the Performance Estimator Tool [15]
2.2. Working/Algorithm/Logic Flow Diagram of the Mission Planner [8]

3. Performance Estimator Tool Benchmarking

3.1. Thrust vs θ_0 plots: B.E.M.T and experimental results on the same chart [3]
3.2. Torque vs θ_0 plots: B.E.M.T and experimental results on the same chart [3]
3.3. Thrust vs Power plots: B.E.M.T and experimental results on the same chart [3]
3.4. Observations, comments, conclusions from the above plots [4]

4. Comparison with CFD Data

4.1. Sectional thrust from CFD vs BEMT (plots on the same chart w.r.t r/R) [3]
4.2. Inflow variation from CFD vs BEMT (plots on the same chart w.r.t r/R) [3]
4.3. Observations, comments, conclusions from the above plots [4]

5. Design Variable Variations

(at least 4 data points for each plot)

5.1. Thrust vs Blades & Power vs Blades and observations [4]
5.2. Thrust vs Taper ratio & Power vs Taper ratio plots and observation [4]
(taper ratio = c_{tip}/c_{root})
5.3. Thrust vs Twist & Power vs Twist plots and observation (twist = $\theta_{root} - \theta_{tip}$) [4]

6. Mission Planner Test

Assume:

(a) Group's common helicopter design,
(b) Installed power loss of 10%

6.1. Maximum Take Off Weight based on blade stall at 2000 m AMSL [1]
6.2. Maximum Take Off Weight based on power requirement at 2000 m AMSL [1]
6.3. Fuel Burn Rate (kg/minute) vs Gross Weight (kgf) plot at 2000 m AMSL [3]
6.4. OGE Hover Endurance (minutes) vs Take-Off-Weight (kgf) plot at 2000 m AMSL [3]

Individual Report Slides (30%)

1. Additional Assumptions/Data for your own helicopter design

1.1. Assumptions/data not covered in or different from the team presentation but used while coming up with own vehicle design. [1]

1.2. Rough schematic sketch of own compound helicopter [1]

2. Preliminary Drone Design

2.1. Describe the design developed by you for the versatile drone helicopter [14]

Parameter	**Rotor 1**	**Rotor 2**	**Rotor …**
Rotor Description (role)			
Airfoil			
Rotor Radius (m)			
Rotor Speed (m)			
Number of Blades			
Chord Length Variation			
Twist Variation			
Root Cutout			

2.2. Maximum main and tail rotor thrusts before stall [2]

2.3. Following plots for all rotors on the same chart: [6]

- <u>Thrust vs θ_0</u>
- <u>Torque vs θ_0</u>
- <u>Thrust vs Power</u>

3. Hover Mission Test

Assume:

(a) Your individual helicopter drone design,

(b) Installed power loss of 10%

3.1. Maximum Take Off Weight based on blade stall at 2000 m AMSL [1]

3.2. Maximum Take Off Weight based on power requirement at 2000 m AMSL [1]

3.3. <u>Fuel Burn Rate (kg/minute) vs Gross Weight (kgf) plot at 2000 m AMSL</u> [2]

3.4. <u>OGE Hover Endurance (minutes) vs Take-Off-Weight (kgf) plot at 2000 m AMSL</u> [2]

4. Bonus Task: Flight Simulator Development

Make additional function that takes in instantaneous forces and moments from all components of the vehicle (rotors, stabilizers, rudder, elevators, etc.) and computes the net instantaneous forces and moments (all three axes) about the vehicle centric reference frame, accounting for the placement of the components. Show the functioning of the simulator using a simple GUI. [Some basic guidelines are uploaded on Moodle]

4.1. Tentative Details on placement of components and C.G w.r.t helicopter nose [2]

Component	**X**	**Y**	**Z**	**Any other necessary information**

Assumed C.G				
Rotor 1				
Rotor 2				
Rotor…				
Wing/Stabilizer - 1				
Wing/Stabilizer - 2				
Actuator – 1				
Actuator – 2				

4.2. Algorithm of the simulator [3]

4.3. 10 second clip (screen-recorded) of the flight simulator in action. Change collective pitch of the rotors and angles of other actuators sequentially and show how the forces and moments about all three axes change (FX, FY , FZ, Mx, My, Mz). [4]

4.4. Observations, comments, conclusions from the simulations [1]

5. Acknowledgement

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

6. References

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

7. Code/Tool

As a separate zip file, along with its user manual

Guidance on the computer program:

1. **Programming language**: Use only freely available ones. Python preferred (-5% for MATLAB, etc.)
2. Make the code modular by splitting it into functions (preferably separate files). Add a preamble to each function file describing what the function is supposed to do, what inputs does it need, what does it output, and any assumptions that have been made. Remember, you will end up using some of the functions across more than one assignments, so doing this will save you from frustration later.
3. Add comment against each variable name to describe what the variable means
4. Add comment for each functional chunk of code to explain what it is supposed to do.
5. Have a separate user input function/file where a user can specify all necessary design details and flight condition.
6. Write a "Readme.txt" file with complete instructions on how to run your code.

References

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