AE 667: Assignment 2

Weightage: 20% of the total grades

Absolute deadline: 28th 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 (flight simulator and mission planned development)
2. **Individual**: Drone 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 2:

1. Advance the performance estimator tool to handle other modes of flight, accounting for main rotor and tail rotor effects. Develop the mission planner to estimate helicopter's performance in forward flight with head/tail wind. (**team effort**)
2. Refine the design of the rotors using the updated tools for other flight modes (**individual effort**)

Assignment 2 Tasks

1. **Augment the performance estimator tool** to compute instantaneous forces and moments about all axes (F_X, F_Y, F_Z, M_X, M_Y, and M_Z) about a reference point due to the rotors for the given set of pilot inputs (collective and cyclic control of rotors) and flight condition.
2. **Understand the control inputs** by observing how all forces (F_X, F_Y, F_Z) and moments (M_X, M_Y, M_Z) vary with the pilot inputs for a given flight condition.
3. **Find trim settings** for the rotors ($\theta_{o,m}$, β_o, $\beta_{1c} + \theta_{1s}$ and $\beta_{1s} - \theta_{1c}$) for the stated steady level forward flight.
4. **Augment mission planner tool** with steady level forward flight modes, calculating range and endurance in these conditions.
5. **Try out the mission planner tool** for the group's helicopter in near-trimmed condition.
6. **Update rotor designs** of own helicopter to perform better in forward flight.
7. **Find trim settings** for your helicopter for steady level flight using the flight simulator
8. **Check the endurance and range** of your helicopter for a given altitude.

Hints:

1. The non-uniform main rotor inflow for forward flight is modelled using the following expression:

$$\frac{\lambda_i}{\lambda_{i_{Glauert}}} = 1 + \left[\frac{{}^4\!/_3\,\frac{\mu}{\lambda_G}}{1.2 + \frac{\mu}{\lambda_G}}\right]\frac{r}{R}\cos\psi$$

   Here λ_G is the total inflow ratio (induced inflow + free stream component) found using Glauert's method and $\lambda_{i_{Glauert}}$ is the induced inflow part found using Glauert's method.
2. Do not forget to check and account for the reverse flow appropriately.
3. Choosing the reference frame wisely while dealing the main rotor will make life easier.

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				

Contribution Level Rubrics:

- **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 [16]
2.2. Working/Algorithm/Logic Flow Diagram of the Mission Planner [8]

For the following sections, assume the group's common helicopter design

3. Pilot Input Tests and Observations

3.1. Plot F_X, F_Y, F_Z, M_x, M_y, M_z with change in all pilot inputs (θ_o, $\beta_{1c} + \theta_{1s}$, $\beta_{1s} - \theta_{1c}$, etc.) [10]

3.2. Observations and reasoning for the behavior of F_X, F_Y, F_Z, M_X, M_Y, and M_Z of the vehicle with variation in pilot inputs [10]

4. Trim Settings

4.1. For a 200 km/h level flight at 2000 m AMSL, fill the following table with the trim settings and resultant forces and moments [12]

θ_o		F_X (Vehicle)	
θ_{1s}		F_Y (Vehicle)	
θ_{1c}		F_Z (Vehicle)	
$\theta_{o,t}$		M_X (Vehicle)	
α_{TPP}		M_Y (Vehicle)	
Any other inputs		M_Z (Vehicle)	
		β_o	

5. Mission Planner Test

Find the following when the group's compound helicopter is in trim condition:

5.1. Maximum Speed based on blade stall at 2000 m AMSL [2]

5.2. Maximum Speed based on power requirement at 2000 m AMSL [2]

5.3. Maximum Range at 2000 m AMSL [3]

5.4. Maximum Endurance 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 with tentative dimensions [1]

2. Updated Helicopter Design

2.1. Describe the updated rotor design 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			

3. Trim Settings

3.1. For a 200 km/h level flight at 2000 m AMSL, fill the following table with the trim settings and resultant forces and moments [6]

θ_o		F_X (Vehicle)	
θ_{1s}		F_Y (Vehicle)	
θ_{1c}		F_Z (Vehicle)	
$\theta_{o,t}$		M_X (Vehicle)	
α_{TPP}		M_Y (Vehicle)	
Any other inputs		M_Z (Vehicle)	
		β_o	

4. Forward Flight Mission Test

Assume your compound helicopter design,

4.1. Maximum Speed based on blade stall at 2000 m AMSL [2]

4.2. Maximum Speed based on power requirement at 2000 m AMSL [2]

4.3. Maximum Range at 2000 m AMSL [2]

4.4. Maximum Endurance at 2000 m AMSL [2]

5. 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]

5.1. Updated 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				

5.2. Algorithm of the simulator augmented for forward flight [3]

5.3. 10 second clip (screen-recorded) of the flight simulator in action at 200 km/h flight. Change collective and cyclic pitch of the rotors and angles of other actuators sequentially and show how the forces and moments about all three axes (FX, FY, FZ, Mx, My, Mz) change in real time. [4]

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

6. Acknowledgement

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

7. References

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

8. 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.