AE 667: Assignment 3

Weightage: 20% of the total grades

Absolute deadline: 3rd Nov. (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 basic helicopter flight simulator and mission planner for training pilots and helping commanders plan their missions with the available helicopters. Individually, you have also been asked to do preliminary design of a helicopter drone for high-altitude operations for Army. The specifics of the requirements are as follows:

Flight Simulator:

1. Should be able to model a conventional helicopter consisting of a single 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)
    - Flight conditions (hover, climb, forward flight)
    - Blade inertia
    - Atmospheric conditions (variation in temperature, pressure, density, etc)
4. It should update all forces and moments about the centre of gravity (or a reference point) 72 times per main rotor rotation (every 5 degrees).
5. The flight simulator tool will serve as the backend for mission planner tool and will also be used for helicopter design.

Mission Planner:

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 warn if it 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 payload in the middle of a mission.

Helicopter Drone:

1. Should be able to take off from 5500 m altitude with at least 50 kg payload and 50 kg fuel.
2. Should be able to fly for at least 10 hours at sea level (without payload)
3. The only available engine is Turbotech. Specifications of the same are provided separately.

Goals of Assignment 3:

1. Advance the simulator further to account for control surfaces/stabilizers (**team effort**)
2. Finish mission planner development to integrate all flight modes (**team effort**)
3. Design stabilizers for your vehicle using the updated flight simulator. (**individual effort**)
4. Demonstrate performance of your helicopter throughout your mission accounting for all helicopter components and interactions. (**individual effort**)

Assignment 3 Tasks

1. **Augment the simulation tool** to account for horizontal and vertical stabilizer forces and moments along with main and tail rotor contributions about all axes (F_X, F_Y, F_Z, M_X, M_Y, and M_Z) about the centre of gravity at any given flight condition.
2. **Find new trim conditions** with the stabilizers added.
3. **Augment mission planner tool** to allow inputting the entire mission with the following segments:
    a. Hover for a specified period
    b. Vertical climb at a specified rate to a specified height
    c. Steady level forward flight at a specified speed, to a specified distance
    d. Steady climb and descent at a specified horizontal speed and climb rate, to a specified height.
    e. Pick up and drop off of a specified load
    f. Slow vertical descent by a specified height at a specified rate

    The mission planner tool should be able to:

    a. Accommodate any mission comprising of the above segments in any order.
    b. Account for head and tail winds in level, climb, and descent flight segments.
    c. Calculate power continuously in each segment (updates every ~5 minutes)
    d. Calculate fuel burn rate and keep track of fuel availability continuously
    e. Terminate the mission where either the peak power exceeds available power, or the fuel is spent.
    f. Indicate the final fuel left after a successful mission completion.
4. **Try out the mission planner tool** for the sample helicopter through 4 different specified missions.
5. **Update design** of your own helicopter to incorporate the stabilizers.
6. **New trim for own design** using the flight simulator and report changes.
7. **Apply the mission planner tool** for your helicopter for challenging missions.

Hint:

Use the simplified power coefficient expression comprising of terms for induced, profile, and parasitic power to estimate main and tail rotor power at each time interval. Tune the empirical coefficients in the expression to approximately match the power estimate from flight simulation code for a few flight conditions.

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

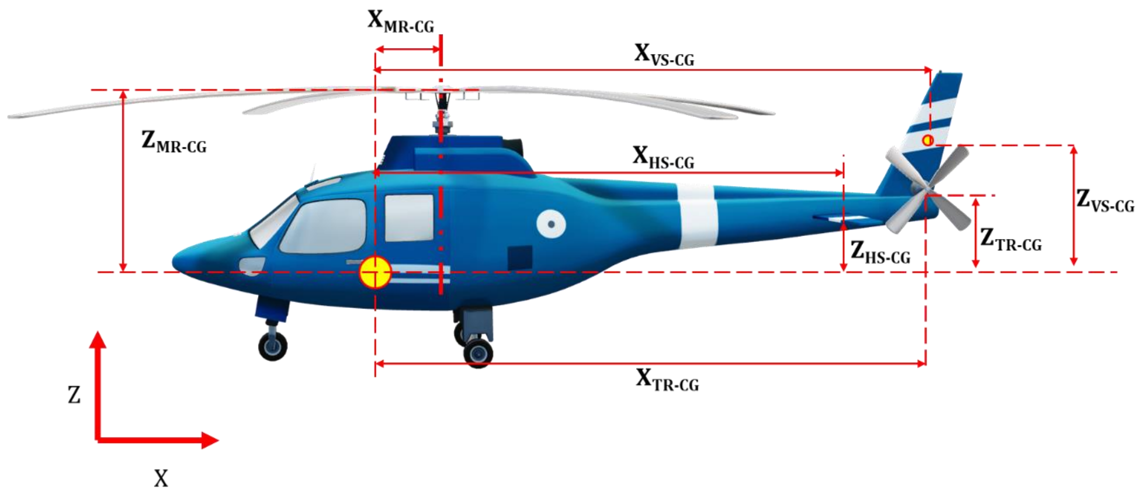
2.1. Working/Algorithm/Logic Flow Diagram of the Flight Simulator Code [8]

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

For the following sections, assume the following test vehicle.

(a) 2m radius main rotor with 3 blades identical to the experimental setup
(b) Fuel tank carrying 50 kg fuel
(c) Turbotech engine
(d) 2-bladed 0.5m radius tail rotor with chord = 0.2m
(e) Installed power loss of 10%
(f) Position details: $X_{MR\text{-}CG}$ = 0.5m ; $X_{TR\text{-}CG}$ = 3m ; $Z_{MR\text{-}CG}$ = 1.5m ; $Z_{TR\text{-}CG}$ = 0.25m;
(g) Horizontal stabilizer: same airfoil, chord = 0.2m, half-span = 0.4m, $X_{HS\text{-}CG}$ = 2.5m; $Z_{HS\text{-}CG}$ = 0.15m

(h) Vertical stabilizer: same airfoil, chord = 0.3m, span = 0.7m, $X_{VS\text{-}CG}$ = 3m; $Z_{VS\text{-}CG}$ = 0.5m



3. Trim Settings

3.1. For a 50 km/h level flight at 2000 m AMSL, fill the following table with the **new** trim settings and resultant forces and moments [6]

$\theta_{o,m}$		F_X (Vehicle)	
θ_{1s}		F_Y (Vehicle)	
θ_{1c}		F_Z (Vehicle)	
$\theta_{o,t}$		M_X (Vehicle)	

α_{TPP}		M_Y (Vehicle)	
β_0		M_Z (Vehicle)	

4. Mission Planner Test

Consider 3 missions as described below for the test vehicle. Numbers not provided are to be assumed.

A. Successful payload drop mission
   a. Takeoff from 2000m AMSL with 50 kg payload and 50 kg fuel
   b. Vertical climb to 2020 m AMSL at a reasonable rate
   c. Steady climb to 2500m AMSL at a reasonable rate with 20 km/h tail wind
   d. Level flight at 2500 m AMSL for some distance with 20 km/h tail wind
   e. Steady descent to 2300 m AMSL at a reasonable rate with 20 km/h tail wind
   f. Hover at 2300 m AMSL for 1 minute
   g. Vertical decent to land at 2290 m AMSL at a reasonable rate.
   h. 50 kg payload drop
   i. Vertical climb to 2300 m AMSL at a reasonable rate
   j. Steady climb to 2500m AMSL with 20 km/h head wind at a reasonable rate
   k. Level flight at 2500 m AMSL for some distance with 20 km/h head wind
   l. Steady descent to 2020 m AMSL at a reasonable rate with 20 km/h head wind
   m. Vertical decent to 2000 m AMSL at a reasonable rate.

   Select values of rates and distances such that the fuel is remaining and mission is successful.

B. Successful payload pickup mission
   Identical to mission **A,** except that the payload of 50kg is picked instead of dropped at the location. Select values of rates and distances such that the fuel is remaining and mission is successful.
C. Fuel limited unsuccessful payload pickup mission
   Identical to mission **B,** except that the distance is such that the fuel runs out in the steady flight after picking the payload.
D. Power limited unsuccessful payload drop mission
   Identical to mission **A,** except that the altitude of payload drop is too high for the helicopter to hover. Adjust all altitudes in the mission segments according to the chosen payload drop altitude.

Plot the following with respect to time (~5 minute intervals) for the entire duration of the above four missions:

4.1. Gross Weight [4]
4.2. Fuel Weight [4]
4.3. Fuel Burn Rate [4]

4.4. Altitude (AMSL) [4]
4.5. Total Power Required and Available Engine Power [4]
4.6. Speed [4]
4.7. Climb rate [4]
4.8. Distance covered [4]

4.9. Comment on major observations from the above plots [4]

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]

2. Drone Design

2.1. Rotor design and placement details **from assignment 2** for reference (updates allowed) [2]

Parameter	**Main Rotor**	**Tail Rotor**
Airfoil		
Rotor Radius (m)		
Rotor Speed (m)		
Number of Blades		
Chord Length Variation		
Twist Variation		
Root Cutout		
Position ($X_{\_-CG}$, $Y_{\_-CG}$)		

2.2. Horizontal Stabilizer details: Airfoil, Chord, Span, X_{HS-CG}; Z_{HS-CG} [5]
2.3. Vertical Stabilizer details: Airfoil, Chord, Span, X_{VS-CG}; Z_{VS-CG} [5]

3. Trim Settings

3.1. For a 50 km/h level flight at 2000 m AMSL, fill the following table with the **new** trim settings and resultant forces and moments [3]

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

4. Helicopter Mission Capability Tests

For your helicopter design, create the following mission profiles

A. 50kg payload drop mission starting from a base at 2000 m AMSL to reach the highest possible drop off location and come back.
B. 50 kg payload pickup mission starting from a base at 2000 m AMSL to reach the farthest possible pickup location at the same altitude, and come back.

4.1. Describe your mission profiles for both the missions with all segments and their details (speeds, climb rates, etc.) [6]

4.2. Plot the following with respect to time for both the missions:

a) Gross Weight [1]
b) Fuel Weight [1]
c) Fuel Burn Rate [1]
d) Altitude (AMSL) [1]
e) Total Power Required and Available Power [1]
f) Speed [1]
g) Climb rate [1]
h) Distance covered [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