ASSIGNMENT HELICOPTERS AE4-314-21

(Group of 2 people or Individual assignment)

You are asked to write a report on helicopter performance calculations, explaining shortly the calculations you have done to answer the questions below (Max 50 pages). Note: you are allowed to use ChatGPT as long as you refer to it and explain in the text how did you use it.

Part 1 -Helicopter Performance Calculation

Question 1.1 Choice of helicopter configuration

First, you are asked to choose a conventional helicopter (1 main rotor with tailrotor) that you would like to investigate further. The choice of the helicopter is free. Please describe the chosen helicopter in terms of type (small/medium/large civil or military), payload, maximum speed, cruise speed, range and/or endurance, hover ceiling, etc. Use for this the data from "Jane's All the World's" Aircraft or refs. 3 and 4.
For the chosen helicopter, during the assignment, you will need to estimate different parameters such as helicopter mass, moment of inertia of helicopter in y axis, mass blades, blade radius, blade chord, number of blades, blade moment of inertia, rotor rpm, fuselage drag coefficient, vertical distance from rotor hub centre to the centre of gravity of helicopter, etc. .

Question 1.2 Induced velocity calculation

For the chosen helicopter, calculate the induced velocity in hovering flight and in forward flight using Actuator disc theory. Represent the variation of induced velocity v_i as a function of forward velocity.

Question 1.3 Performance calculations

Hover calculations

1. Calculate the ideal power.
2. Calculate the power to hover in actuator disc theory (ACT) and in BEM theory (Assume a FM in ACT theory according with your type helicopter).

Forward flight calculations

1. Determine the total power required in forward flight using BEM theory (as given by the summation of parasite drag power, induced power, total profile drag power and including also the tail rotor). Represent the variation of power required as a function of the velocity, starting from hover to maximum velocity. For the tailrotor power, one should apply also BEM theory and take a factor of 1.1. in the tailrotor induced power which accounts for the vertical fin blockage and k_{tr}= 1.3 – 1.5, i.e. $P_{itr} = 1.1 k_{tr} T_{tr} v_{i_{tr}}$

2. Determine the speed for best range and the speed for best endurance. and compare these velocities with manufacturer performance data for the chosen helicopter.

Part 2 -Helicopter Rotor Dynamics

Assume that the helicopter is in forward flight V=20 m/sec with has a body pitch rate q=20 deg/sec and a roll rate p=10 deg/sec.

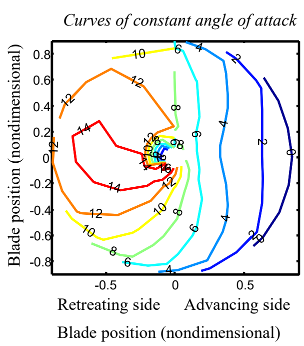
1) Represent the blade flapping angle for the advancing blade for one complete blade revolution. Assume a collective pitch of 6 degrees, longitudinal cyclic 2 deg and lateral cyclic 1 deg.
2) Represent the angle of attack variation for the advancing blade around one complete blade revolution (360 deg).
3) Apply the Fourier series and deduce the disc tilt angles for this helicopter forward flight.

Optional

1. Assume that the blade has a linear twist $\theta = \theta_0 - \frac{r}{R}\theta_{tw}$. What is the effect of twist on the coning angle (hovering helicopter)?

Note

Usually the angle of attack variation is one blade revolution is represented as the figure below giving the curves on the disk where the angle of attack is constant. Try to represent this also for your model.



Part 3 -Helicopter Flight Mechanics Manoeuvre Simulation

Question 3.1 Trim Calculation

Calculate the trim of the helicopter in a 3-degree of freedom longitudinal model for different flight speeds varying from hover to maximum speed and represent the variation of the pilot's controls - collective and the longitudinal cyclic pitch - as a function of the forward velocity V.

Question 3.2 Manoeuvre Simulation

The most comprehensive set of flying qualities criteria for helicopters is provided by the US Army Aeronautical Design Standard ADS-33 [ref.1]. Developed in mid 1980's, ADS-33 contains a database of so-called "mission-oriented" manoeuvres and criteria reflecting how much effort it takes the pilot per specific mission, so actually accounting for the couplings existing between task difficulty and achieved performance.

You are asked to perform a numerical simulation and fly the "**speed control" manoeuvre** from the ADS-33 (see paragraph 3.11.23 in ADS-33). The manoeuvre is described as follows in the ADS-33:

SPEED CONTROL

a. **Objective** Investigate airspeed control to assess adequacy of stick force gradient with airspeed.
b. **Description of Manoeuvre**. From trimmed level flight at 90 knots, decelerate to 70 knots and retrim for hands-off flight. Then accelerate to 90 knots and retrim for hands off flight. Finally, accelerate to 110 knots and retrim.
c. **Performance standards**
Performance-Speed Control Task

	Desired	Adequate
Maintain altitude within ± X ft	100 ft	200 ft
Trim hands-off at target airspeed within ± X knots	3 knots	5 knots
Change from one trim airspeed to another within X minutes	1 minute	2 minutes
Maintain heading within ± X deg	5 deg	10 deg

You are asked to simulate this ADS 33 manoeuvre using a 3-dof model as described in [ref. 2] (more precisely computation scheme at page 96). To fly the manoeuvre one has to develop a pilot model in the form of a P, PI or a PID controller for controlling the longitudinal cyclic pitch and eventually collective. To develop such a controller, use the examples given in [ref. 2] or explained during the lecture classes and the suggestions given in Appendix A. Please interpret the simulation results, discussing on how the pilot is "flying" the manoeuvre.

Optional
Use slTuner option in Simulink to Create and Configure an Interface in your Simulink Model.

Part 4 -Stability

For the chosen helicopter, calculate the frequency and damping characteristics of the **phugoid mode at 70 kts** using phugoid approximation. Discuss on the characteristics of the phugoid mode (frequency and damping). The stability derivatives can be derived either numerically or analytical using ref. 4 or 5.

References

1. AVSCOM, Aeronautical Design Standard (ADS) 33C – Handling Qualities for Military Helicopters, US Army AVSCOM, 2000

2. Holten, Th. van, “Helicopter Stability, Performance and Control” lecture notes, AE4-213, TU Delft 2002

3. Prouty, R.W., “Helicopter Performance, Stability and Control”, Krieger Publishing Company, 1986

4. Padfield, Gareth, D., “Helicopter Flight Dynamics”, Blackwell Science, 1996

5. Pavel, Marilena, D., “Six Degree-of-Freedom Linear Model for Helicopter Trim and Stability Calculation”, Memorandum M-756, TU Delft

Appendix A

Suggestions for Manoeuvre simulation

A few tips for building the helicopter simulation programme

1. Efficient method to compute the induced velocity v_i

The computation scheme from page 96 of the lecture notes “Helicopter Stability, Performance and Control” contains a loop to calculate the instantaneous induced velocity v_i. This is unpleasantly for computing calculations and requires relatively long computing time. Treating v_i as a state variable and adding a new equation to the helicopter system of equations of motion could avoid this problem. This new equation calculates dv_i/dt on the basis of a “quasi-dynamic inflow” as follows:

$$\tau \frac{dv_i}{dt} = C_{T,elem} - C_{T,Glauert}$$

The time constant τ considered in this equation varies between 0.1 and 0.5 sec.

2. Proper choice of the quadrant for angle ε

In the computation scheme from page 96 (see also figure 11.4) the angle of attack of the control plane is given as:

$$\alpha_c = \theta_c - \varepsilon$$

where $\varepsilon = a\tan\left(\frac{w}{u}\right)$.

Please take into account that, during the simulation the situation can arise of flying backwards! Take care and compute in these cases the proper quadrant during the simulation.

3. Tips for a control programme for "altitude-hold"

Build this programme progressively, starting with a simple control task and step-by-step building to the wished result.

Take for example first of all as (provisional) objective a certain desired vertical velocity c_{des} that will be achieved with the collective. During experiment it is a good idea to lock all the horizontal motions.

Try first a proportional controller around an average control position θ_{gen} (global estimated at for example 5 deg):

$$\theta = \theta_{gen} + K_1\left(c_{des} - c\right)$$

Tune the factor K_1 so that a reasonably behaviour of the helicopter is obtained. It will appear –obviously – that continuously a static error arises. Adding an "I-action" can eliminate this:

$$\theta = \theta_{gen} + K_1\left(c_{des} - c\right) + K_2\Delta\theta$$

where $\Delta\theta = \int_0^t \left(c_{des} - c\right)d\tau$.

Implementation of this can be easily done by calculating $\Delta\theta$ as an extra state variable and adding an equation of motion:

$$d(\Delta\theta / dt) = \left(c_{des} - c\right)$$

After again tuning the coupling factors, the "altitude hold" can be achieved by adding:

$$c_{des} = K_3\left(h_{des} - h\right)$$

where the actual height h is once again found by considering this variable as a state variable.

This last operation requires no compensation for the static error. When finally the coupling factors are once again "tuned" the horizontal motion of the helicopter can be reactivated and probably further "tuning" will be necessary.

4. The values of the gain in the PID controller can be derived either by trial and error or by using methods characteristic to control theory (root locus, Nichols charts,

etc.) Think that it is not required to build an optimal automatic pilot but more about forming a global idea on what kind of control actions would carry out a helicopter pilot.