ACS61015 Lab Report

1. Modelling

- Normally in tandem rotor helicopters, the two rotors rotate in opposite directions to counteract the resultant torque generated by each rotor.
- However, in this system, both rotors spin in the same direction (ccw) causing them to both generate reaction torques in the clockwise direction due to Newton's 3rd law. These Reaction forces add up as they are in the same direction.
- This torque would normally act about the yaw axis, but since we don't have one, it causes a change in the pitch axis due to coupling between these axes.
- When both fans are set at the same voltage using the open loop test, the helicopter pitches.
- Therefore, this phenomenon needs to be modelled and implemented into the State space equations in order to minimise the pitch offset from the rotors.
- This was done by adding an additional term to the pitch dynamics generalised force, shown in Equation 1.

$$Q_2 = -k_d\dot{\Psi} + l_2(F_a - F_b) - k_t(F_a + F_b) \qquad (1)$$

- Here, I am subtracting the sum of the fan thrusts multiplied by a torque constant k_t in the pitch axis, to negate the effect of the torques caused by the fans.
- This is then applied to the ordinary differential equation governing the motion about the pitch axis seen in equation 2.

$$\ddot{\Psi} = -k_d\dot{\Psi} + l_2(F_a - F_b) - k_s\Psi - k_t(F_a + F_b) \qquad (2)$$

- The forces to input voltages functions are then inputted to acquire the equation shown in equation 3.

$$\ddot{\Psi} = -k_d\dot{\Psi} + l_2(\alpha k_a(U_a - U_b)) - k_s\Psi - k_t\big((\alpha k_a U_a + \beta) + (\alpha k_a U_b + \beta)\big) \qquad (3)$$

- This is then used to calculate the state space matrices, where only row 5 of the B Matrix is changed, shown in equations (4) and (5).

$$B_{5,1} = \frac{l_2\alpha k_a}{J\Psi} - \frac{k_t\alpha k_a}{J\Psi}$$

$$B_{5,2} = \frac{-l_2\alpha k_a}{J\Psi} - \frac{k_t\alpha k_a}{J\Psi}$$

- K_t was then assigned a value of 0.01, as the effect isn't extreme given the scale of the model.
- The pitch before and after modelling the torque effect can be seen in figure 1.

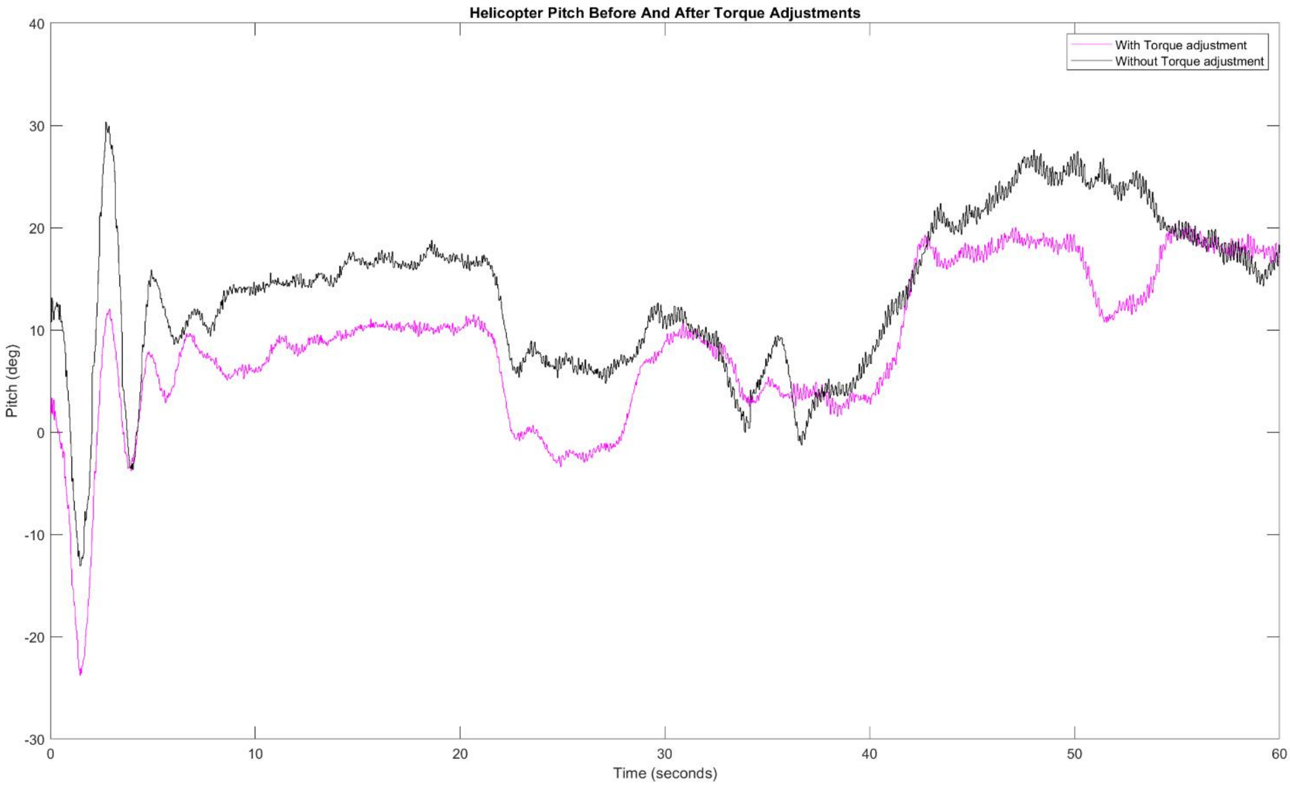

Figure 1: Test response of the pitch axis showing torque effect before and after adjustments

- Figure 1 clearly demonstrates how adjusting for the torque effect helps to bring the pitch towards an average of 0. This can also be backed up by the average pitch values before and after adjustment. Before, the average pitch was 13.6 but after implementing the new B matrix, the average pitch was 8.6, a considerable difference of 5 degrees.
- Further improvement could be made by adjusting K_t more finely to try to achieve an average pitch of 0, however when a larger value is selected such as 0.1, the system becomes unstable as it is overcompensating for the torque effect.

2. Controller design

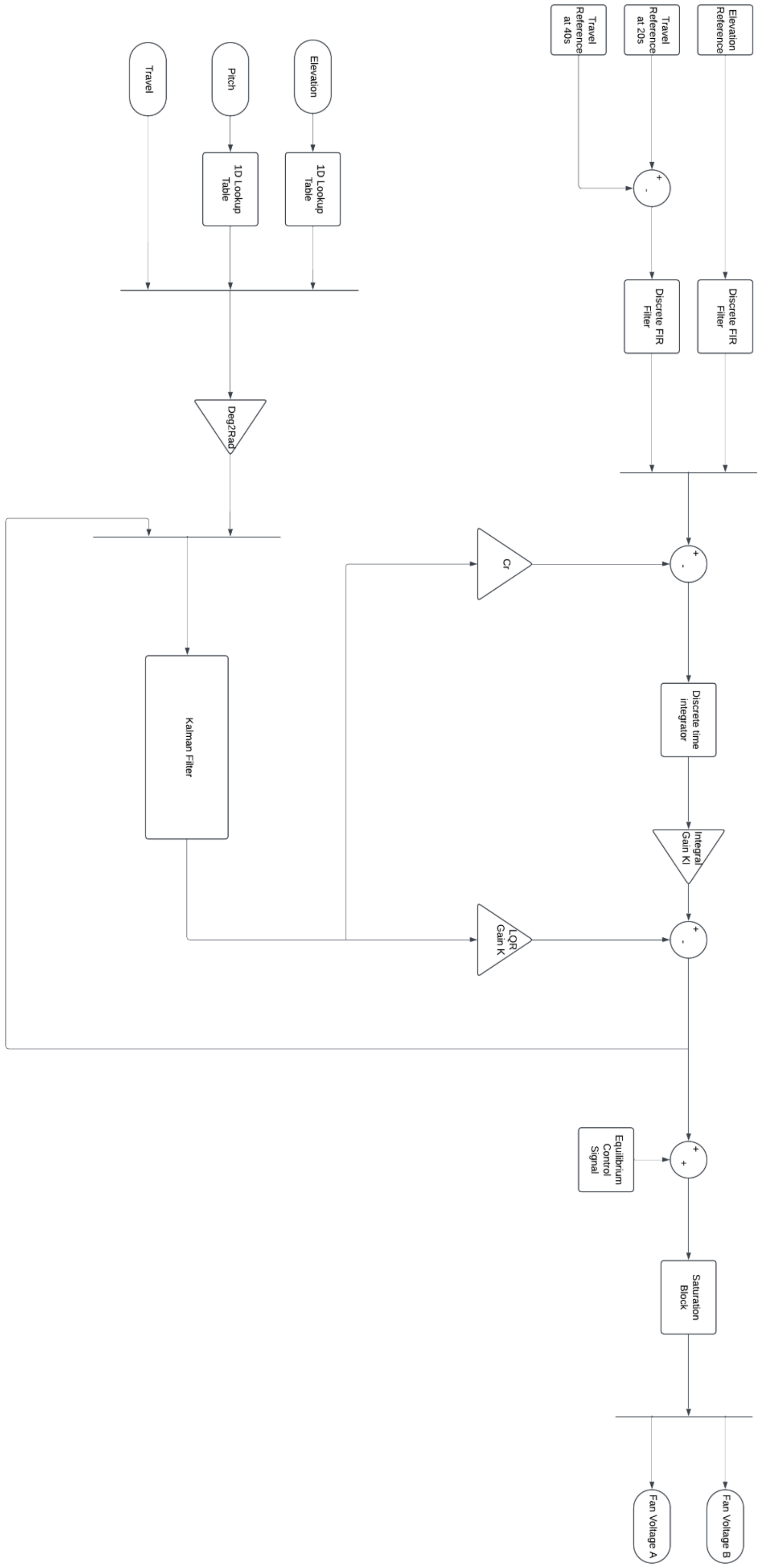

Figure 2: LQG Controller

Linear Quadratic Gaussian Control

Component	Usage	Calculations
Kalman Filter	Estimates the states of the systems, whilst filtering noise, to enable full state feedback.	I used the Kalman function to compute the Kalman filtered A, B, C and D matrices to be put in the discrete state space model block. Gdt and Hdt are set to very small values and zero respectively to show little process noise. Rw, the process noise covariance, was set to ones and the Rv was set to 1e-5 to represent very little measurement noise covariance.
Linear Quadratic Regulator (LQR)	An optimisation-based control method that minimises a quadratic cost function. It ensures optimal trade-off between accuracy (Qx) and effort (Qu) required, resulting in smooth and efficient control. This is able to deal with small disturbances to the helicopter system.	I used the lqrd function in MATLAB to compute matrix Kaug. I calculated Aaug and Baug then set Qx and Qu as follows: Qx = diag([83700,70,20,71500,50,5,7550,2]) Qu =0.5*eye(2) The LQR gain K is set as the first 6 columns of Kaug.
Integral Control	Reduces steady state error in presence of uncertainties and disturbances by using the actual error.	Integral control gain ki is set as the negative of the last two columns of Kaug.
Cr	Used in calculation of Aaug and used as a gain to subtract estimated states of Elevation and travel from the references.	Simple 2x6 matrix with value: [1, 0, 0, 0, 0, 0; 0, 0, 1, 0, 0, 0]; to represent the columns of the Elevation and Pitch.
1D Lookup table	Converts voltages to angle in degrees.	Used LabVIEW to obtain values.
FIR Filter	Used to smooth the step inputs.	The function fir1 uses a Hamming window to design a lowpass filter. An order of 50 and cutoff frequency of 0.004 was chosen to have the reference rise in a smooth way across one second, ensuring the rise time is still short but having a more sensible gradient.
Equilibrium Control Signal	Used to equalize the voltage .	Set as 6 as this is the voltage that the fans require to have 0 degrees elevation.

3. Results and discussion

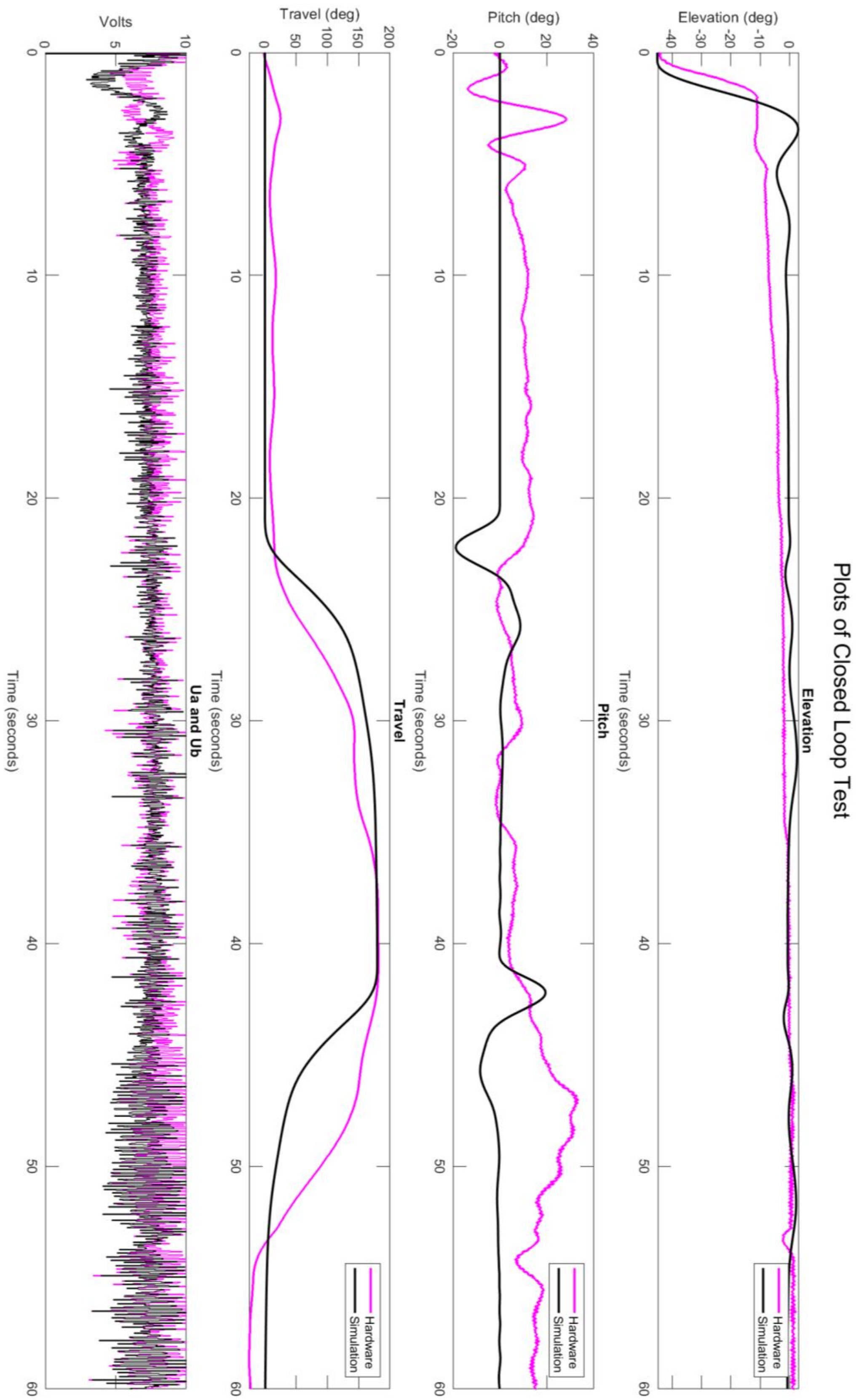

Figure 3: Plot of Simulation and Hardware Response

0 -20 Seconds

- The Helicopter takes off from rest and settles to -3.5° in the elevation axis without overshooting by more than 10°, rise time is quick with a value around 2 seconds.
- The travel angle overshot to 25° but settled to 10° at 20 seconds. I believe this happened due to small differences in the fan's thrusts and differences in transient times of the fans, causing the helicopter to initially pitch and travel. This could be improved by checking transient times and compensating for this, or by having a slower reference input.

20-40 seconds

- The Helicopter maintained an elevation between -3.5° and -0.5° throughout travel.
- The Helicopter smoothly travelled to 181 without any overshoot.

40-60 seconds

- The Helicopter maintained an elevation of around 0° throughout travel.
- The travel angle overshot to -25° and settled at -23°. I believe this happened due to the fact that the helicopter was still slowly travelling once it hit 40 seconds, so the fans changed voltages quickly, overcompensating and causing the travel to overshoot. This could be improved by smoother reference inputs; however, the helicopter took a long time to travel with smoother references, therefore depending on the requirements of the system, the reference input may need to be quicker or smoother.

Additional comments

- The Travel reference input is shown in figure 4. Here you can see the fir filtered reference input that is used to reduce the harshness of a step input. This worked effectively however higher orders could be used if slower but smoother inputs were needed.
- The voltages did hit the saturation limit of 10 a few times throughout the runtime as shown in figure 3. This had an effect on the system making it not able to fairly balance the fans at points, however the system was able to correct itself by lowering the values of the other fans voltages to ensure the travel and elevation requirements were met.

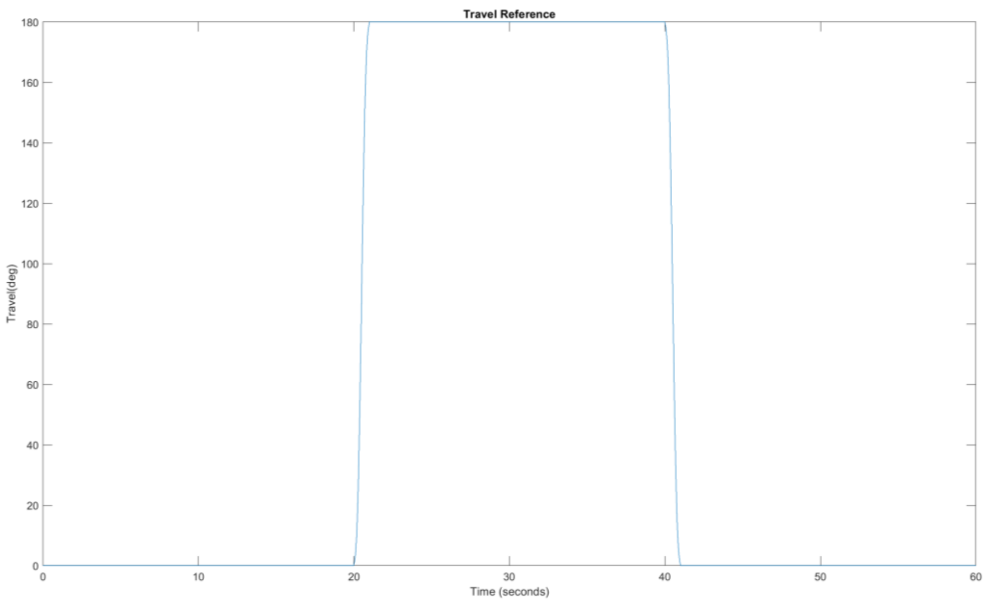

Figure 4: Travel Reference Input