

Massachusetts Institute of Technology
Department of Aeronautics and Astronautics
16.06 Principles of Automatic Control
Fall 2003

Lab #1

Issued: Wednesday, September 24 through Friday, September 26.

Due: One week after your lab session.

Objective

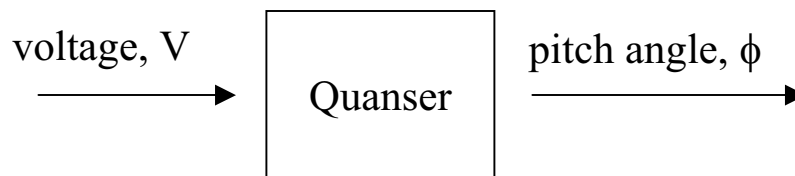
The objective of this lab is to develop a model of the pitch subsystem of the Quanser helicopter system. Along the way, you will familiarize yourself with lab equipment, and use Simulink to plot data and extract an appropriate model.

Introduction

The Quanser system consists of a base upon which an arm is mounted. The arm carries the helicopter body on one end and a counterweight on the other. Two motors with propellers mounted on the helicopter body can generate a force related to the voltage applied to the motors.

The system is free to rotate about three axes, as shown in Figure 1. These three degrees of freedom are the travel, ψ , the elevation, θ , and the pitch, ϕ . The dynamics of the Quanser can be quite nonlinear. In this lab, we will concern ourselves with producing an approximate linear dynamical model for the pitch, ϕ . The stake is there to hold the elevation and travel angles constant. Your Quanser is only free to rotate about the pitch axis.

In this lab, the objective is to match the step response of the pitch angle as well as possible to the step response of a second order linear system. The input to the system will be a step change in voltage, while the output will be the elevation angle as shown below. Note that the plant box includes many different subsystems, such as the propeller motor and the propellers themselves.



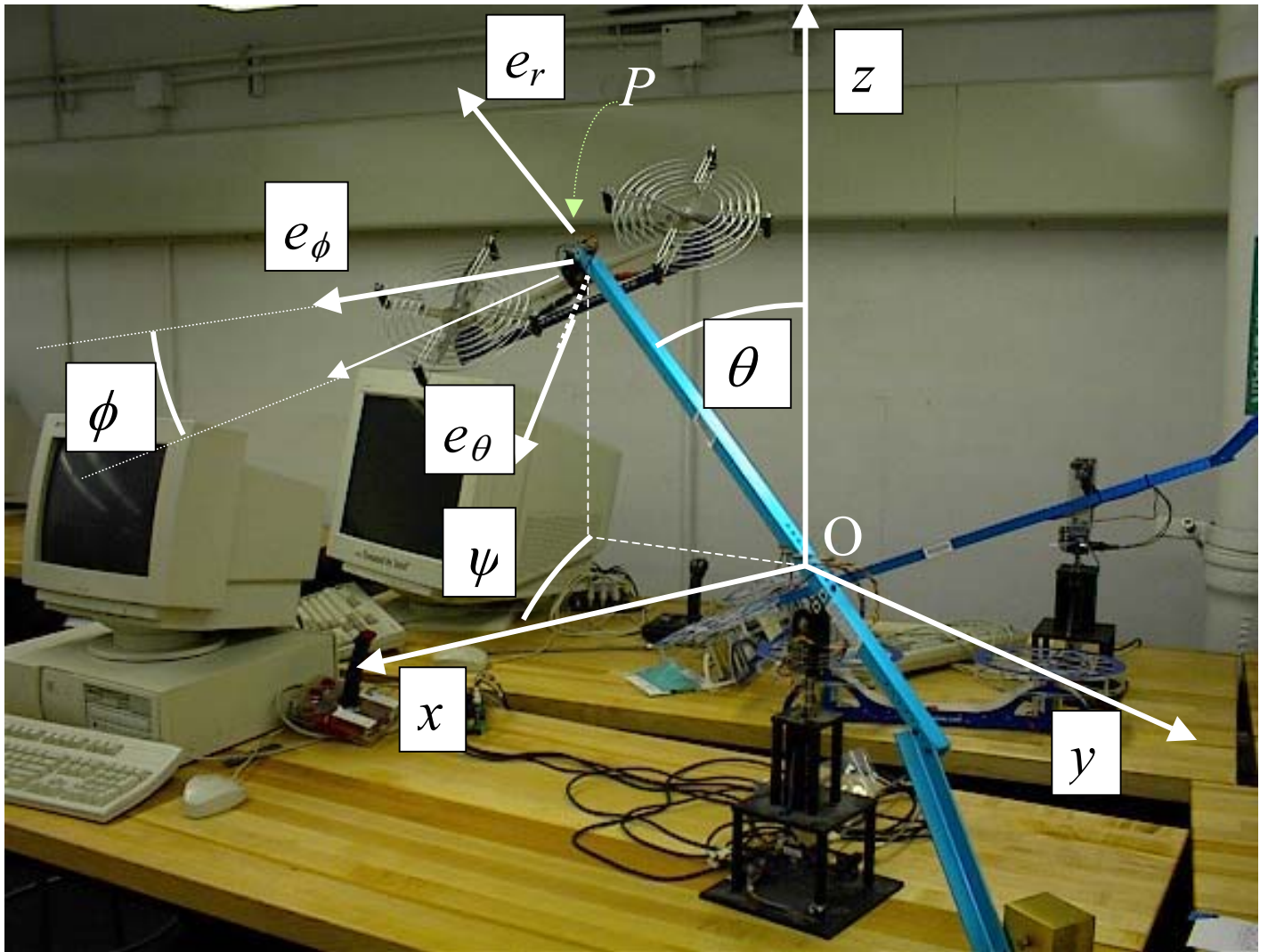


Figure 1: Quanser system with full three degrees of freedom.

In reality, the Quanser is not a second-order linear system. There are non-linearities so that the response depends upon the operating point (how high the Quanser is and how much it is moving). There are continuous aerodynamic disturbances as other fans blow or even as people live and breathe. One of the problems with our knowledge of feedback control is that most of what we can use depends upon a linear time-invariant system model, so we will insist on modeling our system as linear and time invariant even though we know this causes inaccuracies in modeling. One of the beautiful things about feedback control is that it can work when the system is less than perfectly modeled. We say that the feedback system is robust or insensitive to some degree of modeling error.

A major skill in engineering systems is to find the right level of complexity for your models of the real world. If a model is very complex, it may predict the real world behavior of the system very well but it may not produce tractable solutions that lend insight to how to engineer the system. If a model is too simple, it may produce wonderful designs on paper that don't work when applied to the real system. By limiting ourselves to linear time invariant system models we will be able to design controllers that work very well on the model. We will have to wait and see how well these controllers work on the real Quanser system (in Lab 2!).

GETTING STARTED

1. On the computer, make yourself a directory in C:/MATLAB6p1/work/16.060/. Copy the file MATLAB6p1/work/16.060/base/lab1.mdl to your directory. **IMPORTANT NOTE:** at the end of the lab session, you should save all of your work to a floppy disk (or scp it to your Athena account) and clean out the directory on the hard drive. You only need to save your .mdl files and your data. Simulink creates a lot of runtime files that you don't need to save. **IF YOU LEAVE YOUR FILES ON THE HARD DRIVE THEY MAY BE DELETED.**
2. Note your Quanser number and the position of the counterweight and record them for future lab use.
3. Make sure you are working in your own directory. Double click on lab1.mdl to start Matlab. You should see the beginnings of a Simulink model appear. The Heli 3D block is the computer's interface to the Quanser. It applies the given voltages to the two engines and reads the travel, pitch, and elevation angles in degrees. Be aware that the Quanser takes the zero degree position as the angles that exist when you press GO. The common input voltage block provides a baseline signal to the motors (the same to each motor). We will use the differential input voltage to control the pitch angle.
4. You need to add a step input to the Simulink Model. Go to View – Show Library Browser. Click on Sources and find the step input near the bottom of the list. Drag and drop the step input from the Library Browser Window into the Simulink Model Window. Next, you need to connect the step input to the Differential Voltage in the Simulink Model. You can do this by selecting the step input, pressing Control, and selecting the input to the Differential Voltage. You can double-click on the step input in the Simulink Model to change the parameters. Note the parameters of most input blocks can be changed while the system is running. The change takes effect when you hit APPLY or OK.

5. Build the Simulink model by choosing Tools/Real Time Workshop/Build (or Ctrl-B).
6. Before you start your system, set up your scope to capture the data. In the WinCon Server window choose Plot/New/Scope. Open the 'Pitch' folder and choose the scope labeled 'deg'. In the Axis menu of the scope plot choose Auto Scaled. In the Update menu choose Real time and choose Buffer setting it to 60 seconds.

DETERMINING THE GAIN

In a linear system the ratio of the change of steady state output angle to a constant change in input voltage is a constant called the gain, i.e.

$$\text{gain} = \frac{\Delta(\text{output angle})}{\Delta(\text{input voltage})}$$

In the Quanser pitch system the gain is in reality a nonlinear function of the output angle. For this lab, we will ignore this nonlinearity, and calculate the gain using an angle change from 0° to 20°.

7. Find and record the change in differential input voltage required to change the pitch angle from 0° to 20°. Note that the step input box sets an input voltage in units of volts. Calculate the gain – don't forget to include appropriate units.

STEP RESPONSE

We will now measure the step response of the Quanser pitch system in order to create a second-order model. Since in reality the Quanser is not a perfect second-order system, we will take several measurements and average the response.

8. Edit your Step input box: choose the step final value to be the voltage you found in Question 7 and the step time to be 10. Click OK.
9. Press GO and record the step response. After approximately 30 seconds, go to Update-Freeze Plot. You can now save the data to the Matlab workspace by choosing 'File/Save/Save to Workspace'.
10. The plot data is now stored in Matlab. To see its name, type 'who' at the Matlab prompt. Two arrays have been created: 'PLOT_TIME' stores the x-axis (time) and 'lab1_pitch_deg_' stores the y-axis (pitch angle). We need to save the data to a different Matlab variable. We also need to truncate the vector (so that all of our responses are the same length). We will keep the first 25,000 elements of the response. To rename lab1_pitch_deg_ to STEP1 and truncate, type 'STEP1 = lab1_pitch_deg_(1:25000,1);' at the Matlab prompt. Note that your plot data may have a slightly different name.
11. Repeat steps 9 and 10 another nine times. Each time, make sure the Quanser is at rest with zero pitch angle before you start. Make sure you rename your output angle data for each run (e.g. STEP1, STEP2, ... STEP10) and keep only elements 1:25000.
12. We now want to average the data to come up with a step response to analyze. Find the average step response using Matlab (e.g. 'AVG_STEP = (STEP1 + STEP2 +

STEP3)/3;'). Note that you can check any of your results by plotting them in Matlab: 'plot(PLOT_TIME, AVG_STEP, PLOT_TIME, STEP1);' plots the average and the first step response on the same plot. To do this, you will also have to truncate the PLOT_TIME vector to have length 25,000.

13. Create a plot of the average step response and use it to fit a second-order linear model using the parameters discussed in class.
14. Save your step response Matlab data and transfer it to a secure location. To save variables X, Y and Z to a file called lab1.mat type the following at the Matlab prompt: 'save lab1.mat X Y Z' (You can also type 'help save' to get the syntax.)

The final result of your lab should be a second-order, linear transfer function from voltage input to pitch angle output. In your lab report, be sure to discuss errors and assumptions that may affect the validity of your result.

POST PROCESSING AND WRITE-UP

The write-up should be clear and concise (it should not be too long!). Please see the attached handout on "How to Write a Lab Report".

Include graphs or tables of your data as appropriate. Do not include pages and pages of Matlab output. Every graph/table you include should be clearly labeled (caption and axis labels), be referred to in your report text, and be there for a reason!

Each member of your group should do a write-up. The lab should be performed jointly, but the analysis and write-up should be your own work.