8.2. Obtaining the Model and Model Verification.
   • PRINT the displacement plot, label it 8.2.1.
   • From the plot 8.2.1, RECORD the $K_{p,x}$ value that you used to obtain the plot.

   • Use $K_{p,x}$ in order to estimate $b$.

   • WRITE out the full nonlinear equations of motion with all of the parameters filled in with actual values.
• PRINT both the cart and the pendulum plots, label them 8.2.6.cart and 8.2.6.pendulum, and attach them to the end of the report.
• PRINT the resulting plot of both the cart and the pendulum, label them 8.2.7.cart and 8.2.7.pendulum, and attach them to the end of the report.
• COMPARE the plots 8.2.6 and 8.2.7 for both the cart and the pendulum. DESCRIBE how well they match eachother. Pay particular attention to the energy loss and the damping.

• WRITE down the damping parameter you ultimately use to obtain the best response and PRINT the cart and the pendulum plots.

8.3. Linearization and obtaining the Transfer Function.

• OBTAIN the actual open loop $G_\phi(s)$ transfer function.
Show all of your work and make sure to CIRCLE $G_x$.

PRINT and DESCRIBE what happens to the Pendulum Angle.
8.4. P, PI and PID Control for the Pendulum.

- **DISCUSS** whether a stable system is possible and **DESCRIBE** what happens to the unstable root as the gain is increased. **PICK** a gain near $K=50$ (doesn’t have to be exact) and write down the corresponding poles. Also, **PRINT** a root locus of the P control, label it "8.4.P", and attach it to the end of the report.

- **RECORD** how long this takes in seconds. Perform this simulation again for values of $K_{p,\phi} = 50, 100, 150$. For each of these, **RECORD** how long it takes for the solution to go unstable.

- **EXPLAIN** how the length of time it takes to go unstable relates to the pole in the RHP and why it changes when the gain is increased.
• WRITE down the compensator transfer function as seen in the command terminal.

• PRINT a root locus of the P control, label it "8.4.PI", and attach it to the end of the report. 
• RECORD this value as $K_{crit}$.

• CALCULATE the $K_{p,\phi}$ and $K_{I,\phi}$ from the compensator you wrote down in the previous step (see the prelab).

• PRINT the screenshot for 10 seconds of both the cart and pendulum and label them 8.4.PI.Cart and 8.4.PI.Pendulum. 
• DISCUSS how well the pendulum is stabilized and COMMENT on how well the cart stays in the center of the track.
- **OBTAIN** a root locus compensator that puts the poles in the left half plane. **CALCULATE** the $K_{p,\phi}$, $K_{i,\phi}$ and $K_{d,\phi}$ based on the formulas in the prelab.

- **PRINT** the cart and pendulum response, labeling them 8.4.PID.Cart and 8.4.PID.Pendulum.

8.5. **PID Control for the Cart and the Pendulum.** **DESCRIBE** how this ad hoc controller performed compared to the pendulum only controller.