Introduction:

The purpose of the semester project is to simulate a more realistic problem setting for you to practice the gained skills and knowledge. Such situations usually require the following tasks: i) modeling of the system dynamics, ii) characterizing the system dynamics, iii) analyzing stability and frequency response, iv) design of regulator, v) implementation of controller, and vi) testing of controller with fine tuning based on experimental tests. Since our hands-on laboratory portion of the class is under development, this project attempts to simulate a real world environment mainly via Matlab©/Simulink©.

The project will begin with the selection of an example system to be controlled. It is up to you to find and choose your own plant/system.

One such system might be an aircraft. Fig. 1 introduces the general coordinate system used within an aircraft model. For large transport aircraft, the longitudinal dynamics can be decoupled from the lateral dynamics allowing for control of each aspect of flight somewhat independently. A linearized longitudinal L1011 aircraft model for a typical landing scenario (low altitude (below 10,000 ft), angle of attack ($\alpha$) = 5 degrees, flaps = 26 degrees, slats = 30 degrees, $|u| \leq 0.3$ Mach) is given as [3]:
The system must be of at least 2nd order. You are required to have this choice approved.

Nevertheless, the first step in the project is to choose your “plant”/system. Your “plant”/system must be of at least 2nd order. You are required to have this choice approved.

An alternative example aircraft, might be a Boeing 747 longitudinal dynamics which can be linearized as follows [1]:

\[
\begin{bmatrix}
\Delta \dot{u} \\
\Delta \dot{w} \\
\Delta \dot{\theta} \\
\Delta \dot{q}
\end{bmatrix} =
\begin{bmatrix}
-0.0225 & 0.0022 & -32.3819 & 0 \\
-0.2282 & -0.4038 & 0 & 869 \\
0 & 0 & 0 & 1 \\
-0.0001 & -0.0018 & 0 & -0.5518
\end{bmatrix}
\begin{bmatrix}
\Delta u \\
\Delta w \\
\Delta \theta \\
\Delta q
\end{bmatrix}
+ \begin{bmatrix}
0.5000 & 0 \\
0 & -0.0219 \\
0 & 0 \\
0 & -1.2394
\end{bmatrix}
\begin{bmatrix}
\Delta \delta_T \\
\Delta \delta_e
\end{bmatrix}
\]

Likewise the Boeing’s 747 lateral dynamics can be linearized as [1]:

\[
\begin{bmatrix}
\Delta \dot{\beta} \\
\Delta \dot{\rho} \\
\Delta \dot{\theta} \\
\Delta \dot{\phi}
\end{bmatrix} =
\begin{bmatrix}
-0.0619 & 0 & -1.0000 & 0.0373 \\
-1.3459 & -0.4546 & -0.5031 & 0 \\
0.9978 & 0.1123 & -0.1826 & 0 \\
0 & 1.0000 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
\Delta \beta \\
\Delta \rho \\
\Delta \theta \\
\Delta \phi
\end{bmatrix}
+ \begin{bmatrix}
0 & 4.7490 \\
0.1884 & 0.0673 \\
0.0150 & -0.4490 \\
0 & 0
\end{bmatrix}
\begin{bmatrix}
\Delta \delta_n \\
\Delta \delta_r
\end{bmatrix}
\]

Note that each one of these models is a Multi-Input-Multi-Output (MIMO) system. For our project, we will use only a Single-Input-Single-Output (SISO system) transfer function. Thus we must fix the some inputs, the ones we will choose not to control, and develop a transfer function from the remaining variable input to the aspect of the plant that we wish to control -- i.e. the output -- e.g. one might choose to control the altitude of an L1011, w, by controlling the aircraft’s elevator. (In the real world L1011, the pilot’s stick controls the elevator and stabilizer jointly in a coordinated fashion to provide flight path control. In our example, we have decoupled these controls, thereby allowing one to fix one and control the remaining actuator to provide overall plant stabilization. This is done to simplify to control for this example.) Alternatively, one might choose to control an aircraft’s roll, \( \phi \), via the aircraft’s ailerons, \( \Delta \delta_a \).

Nevertheless, the first step in the project is to choose your “plant”/system. Your “plant”/system must be of at least 2nd order. You are required to have this choice approved.
before you start your modeling effort, i.e. find a system’s state space model. Next you
will need to decide on your design goals (rise time, settling time, etc.) and have them
approved as well. Once you have these two approvals, the control design work can begin
--- note as your design progresses and you will learn more about the system’s real
dynamical characteristics and you might discover that your design specifications might
need to be modified; such realizations should be discussed fully within your final report
(also stop by and chat about them).

Description of the Modeling and Design Problem:

The first real step is to simulate the State-Space Model in Matlab©/Simulink© so that a
SISO system can be developed. You will use the model to generate input/output data, so
that you can construct a bode plot from the simulated data, and then extract a transfer
function from it. (Of course since you have the original State Space model you can check
the validity of the model that you develop, note they should not be exactly the same!!!
You will not be able to “check” in the real world so learn how this process works -- when
you can check!!!) This transfer function will need to be tested for its accuracy using
simulations, i.e. chose a particular input set of inputs to apply to both the original system
and the developed transfer function obtained from your measured bode plot. Compare
their respective responses. Considering the correlation of the two responses, you will
need to consider modifications to the transfer function or state argumentations for why
you wish to maintain the obtain transfer function given some inaccuracies.

Next, you will analyze the identified/discovered system (the transfer function) using Root
Locus and Routh Hurwitz techniques. With the analysis completed, you will formulate
performance specification for the closed loop system to be designed. Before
implementing these by designing an appropriate controller, you must have the design
specification approved by the instructor.

Schedule an appointment for the week of March 15th (or earlier) to approve the “plant”/
system before the due date on March 20th. Furthermore, the control system design
specifications must be approved by no later than April 8th. For the approval, you will
need to present your system model and an initial set of design specs.

The assignment:

According to the above description, perform the following tasks:

a) Create a Matlab©/Simulink© model of your approved chosen “plant”/system (this
can be a MIMO plant -- which you will choose one input-output pair to control).

b) Generate input/output data for a SISO sub-system for your plant, suitable to create
a bode plot for the SISO system.
c) Using the bode plot developed in step b, perform the Laplace decompose processes of the bode plot too obtain its basic poles and zeros, so that transfer function can be created for your SISO system.

d) Verify the identified transfer function using a new set of input/output data (i.e. simulate both the original and discovered dynamics by driving both systems with a new input signal and compare their outputs). Take note of the differences. Make necessary corrections and/or statement of why system is sufficiently accurate to proceed.

e) Using the identified/tested/modified transfer function, perform a Root Locus analysis of the system (by constructing the root locus plot by hand, and then verifying it using Matlab©/Simulink© (the hand solution is to be included within an appendix of the final report -- Matlab© is sometimes wrong!!)).

f) Next, check the stability of the system by performing a Routh Hurwitz analysis by hand (also to be included within an appendix of the final report).

g) By considering the system, and its stability, develop a set of performance specifications both in the time and frequency domains. Have these performance specifications approved by the instructor by COB Wed. April 8th (at the latest).

h) Design a controller which achieves your design specifications chosen in step g. Explain what type of compensator was used (PI, PD, PID, lead, lag, lead-lag), explain and justify why in your report. Also, discuss each step throughout your design methodology and explain why this method was chosen (i.e. frequency domain technique, root locus technique, etc.).

i) Test the designed controller on the original system dynamics. Show that the design works for at least three input conditions.

j) Compile your design into a short report which summarizes your project including short explanations of the tasks, the design, and the outcome. Include the items requested in the previous steps. Use appendices to attach all the analysis, the Matlab©/Simulink© files, the plots, and verification simulations, etc.

Grades and Evaluation Criteria:

Grades are based on the accuracy and the details included in your design report. The more details and the clearer (logical) explanation of your simplifications made during the derivation of your system transfer function the better. Also, the more details and clearer discuss of the overall system performance of the controller when applied to the original State Space model, the better your grade will be. Note, better control performance, i.e. meeting your controller specifications, occurs when fewer system simplifications are made during the creation of the SISO transfer function. You will turn in a technical report detailing all of your assumptions, simplifications, calculations, simulations, Matlab©/Simulink© code, and designs attached. The project report, is meant to be a short concise (but complete) description of your work. Use appendices to attached step-by step calculations used in the design process. (Please do not write a thesis here!!!) The report: the design and computations should be done in a professional manner: use your
computer to generated graphs, an equation editor to write the equations (in the body! not in the appendix), use a text processor for the body, and hand written-scanned-in pages are acceptable in appendices. The entire document (report, simulation output figures, hand calculations, and simulation codes (appendices) should be submitted in one document!) Please submitted via email in addition to a printed version. The emailed report is to be submitted in PDF format (there are free translators on the web)!

Note: This is an individual project. Team-work obtaining the same design will result into an F for both individual’s projects.

Cited References: