CSD

Control System Designer (CSD) tool is an interactive GUI environment for analyzing and modifying feedback control systems.

. CSD was introduced in R2015a
. previous, we used 'SISOTool'

To start CSD, type in Command Window:

>> controlSystemDesigner

The legacy siso command is also recognized:

>> sisotool

Before starting CSD, run a MATLAB program to create the basic system G(s).

- Single input, single output (SISO)
- Graphical User Interface (GUI)
- Requires separate definition of plant transfer function G(s) through an m file

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CSD

Control System Designer

Design single-input, single-output (SISO) controllers

Description

The **Control System Designer** app lets you design single-input, single-output (SISO) controllers for feedback systems modeled in MATLAB or Simulink (requires Simulink Control Design™ software).

Using this app, you can:

- Design controllers using:
  - Interactive Bode, root locus, and Nichols graphical editors for adding, modifying, and removing controller poles, zeros, and gains.
  - Automated PID, LQG, or IMC tuning.
  - Optimization-based tuning (requires Simulink Design Optimization™ software).
  - Automated loop shaping (requires Robust Control Toolbox™ software).
- Tune compensators for single-loop or multiloop control architectures.
- Analyze control system designs using time-domain and frequency-domain responses, such as step responses and pole-zero maps.
- Compare response plots for multiple control system designs.
- Design controllers for multimodel control applications.

Open the Control System Designer App

- MATLAB Toolstrip: On the **Apps** tab, under **Control System Design and Analysis**, click the app icon.
- MATLAB command prompt: Enter `controlSystemDesigner`.
- Simulink model editor: Select **Analysis** > **Control Design** > **Control System Designer**.

Examples

- "Control System Designer Tuning Methods"

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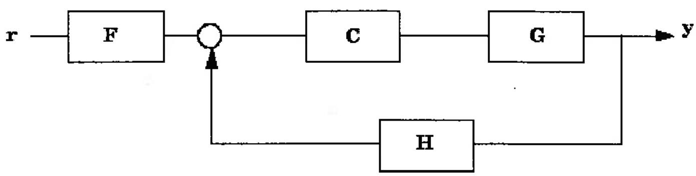
CSD

- “Bode Diagram Design”
- “Root Locus Design”
- “Design Compensator Using Automated Tuning Methods”
- “Design Multiloop Control System”
- “Analyze Designs Using Response Plots”
- “Compare Performance of Multiple Designs”
- “Multimodel Control Design”

Programmatic Use

`controlSystemDesigner` opens the **Control System Designer** app using the following default control architecture:



The architecture consists of the LTI objects:

- G — Plant model
- C — Compensator
- H — Sensor model
- F — Prefilter

By default, the app configures each of these models as a unit gain.

`controlSystemDesigner(plant)` initializes the plant, G, to `plant`. `plant` can be any SISO LTI model created with `ss`, `tf`, `zpk` or `frd`, or an array of such models.

`controlSystemDesigner(plant,comp)` initializes the compensator, C, to the SISO LTI model `comp`.

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cSD

`controlSystemDesigner(plant,comp,sensor)` initializes the sensor model, *H*, to `sensor`. `sensor` can be any SISO LTI model or an array of such models. If you specify both `plant` and `sensor` as LTI model arrays, the lengths of the arrays must match.

`controlSystemDesigner(plant,comp,sensor,prefilt)` initializes the prefilter model, *F*, to the SISO LTI model `prefilt`.

`controlSystemDesigner(views)` opens the app and specifies the initial graphical editor configuration. `views` can be any of the following character vectors, or a cell array of multiple character vectors.

- `'rlocus'` — Root locus editor
- `'bode'` — Open-loop Bode Editor
- `'nichols'` — Open-loop Nichols Editor
- `'filter'` — Bode Editor for the closed-loop response from prefilter input to the plant output

In addition to opening the specified graphical editors, the app plots the closed-loop, input-output step response.

`controlSystemDesigner(views,plant,comp,sensor,prefilt)` specifies the initial plot configuration and initializes the plant, compensator, sensor, and prefilter using the specified models. If a model is omitted, the app uses the default value.

`controlSystemDesigner(initData)` opens the app and initializes the system configuration using the initialization data structure `initdata`. To create `initdata`, use `sisoinit`.

`controlSystemDesigner(sessionFile)` opens the app and loads a previously saved session. `sessionFile` is the name of a session data file on the MATLAB path. This data includes the current system architecture and plot configuration, and any designs and responses saved in the **Data Browser**.

To save a session, in the **Control System Designer** app, on the **Control System** tab, click **Save Session**.

See Also

Apps
Control System Tuner

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CSD

Functions
`pidTuner` | `sisoinit`

Introduced in R2015a

‘Control System Designer’ MATLAB Tool

Aircraft Roll Motion Autopilot Development
PD Example

Table of Contents:

1 CONTROL SYSTEM DESIGN OBJECTIVES

Consider the aircraft roll transfer function $G(s) = \dfrac{K}{Js^2 + cs} = \dfrac{114}{10s^2 + 4s}$

Design a feedback control system to control the aircraft roll motion with the following control design objectives:

<u>Design Objective 1</u>: Control the unconstraint aircraft motion resulting from an aileron input. Have a autopilot system that can maintain the aircraft at a constant bank angle

We will achieve this objective through feedback (FB)

<u>Design Objective 2</u>: Achieve a reasonable aircraft roll response.

<u>Design Objective 3</u>: Ensure safe and stable operation of the feedback control system

We define 'reasonable response' using two control design specifications:

- DS1: Fast response time as measured by rise time
  $t_r \leq 1.5$ sec
- DS2: maximum percentage overshoot for step input less than 20%
  $M_p \leq 20\%$

We ensue safe and stable operation of the feedback control system by meeting a third design specification based on stability margins:

- DS3: $GM = 10\,\text{dB}$, $PM = 60°$

2 CREATE PLANT TRANSFER FUNCTION G

Run m-file `"aircraft_roll_model.m"` to create the plant transfer function G in the Workspace (Figure 1)

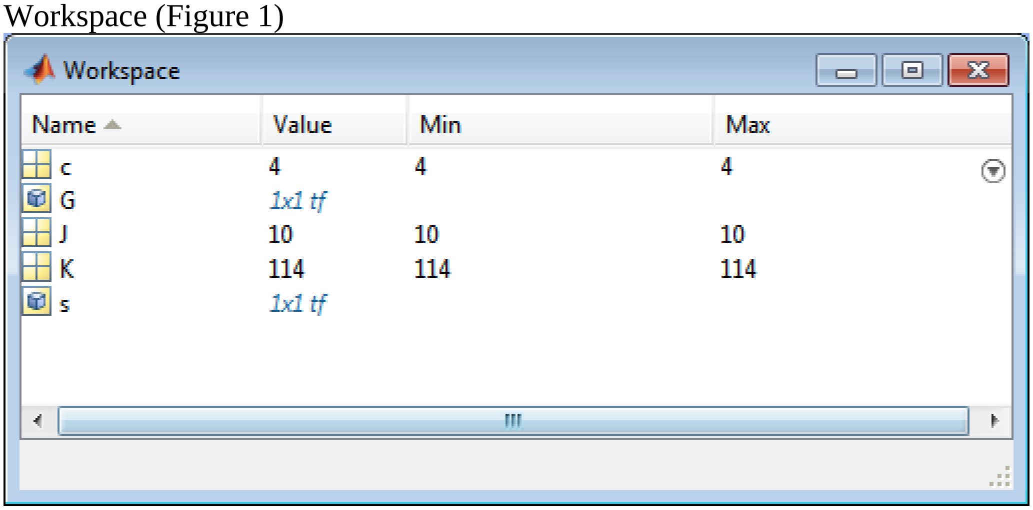


Figure 1

3 CREATE ‘CONTROL SYSTEM DESIGNER’ MODEL

3.1 OPEN ‘CONTROL SYSTEM DESIGNER’ SOFTWARE TOOL

In the Command Window, type “`controlSystemDesigner`”
`>>controlSystemDesigner`
(legacy name “`sisotool`”, also works, i.e., `>>sisotool`)

The Control System Designer GUI opens as shown in Figure 2.

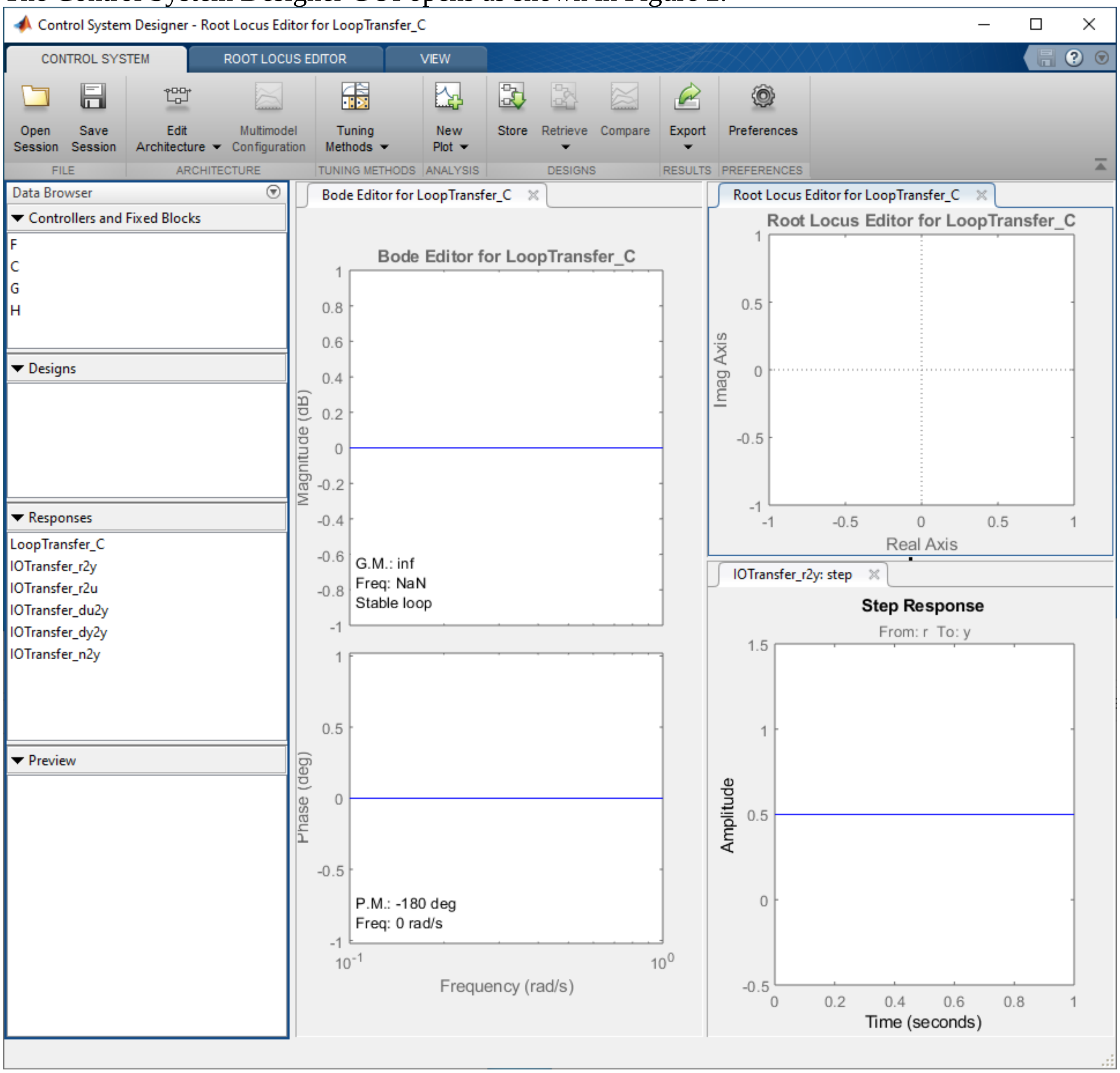


Figure 2

The default configuration has four blocks (F, C, G, H) as indicated in the LHS pane. All the blocks in this configuration are set to be unitary transfer functions by default (the plant block G, which is selected in the upper LHS pane, is shown in the lower LHS pane with Value: 1).

3.2 IMPORT PLANT TRANSFER FUNCTION G

Press “Edit Architecture” button to import the system G data from the Workspace (Figure 3).

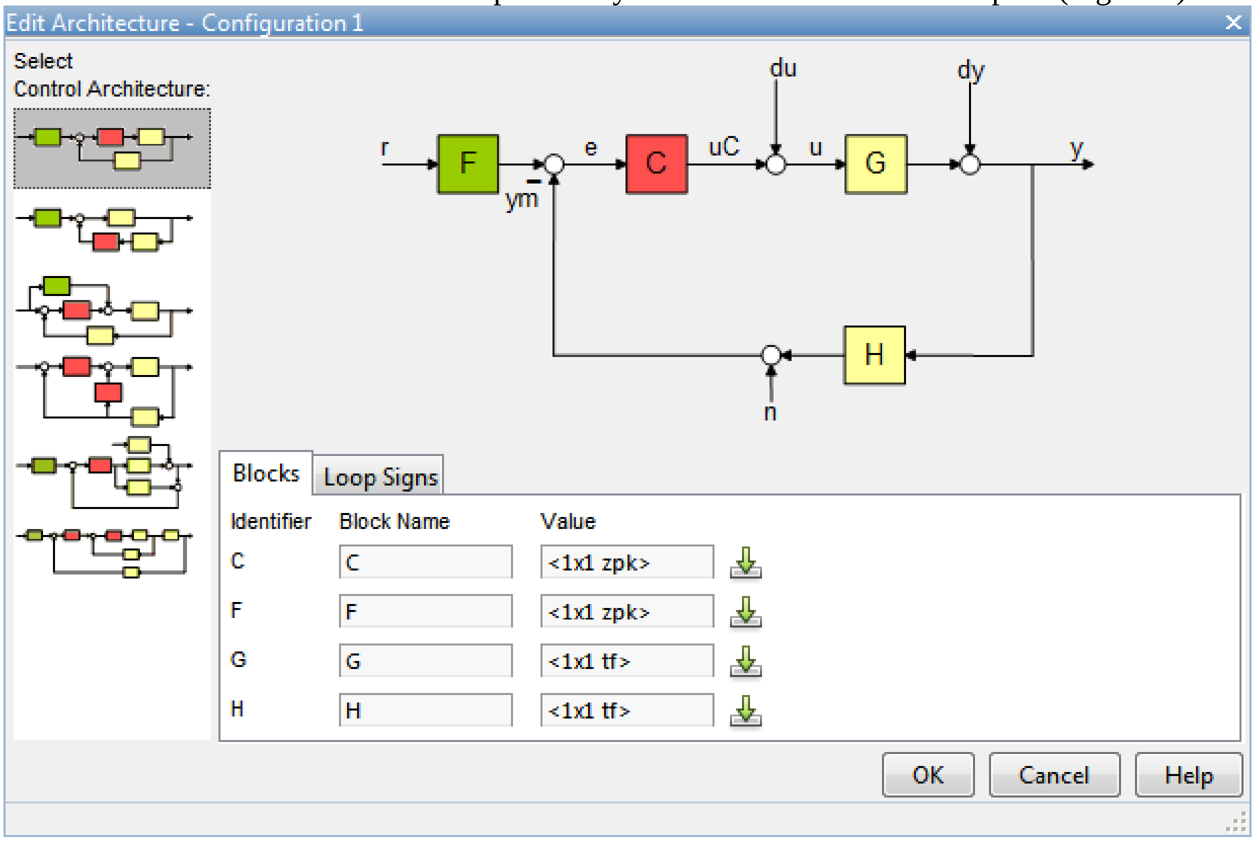


Figure 3

Note that the first control system configuration is selected by default (this is the configuration we work with, no need to change it.)

Press the down arrow icon at the RHS end of the G row to open the “Import Data for G” dialog box and select ‘G’ from the Base Workspace (Figure 4).

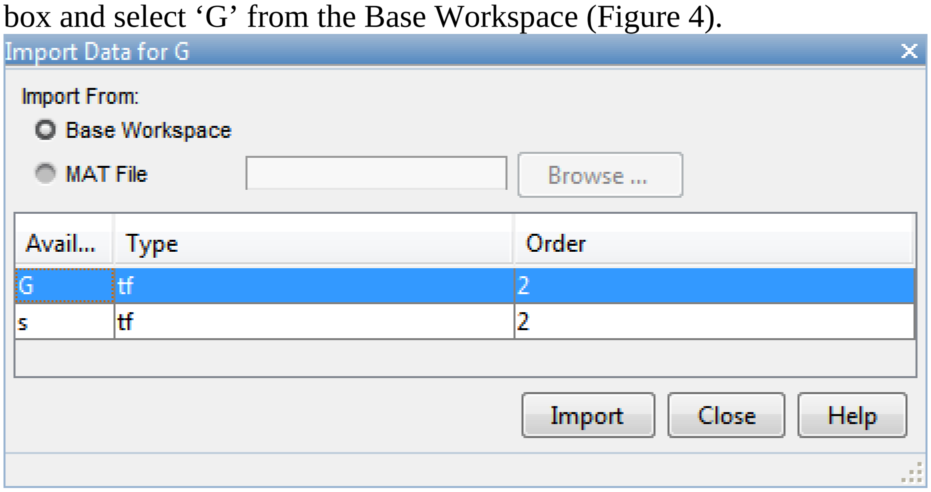


Figure 4

Press ‘Import’ to return to ‘Edit Architecture’ dialog box and press OK to return to the main view. Now, our system $G(s)=\dfrac{114}{10s^2+2s}$ is shown in the lower LHS pane of the model (Figure 5)

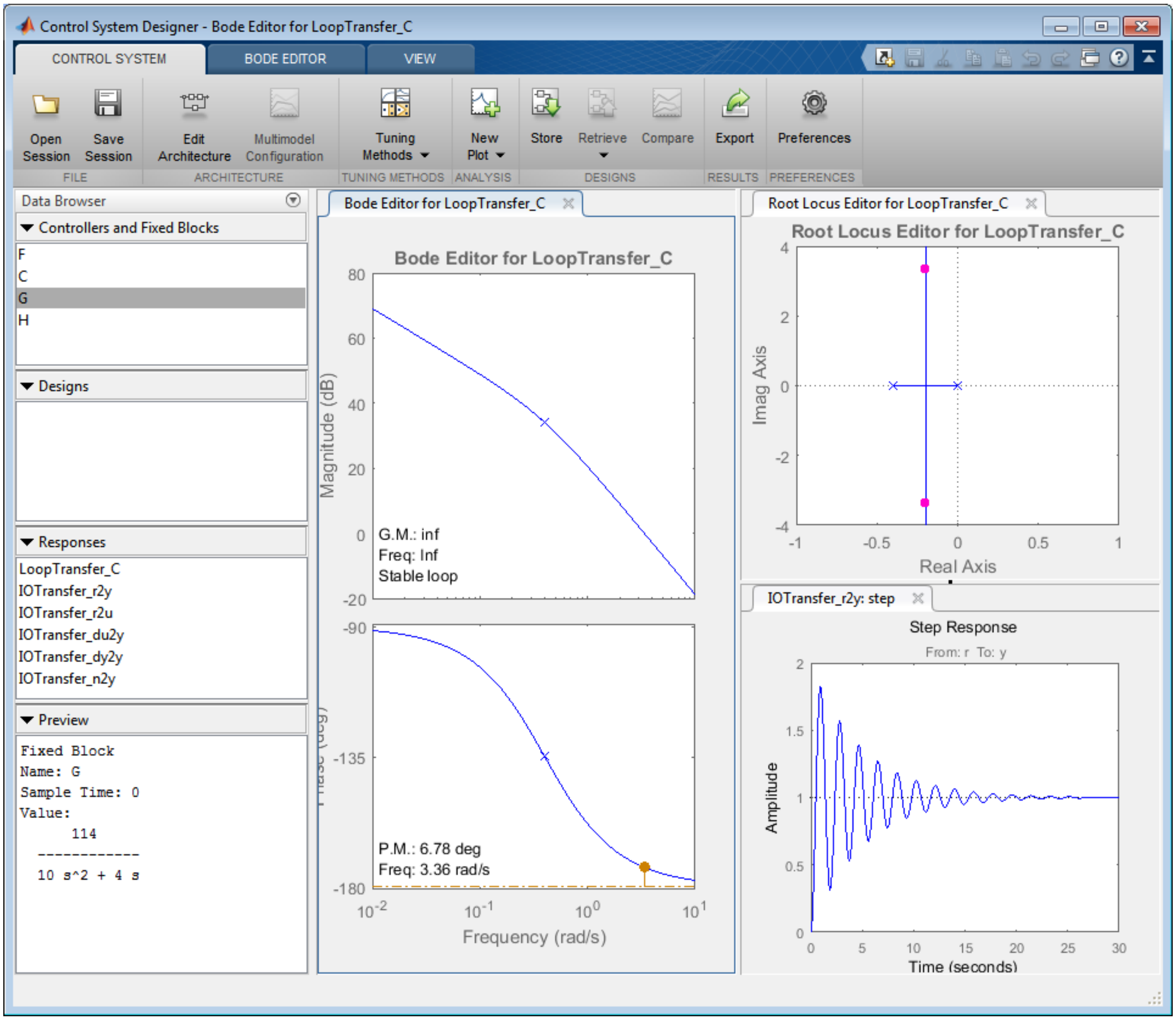


Figure 5

3.3 Add Design Specifications

Right-click on the Bode Editor window and select Design Requirements → New. The following window shown in Figure 6 appears:

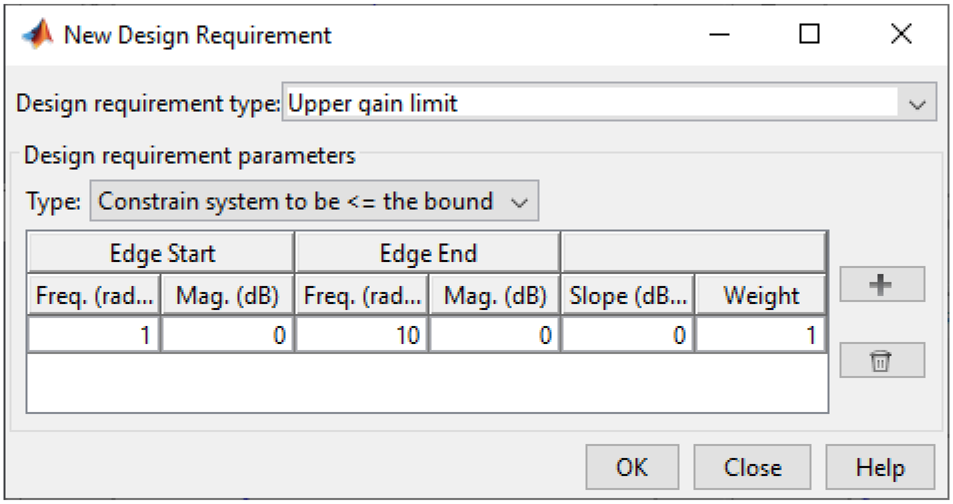


Figure 6

From the pull-down menu "Design requirement type" select "Gain & Phase margins" and enter the required DS3 values 10dB and 60deg to make the window look like shown in Figure 7.

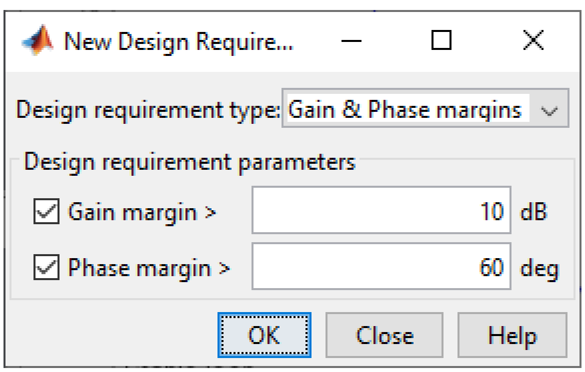


Figure 7

Press OK. Your screen should look like Figure 8.

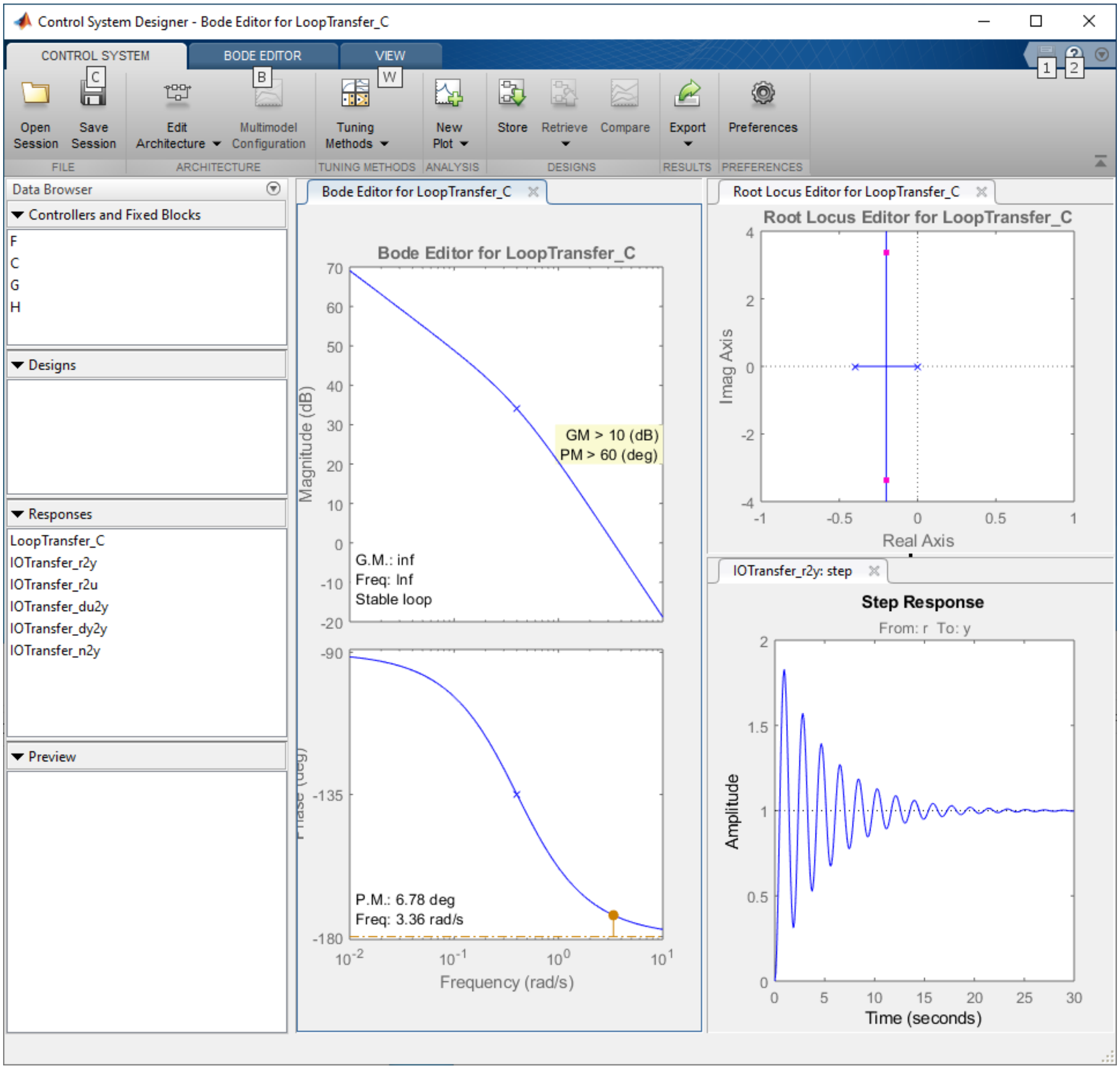


Figure 8

3.4 STORE THE BASELINE DESIGN AS G

Press ‘Store’ button to store this design; it will shown as ‘Design1’ in the second LHS pane. Save the CSD Sesion: press ‘Save Session’ button and save your session with the name ‘CSD_aircraft_Session_20200116’. The extension of the file, if shown, should be ‘.mat’. Your screen should look like Figure 9.

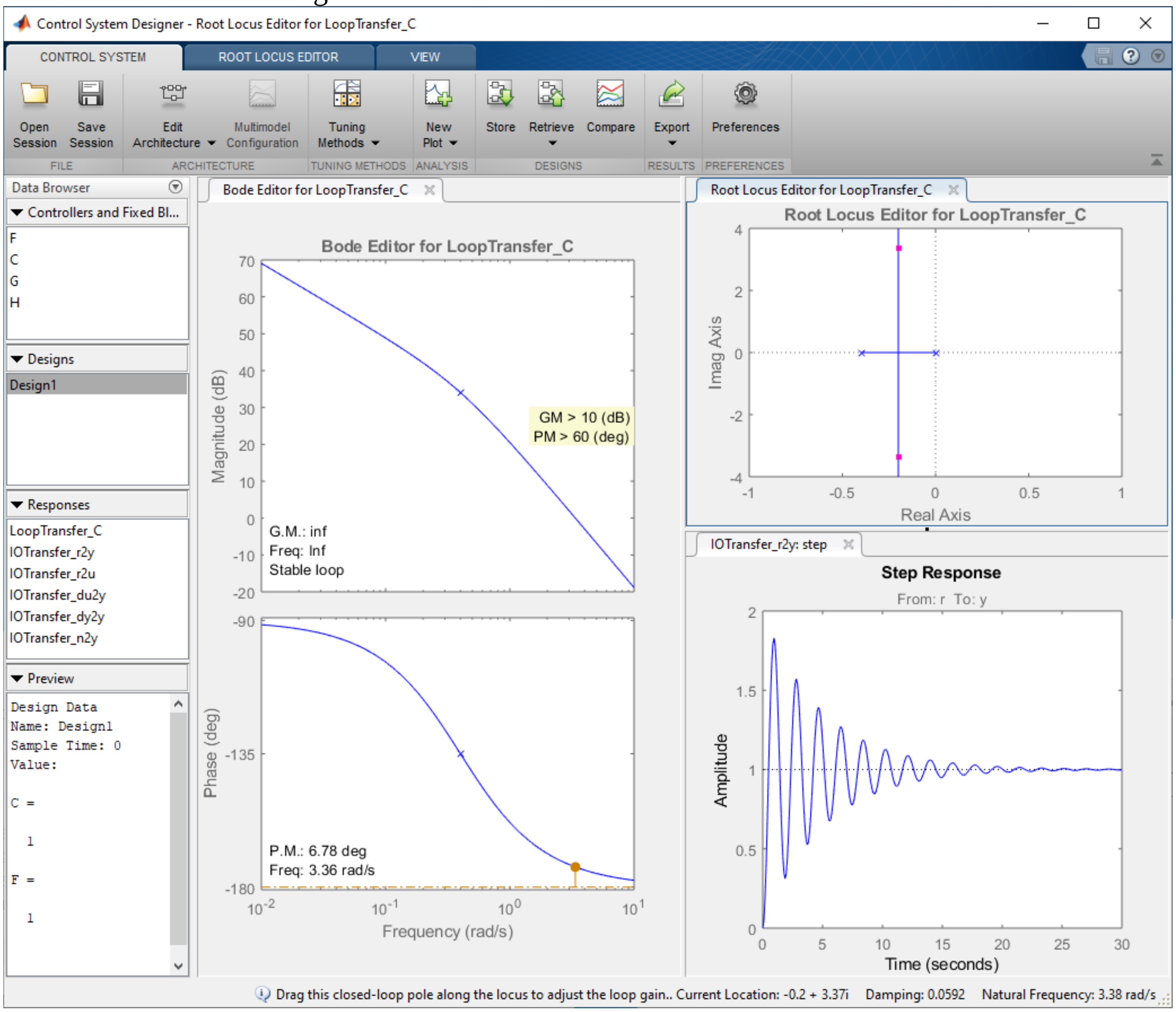


Figure 9

3.5 Record the Baseline Performance and Stability Reading of G Design

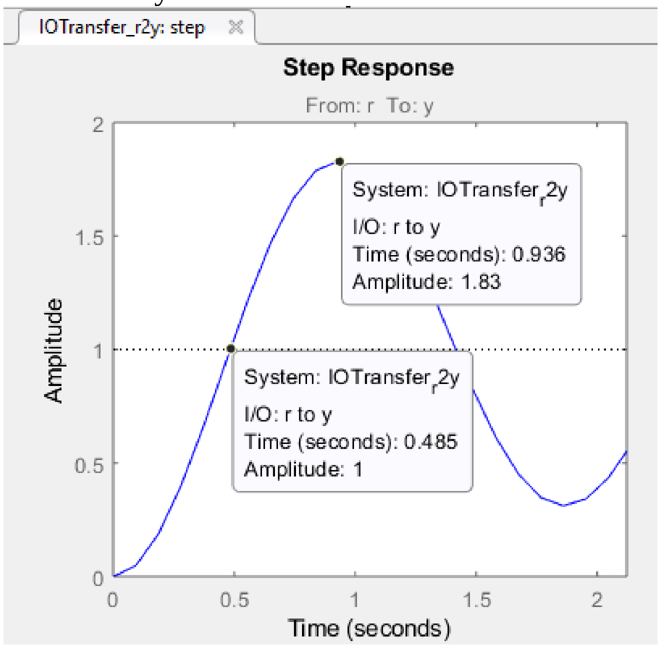
Record the following readings from this CSD windows:

- GM: inf
- PM: 6.78 deg at 3.36 rad/s
- CL poles $-0.2+3.37i$ and $-0.2-3.37i$ shown as the two red dots in the Root Locus Editor. Click on them and read the values at the bottom of the window.
- A lightly damped step response ‘r2y: step’ (i.e., from input r to output y) with a large overshoot

It is apparent that the response is unsatisfactory because:

- many oscillations until it settles down to $x_{ss}=1$
- large overshoot
- insufficient phase margin

Zoom into the 'r2y: step’ window and use data tips to mark the rise time t_r and overshoot M_p and make the r2y window look as shown below



3.6 Verify Design Specifications

It is apparent from the reading taken so far that:

DS1: t_r=0.485 sec < 1.5 sec indicating that DS1 is satisfied
DS2: M_p=83% > 20% indicating that DS2 is NOT satisfied
DS3: GM= inf; PM=6.78 deg indicating that DS3 is NOT satisfied

A controller must be design to improve system performance and satisfy all the design specifications.

4 PID CONTROLLER USING AUTOMATIC PID TUNING TO GENERATE DESIGN1

In this section we explain how a PD controller can be added and tuned to give a better system performance that satisfies all the design specifications.

Press ‘Tuning Methods’ and select ‘PID’ from the pull-down menu. The ‘PID Tuning’ window opens up (Figure 10).

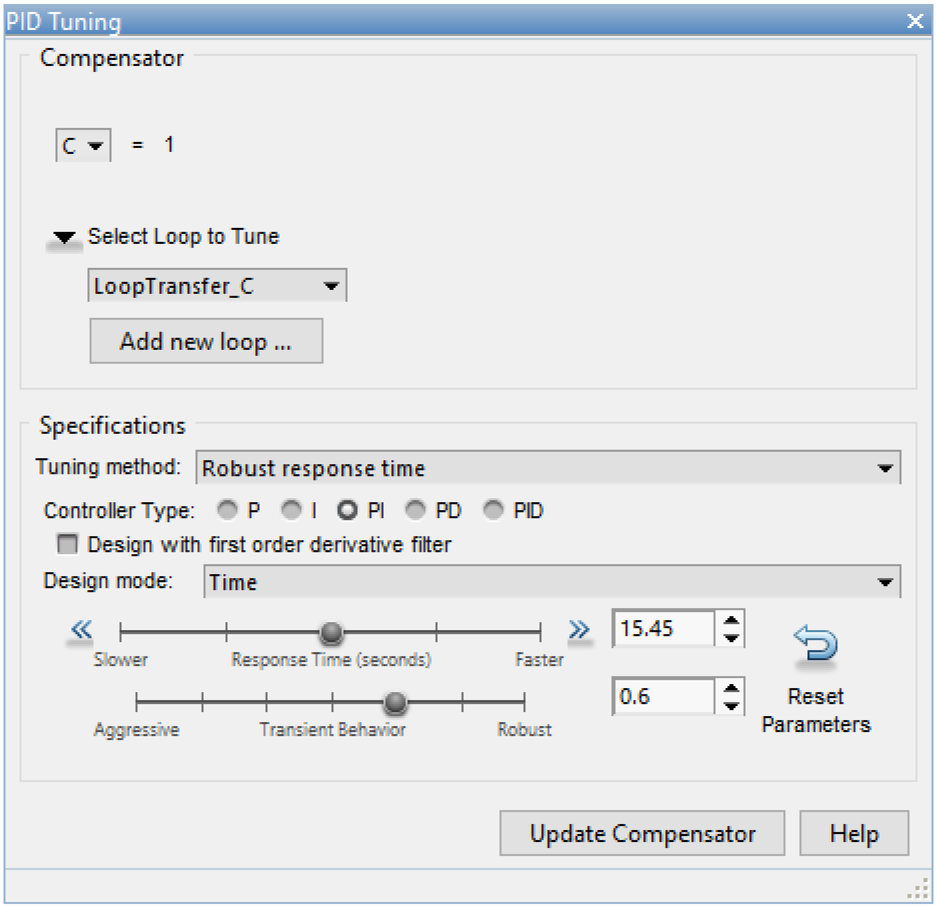


Figure 10

4.1 Choose PD Controller and Adjust ‘Response Time’ Range

Select ‘PD’ on ‘Controller Type’ line. Press the >> arrow on the RHS of the ‘Response Time’ bar to see ‘1.545’ in the RHS window. Use the up/down scroll (or just type in the value) until it shows the value 1.5 (see Figure 11).

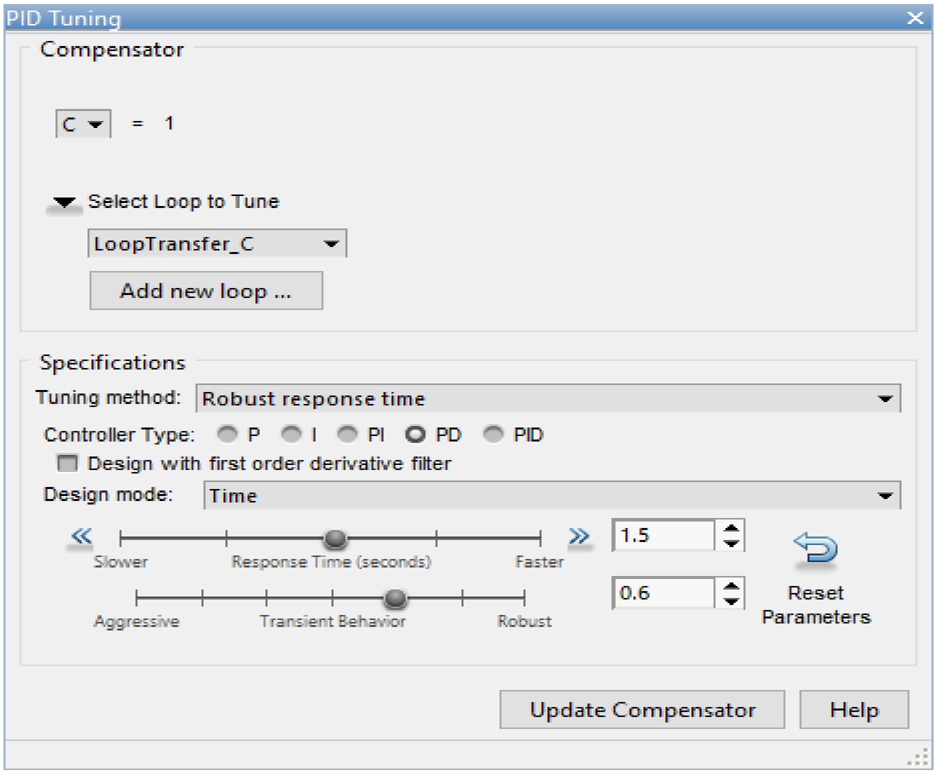


Figure 11

Press 'Update Compensator'button. The 'PID Tuning' window looks as shown in Figure 12.

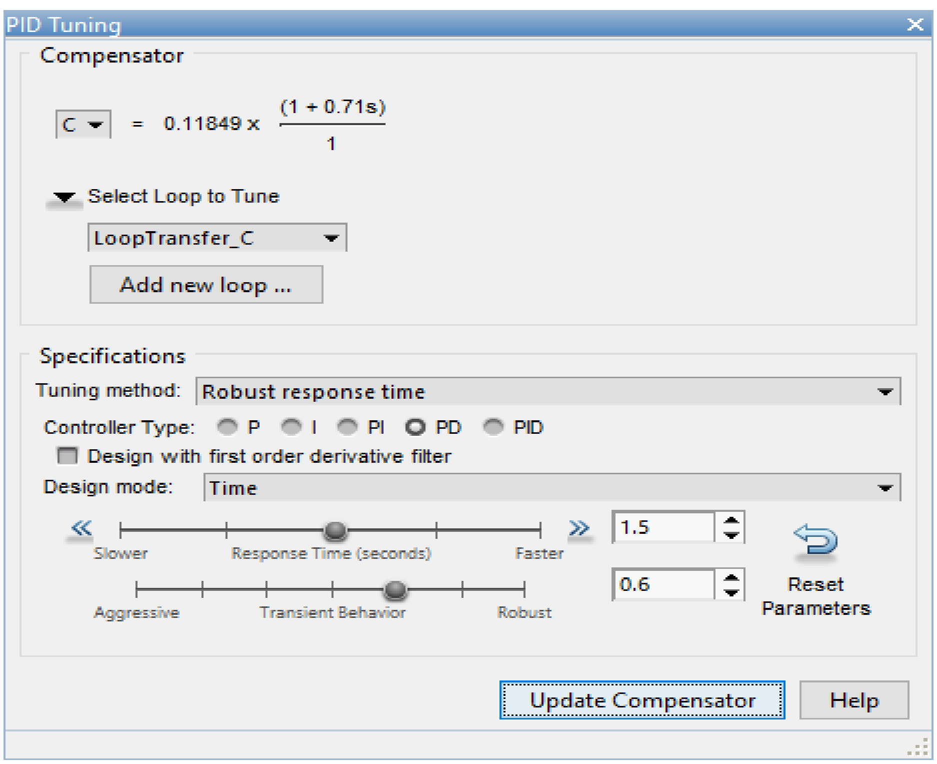


Figure 12

5 EVALUATE DESIGN1 MODEL

Close ‘PID Tuning’ widow and return to the ‘Control System Designer’ main window. Press ‘Store’. A new name appears in the ‘Designs’ LHS window; the new name is ‘Design2’. Restore the original view in the step response window using the zoom -out button. Now, the main window looks as shown in Figure 13.

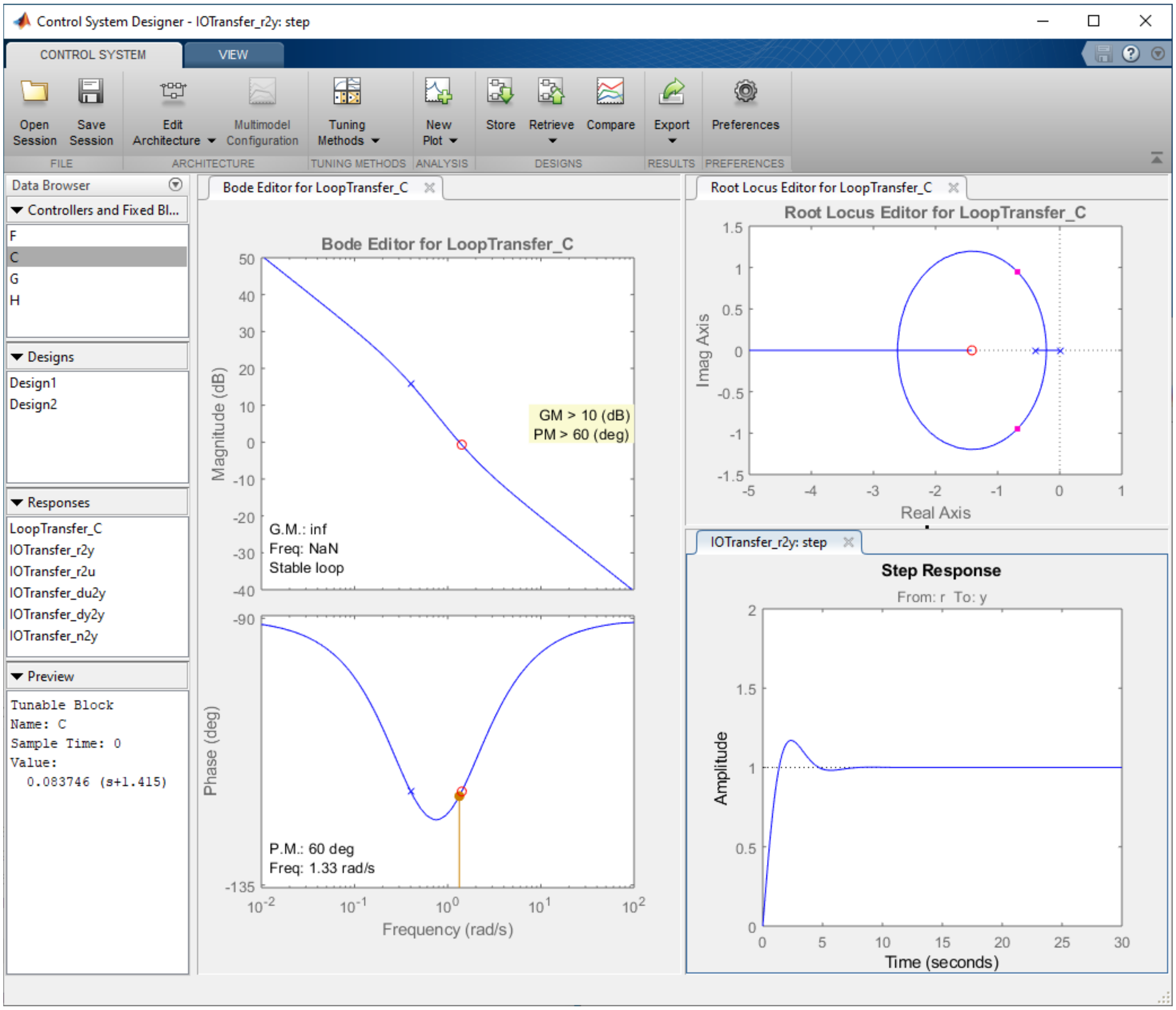


Figure 13

Note that the controller formula appear as

```
Tunable Block
Name: C
Sample Time: 0
Value:
  0.083746 (s+1.415)
```

5.1 PERFORMANCE INDICATORS OF DESIGN2 MODEL

Next, verify the status of DS1 and DS2 conditions. Recall

- DS1: Fast response time as measured by rise time
  $t_r \leq 1.5$ sec
- DS2: maximum percentage overshoot for step input less than 20%
  $M_p \leq 20\%$

Use datatips to read t_r and M_p on the 'Step Response' plot for the closed loop system 'IOTransfer_r2y: step' (Figure 14).

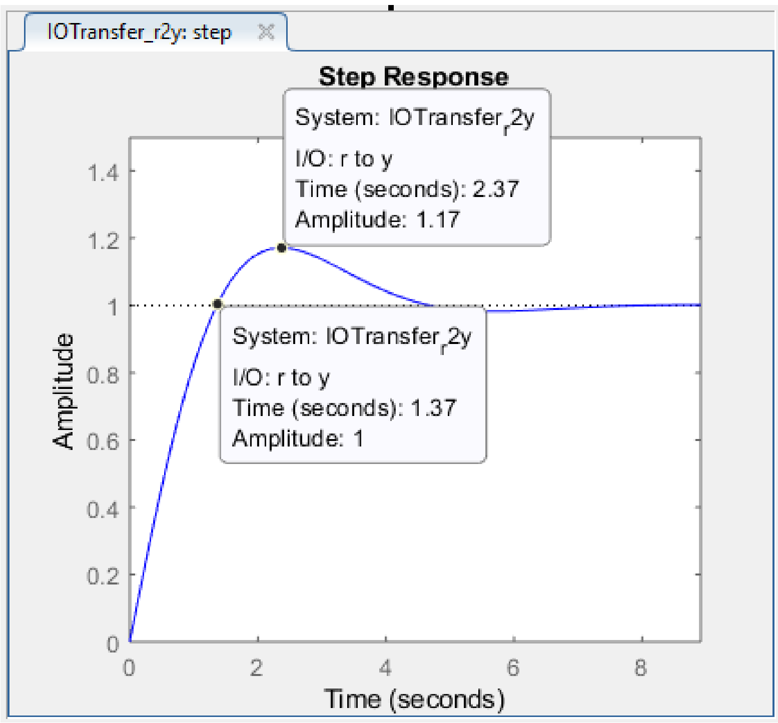


Figure 14

It is apparent that:

- t_r=1.37 sec < 1.5 sec which means that DS1 is satisfied
- M_p=17% < 20% which means that DS2 is satisfied.

5.2 STABILITY MARGINS OF DESIGN2 MODEL

The stability margins can be read in the Bode plot of Figure 13; they are much better than in the original design:

- GM: inf which is better than $GM = 10\,\text{dB}$ required by DS3
- PM: 60 deg, which meets the value $PM = 60°$ required by DS3

The stability margin criteria are satisfied which means that DS3 is satisfied.

We state that all three design specification DS1, DS2, DS3, have been met and the control system design process has completed successfully.

6 COMPARE THE STEP RESPONSE OF THE INITIAL AND FINAL DESIGNS

To compare the initial and final designs, do the following:

Press ‘Compare’ button and a ‘Compare Designs’ window pops up (Figure 15).

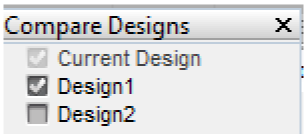


Figure 15

Check box in front of ‘Design1’. The step response plot contains the two responses overlapped (Figure 16).

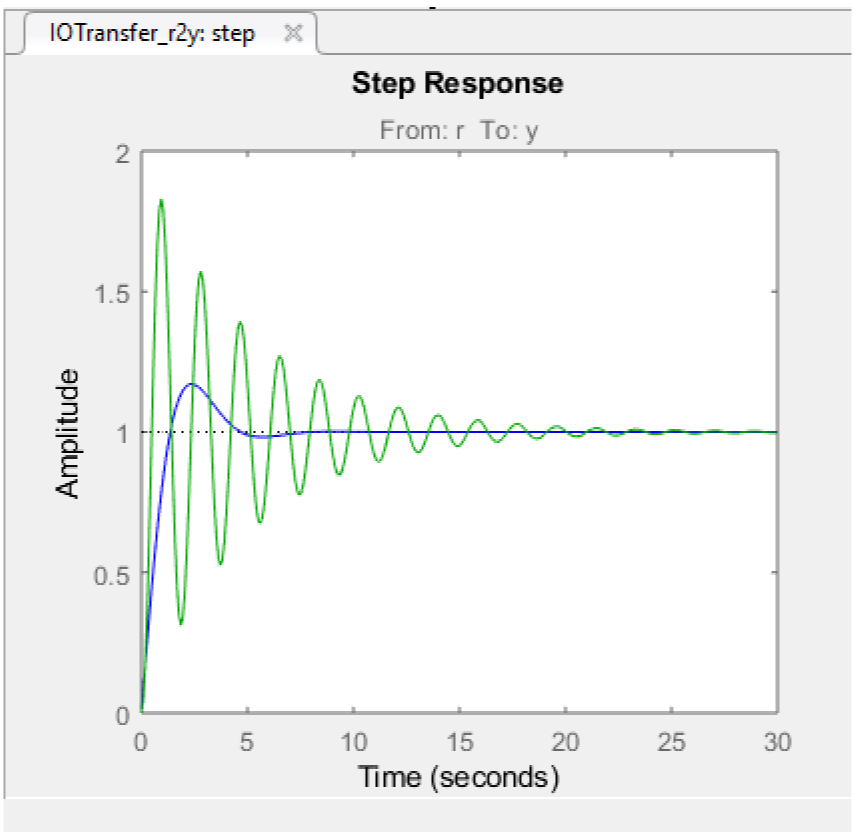


Figure 16

The initial design ‘Design1’ is shown in green, whereas the current design is shown in blue.

The response improvements achieved through this controller design process are quite apparent.

aircraft_roll_model.m

```
%% description
%{
aircraft roll model for use with CSD Tool
%}
%% initialization
clc                        % clear command window
clear                      % clear workspace
% close all                  % close all plots
format compact
s=tf('s');
%% aircraft model
K=114;
J=10;   % inertia
c=4;    % damping
G=K/(J*s^2+c*s)      % plant
controlSystemDesigner
```

‘Control System Designer’ MATLAB Tool

Aircraft Roll Motion Autopilot Development
PID Example

Table of Contents:

1 CONTROL SYSTEM DESIGN OBJECTIVES

Consider the aircraft roll transfer function $G(s) = \dfrac{K}{Js^2 + cs} = \dfrac{114}{10s^2 + 4s}$

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Design Objective 1: Control the unconstraint aircraft motion resulting from an aileron input. Have a autopilot system that can maintain the aircraft at a constant bank angle

We will achieve this objective through feedback (FB)

Design Objective 2: Achieve a reasonable aircraft roll response.

Design Objective 3: Ensure safe and stable operation of the feedback control system

We define 'reasonable response' using two control design specifications:

- DS1: Fast response time as measured by rise time
  $t_r \leq 1.5$ sec
- DS2: maximum percentage overshoot for step input less than 20%
  $M_p \leq 20\%$

We ensue safe and stable operation of the feedback control system by meeting a third design specification based on stability margins:

- DS3: $GM = 10\,\text{dB}$, $PM = 60°$

2 CREATE PLANT TRANSFER FUNCTION G

Run m-file `“aircraft_roll_model.m”` to create the plant transfer function G in the Workspace (Figure 1)

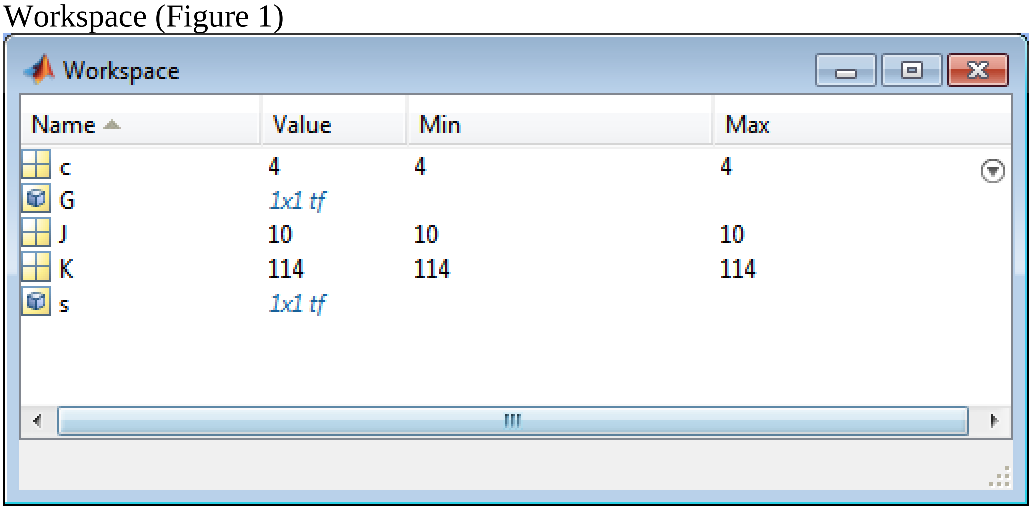

Figure 1

3 CREATE ‘CONTROL SYSTEM DESIGNER’ MODEL

3.1 OPEN ‘CONTROL SYSTEM DESIGNER’ SOFTWARE TOOL

In the Command Window, type “`controlSystemDesigner`”
`>>controlSystemDesigner`
(legacy name “`sisotool`”, also works, i.e., `>>sisotool)`

The Control System Designer GUI opens as shown in Figure 2.

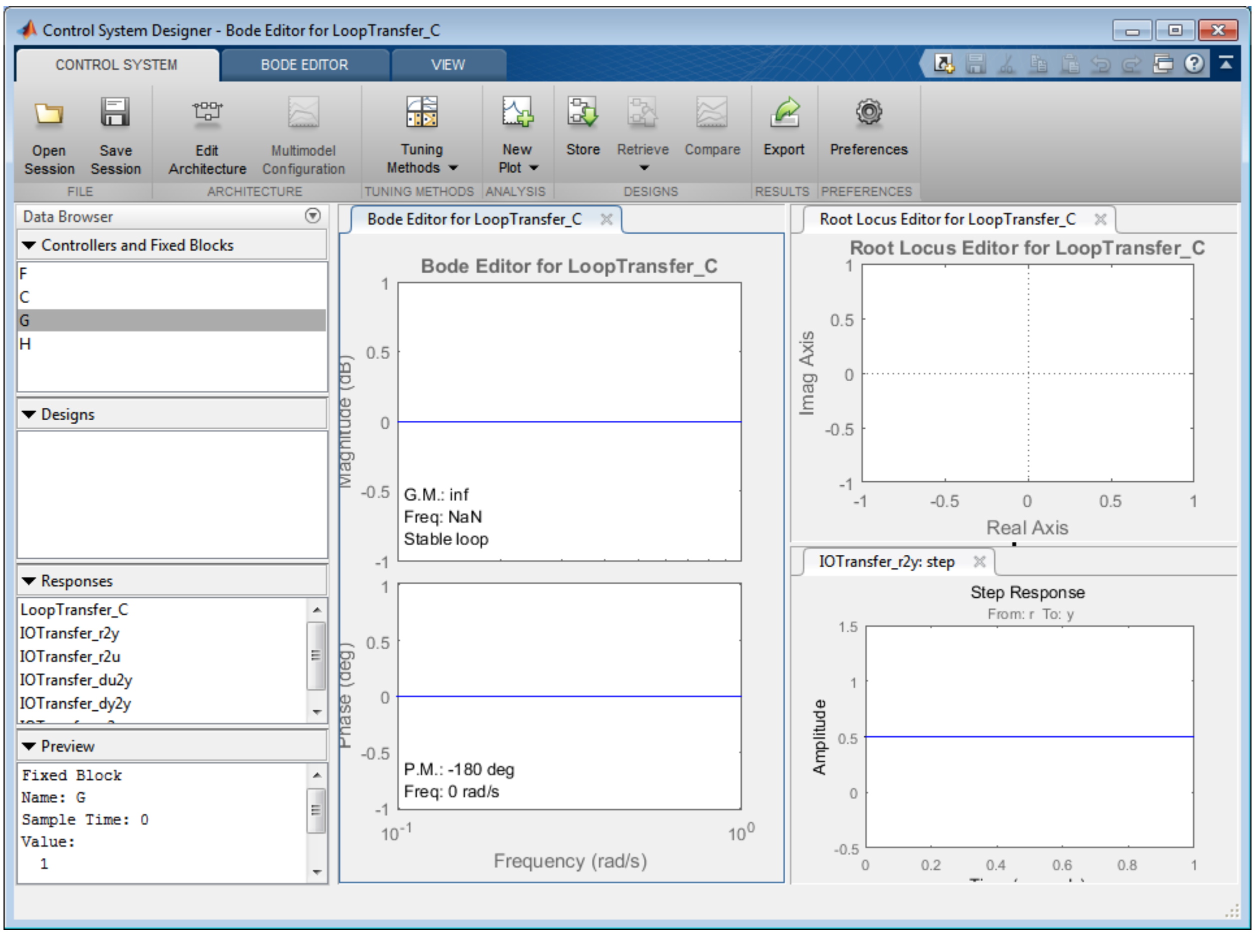

Figure 2

The default configuration has four blocks (F, C, G, H) as indicated in the LHS pane. All the blocks in this configuration are set to be unitary transfer functions by default (the plant block G, which is selected in the upper LHS pane, is shown in the lower LHS pane with Value: 1).

3.2 Import Plant Transfer Function G

Press “Edit Architecture” button to import the system G data from the Workspace (Figure 3).

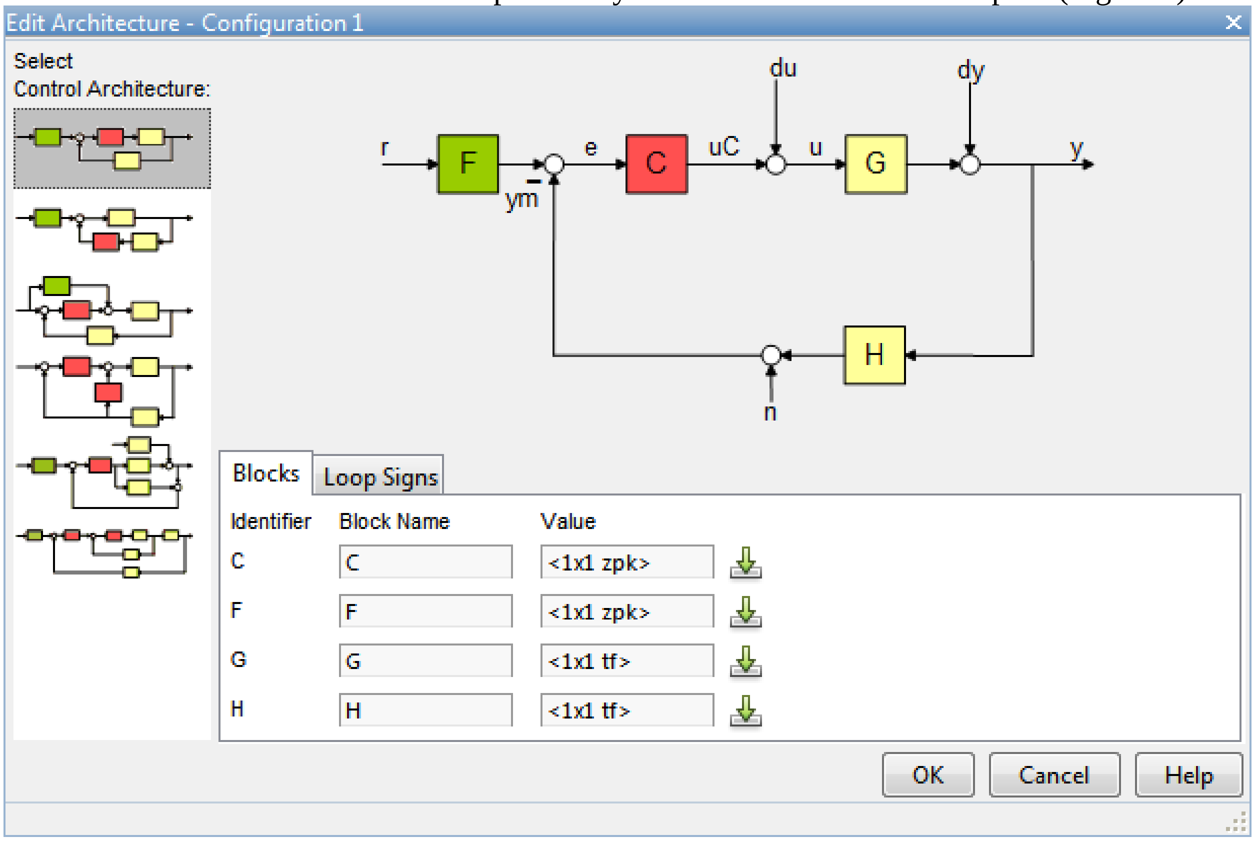

Figure 3

Note that the first control system configuration is selected by default (this is the configuration we work with, no need to change it.)

Press the down arrow icon at the RHS end of the row G to open the “Import Data for G” dialog box and select ‘G’ from the Base Workspace (Figure 4).

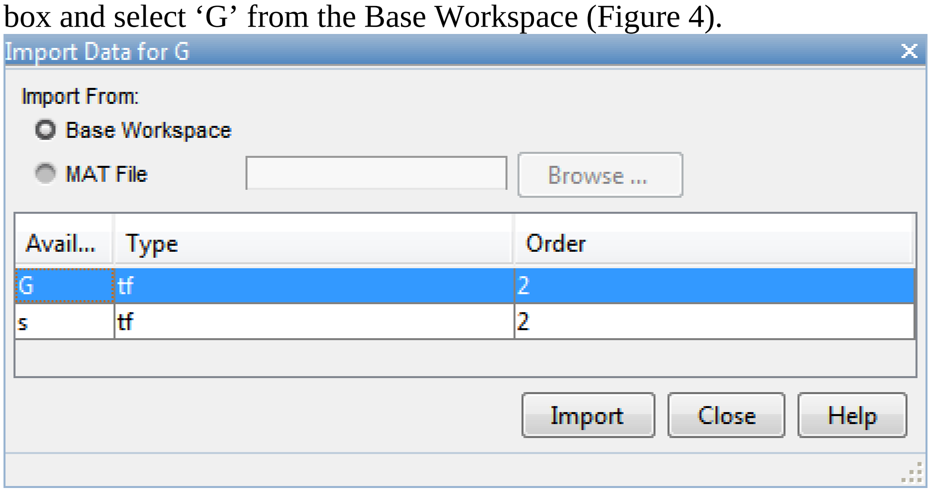

Figure 4

Press ‘Import’ to return to ‘Edit Architecture’ dialog box and press OK to return to the main view. Now, our system $G(s) = \dfrac{114}{10s^2 + 2s}$ is shown in the lower LHS pane of the model (Figure 5)

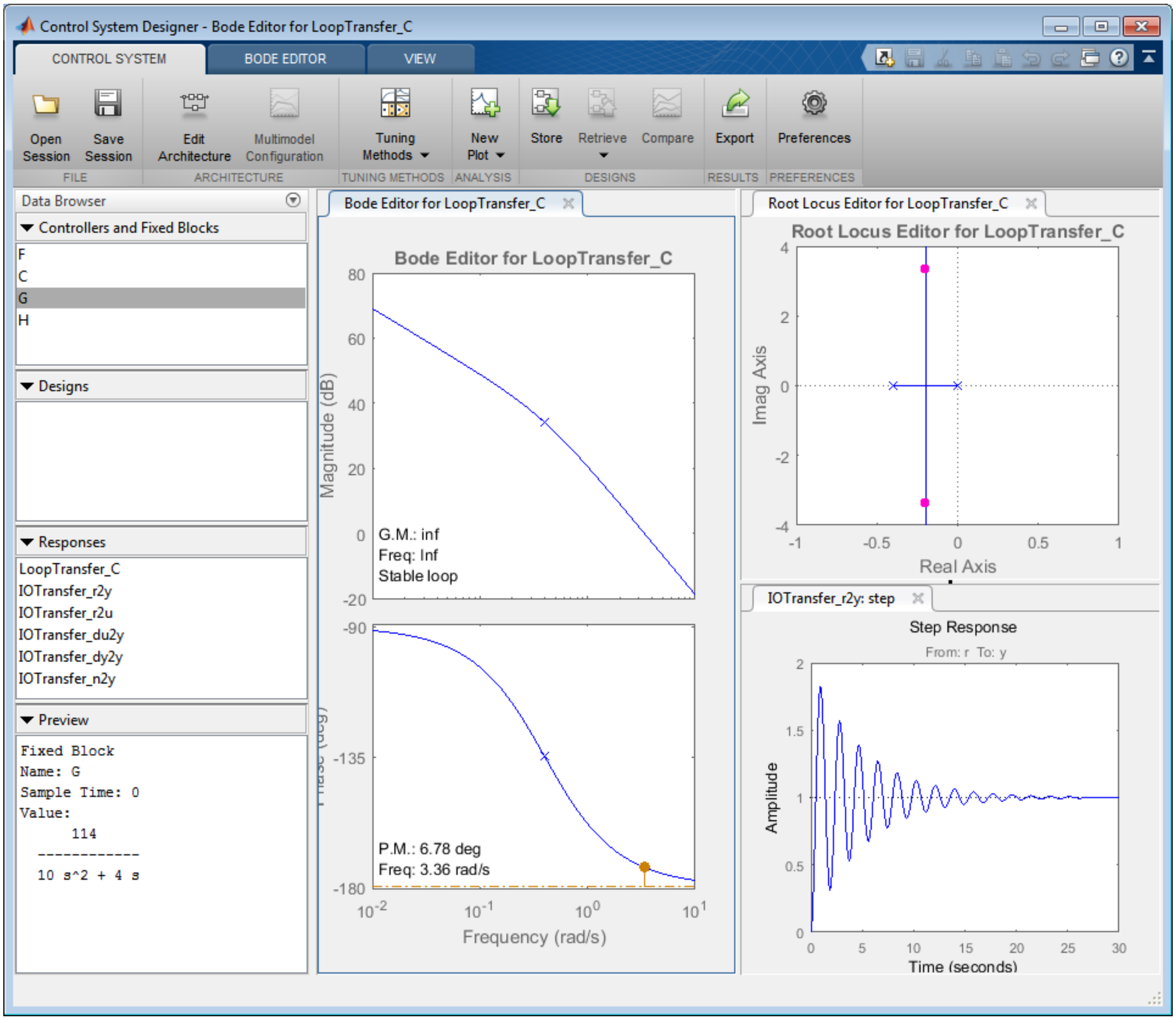

Figure 5

3.3 Store the Baseline Design as G

Press 'Store' button to store this design; it will shown as 'Design1' in the second LHS pane; double click on it to allow name edit and rename it as 'G'. Your screen should look like Figure 6.

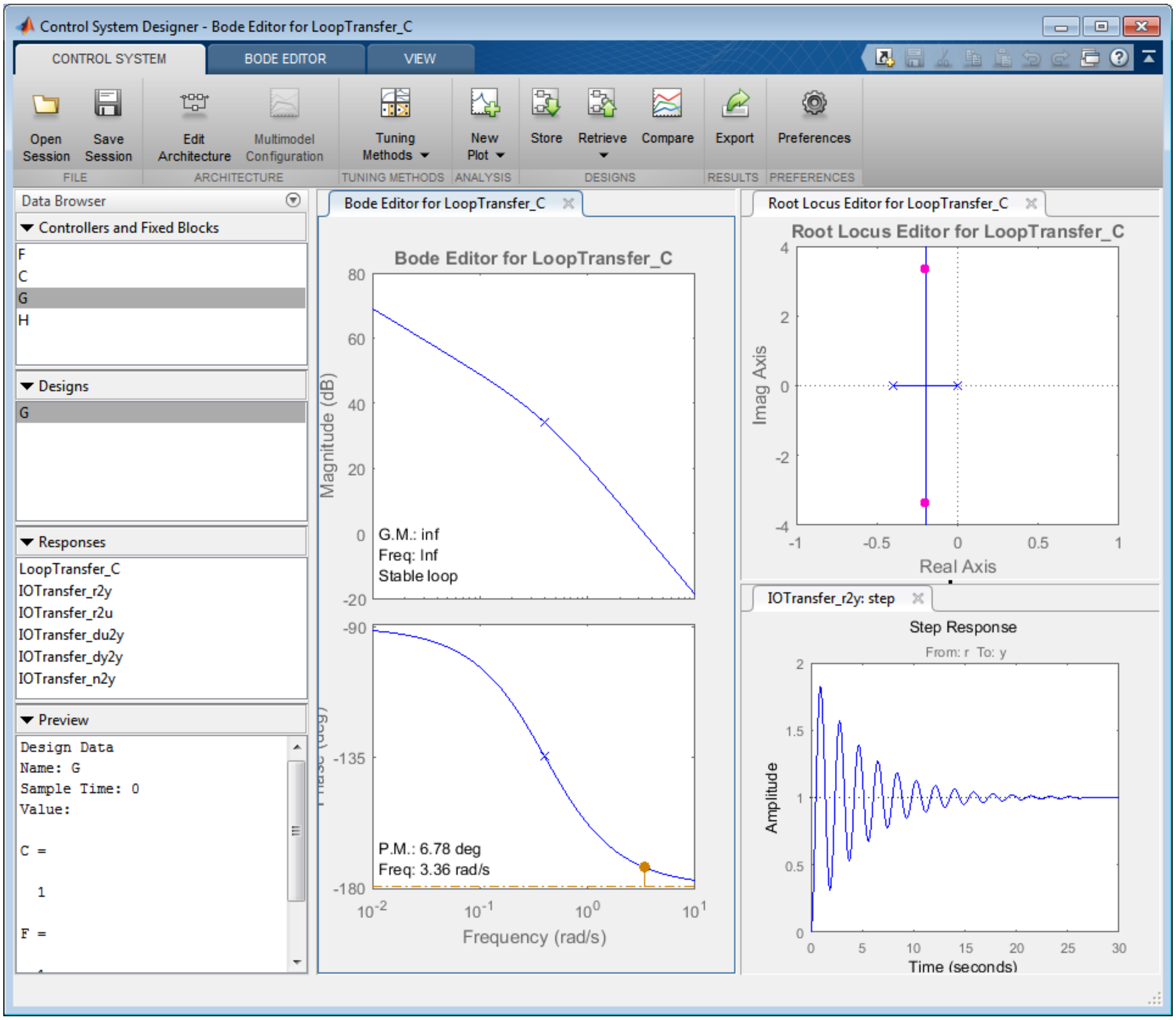

Figure 6

3.4 Save the CSD Sesion

Press 'Save Session' button and save your session with the name 'CSD_aircraft_Session_20161219'. The extension of the file, if shown, should be '.mat'.

3.5 RECORD THE BASELINE PERFORMANCE AND STABILITY READING OF G DESIGN

Record the following readings from this windown:

- GM: inf
- PM: 6.78 deg at 3.36 rad/s
- CL poles $-0.2+3.37i$ and $-0.2-3.37i$ shown as the two red dots in the Root Locus Editor
- A lightly damped step response 'r2y' (i.e., from input r to output y) with a large overshoot

It is apparent that the response is unsatisfactory because:

- many oscillations until it settles down to $x_{ss}=1$
- large overshoot ($x_p \approx 1.8$, $M_p \approx 80\%$)
- insufficient phase margin

4 PID CONTROLLER USING AUTOMATIC PID TUNING TO GENERATE DESIGN1

Press 'Tuning Methods' and select 'PID' from the pull-down menu. The 'PID Tuning' window opens up (Figure 7).

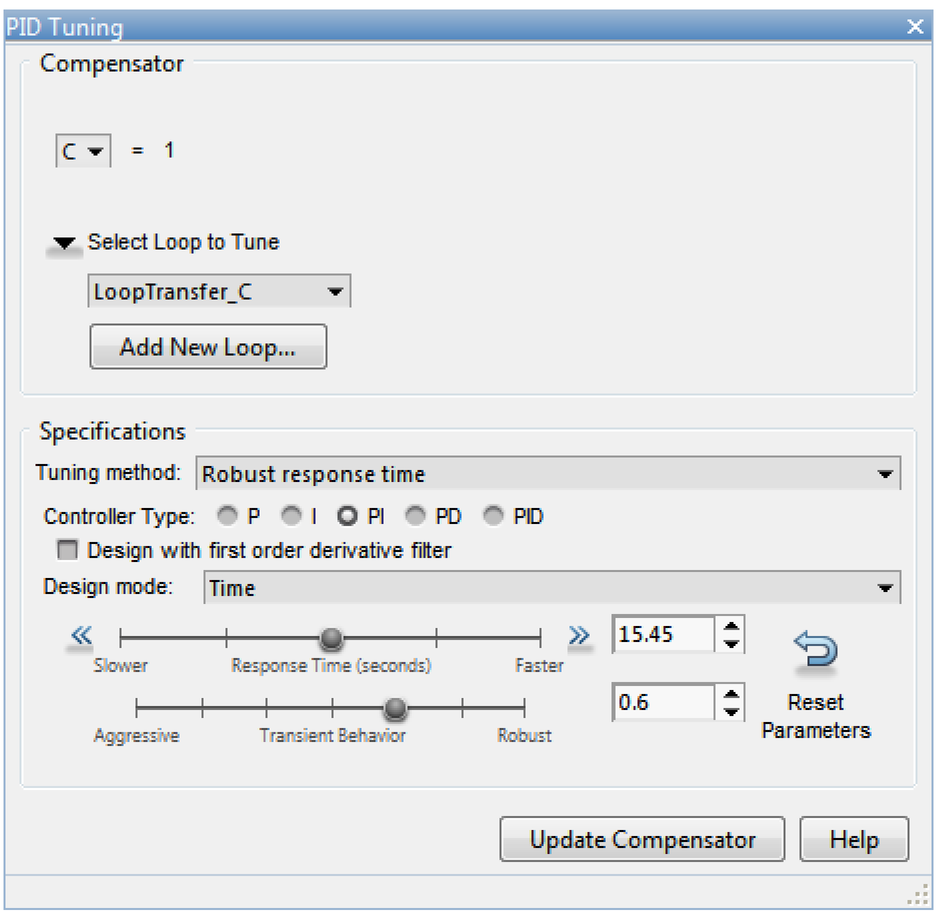

Figure 7

4.1 ADJUST 'RESPONSE TIME' RANGE

Select 'PID' on 'Controller Type' line. Press the >> arrow on the RHS of the 'Response Time' bar to see '1.545' in the RHS window (Figure 8).

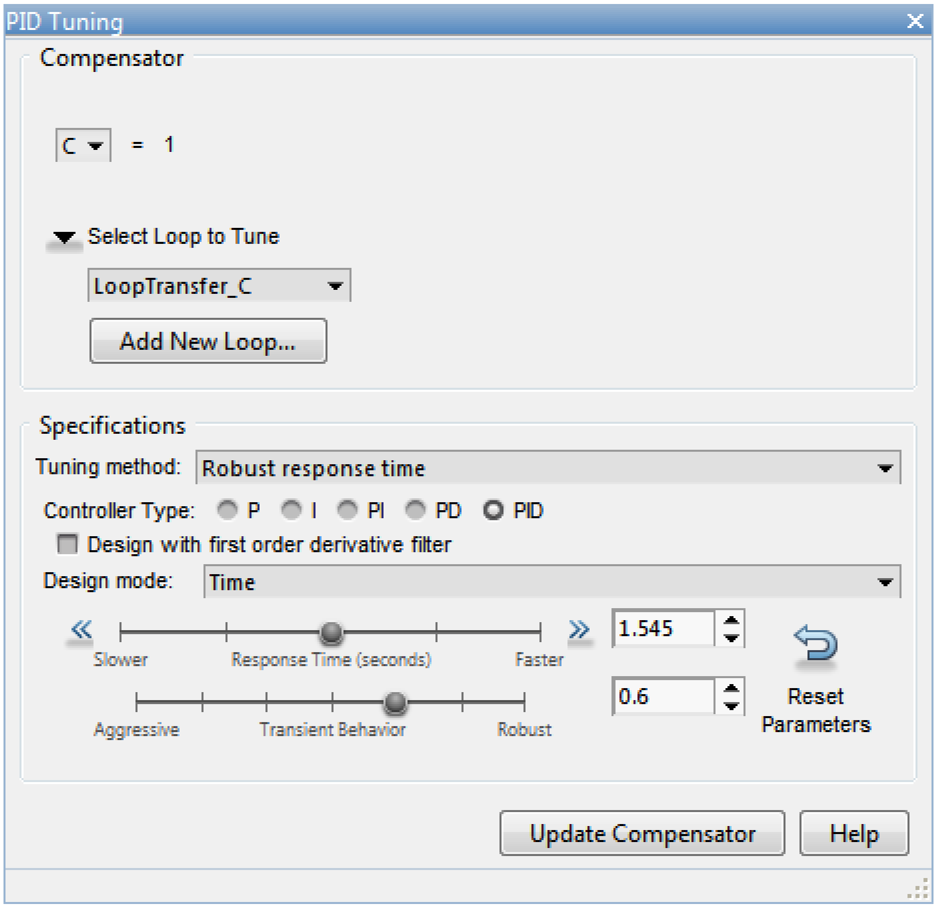

Figure 8

4.2 ADJUST THE 'TIME RESPONSE' AND 'TRANSIENT BEHAVIOR'

Use the up/down arrows to make the 'Time Response' reading in the RHS window '1.422' and the 'Transient Behavior' reading in the RHS window be '0.6'.

Press 'Update Compensator'button. The 'PID Tuning' window looks as shown in Figure 9.

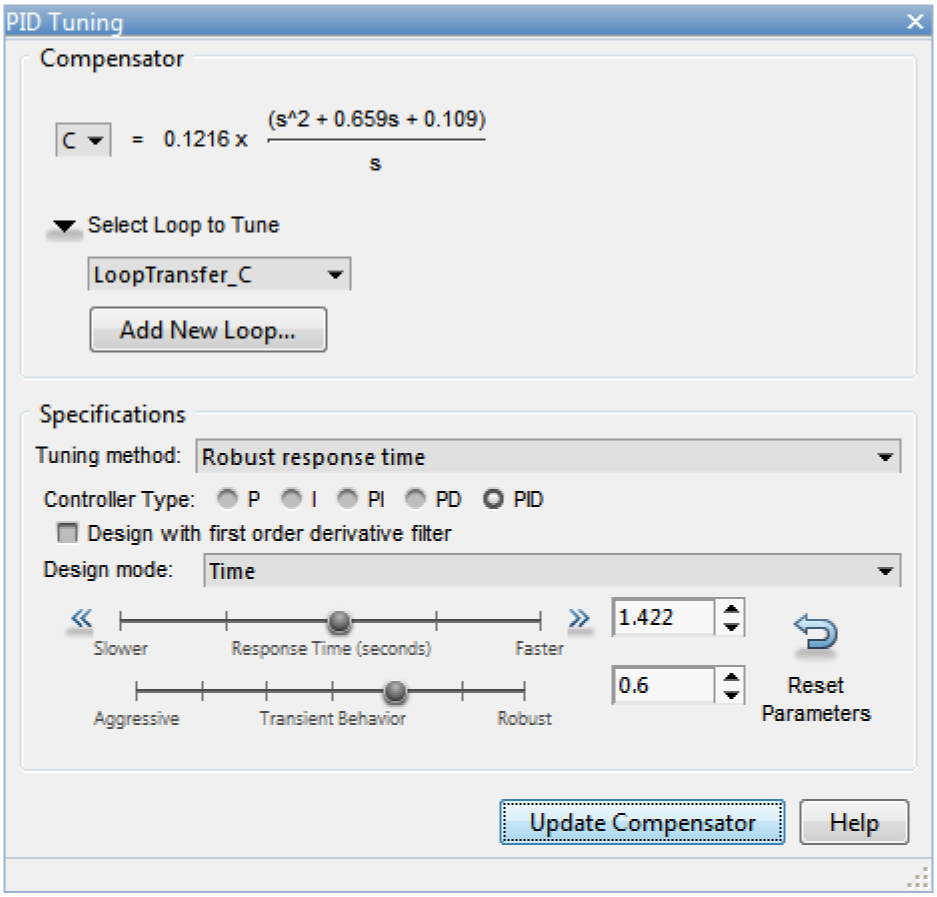

Figure 9

5 EVALUATE DESIGN1 MODEL

Close ‘PID Tuning’ widow and return to the ‘Control System Designer’ main window. Press ‘Store’. A new name appears in the ‘Designs’ LHS window; the new name is ‘Design1’. Now, the main window looks as shown in Figure 10.

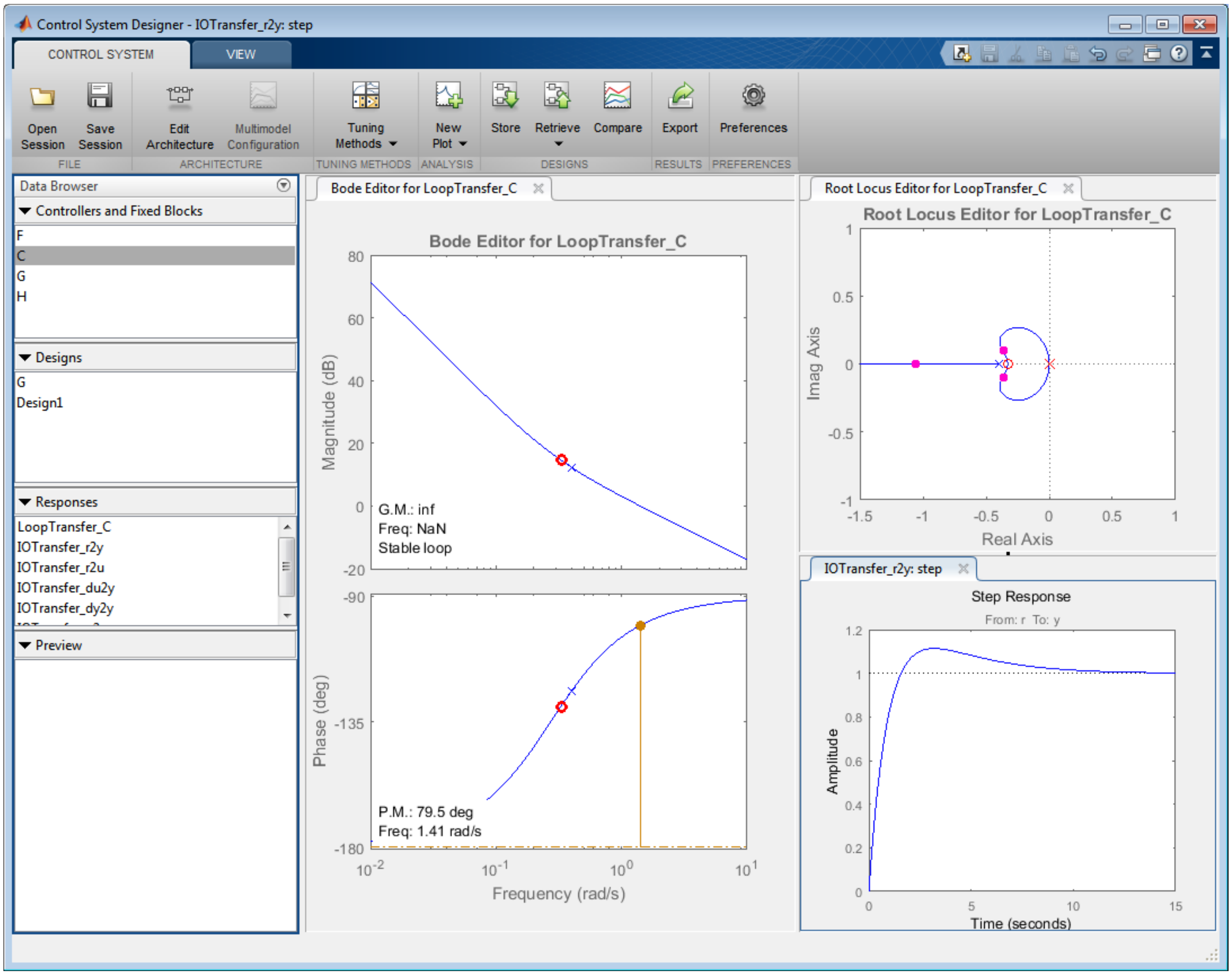

Figure 10

Note that the compensator formula appear as

```
C =

  0.11236 (s+0.3118)^2
  --------------------
           s
```

5.1 STABILITY MARGINS OF DESIGN1 MODEL

The stability margins can be read in the Bode plot; they are much better:

- GM: inf which is better than $GM = 10\,\text{dB}$ required by DS3
- PM: 79.5 deg, which is better tan , $PM = 60°$ required by DS3

The stability margin criteria are satisfied and hence we can say that DS3 condition has been met.

5.2 PERFORMANCE INDICATORS OF DESIGN 1 MODEL

Next, verify the status of DS1 and DS2 conditions. Recall

- DS1: Fast response time as measured by rise time
  $t_r \leq 1.5$ sec
- DS2: maximum percentage overshoot for step input less than 20%
  $M_p \leq 20\%$

We use datatips to read t_r and M_p on the 'Step Response' plot for the closed loop system 'IOTransfer_r2y' (Figure 11).

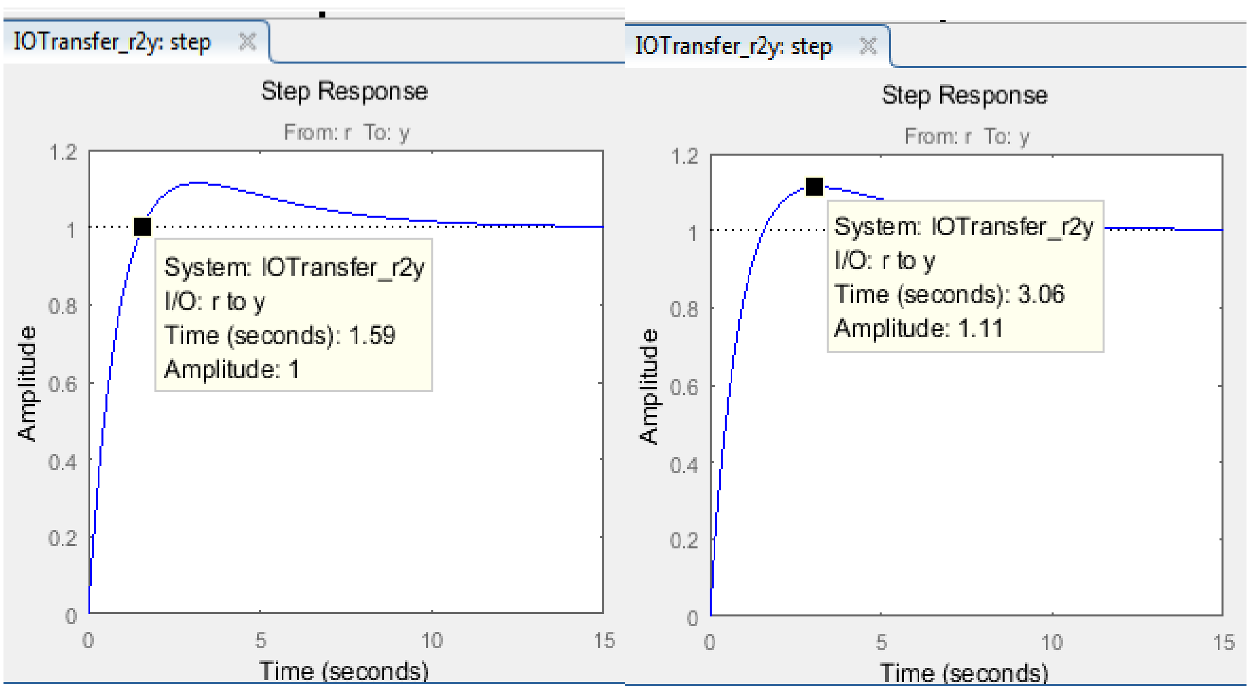

Figure 11

It is apparent that $t_r = 1.59\,\text{sec}$, $M_p = 11\%$

It seems that DS2 has been also satisfied byt DS1 is not yet fully satisfied (though it is very close to it).

6 MANUAL ADJUSTMENT OF THE CONTROLLER – DESIGN2 MODEL

To further improve the system performance and meet the design specifications, we perform manual tuning in the Bode diagram.

6.1 Grab and Move Compensator Zero to Improve Design

Grab the compensator Zero shown by a red circle on th Bode Phase plot (Figure 12).

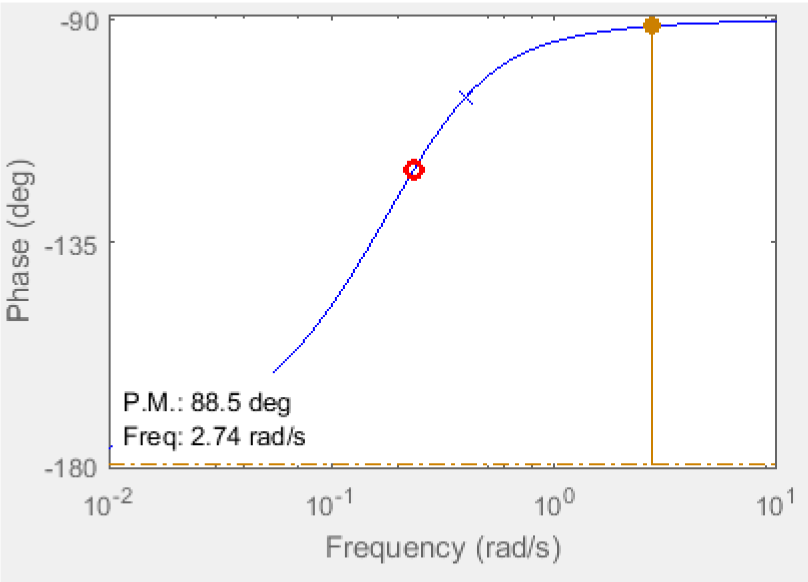

Figure 12

Move this red circle slightly to improve the response time t_r while maintaing GM: inf and a large PM.

This manual adjustment operation must be performed with great delicacy and in very small steps. Continous monitoring of the changes in stability margin should be done continously. If stability is lost, than it should be restored immediately through a backward step and fine adjustment should be continued with delicacy. Note that the gain margin GM is prone of jumping from ‘inf’, which is OK, to a large negative value which is not OK!

When a satisfactory situation has been met, press ‘Store’; a new design named ‘Design2’ appears in the ‘Designs’ LHS pane. The overall picture is shown in Figure 13.

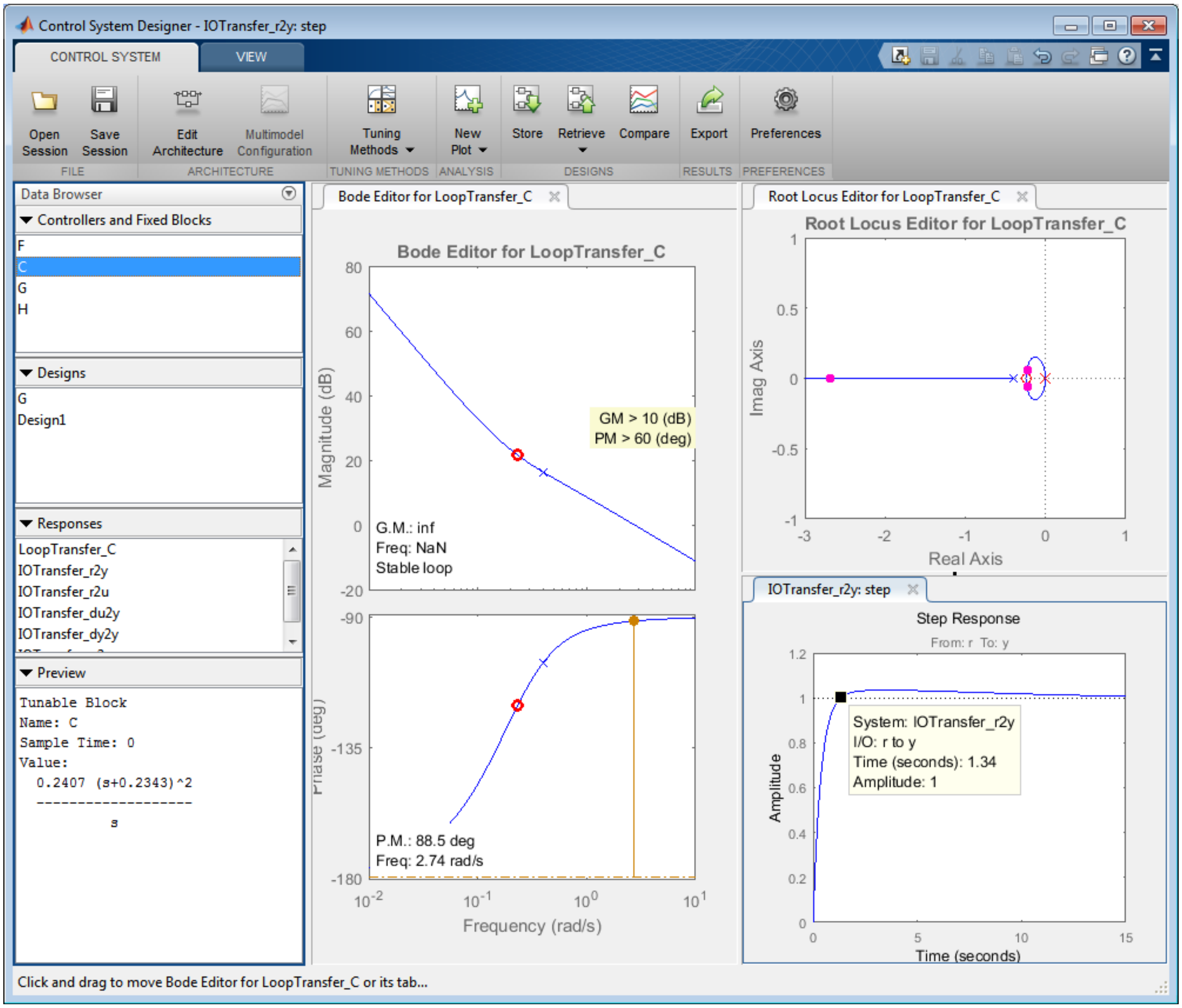

Figure 13

6.2 ADJUST COMPENSATOR IN COMPENSATOR EDITOR

One can also adjust the compensator directly by entering values for its properties. Right click on ‘C’ in the upper LHS pane and choose ‘Open Selection’ from the pulldown menu. The ‘Compensator Editor’ window opens as shown in Figure 14. The compensator properties, e.g., the ‘Real Part’ of the Complex Zero can be entered here.

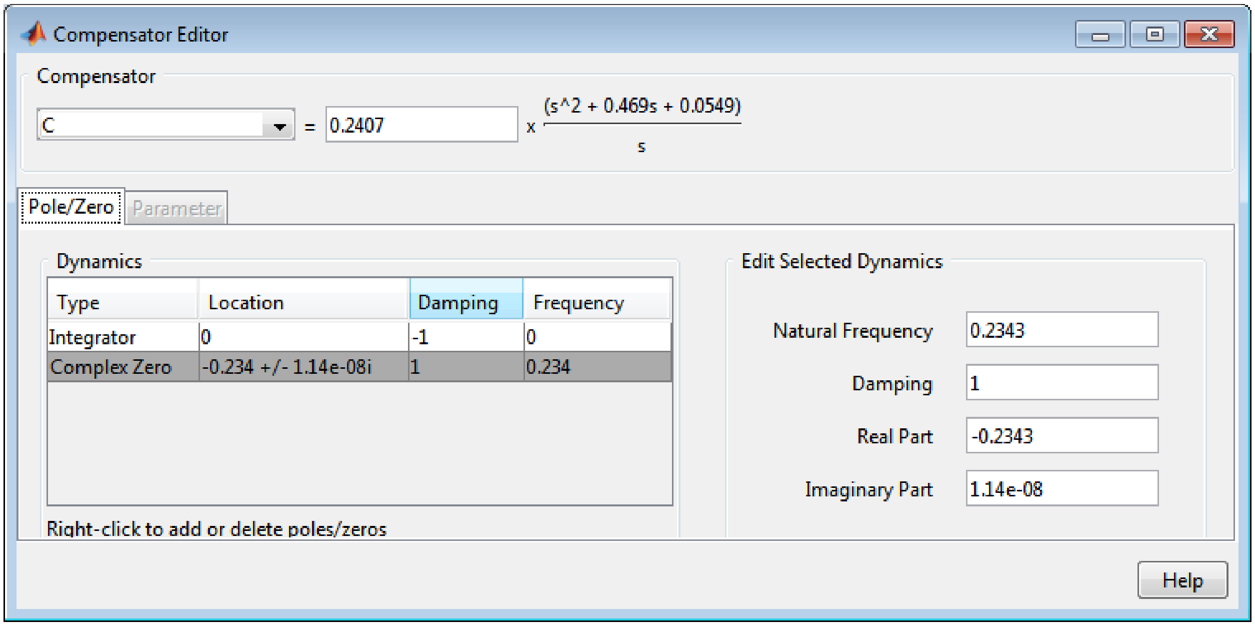

Figure 14

6.3 SAVE THE CSD SESION

To save the latest designs, press the 'Save Session' button and save your session with the name 'CSD_aircraft_Session_20161219'. The file extension, if shown, should be '.mat'.

7 EVALUATE DESIGN2 MODEL

7.1 STABILITY MARGINS OF DESIGN2 MODEL

The stability margins can be read on the Bode plots of Figure 13; they are very good:

- GM: inf which is better than $GM = 10\,\text{dB}$ required by DS3
- PM: 88.5 deg, which is better than $PM = 60°$ required by DS3

The stability margin criteria are satisfied and DS3 condition has been met.

7.2 PERFORMANCE INDICATORS OF DESIGN2 MODEL

Figure 13 indicates that the step response has a faster response time and a smaller overshoot than before (Figure 15).

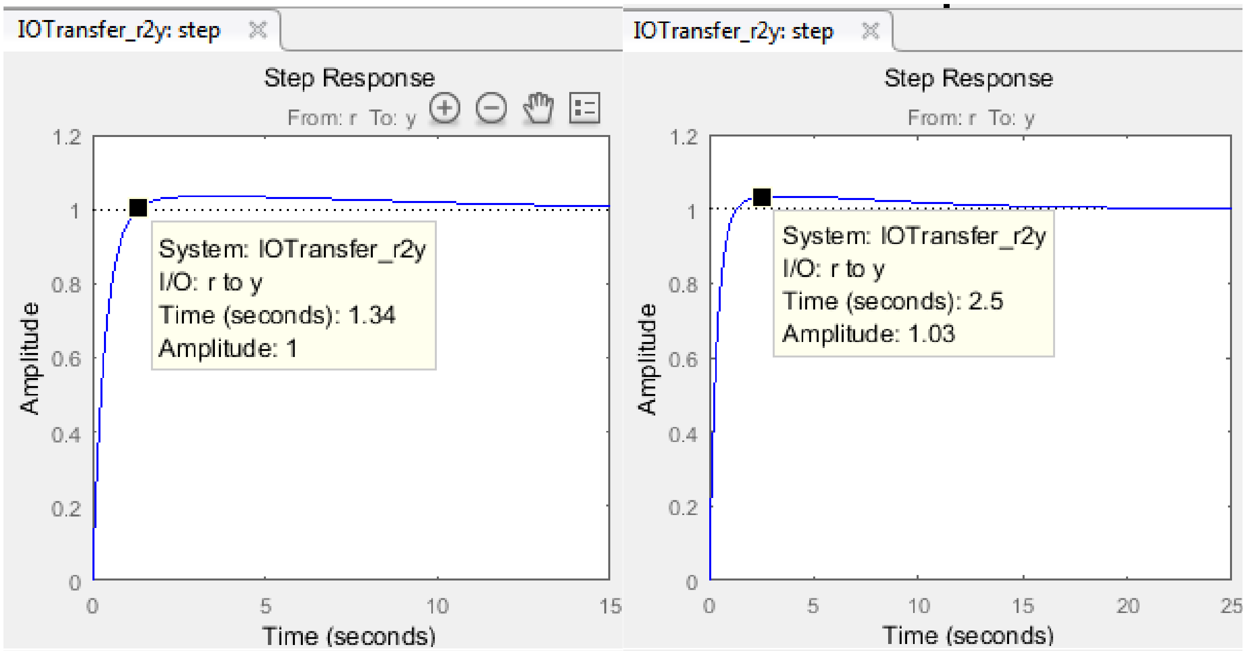

Figure 15

From Figure 15, we read: $t_r = 1.34\,\text{sec}$, $M_p = 3\%$.

It seems that DS1 and DS2 have been met.

The only drawback this this Design2 situation could be that the system seems to take longer than before to settle down to the steady state value.

Further tweaking of the controller could be attempted to overcome this aspect if considered important.

However, for now, we state that all three design specification DS1, DS2, DS3 have been met and the control system design process can be considered complete.

8 COMPARE THE STEP RESPONSE OF THE INITIAL AND FINAL DESIGNS

To compare the initial and final designs, do the following:

Press ‘Compare’ button and a ‘Compare Designs’ window pops up (Figure 16).

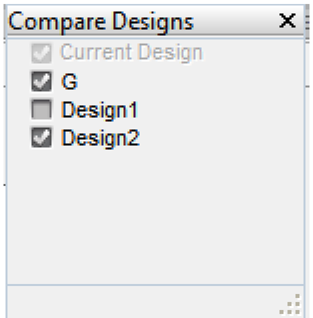

Figure 16

Check boxes in front of ‘G’ and ‘Design2’. The step response plot contains the two responses overlapped (Figure 17).

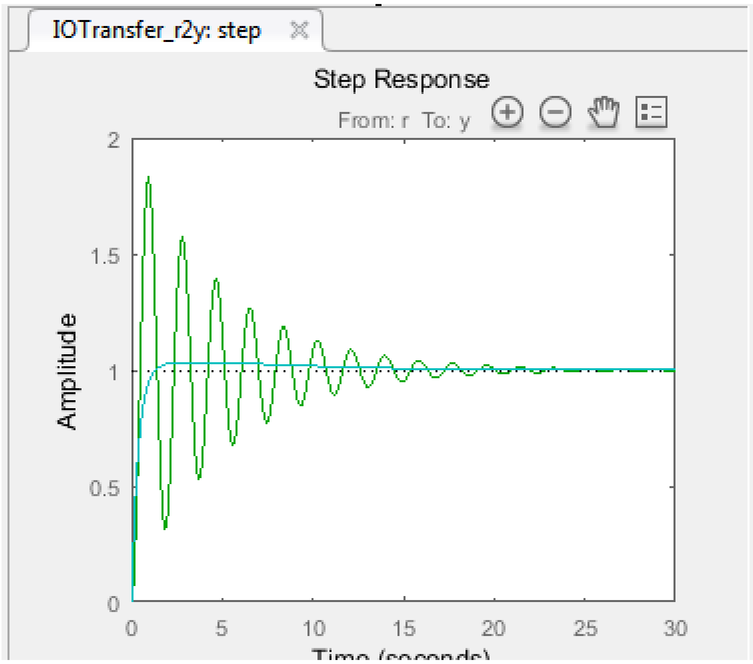

Figure 17

The initial design ‘G’ is shown in green, whereas the final design ‘Design2’ is shown in blue.

The response improvements achieved through this controller design process are quite apparent.