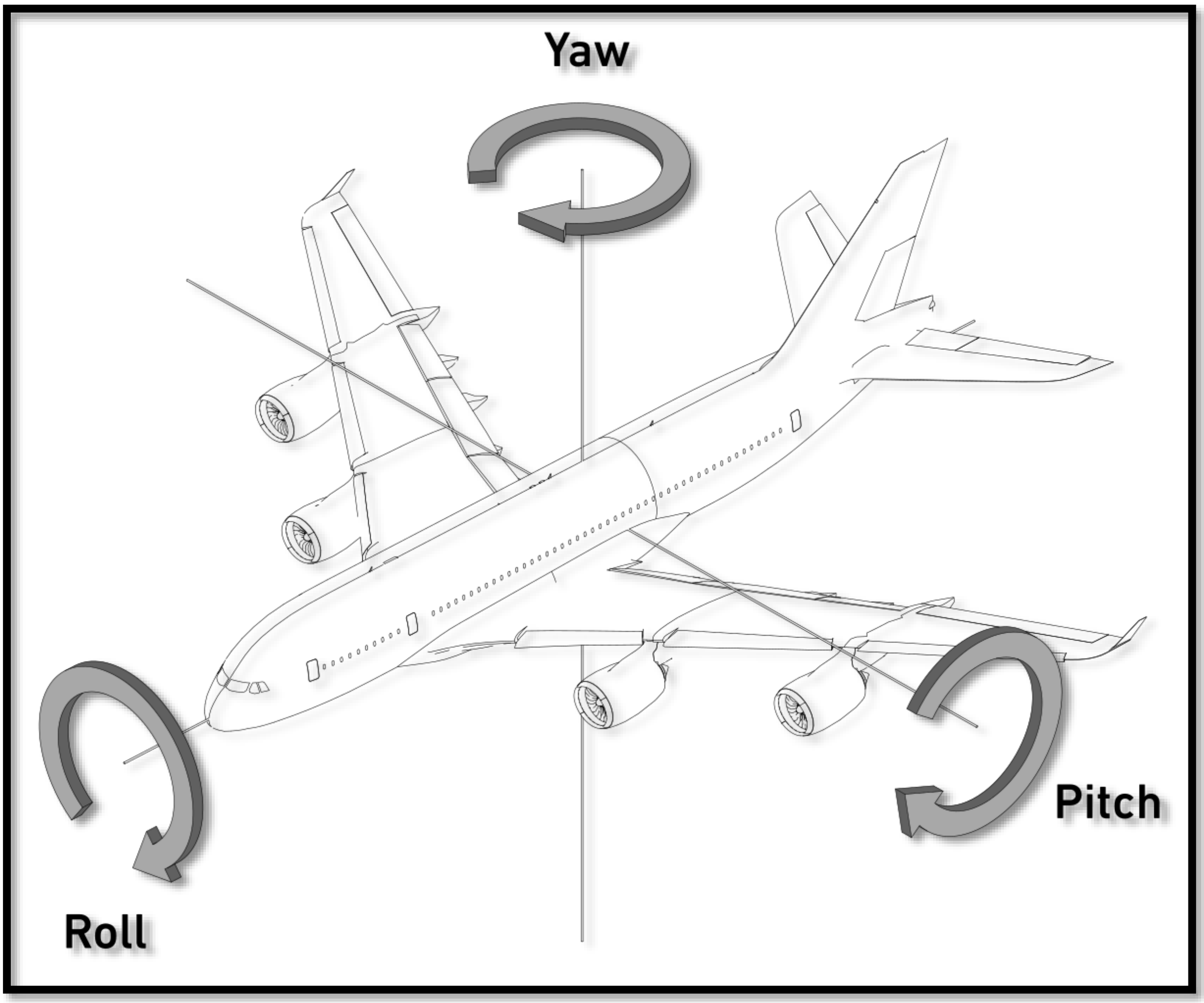
# MATLAB/Simulink Modelling of Autopilot System




**[2]**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## Introduction:

For this assignment, MATLAB and Simulink will be used to simulate the control system for the aileron used on an aircraft. The first part includes the simulation of an open loop system with no feedback system in place. From this a scope can, be used to view the roll rate and roll angle of the aircraft. Since the system is constructed using a transfer function the numerator and denominator can be changed, with the effect being observed from the scopes.

The next part requires the calculation of the two poles for the second order system when there is a feedback loop and a gain amplifier is added to the system diagram. Taking the results of the system with a three-input scope, the values for the system can be viewed and compared on a single graph. At this point a screen shot is taken of the resulting graph before a second transfer function is added to the system between the adder and the roll rate TF block. After adding this TF to system taking a secondary set of results, comparing the two and commenting on the changes.

The final part requires the use of the MATLAB environment, using the rlocus function to draw a graph of the third order system. Using the rlocfind function in conjunction with this, MATLAB will be able to calculate and give the values for all the poles in the system just by clicking on the point where the locus and line constant damping intersect.

## Part A

This system below is an open loop step response that will show the roll rate and roll angle response for an aileron system on the wings of a plane, and how the system will react to the input change.

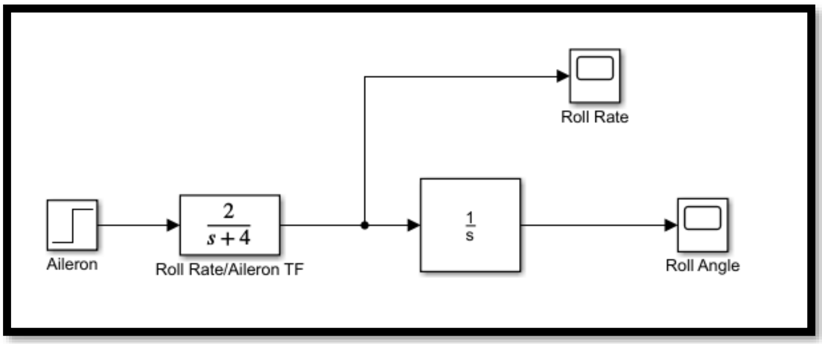
An aileron are the fins of the wings of the plane that help the aircraft to pitch and roll. These can be found in the end of an aircrafts wings and are primarily used for take-off and rolling. A better way of describing this action is 'banking' the aircraft, which translates into only slightly rotating the aircraft.

When the Ailerons move, they create an *'unbalanced side force component'* of the wing lift. This has the effect of altering the flight path to a curve. This is the reason for the banking of an aircraft created by ailerons instead of the ruder input.

This works by changing the angle of deflection at the back of the air-foil. This changes the lift that the foil generates. When pointed downward, this increases the lift upwards and vice versa. For example, if the left side is pointed down and the right is pointed up, then the aircraft will bank to the left side since that is where the lift is occurring while the right has a decreased lift. The force of the lift which is 'Fr' or 'Fl' of 'the wing section through the aileron is applied at the aerodynamic centre'. This aerodynamic centre is L distance away from the centre of gravity of the aircraft, creating a torque. This can be expressed in the formula…

***T = F * L***

When the force and distance is equal, then there is no net torque. If the forces are uneven however, then a net torque is applied, and a rotation occurs at the centre of the aircraft's gravity.


Roll Rate
Aileron
$\frac{2}{s+4}$
Roll Rate/Aileron TF
$\frac{1}{s}$
Roll Angle

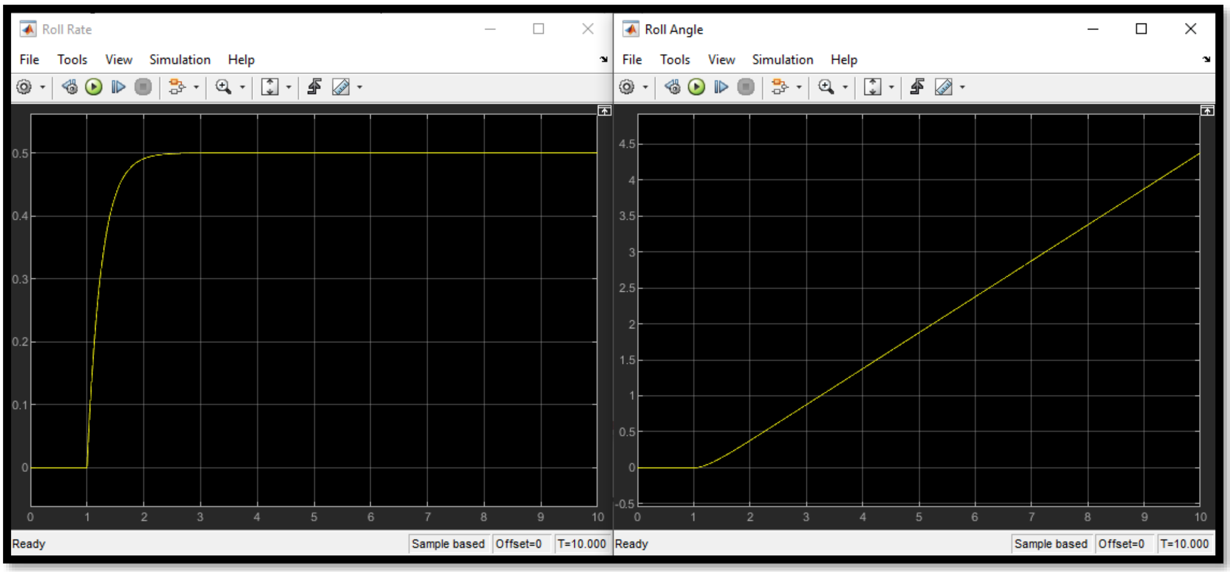
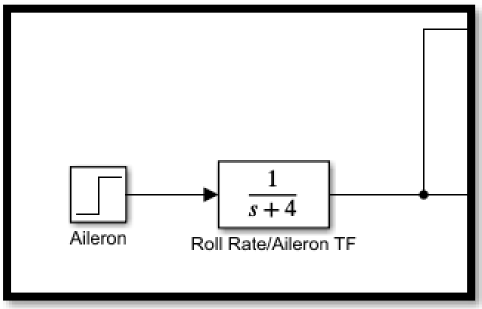

Roll Rate
File Tools View Simulation Help
Ready
Sample based
Offset=0
T=10.000
Roll Angle
File Tools View Simulation Help
Ready
Sample based
Offset=0
T=10.000

figure 1.1


Aileron
$\frac{1}{s+4}$
Roll Rate/Aileron TF

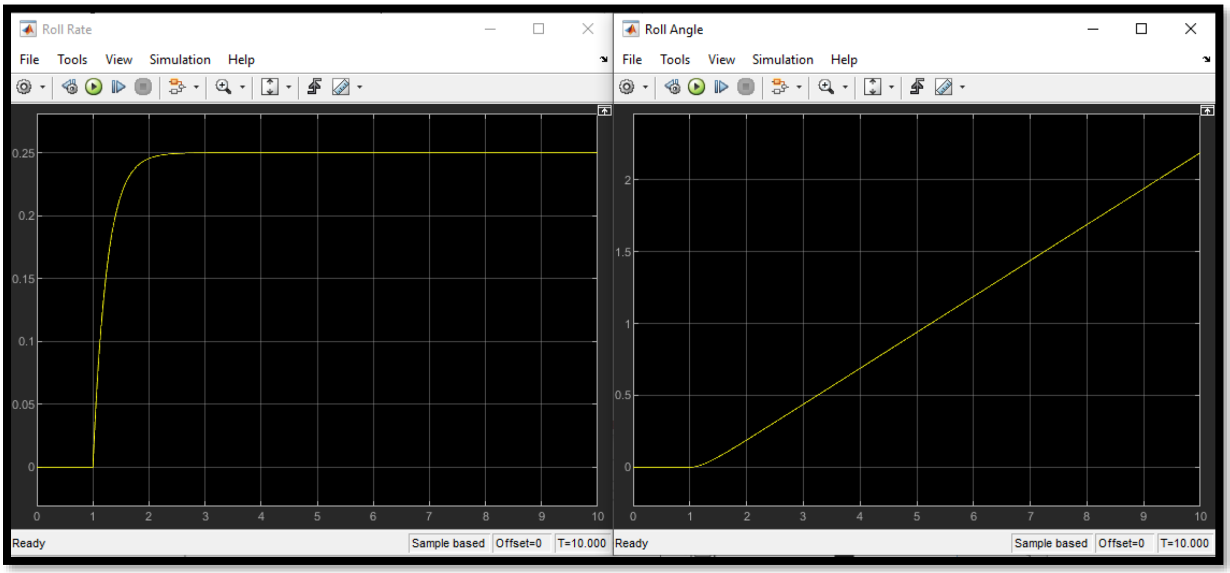



Figure 1.2

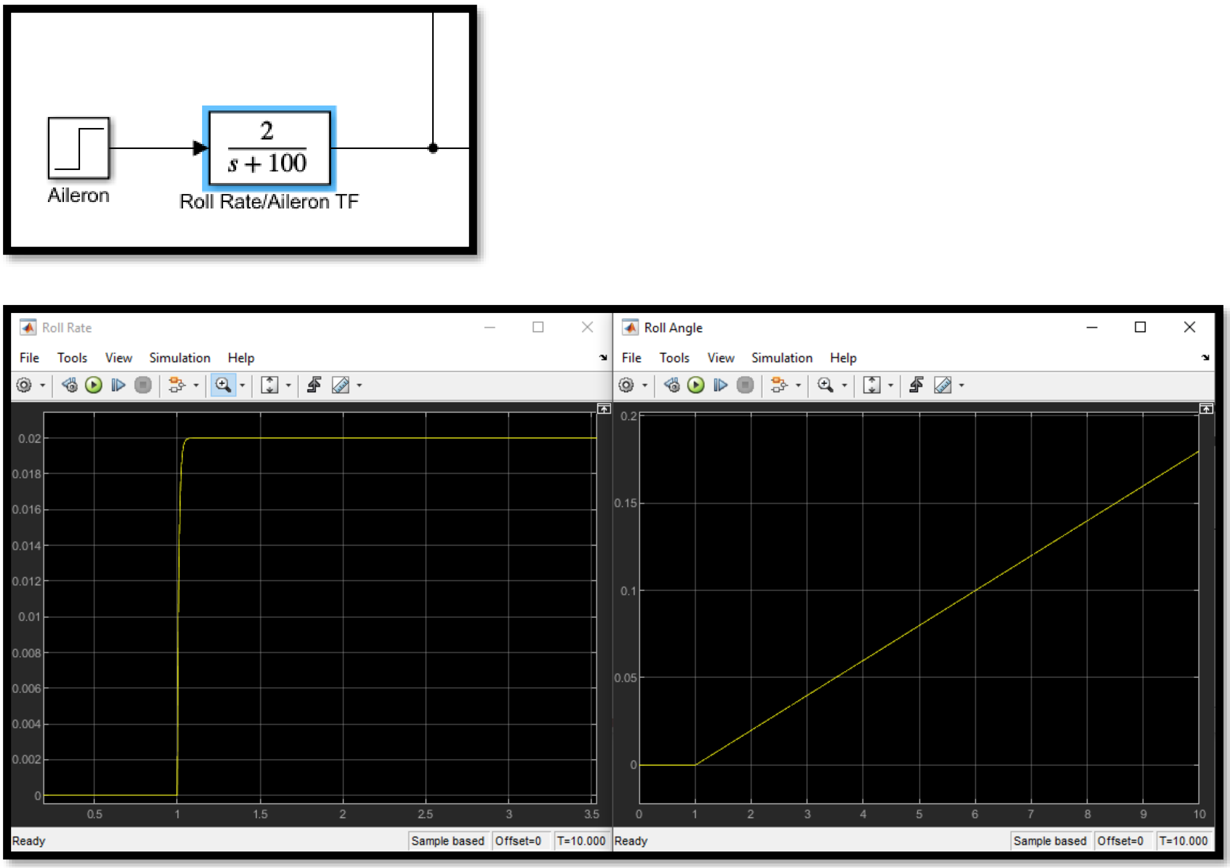
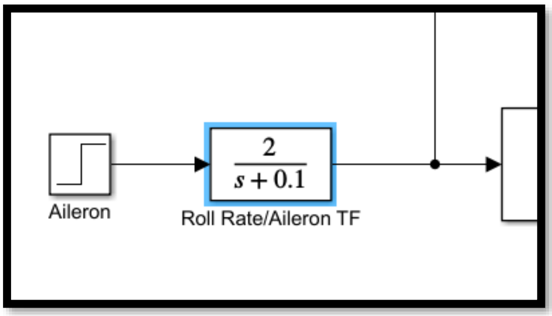



Figure 1.3



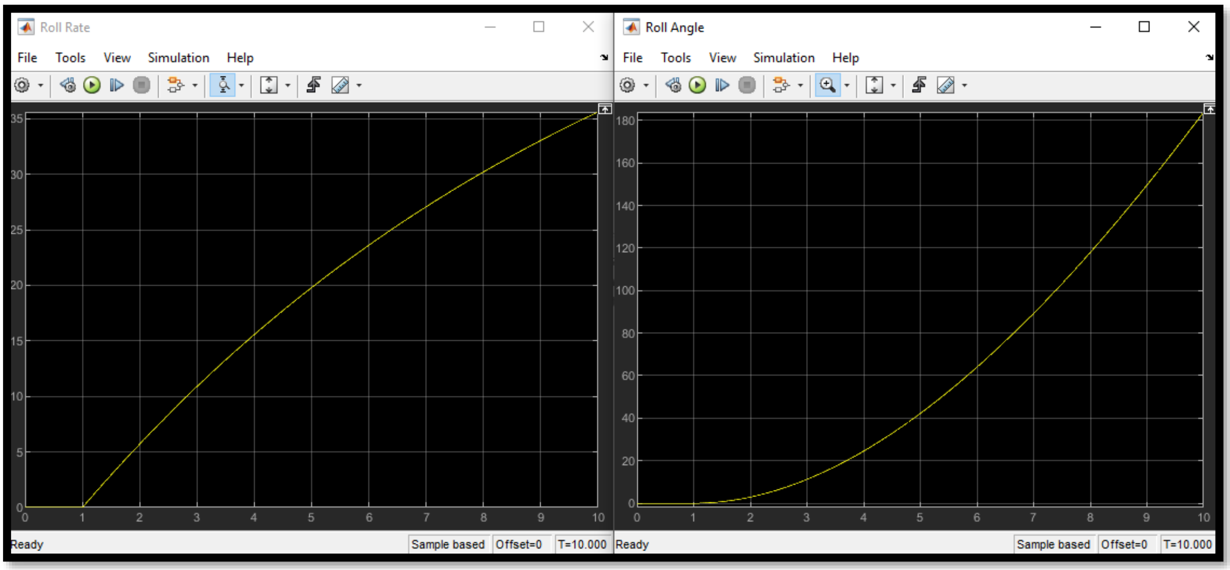




figure 1.4

When the Numerator (the top number) is increased, it influences the amplitude of the roll angle and the roll rate while the response time of the signals remain the same. This can be seen in the figures 1.1, where the amplitude is high when the Numerator is higher, and 1.2 where it is a lower amplitude when the value is lower.

If the response time was required to change by happening at a faster rate or a slower rate, then the bottom denominator would then be altered in this scenario. Increasing the denominator would cause a tighter response time while a smaller number would result in a much slower response time. This can be seen in figures 1.3, the faster response time, and 1.4, the slower response time.

## Part B

To calculate the poles for the closed loop, the gain, transfer function and the integrator must be multiplied as one formula. This can be seen below…

***K * TransferFunction * integrator***

***1 * 2/(s+4) * 1/s***

***1 * 2/(s+4)  =  2/(s+4)***

***2/(s+4) * 1/s = 2/s(s+4)***

Then after completing this step, the denominator is taken to give the equation…

***0 = s^2 + 4s***

So, the two values for s can be shown as…

***s = 0, -4***

***(-4±sqrt(16-8)) / 2***

***First pole = -2+sqrt(2) = -0.59***

***second pole = -2-sqrt(2) = -3.41***

Yellow = aileron angle

Blue = Roll rate

Red = roll angle

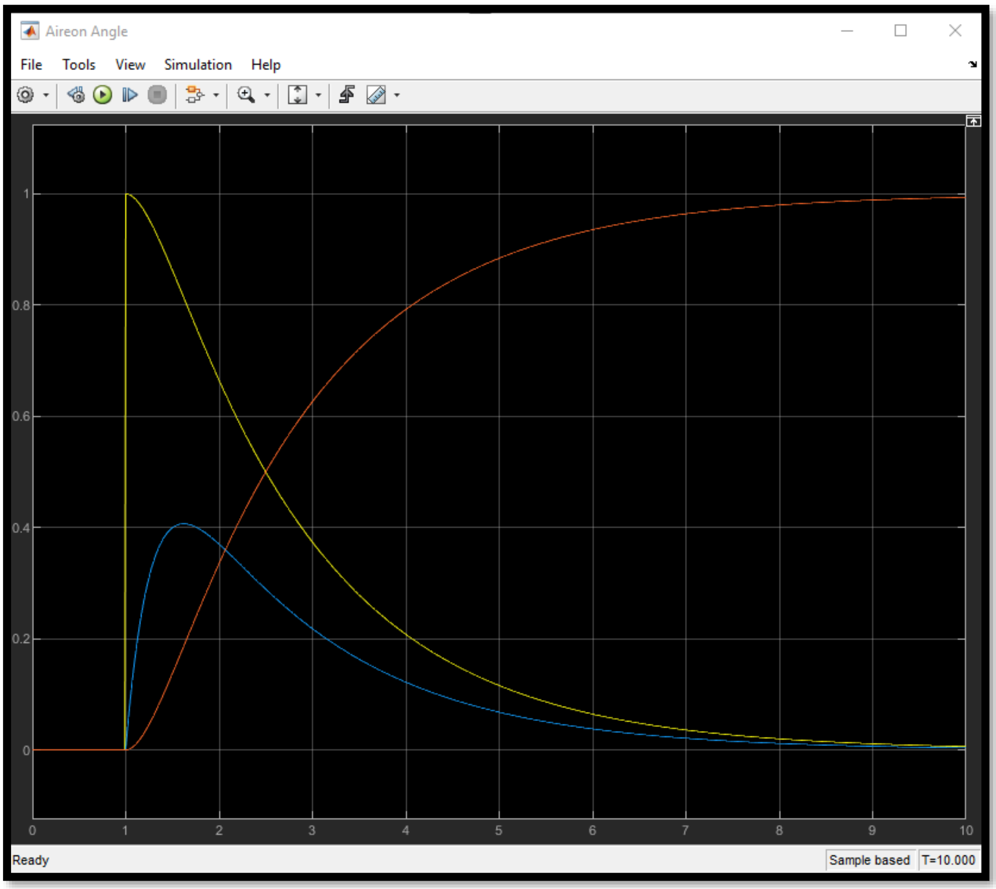


Figure 2.1 (Before PFCU)

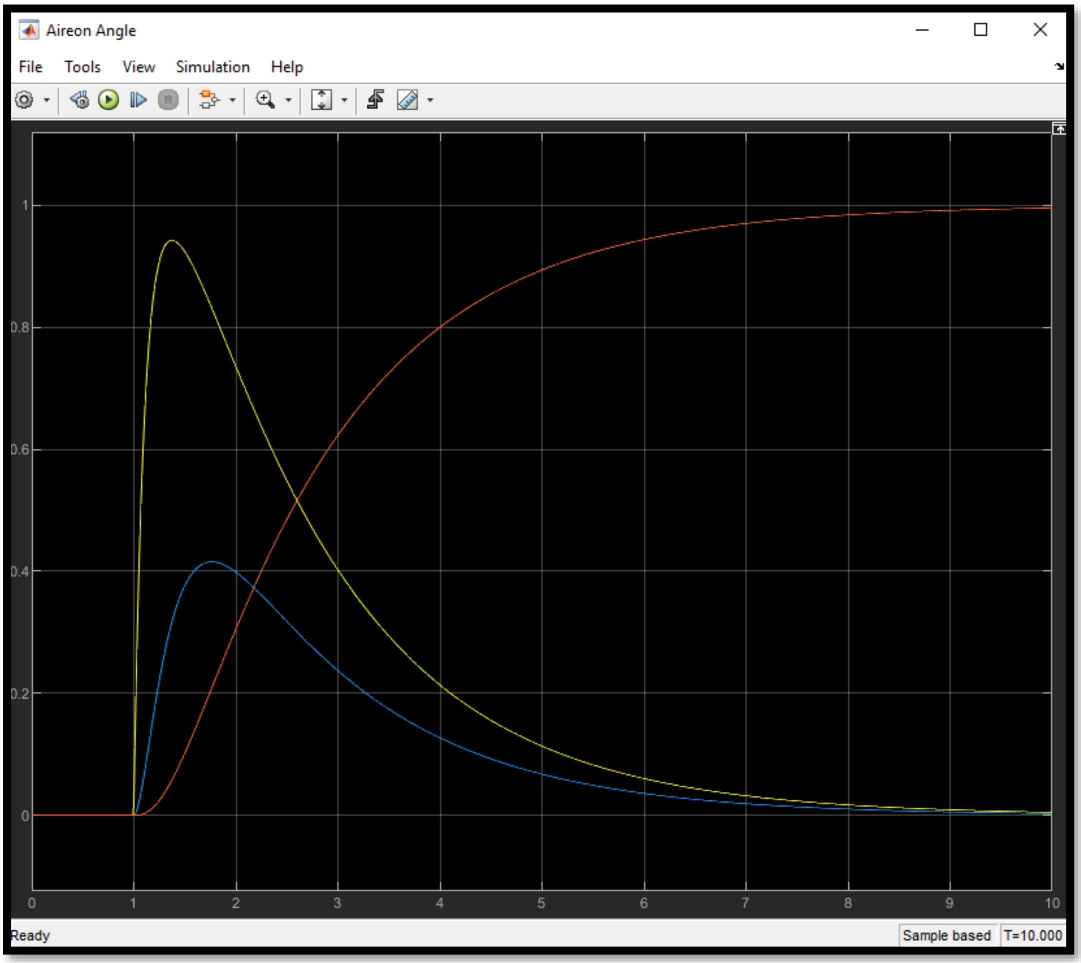



Figure 2.2 (after PFCU)

From here it can be seen that when a PFCU transfer function is added to the block diagram, the angle of the aileron, in yellow, is given a smoother, delayed time response with a slight decrease in speed to allow for a smoother roll turn.

The roll turn can be seen in red, and when 2.1 and 2.2 are compared to each other, it can be seen that the base start of the roll angle has a smoother turn transition when the PFCU was added. This will prevent any jerky motions that could be dangerous for the plane in future flights.

The section in blue is the roll rate of the aircraft, showing the speed at which, the aircraft can roll determined by the current angle of the aileron as shown in this graph. The PFCU also smooths the roll rate and increases its speed slightly also.

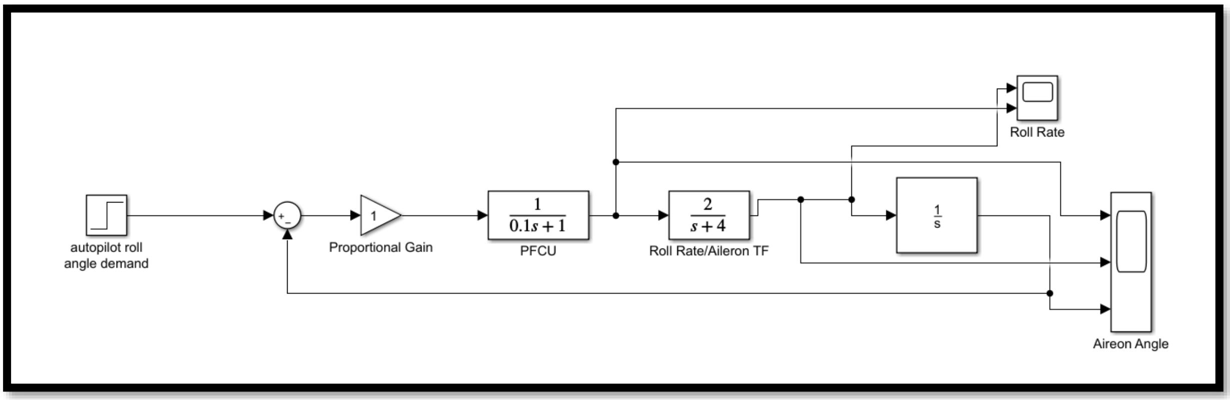



Figure 2.3

## Part C

This next step will show the Root Lucus method of finding the poles of a third or higher order system, showing its charactersistics on a graph.

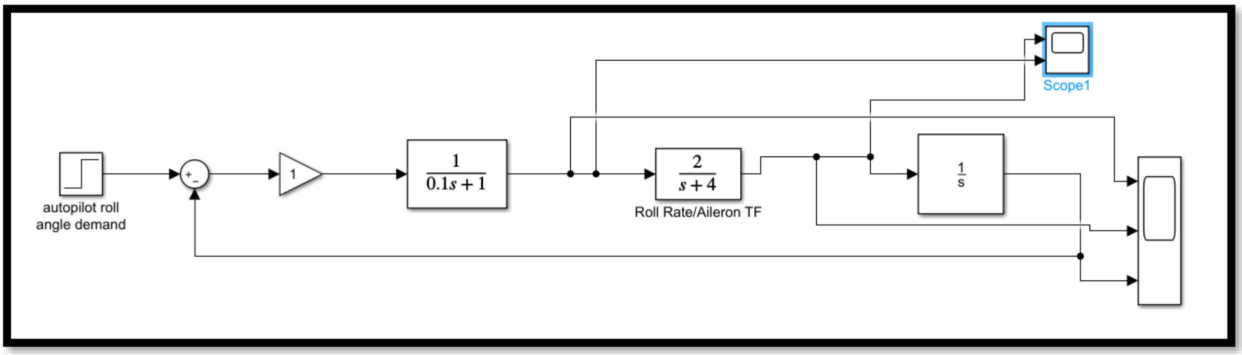



Figure 3.1

Using the same system as in part B, the Root locus graph can be made to show the characteristics of the system, where using the standard second order system method would be used to find the poles.

First was to go back into MATLAB and write down the coefficients for the variables 'num' and 'den'. Using the line…

***rlocus(num,den)***

… would bring up the graph shown in figure 3.2 and 3.3. Typing 'sgrid' would then draw the lines of constant natural frequency and the damping ratio would appear on the plotted graph. The command sgrid(zeta, 0) is then used to draw the required line of constant damping. Zeta = 0.7 in this example.

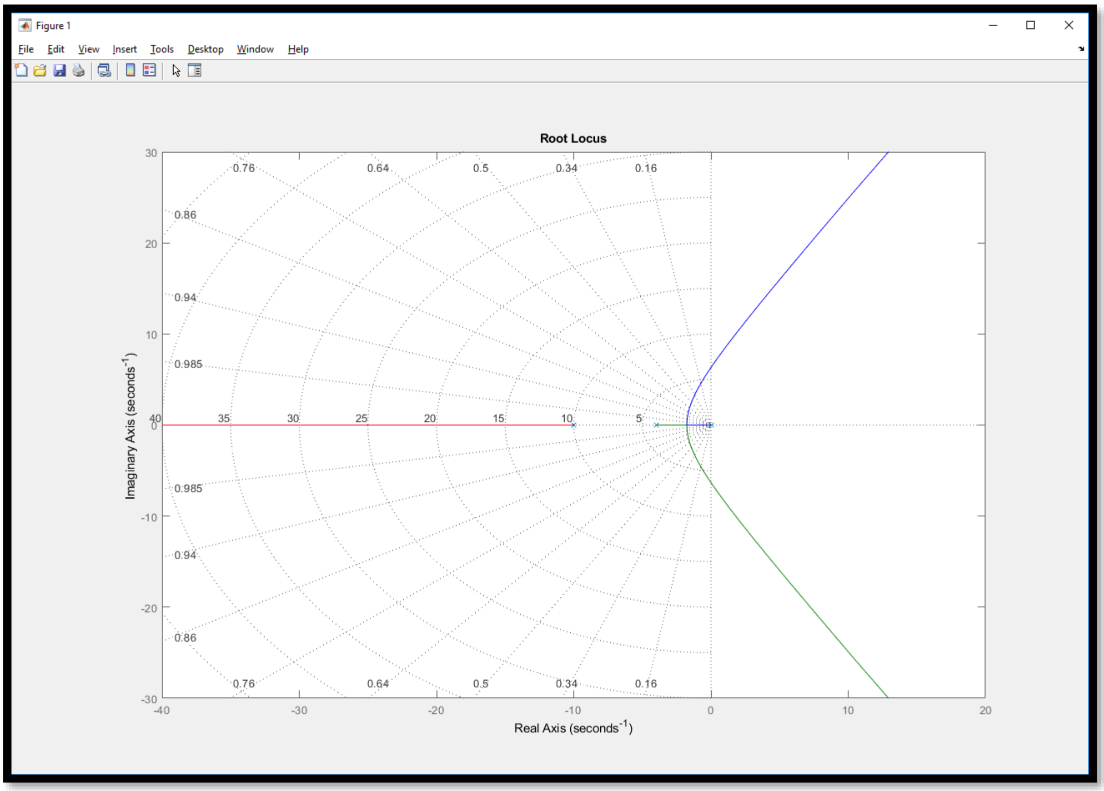



Figure 3.2

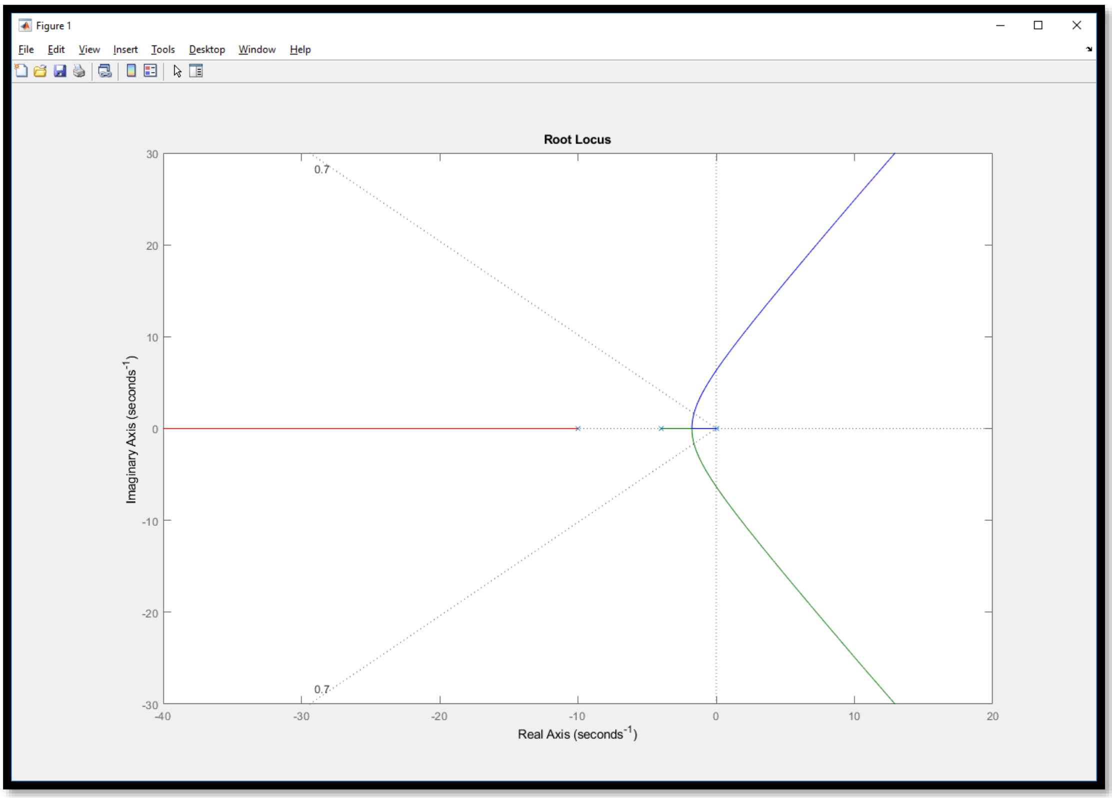



Figure 3.3

After this, entering the command…

***[K,poles] = rlocfind(num,den)***

… would then give the ability for the user to move the crosshairs to the point where the locus and line constant damping intersect and place the curser there. The values for K and the poles are then returned to the workspace, which can be shown in figure 3.4 below.

```
>> [K,poles]=rlocfind(num,den)
Select a point in the graphics window

selected_point =

  -1.6076 + 1.6308i


K =

    2.8342


poles =

 -10.7762 + 0.0000i
  -1.6119 + 1.6315i
  -1.6119 - 1.6315i

fx >>
```

Figure 3.4

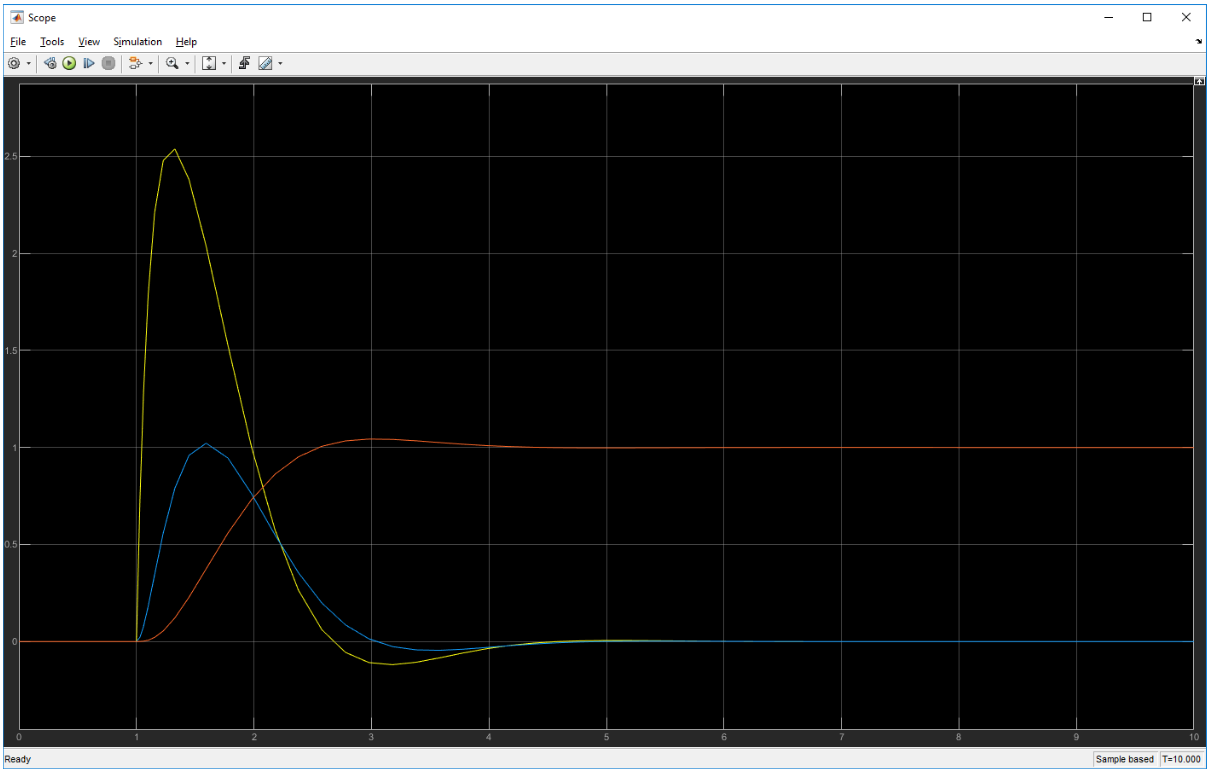



Figure 3.5

Gain of 2.8342 and red line is final value. A little overshoot.

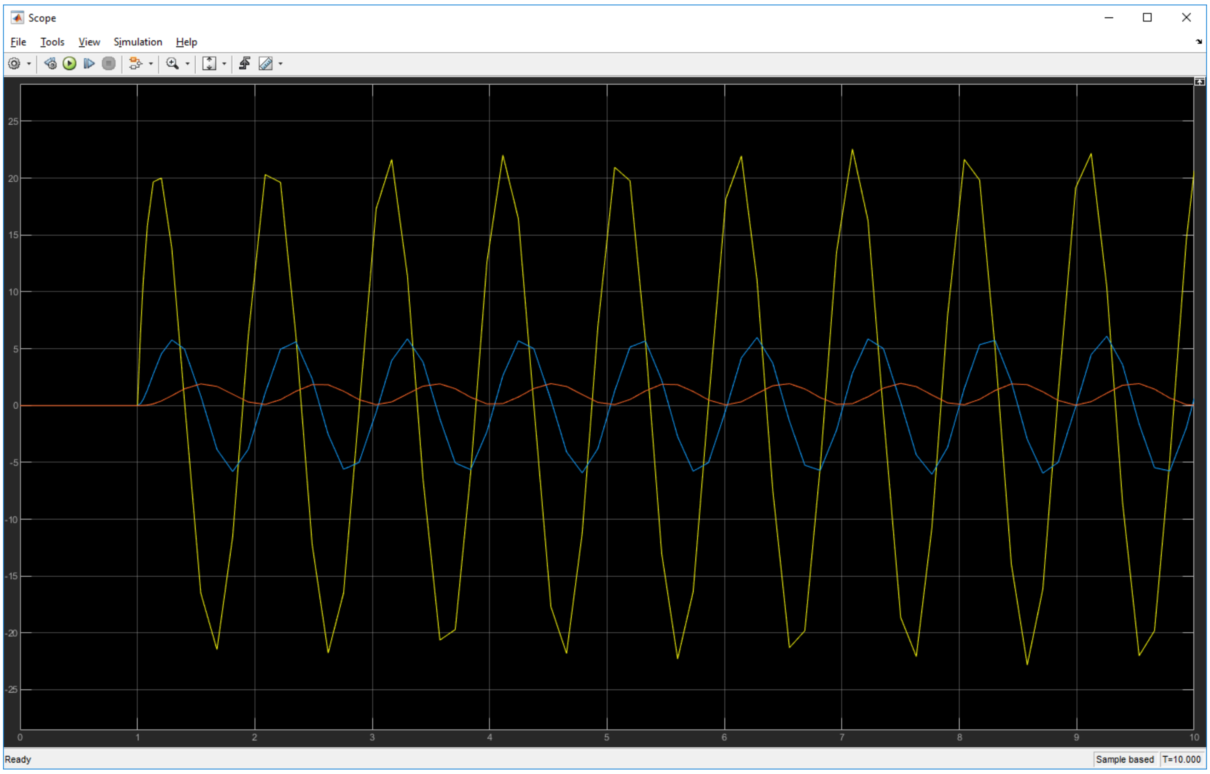



Figure 3.6

Gain of 28.1716 and red line is final value. Unstable system.

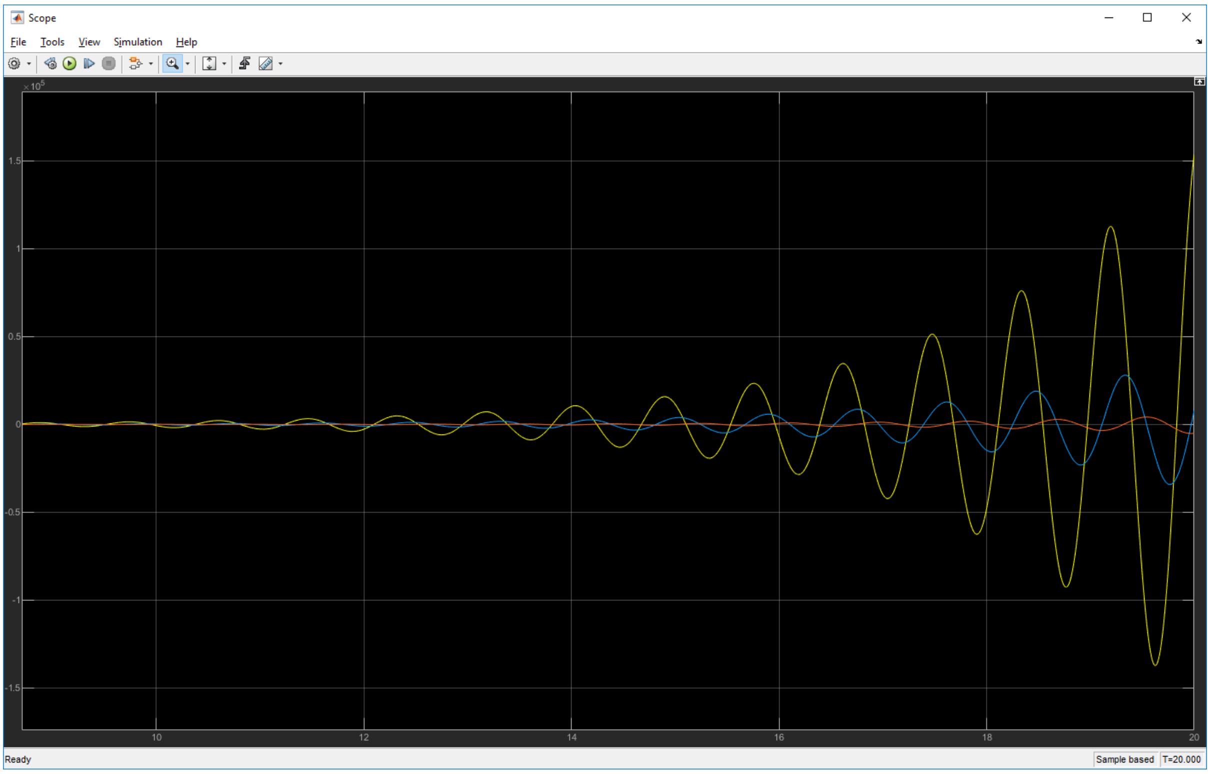



Figure 3.7

Gain of 40 and red line is the final value. Unstable system.

Comparing the results of the different values for K, it can be shown that a higher gain will cause the system to become unstable, destabilising over a period of time, becoming more uncontrollable. The severity of this cascade can be seen from figures 3.5 – 3.7, from the lowest gain to the highest. At the low gain of 2.8342 there would be a single pulse and would then stabilize at the value shown. There would be a little overshoot which would then be corrected by the system.

The gain of 28.1716 shows the system in a constant state of pulsating, the speed being consistent, but is still an unstable system due to the system not stabilizing.

The gain of 40 shows the worst scenario with the system stability getting worse and worse with every second. This would have caused the aircraft to roll uncontrollably, increasing its roll rate over time.

## Conclusion:

In conclusion, the characteristics of a control system can be altered when changing the numerator, denominator of a transfer function and gain of the overall system. The higher the gain, the more unstable the system would then end up, becoming more unstable over a period of time upon action. Increasing the value of leading coefficient in the denominator of the transfer function would have a similar effect to when the gain is set to a high value. However, instead of becoming more unstable over time, it becomes more stable, starting off as a large cascade and then reducing down to a stable level. This is only when that coefficient is at a high value, however.

By adding a second transfer function the system would then become a third order system, fine tuning the characteristic of the system to have a smoother output when the aileron angle changes.

It is also possible to use MATLAB can be used to calculate the poles of a third order system. however, it will not be 100% accurate as it requires the input of the user by having them click on the point where the user wants the software to calculate from.

## Referencing:


1. Grcnasagov, 2018. Grcnasagov/www/k-12/airplane/alrhtml. [Online].[15 April 2020]. Available from: https://www.grc.nasa.gov/www/k-12/airplane/alr.html
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