Advanced Aircraft Control Systems With MATLAB / Simulink

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Lecture 25

Stability Augmentation for lateral-directional dynamics

Hello everyone, this is a very important lecture. So, here we are starting the lateral stability augmentation system. First, we will start with the open-loop system behavior, how the system is going to respond without any control. Then we will use the state feedback control concept, which we have done before. Then we have the control authority, how we can come up with G, which we discussed in the last lecture, in the control authority concept, how we can come up with the closed-loop system response for multi-input controls.

So, first, let me discuss the problem that we are going to address. This is very, very important; here, I am going to do a lot of stuff. We will look at the system from the beginning, how we will go step by step to design the control. And the natural stability, the natural state space, state space equations are defined as So, we are going to consider the full lateral dynamics

$$\begin{bmatrix}\Delta\dot{\beta}\\ \Delta\dot{p}\\ \Delta\dot{r}\\ \Delta\dot{\phi}\end{bmatrix} = \begin{bmatrix}-0.05 & -0.003 & -0.98 & 0.2\\ -1 & -0.75 & 1 & 0\\ 0.3 & -0.3 & -0.15 & 0\\ 0 & 1 & 0 & 0\end{bmatrix}\begin{bmatrix}\Delta\beta\\ \Delta p\\ \Delta r\\ \Delta\phi\end{bmatrix} + \begin{bmatrix}0 & 0\\ 1.7 & -0.2\\ 0.3 & -0.6\\ 0 & 0\end{bmatrix}\begin{bmatrix}\Delta\delta_a\\ \Delta\delta_r\end{bmatrix}$$

So, this matrix varies for different flight regimes and different aircraft. So, this can be for the particular aircraft. And here the question is this: this aircraft is found to have poor handling qualities. Why these poor handling qualities? We will discuss this. Qualities in lateral directional lines. Design a stability augmentation system such that the desired eigenvalues for lateral characteristic damping ratio for roll is

$$s_{roll} = -5.5$$

this is roll mode, ok. This should be the eigenvalues. And a spiral, as you know, for the lateral direction of motion, we are having three different approximations: roll, spiral, and dutch roll. These things we have already discussed in our first course, Introduction to Aircraft Control System. A spiral,

$$s_{spiral} = 0.05$$

This is also called spiral mode.

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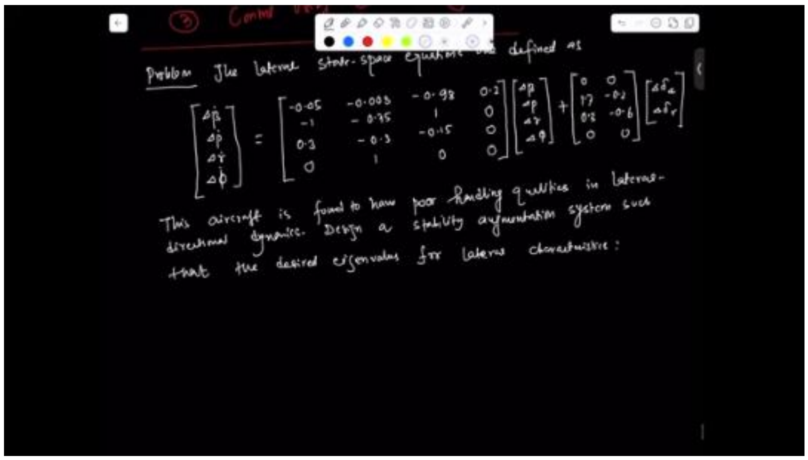

And this dutch roll is

$$s_{DR} = -0.35 \pm 1.5i$$

This is called dutch roll mode. So, based on the roots, we can define the different modes. So we have to design the control stability augmentation system for this particular aircraft. First, we have to check whether the overall system is controllable or not. So, for that, we can in the MATLAB command, we can find the P matrix.

$$P = ctrb(A, B);$$

$$r = rank(P);$$

$$r = 4$$

R is found to be 4, means the system is controllable. So, we can control all the states in the system; all states are affected by controlling it. Now, we will find the open-loop poles of this system, whether the system is stable or not. So, for that, we can use the system stability as we write; system stability we can say. For this, we have to use the command

$$[\omega_n \quad zeta \quad poles] = damp(A)$$

$$\omega_n = [0.98 \quad 0.88 \quad 0.88 \quad 0.03] \, rad/s$$

$$zeta = [1 \quad 0.004 \quad 0.004 \quad -1]$$

$$poles = [-0.98211 \quad -0.0035 \pm 0.88i \quad 0.039]$$

Pole in the right-hand side, and this causes the system to be unstable.

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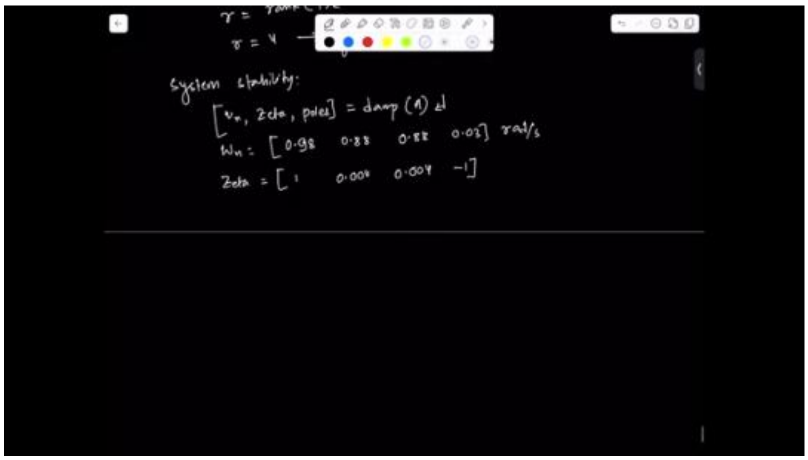

In other words, you can say the lateral handling quality is poor. So, you can write for this condition the lateral handling. Is 4, and the system is unstable, right? So now, we can, we have, if you notice in the last few lectures, we are talking about unstable system, unstable, so let's look at the response with this open-loop system. If there is no control in the system, how we can study the system characteristic over time. So, here we have the plot for this.

So, if you notice in this, this is the MATLAB code. So, here you can see that the system is unstable. So, it is, though it is bounded, but it is actually oscillating; the system response is oscillating over time, it is not fixed to some value, it is not stable. So, we can say here, one thing I have to say also here.

So, here the initial conditions are very important; these are the initial conditions we assume: 0, 0, 0, 0, 0, 1, and are in radians, right? So, here the system is unstable because one of the poles of the system is found to be on the right-hand side. Now we will design the control and we will see how this response goes to 0 over time. The initial conditions will be assumed to be the same, and how the control is going to

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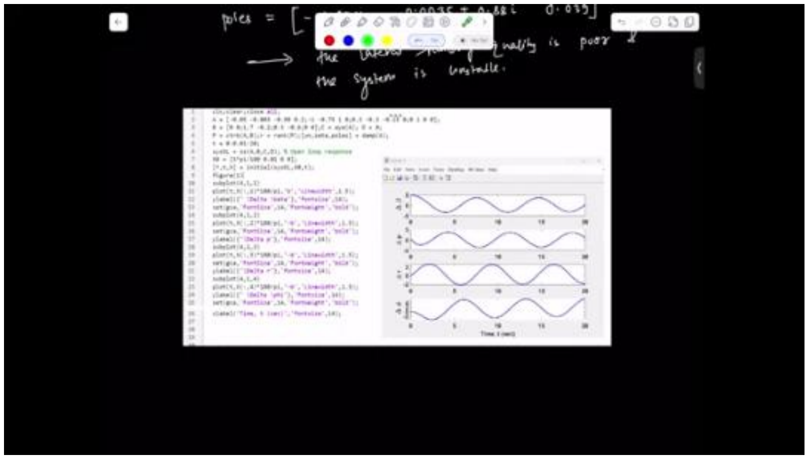

mitigate these oscillations over time. So, for that, we have to design the control. So, let us find the control gain matrix. So, already we have the poles of the system. So, these are the poles that have been given in the problem. So, here we can form we can write here control design control design it will help us to mitigate these oscillations these oscillations so now we have the desired poles given in the problem so from that we can form the v matrix of the vector

$$V = [-5.5 \quad 0.05 \quad -0.35 + 1.5i \quad -0.35 - 1.5i]$$

so this is the desired poles so now we can use the place command to find the control gain parameters

$$K_{place} = place(A, B, V);$$

$$K_{place} = \begin{bmatrix} 0.22 & 3 & 0.29 & -0.12 \\ 3.55 & 2 & -0.68 & 0.03 \end{bmatrix}$$

now from this we can find the closed loop matrix or the augmented matrix control matrix. So, the augmented or you can say controlled matrix you can say

$$A_{CL} = A - BK$$

acl equal to a minus bk. So, here we can use the command So, here actually I am not going to discuss on this because the MATLAB code simply. So, the MATLAB code of the flow slope system it can found to be the code is given on things written here. So, here is the response. So, come to the next page. So, here the state by state given this is the And this is the system state space form, and if you write the initial command, it will give you the values of the states, and if you plot, this is our response. Now, if you, so whatever things we have done here, this is in the code, and plotting the response of the system, they are the same function we use here.

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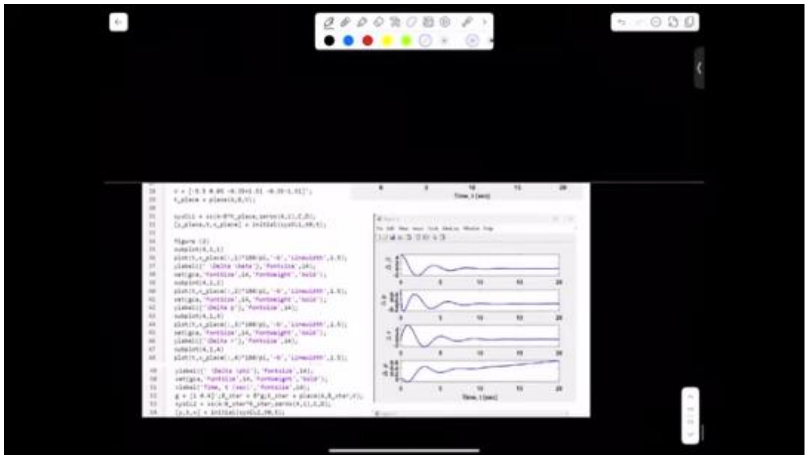

Here, if you notice carefully, $\Delta\beta$, Δp over time goes unstable. The oscillations are nice and go to the stable condition. But the problem is $\Delta\phi$ if you notice carefully, though in 15-20 seconds it was bounded, but if you plot for a longer time, it is actually increasing. Increasing, so it means this is basically the handling quality for the held up by not both, so here we can use the control authority methods what you have done in the last lecture, so this method will be using, so this part we have done, so now we are going to do what we have done in the last lecture. Now, the control authority design concept which helps us to control this parameter state. So, here we are defining, let us define, let us define, you can try, this code you can try in your MATLAB command. And I request you, please do it so that you can understand how you can write the code. This is nothing but the autopilot, we have designed the autopilot for the system, right. So, let us define control authority as this

$$\delta_a = 2.5\delta_r$$

$$\frac{\delta_r}{\delta_a} = 0.4$$

$$g_1 = 1, \quad g_2 = \frac{\delta_r}{\delta_a}$$

$$G = [1 \quad 0.4]'$$

$$B^* = B * G;$$

$$K_{star} = place(A, B_{star}, V)$$

$$K_{star} = [13 \quad 3.6 \quad -11.5 \quad -0.27]$$

So, here actually it is not a matrix, no more it is a vector instead of that. You can use the same command, you can find

$$sysCL2 = ss(A - B_{star} * K_{star}, zero(4,1), C, D)$$

$$[y, t, x] = initial(sysCL2, x_0, t)$$

and we need to have the initial condition same initial condition we are assuming. and we will have a list of data, and this is the data, and you can plot them, right. So, the response is found to be this is the response, the response of the system. So, if you notice carefully here, you can see that now the problem what you had in the previous case now it is stable, it is going to 0 over time.

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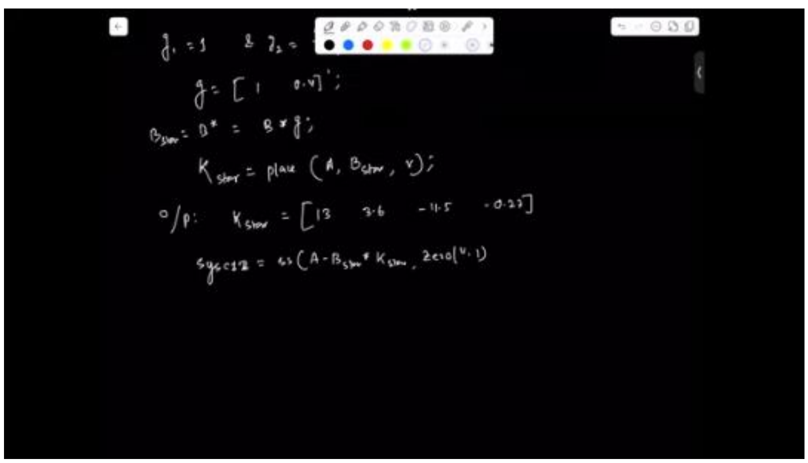

At 20 seconds, all states are converged to 0. So, now the system is controlled. So, using this control authority concept, we are now able to get our desired response. So, this example is very, very important. So, in this example, we studied how to analyze the open-loop system.

And also, if you want to design to mitigate the oscillation in the response, we will introduce the state feedback control. We also found that one of the states was not going to 0; it was increasing over time in magnitude. If you use the control authority function, what you have done here, using that, we can achieve our desired goal. So now, this is how we can design and improve the handling qualities of the aircraft system. So, it fulfills our objectives. I hope these codes are very important for you, as we need them for different cases.

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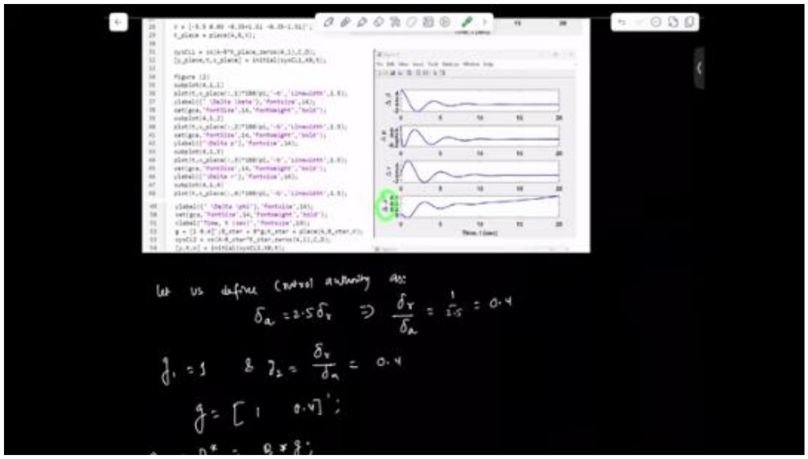

This is for the open loop; there is no control, so that's why the system is And here, we have designed the control, but one of the states was not controlled. Then, we applied the control authority concept, and based on that, the redefined control algorithm was able to improve the handling qualities of the system. So, let us stop here. This is the last, One more lecture on how to design the altitude hold controls of the aircraft, and after that, we will move to the non-linear control concept.

Let us stop here. Thank you.