Advanced Aircraft Control Systems With MATLAB / Simulink

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Lecture 59

Recap and Conclusion

Hello everyone, we are almost end of the course and this is the last lecture in this course. We are going to brief what we have done in this course from the linear part and non-linear part. We have started the first half of this course with the linear control synthesis or the modern control part or the state-space-based control and we have designed all the control techniques for this six-dof equation of motion of the aircraft and this six dof equation we have divided into two parts one part is the longitudinal motion dynamics and another part is the lateral and directional motion so longitudinal motion actually how the motion along the this axis okay and your lateral directional motion actually this and along y axis g axis so if you notice carefully these two equation sets are highly non-linear because there are coupling terms sine theta cos theta terms so to study the linear controls for the system we need to linearize this two set of equations

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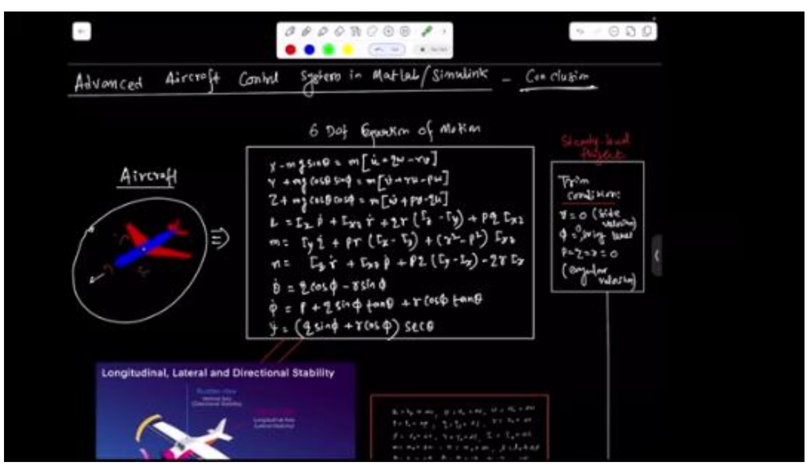

for linearization we need to have the some reference point around which the system can be linearized right that is already you have covered in this course so the linearized model or the trim conditions we can say trim condition around which the system can be linearized uh we have considered the steady level flight and for the steady level flight we have considered these are the condition for trim values stream values these are the different state values. So, side velocity assumed to be zero and phi is zero, winning level is zero basically and the rates of the body assumed to be zero. So, this is the condition for the steady level flight and this nonlinear equation also includes the perturbations or the external disturbances into the system And due to these external perturbations or disturbances, the states, different states in this equation are going to be affected.

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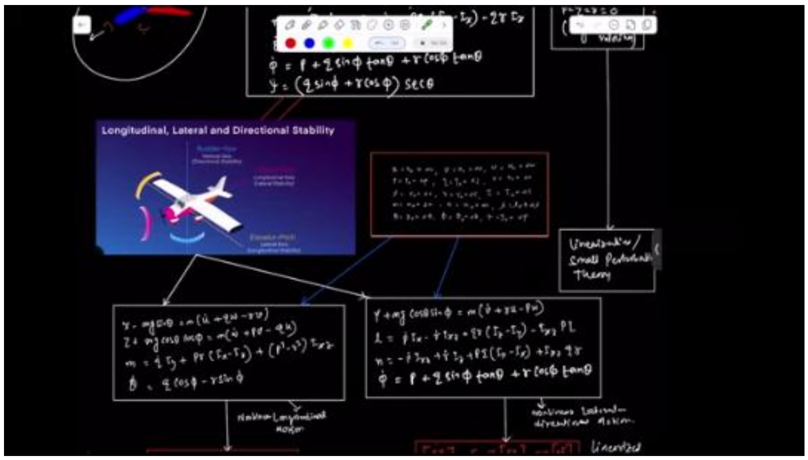

So, in the presence of these external perturbations, your systems gets deflected from these trim values, right? This is the ideal condition system should follow. But in the presence of these perturbations, in practically, the system is difficult to maintain the trim values. So what you have done is we have used the small perturbation theory. So in the presence of the external perturbations or disturbance, the system states are affected and they shifted from the ideal values to some delta value. So in this equation, the different states we have used to define the dynamics, The defined states are affected in the presence of the perturbations of the system. So once you include these perturbations in the original dynamics, then we can come up with the perturbed system. And once you have the perturbed system, we can use the Taylor series expansion to linearize the system. The whole stuff we have done in the first course.

Aircraft control system we have already detailed, so if you want, you can refer to the first course on aircraft control system. So if you use the small perturbation theory or the Taylor series expansion to this equation, we can get the linearized model of the individual systems. So, these are the linearized systems of the longitudinal motion, and this is the linear system of the lateral-directional motion. And these equations, these two equations, are in state-space form. So, in the longitudinal motion, these are the state variables, and these are the controls: elevator and forward thrust. And for the lateral-directional motion, we have the aileron control and rudder control. And these are the state variables which are involved in the lateral-directional motion. And if you write in compact form, we can write in state-space form like this. This is the standard way you can define the state-space equation of the system. Now, we can study the control for these two different systems separately. So if you are going to study the longitudinal motion of the aircraft, first we can study the system, how the system is stable or not. And based on that, we can design the control. Similarly, for the lateral directional motion, we can analyze the system based on the eigenvalues. Of a matrix, and based on the eigenvalues, we can comment on whether the system is stable or not. Based on that, we can design the control. Then we started the control design in this course. So, for example, this is our linear motion—it can be lateral directional or longitudinal motion. So what you have obtained from these two stages, and based on this linear system, we can study the open-loop analysis. In the open-loop analysis, what you have done is we first started by transforming the system into a different form, which is basically the canonical form. We have explained in this course how we can get the canonical form, and this canonical form can be obtained through linear transformation, which we have discussed in detail. Before designing the controller—this control algorithm for these systems—we need to check whether the system is controllable or not. This controllability test can be done by checking the rank of the A and B matrices. If the rank is full, then the system is controllable, meaning all states are affected by the control inputs. If the rank is deficient, then the system is not controllable, right? Then, we can also study the stability of the system. This means we can check the eigenvalues of the system matrix and conclude whether the system is stable or not. These are part of the open-loop analysis—how we can study the system before designing the control. Now, once the system is converted into canonical form, we can design the controller.

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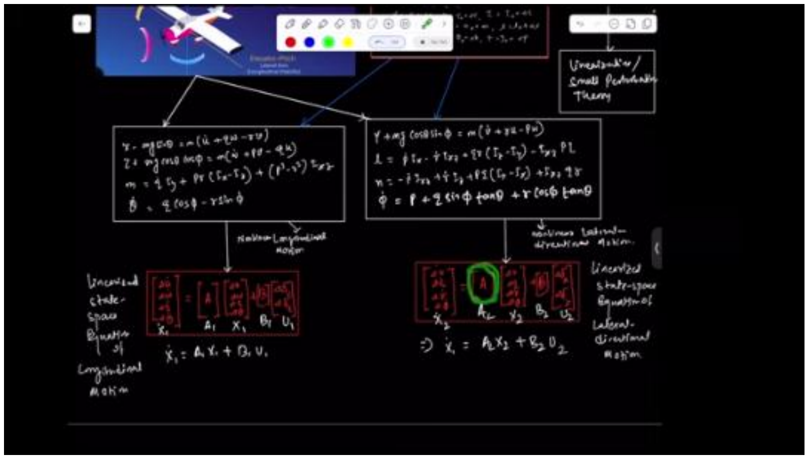

So, in this course, we have studied state feedback control—how we can design state feedback control based on the desired dynamics. Under that, we have studied the Ackermann formula for designing control, and we have also used optimal control to design the control. Here, we have used some cost function that needs to be minimized so that the system can reach the desired state. We also studied observer design—how we can design an observer for the system. In the observer, we have used the Luenberger observer. For designing the observer, there is another test called the observability test. In that case, we have to check the observability of A and C. Based on that, we can design the observer. If the rank of the observability matrix (A, C) is full, the system is observable. If it is not full rank, then the system is not observable, right? So, these are the things we have covered in this course—how we can design modern control for this linear system. We have given a lot of examples and MATLAB code. If you want to design these control techniques for your own system, you can follow the same steps. If you are considering a nonlinear system—any nonlinear system—you have to go through all these steps, come up with the linear model, and then design the control. So, these are part of the state-space-based controller that we have covered in the first part of this course. Then, we move to nonlinear control techniques. In nonlinear control techniques, we have taken the original system—the original nonlinear longitudinal and lateral motion.

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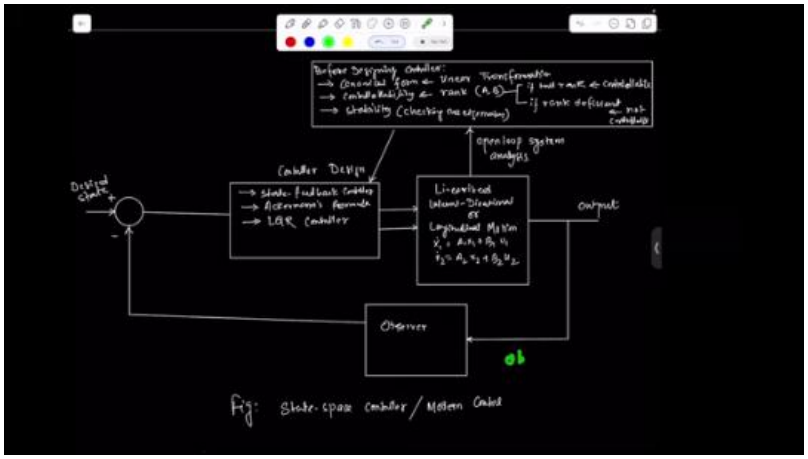

And here, to study the system, we have used these tools. First, we found the equilibrium point. Then, we studied how the system behaves based on the equilibrium point, and we performed stability analysis. We also used the phase portrait method, where we can check whether the system is stable or not. Additionally, we used the energy function—basically, the Lyapunov method. We generally use the total energy of the system, and over time, we observe how the energy of the system changes. If it is increasing, the system is unstable; if the energy is decreasing, the system is stable. These are the open-loop system analysis tools we have used to study the nonlinear system before moving to the controller part. Then, we studied different control techniques for this nonlinear system. These are the nonlinear control techniques we have considered for designing control for this nonlinear system. Here, we have used different control techniques like Lyapunov-based control.

And feedback linearization-based control and backstepping control. Backstepping basically involves the system if it is recursive in how we can design the control. In feedback linearization, it's about how we can convert the nonlinear system into a linear form, and you can design the linear control to come up with the overall nonlinear control for the nonlinear system. And Lyapunov-based control basically considers the energy of the system, and based on that, we can come up with the control algorithm in such a way that the energy of the system will be minimized—the total energy of the system. In sliding mode control, we choose a stable sliding surface, and our main aim is to design a controller that can force the system to follow the sliding surface. The sliding surface is generally considered a stable sliding surface. We also combine backstepping and sliding mode control to achieve better robustness of the system. Additionally, we have explained how to design adaptive control. Adaptive control is used when the system has time-varying parameters that can deviate the nonlinear system from the equilibrium point. And how we can derive the adaptive laws to determine the adaptive control gains. Based on these adaptive control gains, we can design the controller even if there is a time-varying function in the system. So, this is how we can—these are the topics we have covered in this course, and I hope this course will give you a lot of impetus to design your own controls. For the system you are considering, the MATLAB code provided in this course will help a lot in generating simulation results for your own system. If you have any questions or doubts, you can reach us anytime, and we'll be happy to provide your credits.

And this is what we have covered in this course. Let's wind up here. Keep in touch—we'll be happy to answer your queries. Thank you.

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