Introduction to Aircraft Control System

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Week – 01

Lecture – 01

Hello, everyone. This is the first lecture in this course, aircraft control system. We will start with a brief introduction of the course, how we will be moving from nonlinear system to linear system, and how we can design linear control synthesis for a nonlinear system. Then we will move to the brief outline of the course, what are the different contents we will be covering in this course, followed by the list of some strict references. Then we will conclude the lecture, why the control system plays an important role for control applications. In this lecture, we will be learning how the control system plays an important role of an aircraft, which provides safety, stability, and controllability.

So the aircraft control system plays an important role which provides safety, stability, and controllability. Before we proceed to the main content of this course, I would like to highlight how we will be moving on in this course. Suppose we have a nonlinear system, any nonlinear system. Why a nonlinear system? Because most of the practical systems around us are nonlinear in nature.

Let's assume this nonlinear system, our aircraft system. And also in this course, since we will be dealing with linear control techniques, and linear control means we have to design the control algorithm for the linear system. And from the nonlinear system to linear system, we need to use some kind of technique, which is called linearization. But through linearization, we can come up with a linear model of this nonlinear system. We will be learning how this linearization takes place, how we can convert the nonlinear system to a linear system, we will be going through extensively in the subsequent lectures.

Now, based on the linear system, we will be going through some stability analysis. So first we will go to the concept of statically stability. First we will check if the system is statically stable or not. So what is statically stable? Let me define it. The tendency of the system to move back towards equilibrium point.

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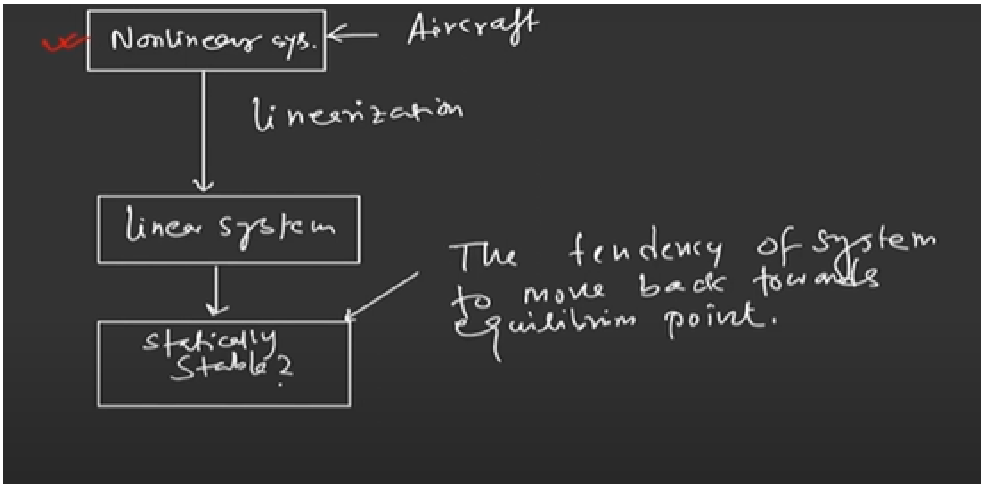

So equilibrium point is a point where total force and moments are balanced. So all systems want to stay in the equilibrium point. And how to find equilibrium point, this is also we will be covering in this course from the nonlinear system, how we can come up with the equilibrium points of the system, and how we can linearize this nonlinear system about the equilibrium point. So now, if the system is statically stable, so there are two conditions we have to check, whether the system is statically stable or not. If it is yes, then again we have to do another stability analysis, which is called dynamically stable or not.

So if the system is statically stable, the system may be dynamically stable or not. The dynamic stability basically talks about the time history of the system, how the system evolves over time. Let me define it. The tendency of the system to eventually return to its equilibrium.

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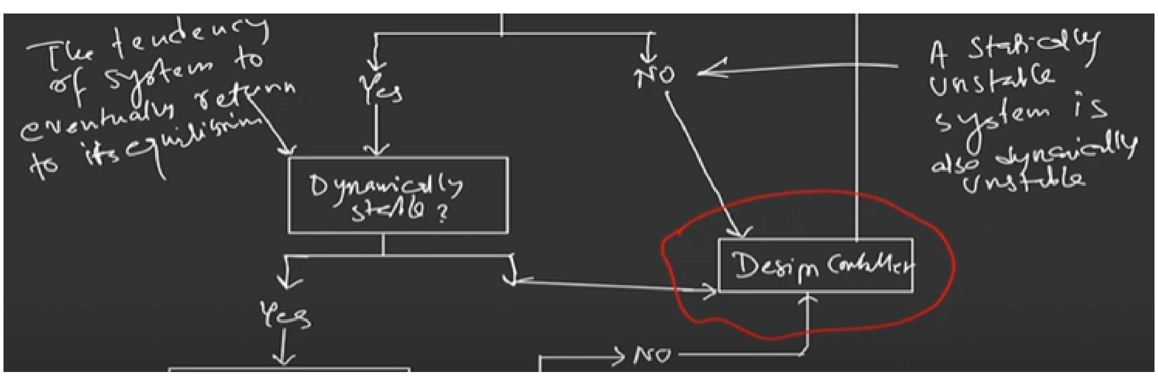

Under this, again, we need to go through two conditions, whether the system is dynamically stable or not. So if the system is dynamically stable, let me write it. If the system is dynamically stable, if it is yes, then again we have to check whether the system satisfies the stability margins. It means the mission objective, whatever the mission we are having, whether it is satisfying or not. So we have to go to another condition, more stability margin. If it satisfies the stability margin, then for example, the system is satisfying the stability margin.

If it is yes, then no need to design the control. Because the system is dynamically stable, also it is satisfying the stability margins of the system. If it is not satisfying the stability margin, if it is no, then we have to design some kind of algorithm which will modify the stability margin. And we will modify also, I mean, the system will be stabilized.

So, controller design. We have to design a controller, which will help us to fulfill our mission objective. Now, if it is through the controller, if it is found that the system is stable, then again, we have to go through this. So we are dealing with the linear system, we have designed the controller for the linear system. And if it is not dynamically stable, then we have to design control also.

Also, you have to design control. Now, the thing is, so based on the dynamic stability of the system, we need to design the controller for our linear system. And if the, now let's go back to the again statically stability part. If it comes out to be that my system is not statically stable, it means the statically unstable system is also dynamically unstable. So, in this case, again, we have to design controller.

So, again, we have to design controller. So, controller here plays a pivotal role. This controller plays an important role for making the system stable. So, that's why control system or aircraft system or any other dynamical system is very important part, integral part for fulfilling our mission objective. So, that's why we need to design control system or autopilot for our aircraft system, which will help us to fulfill our mission objective in terms of translation motion and rotational motion of the aircraft.

So, now we will be based on this motivation, what are the contents we'll be covering in this course. Let me define. First two lectures, we will be devoting the importance of the control system in aerospace. Importance of control system for aircraft systems. Factors that modify the transient behavior and effect of disturbance in the dynamical system.

In this lecture, we'll be covering around 8 to 10 lectures, how we can convert the nonlinear system to linear system and how we can check the system is linear or not.

Also, we'll be talking about LTI system linear time invariant system, because in this course for designing control algorithms, we'll be considering linear time invariant system. And also, how we can come up with the transfer function and the relation between the transfer function and state space model. So, all these topics we'll be covering in this two parts. And then we'll move to autopilot design for attitude control of an aircraft.

So, attitude means orientation control. How can control the attitude of an aircraft using classical controls mainly PID control or PD proportional derivative integral control. So, some classical control technique you'll be using. And also, we'll be coming up how we can come up with the gain tuning of the controller, which will fulfill the objective, mission objective of the system. So, all this topic we'll be covering in this part.

Then we'll move to design of classical controls to aircraft autopilot design. So, here we'll be considering the concept of root locus to find the gains of the system. That is also very important part for finding the optimal gains in the system, which will help us to modify the transient response of a system. Then we'll move to application of linearization technique for the aircraft equation of motion.

So, here we'll be spending maybe around more than 10 lectures, how we can come up with the linear model of 6DOF equations of an aircraft. So, here mostly we'll be covering the lateral and longitudinal motion of the aircraft. And how we can come up with the linear model of the system, linear transfer function, basically linear equation of motion of the system. Once we have the linear model of the different motions in lateral and longitudinal motions, we'll be again moved to the control design. So, application of classical control to the lateral and longitudinal motions.

So, here actually we'll be considering the linear model of the system to apply the classical controls because linear controls are designed for the linear systems. Then we'll shift our motivation to design the modern controls, model control techniques for the aircraft autopilot design. So, here basically we'll be considering the state space model of the system because once you'll see that longitudinal equation of motion and lateral motion are basically, we'll come up with the state space problem and how we can design control algorithm for these state space models. So, we'll be covering this part in this modern control technique. So, this is how we'll be moving within this course.

Now, I'd like to mention few references which you can follow. This is the first reference and it is very important because in this, let me define the, write the book, Tewari, modern control design with MATLAB and Simulink. This book written by Professor Ashish Tewari from our department in IIT Kanpur Aerospace Department. So, in this book, we can come up with how we can design the autopilot for different motions, lateral motion, longitudinal motion, and also modern control techniques also it is extensively discussed. Second reference, Ogata, K, modern control engineering.

This book is also very important for understanding the basics of control system. In this book, there are lots of contents on how to design classical controls for a linear system and how we can come up with the linear model of our non-linear system. So, it is extensively discussed in this book. And third reference, flight dynamics and control of aero and space vehicles. In this book, there is a connection how we can design the classical control system for flight vehicles.

Here also a lot of, I mean, control techniques have been discussed in this book. This book also you can refer. Another book, this book is actually specially designed for spacecraft system, but the techniques discussed for the spacecraft, the same technique can be also used for aircraft system. This is spacecraft dynamics and control. This is a very good book, I should say.

So, these four references can help you to understand this course. If you want to know more about this course, you can follow this book. Now, let's start with some basics on control system, why it is important to design control system for a non-linear system. So, let's start with what is control system. What is control system? A control system is defined as a control system that is defined as systems of devices that manages commands, directs or regulates the behavior of other devices or system who achieve a desired result.

So, it is basically a device which regulates the other devices to fulfill the objective. Now, also you can define in another way, starting with the way of control system involves developing a mathematical model for each component of the control system. Thus, here the system is a set of self-contained processes under study. A control system consists of the system to be controlled called plant. As well as the system which controls over the plant called controller.

So, if I look through block diagram, suppose this is the controller, it will control another system or another device which we call plant. So, controller is the device which controls other system or plant. Now, let me go through some mathematical way how we can define the control system, why it is important. So, let's define or let's consider a system which is written in mathematical form.

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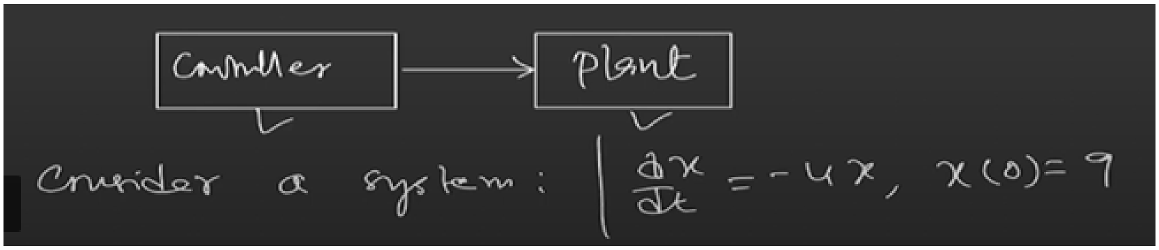

Let's assume $\frac{dx}{dt} = -4x$ and we have initial condition for example 9. So, here we have some natural system and also we are given the initial conditions. The solution of this above system, the solution of the above system we can write $x(t) = x(0)\,e^{-4t}$ So, $9\,e^{-4t}$.

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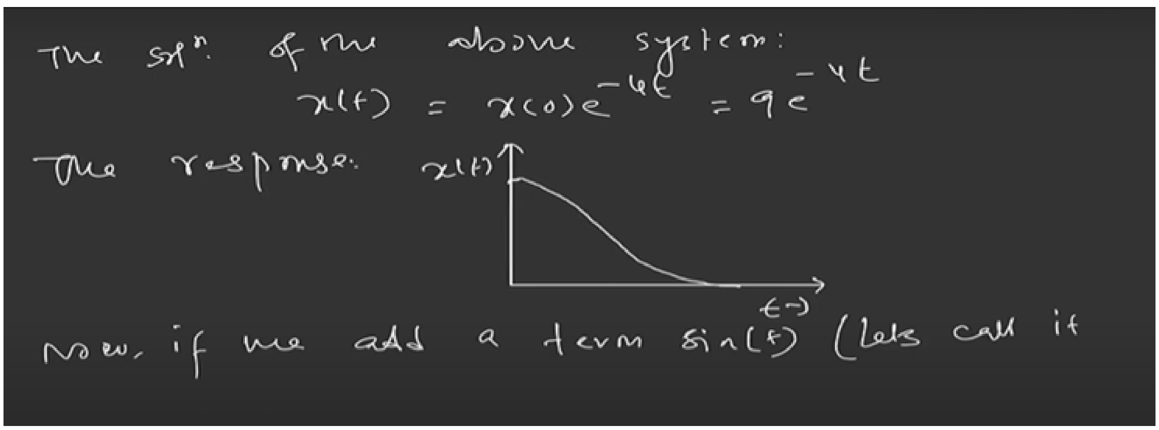

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So, $9\,e^{-4t}$. And if you see the response of the system with respect to time, the response of the system, this is $x\,(t)$, it is t axis, it will start from 9 and eventually it will decay into zero as time tends to infinity. So, system is exponential stable of course. Now, if we if you want to modify the response, for example, we don't want this kind of response, we need to some different objective, need to have different objective and how we'll achieve it. So, now if you know, if we add a term $sin\,(t)$, for example, and let's call it, it is a forcing term, let's call it. So, this $sin\,(t)$, let's assume it is, this is my plant, this is the plant, this is basically $\frac{dx}{dt} = -4x$.

Now, we want to add some term, let's assume $u\,(t)$, which is given by the controller, let's assume. And let's consider this $u\,(t)$ is $sin\,(t)$, for example, let's call it forcing term. So, in this case, our equation will be

$$\dot{x}(t) = - 4x + 4t$$

And we have initial condition $x(0)$, same initial condition, 9. And if you know, if you put the value of u(t) here, it is $sin(t)$.

Now, if you find the solution of the system, we can write $x(t) = 9e^{-4t} - cos\, t$. So, this is the solution of this system. Now, if you see the response of the system, this is $x(t)$, this is t, it will start from somewhere here and it will go like this. So, now, if you notice carefully, the response, our initial response was this, and the response has been changed. So, this actually controls how we can modify the response of a system with applying some term, which is called forcing term or some input, so that we can modify the response of the system.

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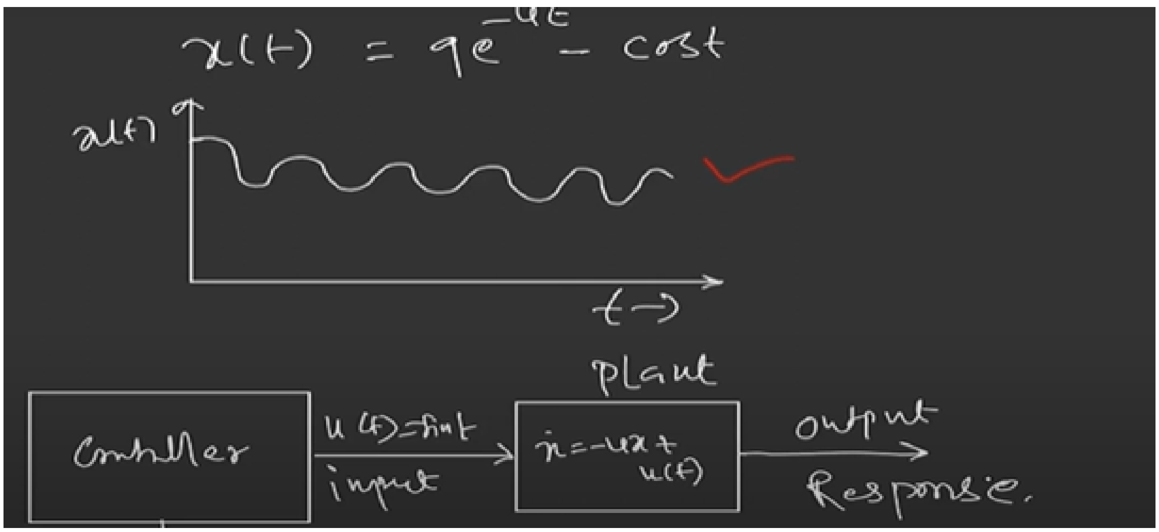

This is how we design the control system and we'll modify the response of the system, original system and the natural system. So, if you write in blocks, we are having the controller, we are sending the signal to the plant, $u(t)$, $sin(t)$, and this signal, I am going to modify the response of the original system, $\dot{x} = - 4x + u(t)$. Here, this controller can be a human being or artificial device. The controller that sends the signal to the plant, this is my plant, basically, the controller that sends the signal to the plant is called input, this is basically also called input to the plant, and the output from this plant, output equal response. Let's stop it here, we'll come to it from the next lecture, why the control system plays an important role for an aircraft.

And also, we'll be talking about what are the different devices or systems connected in closed loop to fulfill our mission objective. Thank you very much.