Modelling and Simulation of Dynamic Systems

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Lecture – 1
Introduction to Modelling

Welcome to this NPTEL course on Modelling and Simulation of Dynamic systems. I am Pushparaj Mani Pathak – Associate Professor in Mechanical and Industrial Department and I will be taking this course for you. Now this modeling and simulation course consists of many sub models so briefly, I will explain to you what the contents of these sub models are going to be and after that we will start with the first module.

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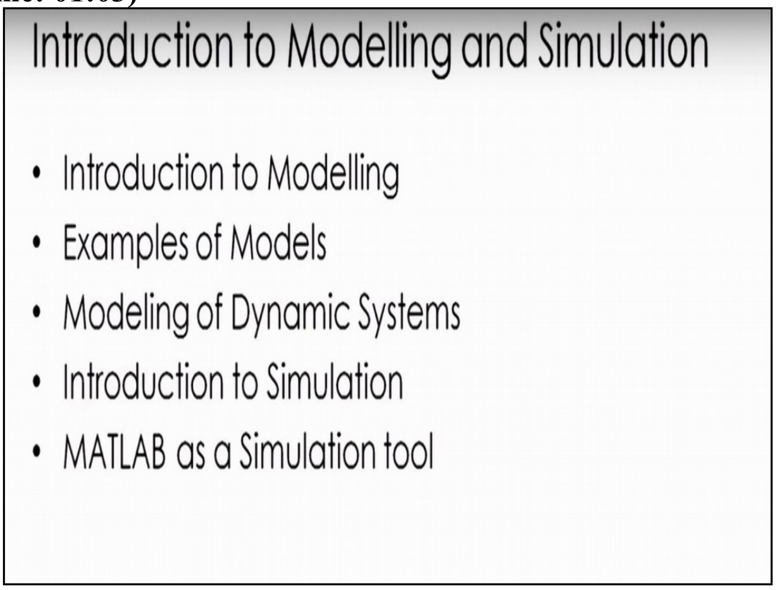

So, the first module is introduction to modelling and simulation, here basically, I would introduce to you the course on modelling and the course on simulation. So here, I will introducing modelling to you. We will be seeing the various examples of the model and how the dynamic systems are modeled. After this modelling, we will be looking at the simulation and the MATLAB simulation tool. The next module is on bond graph modelling of dynamic system.

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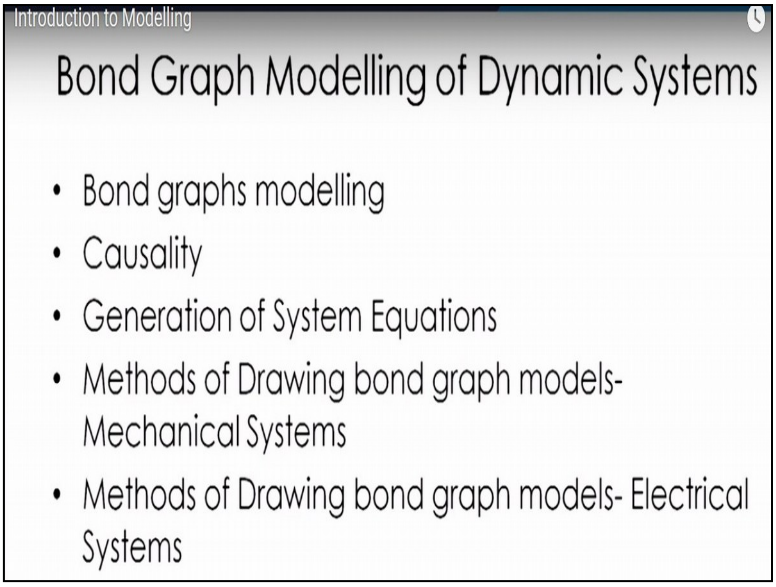

The bond graph is a very powerful tool in system modelling so we will be taking up a few lectures on this tool, as such, I will be taking up various examples on the modelling of the systems using bond graph.

So here initially, I will be talking about introducing to you the topic on bond graph modeling, then I will discuss the causality which is nothing but, the cause and effect relationship, a very unique concept which has been inbuilt into the bond graphs and then I will be discussing how the system equations are generated from these bond graphs, and after this basic introduction we will be seeing how can we model a mechanical system and an electrical system using bond graph.

So, here we will be looking at the modelling of these types of systems and derivation of the systems equations using bond graph. The next module is on basic system models.

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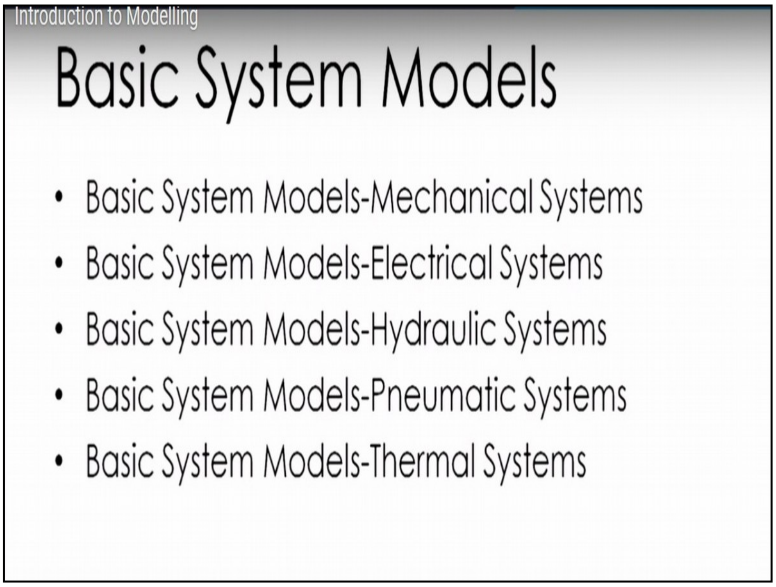

Here, essentially we will be looking at the modelling of some of the basic systems from the general modelling perspective and these systems which, we will be considering here are the basic mechanical systems, electrical systems, hydraulic systems, pneumatic systems and the thermal system.

So these systems will be considered independently and the system equations will be developed for these systems independently, rather than what we can say. Here we will be considering some sort of the sub models or systems which could be the sub systems for the bigger system. So here comes the system model of combined systems.

Now, whatever we have seen previously the basic mechanical, electrical, hydraulic or pneumatic systems, here we will try to combine some of those systems and would like to see how the modelling can be carried out using combinations of those systems. So, before introducing this topic I will be talking about linearity and non-linearity in such systems and then we will see the various combinations as I just told you.

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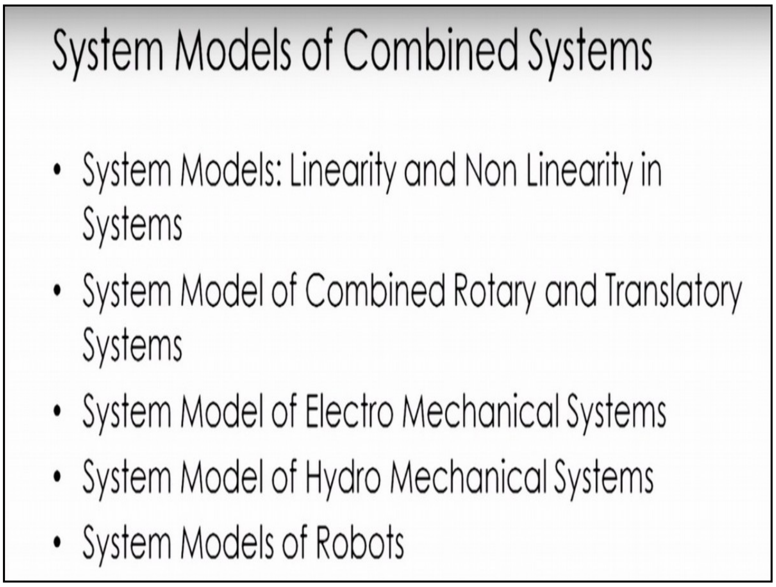

These combinations could be rotary and translatory systems, then electro-mechanical systems hydro-mechanical systems, and at the end of these sections we will be seeing how we can develop a model of robot, which is an example of mecotronic system where we have arms of the manipulator which essentially constitutes the mechanical system and we have the actuator sensors which constitute the electrical systems.

After building up the model, we would like to see the response of our models. So here, in this topic we will be looking at the dynamic response and the system transfer functions.

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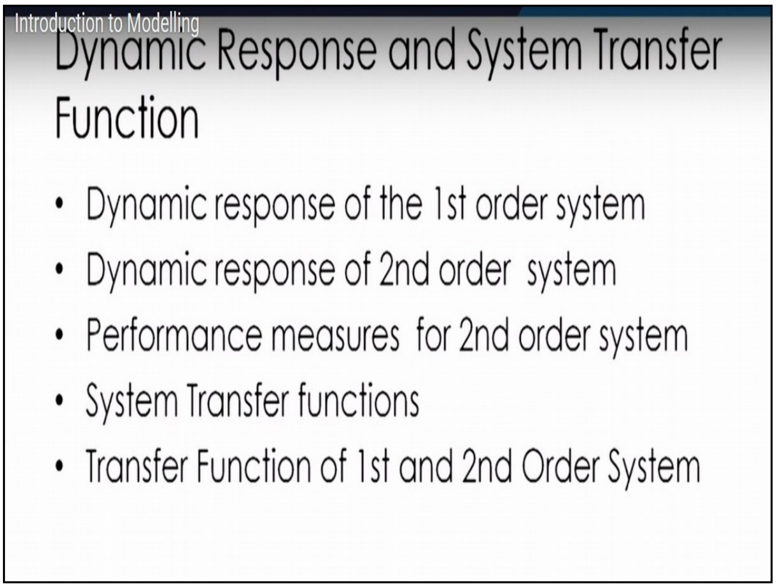

Now here, our model could be a first order system or second order system. We will be seeing the dynamic response of the first and second order systems and we will be looking at the various performance majors for the second order system. We will be defining the system transfer functions and at the end we will be looking at the transfer functions of the first and second order system.

So, this is what we will be looking at in this model on dynamic response and system transfer functions. Then there are various other tools for the system modeling. So the tools we will be looking at are,

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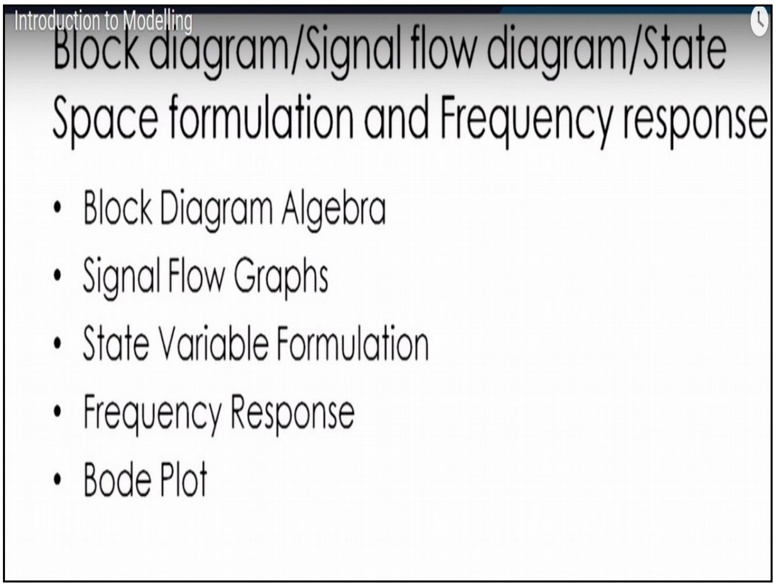

The block diagram, the signal flow diagram, state space formulation and the frequency response. So the block diagram algebra we will be looking at the one lecture. I will be taking up on the block diagram algebra, then we will be seeing the signal flow diagram the signal flow graphs and how in this state the variable formulations can be carried out. We will be looking at the frequency response and the bode plots as well.

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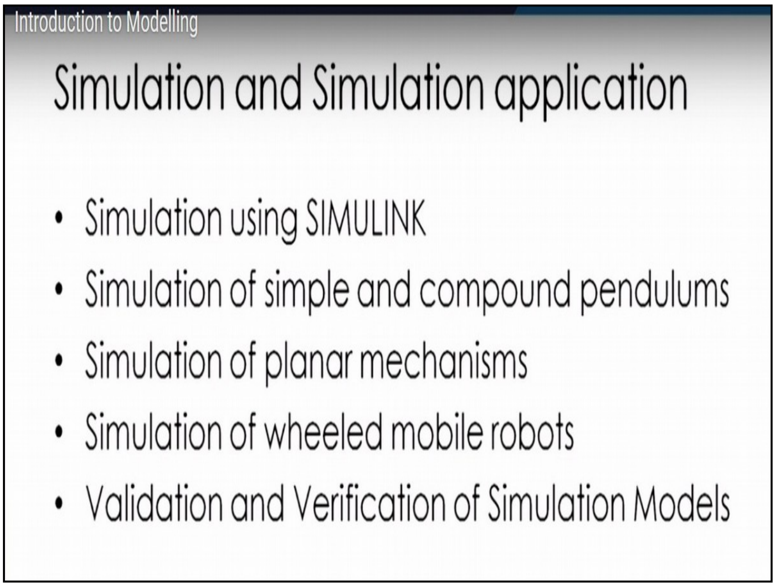

After these modeling exercises we will like to go for simulation and simulation applications. So here, I would like to introduce you to similar link which is a very popular tool used by many academic Institutions, engineers and researchers for simulation purposes and after that I will be taking up some examples for these simulation problems of simple and compound pendulums.

So, how can we study the simple and the compound pendulum and how we can simulate the system, we will be looking at some simulation planner mechanisms. I will be including a planner robot if, I want to simulate and see the behavior of the robot that I can look at. Then we will also be looking at simulation of wheel mobile robot the validation and verification of the simulation model.

Whatever we simulate, we need to verify that whatever simulation results we are getting are correct or not. So, we will be looking at the various ways of validation and verification of these models. At the last of the module here we will be looking at some of the properties of the systems, for example, the parameter estimation of the systems; here we will be looking at the estimation of the system the various parameters of the system, the system identification and the optimization.

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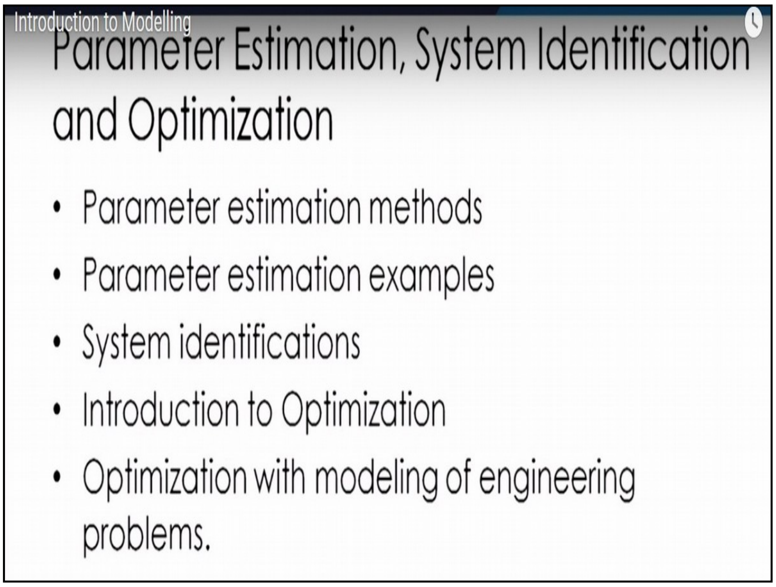

We will be looking at the various parameter estimation methods; the parameter estimation examples and we will take system identifications and a little introduction of optimization method and optimization with modelling of engineering problems. So this is what I have in store for you in our coming lectures. Now, let's begin the formal course on modeling and simulation.

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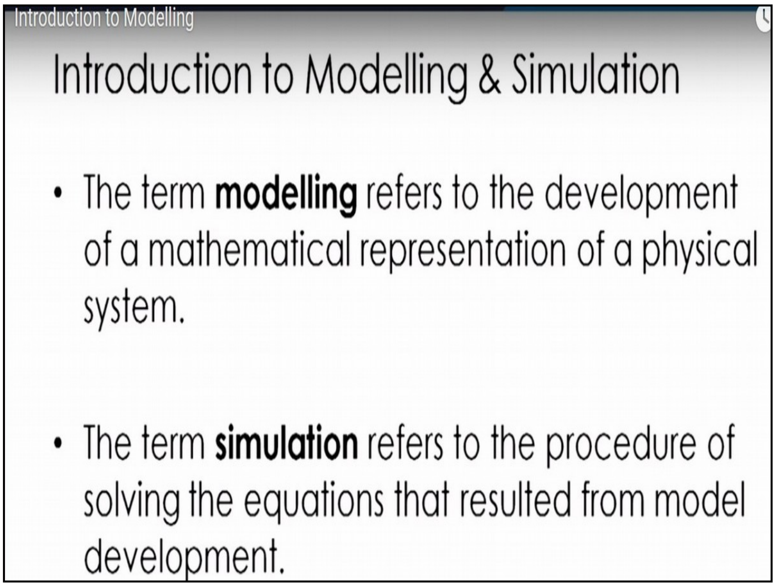

Now see the modeling, basically refers to a development of a mathematical representation of a physical system. So suppose, I have got a physical system and I want to see the behavior of that physical system, rather than making that physical system itself I make that physical system to operate and look at the behavior of the physical system. Here, what we engineers do is that, we develop a mathematical representation of a physical system.

Then through that mathematical representation we try to predict or through that mathematical formulation is further worked out we will be seeing that those mathematical formulations will be simulated in order to determine the behavior of the system or to study the behavior of the system. So, the simulation refers to the procedure of solving the equations that resulted from the model development.

So essentially, first we have a physical system. That physical system we represent a mathematical model of it, this is what we call modeling and that mathematical model development. We try to simulate, or try to solve those equations and that is what we call as simulation. Let us take an example of a very large physical system of the distribution of Electricity in some city.

Now this physical system consists of if, we begin with say a reservoir which stores water and from that reservoir the water comes through a conduct there are surge tanks in between and from the conduct the water comes through penstock it goes to the turbine the turbine rotates the generator and generator develops or generates the electricity and that Electricity is supplied to the load center through transmission.

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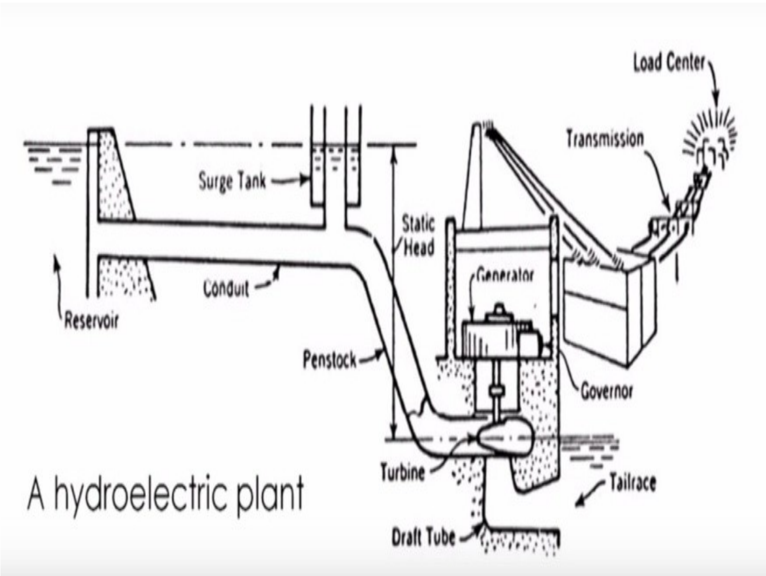

Now here, you see that the entire system is composed of many parts, for example, we have the system which consists of the hydraulic domain then we have the system consisting of the mechanical domain. Say turbine system which is in the electrical domain generator and we have the transmission system and the load center.

So your system can be as huge as this system. Now, if I want to do the modeling or the modeling exercise then, here is what I have to essentially do is that, I have to draw or I have to derive the mathematical system equation for this whole system which will be of course having the behavior of the hydraulic, mechanical, electrical and all the parts, and my simulation aim could be for example that for a load for so many mega watts, what should be my water level required in my reservoir. So this could be my simulation objective.

Now, as the course title suggests we will be talking about the modeling and simulation of dynamic systems. Now these dynamic systems could be as I was just telling you in my previous slide the system could be in any form of any of the energy domains.

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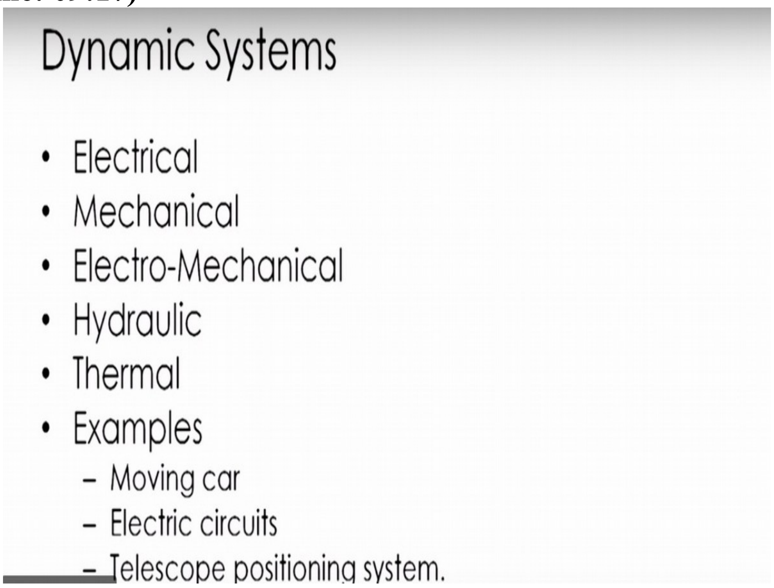

So our dynamic system could be either in the electrical domain in an electrical system, a mechanical system, or it could be an electro mechanical system, or it could be a hydraulic system or it could be thermal system.

There are numerous types of such systems. I stated few, say a moving car it is a very good example of mechanical system and the electrical circuits example of the electrical system then we have the telescopic positioning system. Of course, you see here we have the combinations of the mechanical and electrical control systems. Now when we talk about dynamic system there are various stages involved in the design of dynamic system or you can say that, there are various stages involved in the modeling and simulation activity altogether.

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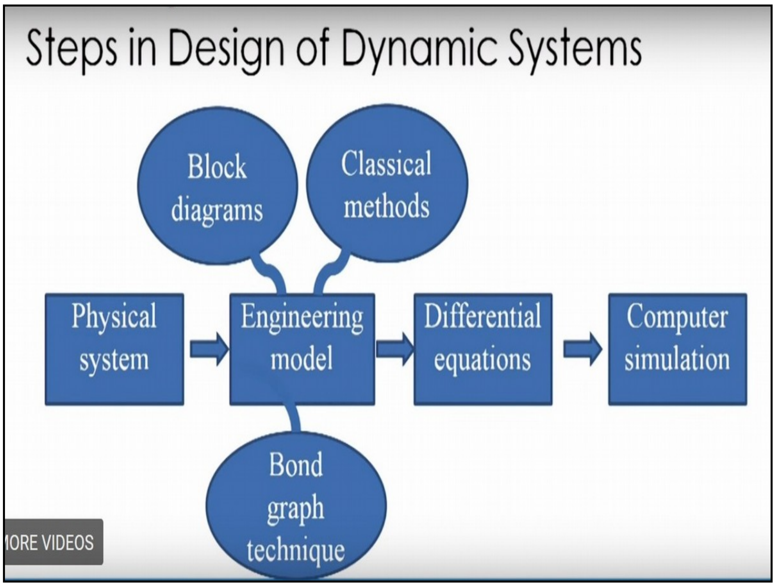

So things begin with the physical system. Okay, so we want to basically simulate a physical system the thing here is, what is done first of all we create an engineering model of the physical system. Now physical system may have many properties or many features but we consider only properties or features which are of interest to us or which are going to affect the performance of the system. Again so, in engineering model rather what we can say is that the physical system is simplified and converted into an engineering model.

Now we can play with this engineering model we do certain analysis of these engineering models and this analysis can be done either using block diagram method, or classical method, or we can use the bond graph technique which I have introduced you to in the beginning and we will be taking up in our next module. So I can use any of these 3 methods to analyze my engineering model. Now once we have analyzed this engineering mode what essentially is the outcome of the analysis is basically the differential equations.

So these differential equations essentially represent my simplified form of my physical system or what I call as the engineering system. So these differential equations represent the behavior of the engineering system or rather represent the characteristics of the engineering model. Now, if I want to see the behavior of the system subjected, to different boundary conditions then I can go for the computer simulation.

So for the computer simulation what essentially we do is that, we do the numerical integration of these differential equations using various integrated techniques and give the initial boundary conditions and supply the parameter of the system and we carry out the computer simulation. So this way this slide explains all the activities associated with any modeling and simulating type of task.

Let us take an example of suppose, I have got a water tank and I want so to study the behavior of this physical system when it is subjected to a very high wind.

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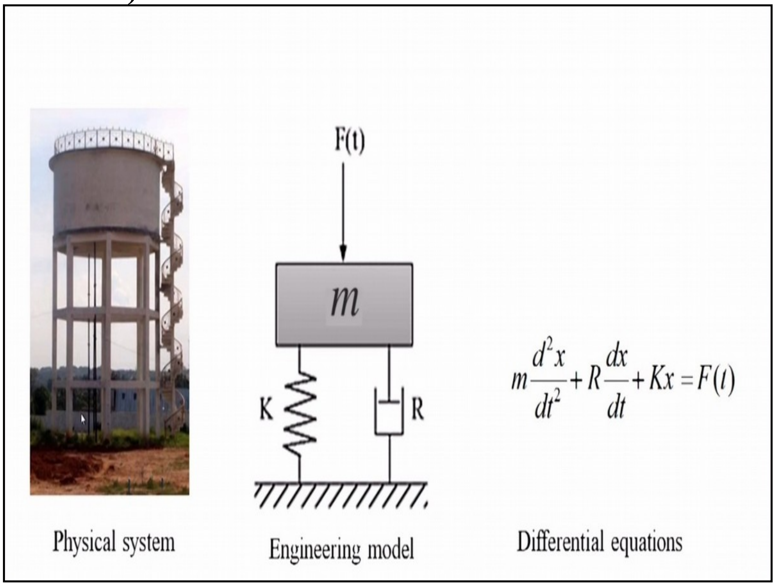

So let us assume that this physical system that is the water tank is located in area where very high speeds winds do occur, so we want to study these physical systems. Now you can see that this physical system is composed of a lumped mass or say the mass of the water tank and there are pillars and these pillars essentially behaves as speed.

So, the behavior of these pillars are essentially springs because whenever certain loads come, they try to resist that load and of course if you are interested in finding out the stiffness in the simpler case we can consider it as a cantilever beam, a cantilever beam type of element and we can find out the stiffness. So what altogether I want to say is that, this physical system can generate a mathematical model of this physical system.

First, I convert this physical system into an engineering model, for that conversion we can see that the lumped mass I am representing by a mass, and the pillar behavior I am representing by stiffness and whatever material damping is represented in the pillar by a material damping or damper. So, this physical system essentially reduces into an engineering model consisting of a spring mass and damper.

So here, the excitation which is coming due to the wind is represented by a force (ft). Now if, you look at this engineering model you can recall from your earlier studies that, this is a simple model of spring mass and damper system.

For this spring mass and damper system we can draw the free body diagram of this system and we can derive the system equations which are nothing but, Where M is the mass of the bulk mass the X is the displacement of the mass.

R is the damping quotation of the damper and K is the stiffness of the spring. Of course, F is the external force. So, here altogether what we have done is that, we have rather represented this physical system by this differential equation, and now we can do the numerical integration of this differential equation okay and we can proceed for the simulation.

Of course, we will be discussing lot more about this simulation in our coming modules. Let's take another example, a simple car,

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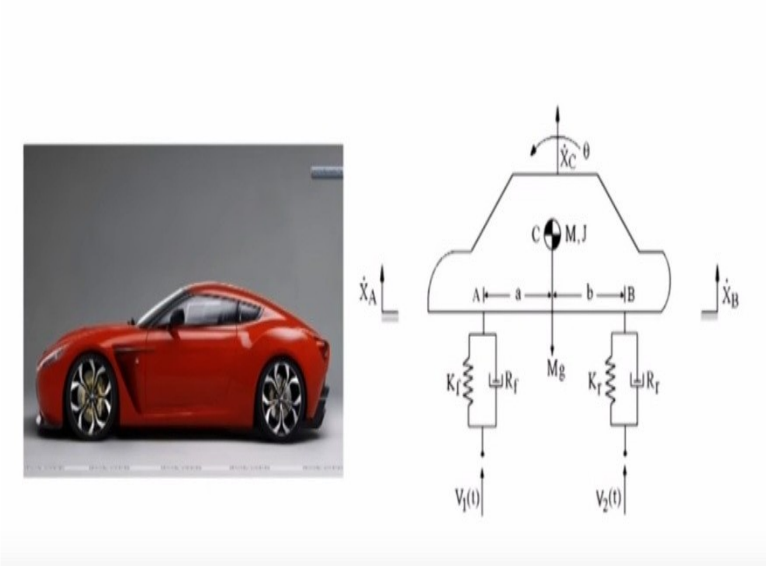

So this car is my physical system and I can convert this physical model of the car into an engineering model. As you can see in this figure of the car sidewise; the front and the rear suspension I have put into a car body having the car mass and the car puller movement of inertia and the vertical motion as well as the pitching of the car has been in physical model.

So in this way, I can replace the physical system by the engineering model by using any of the model reduction or the modelling method I can get the mathematical expression for this model. Now before we proceed ahead, let's have some concept of the systems, because we are going to model the various systems so let's have some basic knowledge of the system what we mean by static system and what we mean by dynamic systems.

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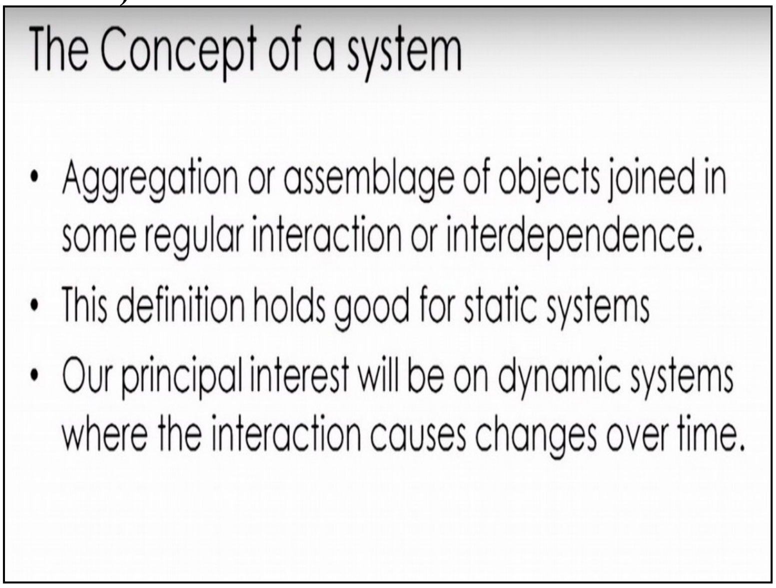

So the systems definitions if we look at are given as aggregation or assemblage of objects joined in some regular interaction or interdependence. So there are assemblers of the object which are joined together at regular intervals or interdependence. Now, this definition holds good if, your system is a static system as the title of the course is dynamic system where rather we will be more interested in looking at the behavior of the system with time so how the system behaves with that time will be the principal aim of our study.

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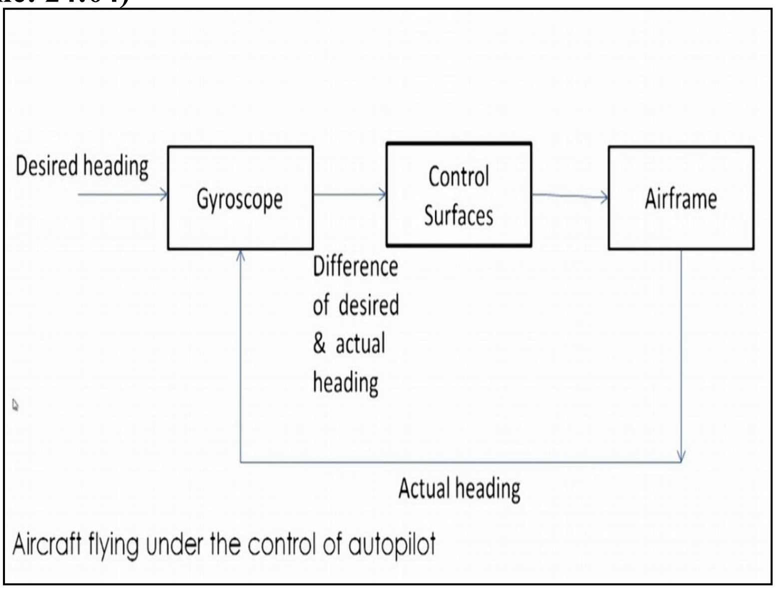

We can take an example of the system as saying a simple aircraft flying under the control of autopilot. So, if I take this system then there could be various sub components of this system, for example, a desired heading is required for the aircraft and for the air frame through the gyroscope one can find out the actual heading of the aircraft. We can find out the error in difference of desired and actual heading of course, this error can be sent to the control surfaces and from the control surfaces the airframe can be controlled and the desired heading can be obtained.

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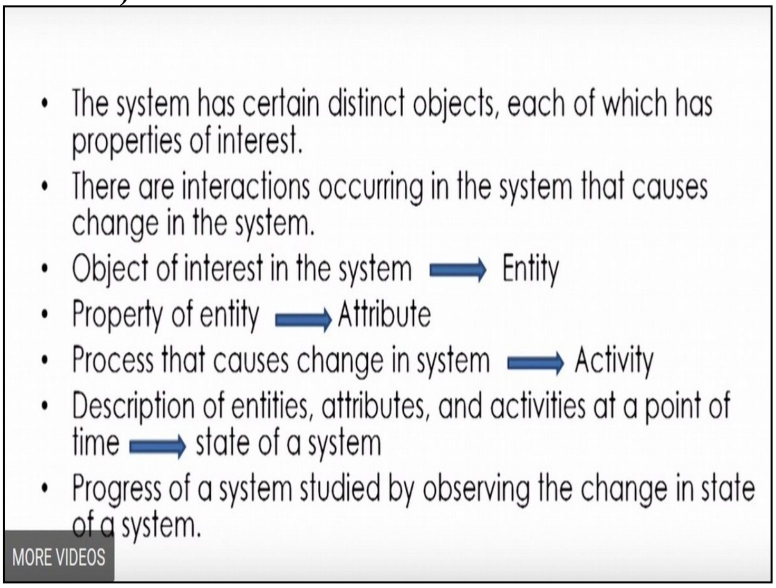

Before we can go further, let us look at the various sub components of various distinct objects which, I talked about, in my previous slide, which the system has certain distinct objects, each of which has properties of interest. There are interactions occurring in the system that causes changes in the system. Object of interest in the system is what we call as entity, and the properties of these entities are called attributes and the process that causes changes in the system is what we call as activity and the description of entities, attributes and activities at a point of time is what we call as state of a system.

Now progress of a system studied by observing the change in state of a system, how the system changes, by studying that, we can study the progress of the system. Now in this example of how the autopilot controls the aircraft; the entities could be the airframe, the control surface and the gyroscope. Attributes could be the speed and control surface angles and the gyroscope settings the response of the airframe to control movement. This control surface of the control systems always interacts with the environment.

So the system environment is very important in order to understand the control functions, to work properly.

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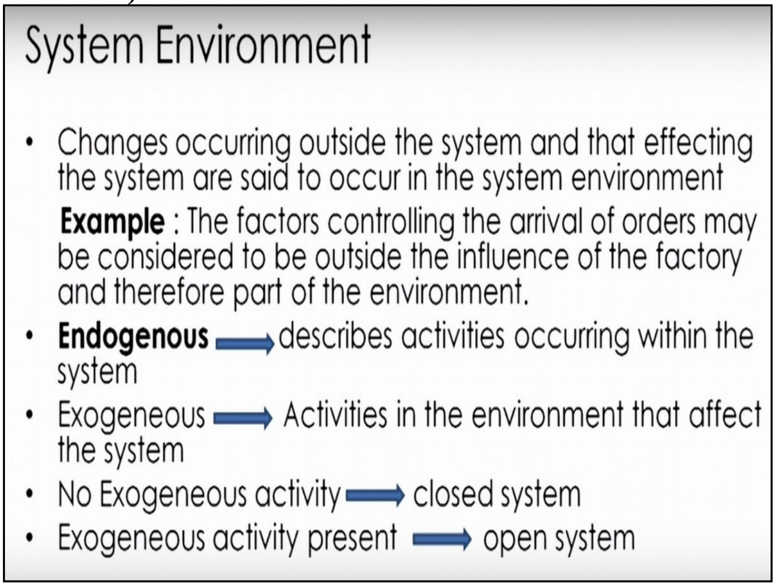

Now the changes occurring outside the system and that, affecting the system are said to occur in the system environment. Now this system environment could be endogenous which describes activities occurring within the system or exogenous which affect the activities in the environment, which affects the system. Now if there is no exogeneous activity, it is call a closed system and exogeneous activities if they are present, we call it as the open system.

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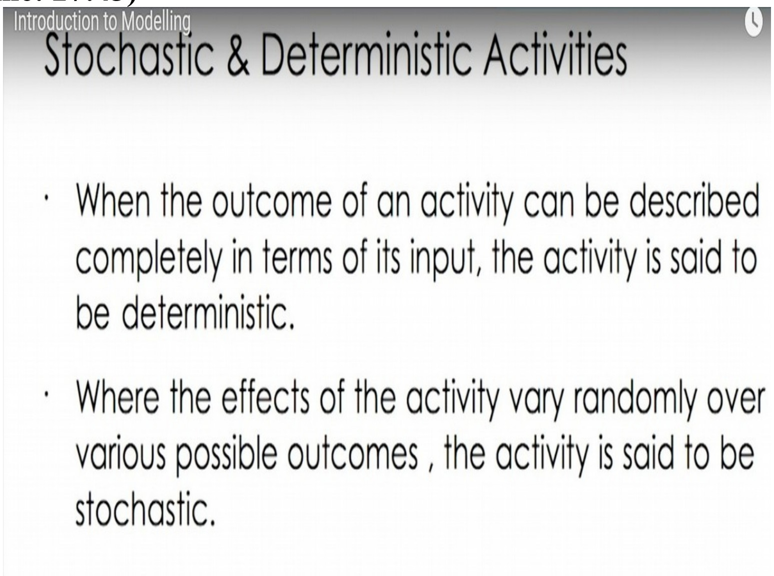

Now if we know the system behavior, and if we find out the system behavior completely we call the system as deterministic system, where we are not sure of the system behavior that affects the activity very randomly over various possible outcomes these type of activities is called stochastic activities.

Next, the system can be continuous system or discreet system for example, the aircraft CPU scheduling modeling system can be a continuous system or we can have the discreet system where the changes are predominantly discontinuous.

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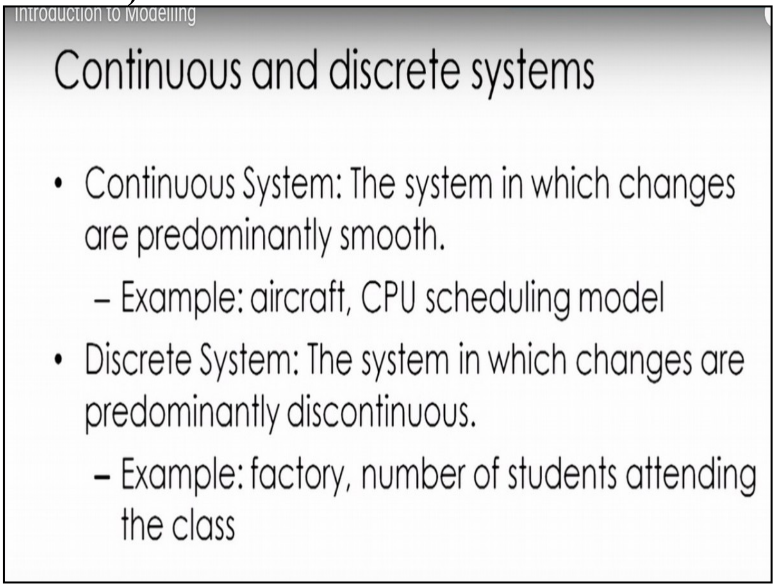

Such as, factory and number of students attending the classes. The system modeling after studying the system characteristics, as I said in the beginning of my lecture the aim of the system modeling is, to predict the behavior of the system. So this modelling or the study of this system itself mostly is to study the behavior before the system is built.

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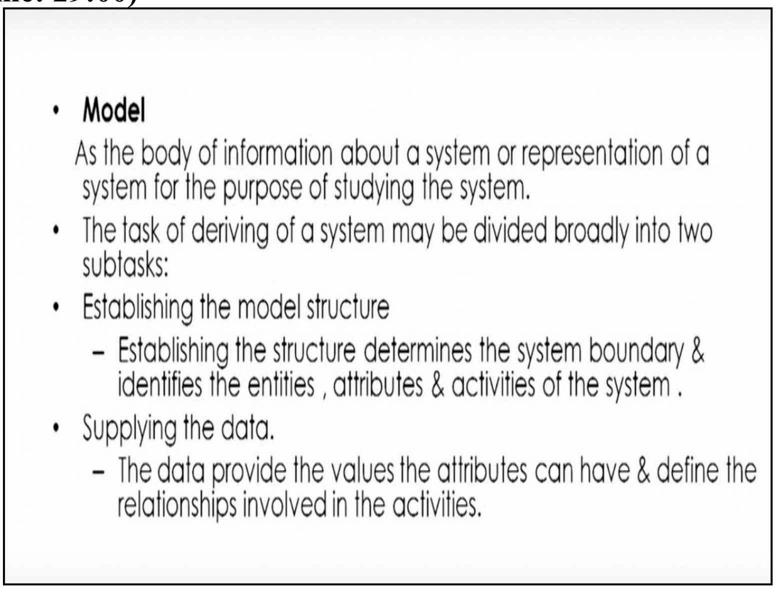

So, for this system modeling we actually create a model which is nothing but, a body of information about the system or representation of a system, for the purpose of studying the system and this model building basically consists of two stages establishing the model structure and supplying of the data. So, this is all about the introduction to the modeling in this lecture today. Thank you.