Vehicle Dynamics
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Lecture - 01
Introduction to Vehicle Dynamics

Welcome to this course on vehicle dynamics. We are going to spend the next 35 hours on understanding the dynamics of vehicle. As the name indicates, vehicle dynamics simply means that we are going to study vehicles in motion. So we are going to look at how vehicles are going to behave. Before we go into a formal introduction of this course, let us first look at what are the books that I am going to follow.

We will follow that with the syllabus and then brief introduction. This will be the first class. This class will be towards motivating you to look at vehicle dynamics.

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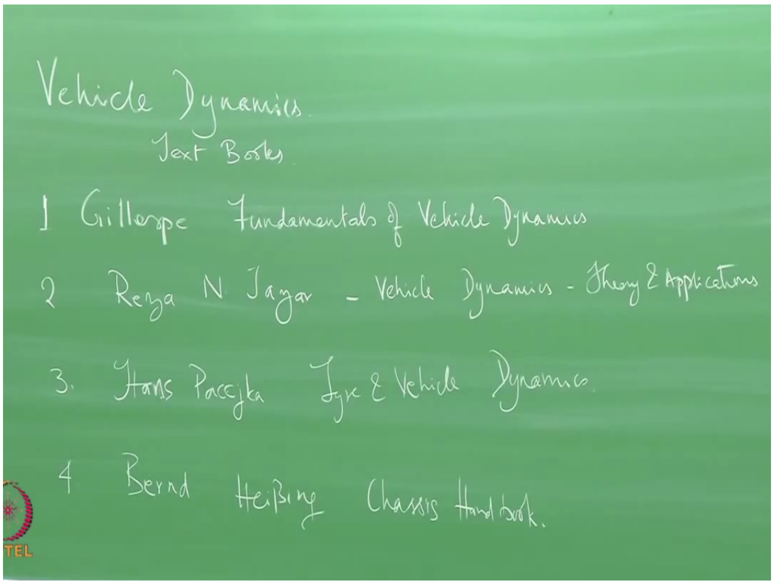

So these are the text books that I am going to follow. The text books are you know Gillespie, fundamentals of vehicle dynamics, a very well-known textbook in this field. Reza Jazar, vehicle dynamics, theory and applications springer book. Hans Pacejka, tire and vehicle dynamics slightly advanced when compared to the first 2 books and then Bernd HeiBing chassis handbook where we will take some data in order to illustrate the practicality of what we are going to see in this course.

So I suggest that you periodically look at these books in order to understand what is being done in this course okay. Let us now start with the formal introduction. This is going to be chalk and talk, I may use or I will use the power point presentations especially when the figures and the drawings are bit difficult. I may use that if it is difficult to draw in the board or else it will only be with the chalk that I am going to talk.

The reason is that I want to give you time to assimilate things especially there will be lot of derivations in this course and it is important that you have the time to assimilate as I write down these equations. Hence the course will completely be based on this method okay. We will have the class on Mondays, Tuesdays tomorrow at 8 o' clock and Wednesday at 12 o' clock okay it has been 3 hours.

Okay as I told you vehicle dynamics is a dynamics or the vehicle in motion and we are going to study what happens in motion. Of course when you talk about vehicle, a number of things come to your mind. The first thing that come to your mind is the part of the vehicle. So if you study this as a course what constitutes a vehicle, just briefly let us review quickly what are the components of vehicle that will be involved in what we are going to study now.

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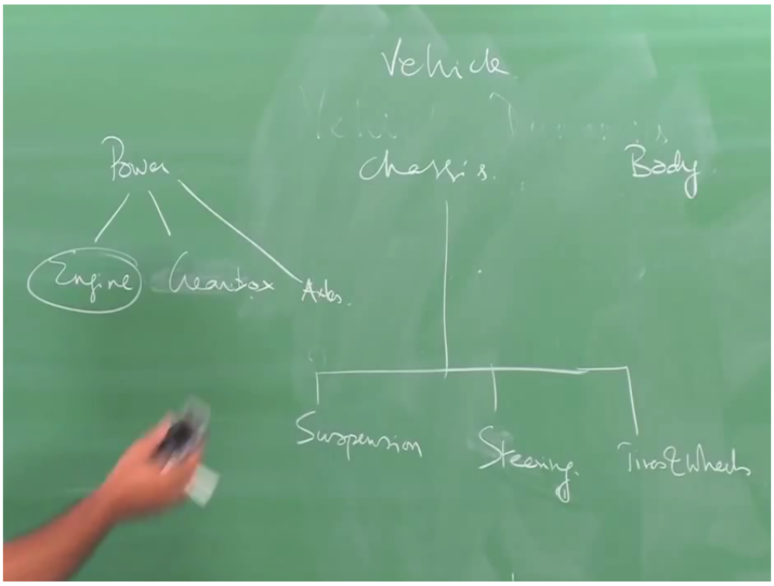

So if you look at the vehicle per se you can broadly classify them into the power module okay, which involves engine and so on. The chassis module and if you want to add you can further divide this and say that you can involve this what I call as a body module. Say anything and everything of the vehicle can be brought into these 3 categories. For example, if you look at the power train or the power, which gives the power to the vehicle.

You can include the engine, which is of course the most important thing for power as well as other subsidiary equipments or the components, which actually take the power to the wheel. So if you look at the power that is given to the vehicle, it is given by the engine and the power that is developed by the engine goes to the wheel. So you can include all those transmission systems that go to the wheel, which you can say gearbox etc okay.

Now if you want you can also in this category include also the axles. It does not matter we are only categorizing them okay. If you are looking at the chassis then you are looking at a number of subsystems, which is say for example the suspension systems, you are looking at the steering system, and you are looking at tires and wheels, which you can include here or you can include in the axle system okay.

Of course, you are the body okay, which makes you comfortable to sit in the vehicle or carry goods and so on. So broadly in other words, this is not complete but I know that you know all these things, you know the mechanisms of many of these things so I am not going to cover that. Broadly vehicle consists of a number of subsystems. All these subsystems are going to act in order that you carry from one place to the other.

And so what is the fundamental requirement of a vehicle or what does these subsystems do when you go in a vehicle? Or in other words what are the requirements of the vehicle?

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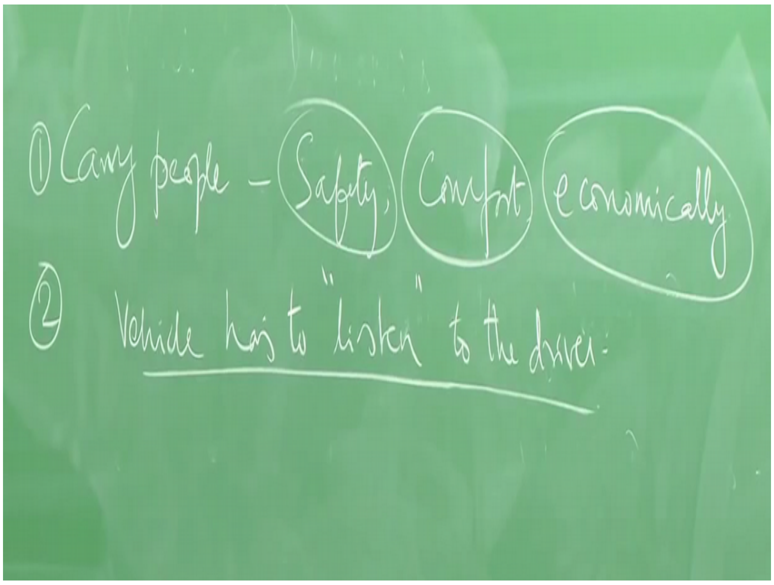

Of course, it has to carry people, do not tell me that it has to carry people, yes of course it has to carry people, but they have 3 important requirements when it carries people. Obviously, safety, it has to carry people safely, it has to carry people comfortably and of course economically okay. So these are the 3 fundamental requirements if you look at vehicle as it moves.

The second category, I am not saying it is not important, as important as the first one is the driver interaction with the vehicle. So in other words, the vehicle has to listen to the driver. It has to do what he wants him to do and it has to do that again in a prompt and effective way. So in this course, this is what essentially we are going to study. What are the factors which affects safety?

Now when I say safety, we are not looking at things like crash that is not our interest okay that is not our interest. So for example, when we say safety what is that we mean? For example, when a vehicle takes a turn okay how does it behave? Okay when you brake how does it behave and so on? So when we say safety, we are not looking at situations like crash okay.

So we are looking at safety for our dynamics point of view. Comfort, we are going to look at how your comfort as you travel in the vehicle is affected? How do you characterize comfort? What are the subsystems of the vehicle, which you are going to have an effect on comfort? Okay how does the road profiles interact with the vehicle and affect your comfort? And more importantly what defines comfort?

So these are the things that we are going to look at in terms of comfort. We are not going to spend lot of time on economical part of your travel, but we are going to concentrate here and there the economics of vehicle operations. In this course, we are not going to cover for example engines, that is the separate course okay, but we will talk about certain other subsystems like tires, how that affects the economics of vehicle motion?

So essentially we will be concentrating on these 3 aspects. Safety is linked with the second part of this categorization. Safety is the result of the vehicle properly listening to the driver. Hence, that is why I have put that as a second category and that the vehicle has to listen, listen in such a fashion that it is safe for the people inside. So we are going to look that as well okay.

So for example we are going to pick up the difference between a Formula 1 Car and for example the cars you drive. What is the difference between that 2? We are going to look at that kind of very exciting things in this course right. So these are the things that we are going to look at it. The same thing can be looked at in different perspective. In other words, there are various perspectives to look at these 3 aspects and that is what we are going to cover in the next 30 minutes.

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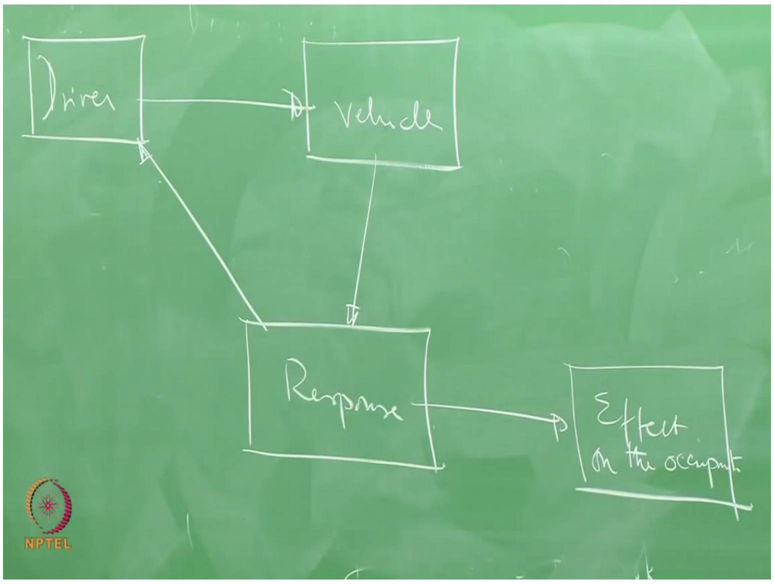

In other words, a broad picture emerges when we talk about this in terms of a driver. This is simple maybe you very easily understand this and already know it, but this gives us a picture of what we are going to do, a driver, a vehicle, a response, and then effect. So the most important thing is that triangle. The driver interacts with the vehicle because of his interaction say for example what is meant by interaction?

He may give a steering input, he may accelerate the vehicle, he may brake the vehicle and so on. So he interacts with the vehicle okay by means of things, which are around him okay. Because of that there is a response of the vehicle. The vehicle responds, the vehicle decelerates, the vehicle takes a turn and so on. So this is the response to the input okay and the response may make him modify or not you know depending upon what is the response.

So there is a lot of feel depending upon what is the response, the driver may modify his input okay. So in other words, there is a very close interaction between the driver, vehicle and the response okay. The response has another effect. The response has an effect on the occupants of the vehicle. So in other words, the effect on occupants okay is also important right. Now this is what we are going to look at.

We will not be going into details of what is the effect of the occupants and so on, but we will definitely point out under normal circumstances what is the effect on the occupants? Okay so we are going to look at these 3 things very carefully. So the driver of course as I said accelerates and brakes. Now how are we going to study this? We are going to study this using mathematical models.

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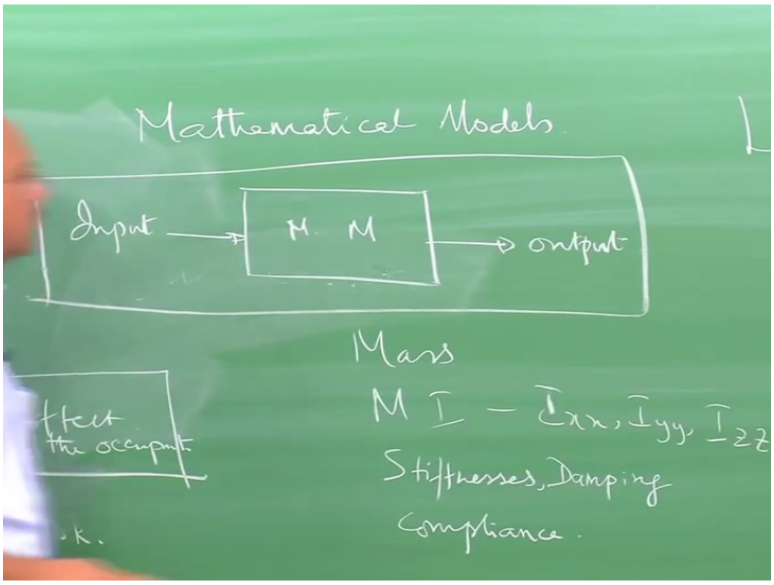

Now what do I mean by mathematical model? So I have a vehicle is represented by means of a set of differential equations. So vehicle which was introduced 5 minutes back to have subsystems consisting of a number of them okay can be also looked at from a very different perspective okay as a set of differential equations okay. So this forms a very important part of this course or the core of this course a mathematical model of the vehicle.

So what are the things that participate in this mathematical model will come to that in a minute. So this mathematical model will have an input okay, which will be from the driver. So we are going to deal with this input and you will get a set of output. So in other words, the vehicle will be reduced to a system with an input and an output. Of course, you can add a feedback, you can modify this like in what you did in control systems and so on.

We will do that; we will use a lot of control system concepts in this course okay. We will of course revise some of them as we go along, but the perspective now of a vehicle is that of a mathematical model okay. So what is this mathematical model and what is it based on? Very simple all of us know it okay. When you talk about dynamics we have to talk about Newton. We have to talk about Euler. Of course, we have to talk about Newton-Euler equations and so on.

So these equations okay will form the basis of our development of mathematical model. So that being the basis, the language of defining the vehicle is going to be different. It is not in terms of the subsystems, which we had defined. It will be in terms of mass of the vehicle. We will talk in terms of moment of inertias of the vehicle. Moment of inertia and say I xx, I yy and I zz and so on okay.

We will see that we will use 3 moment of inertias and not I xy and so on. We will talk about stiffness or in other words we will include in this stiffnesses. We will talk about the stiffness of the springs, which form a part of the suspension system. We will talk about damping. So damping, stiffness these are the things that enters into the mathematical model. The other things which enter into the model are compliances just opposite of stiffnesses.

And there are going to be very special terms, which may also be used here and we will introduce that as we go along. So in other words, the mathematical model looks at the vehicle from a very different perspective or in terms of very different quantities whose definition most of it at least you already know clear okay. So I hope you remember all the dynamics that you did in your previous classes, which will be used and which will be applied in this course clear.

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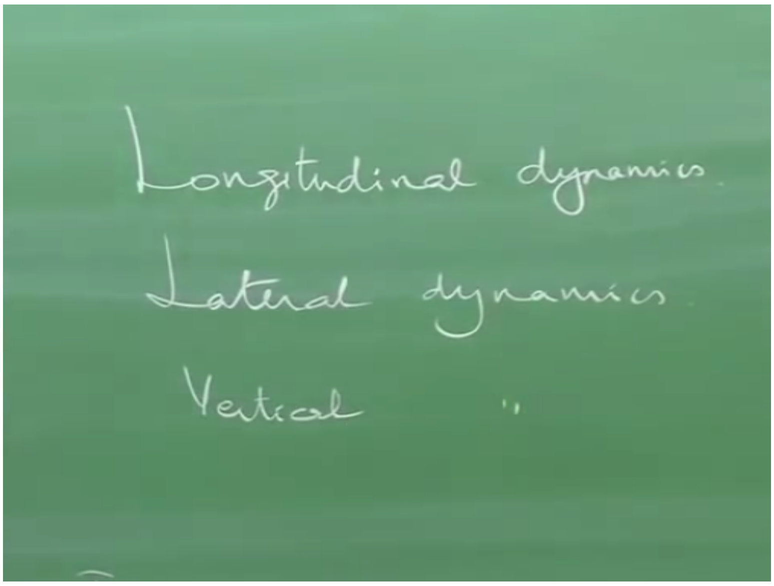

From another perspective, the vehicle dynamics study can be broadly classified into what is called as longitudinal dynamics, lateral dynamics, and vertical dynamics. In other words, a mathematical model covers the vehicle behavior in the longitudinal direction, the lateral direction, which is perpendicular to the vehicle and in the vertical direction okay as it goes over a bump or as it goes in a rough road and so on.

So basically, the mathematical models are the ones, which are written in such a fashion that we understand what happens in these 3 directions clear okay. Now you may ask a question what is this input? Say steering behavior, what do you mean by steering behavior? What is deceleration, acceleration and so on? Because the question that may come to your mind is when I drive my vehicle in a crowded road okay in the traffic then I give all sorts of inputs okay.

It can be a sudden braking or I can do a maneuver which is very fast maneuver, I can do lane change and so on. In other words, there are so many things that I do when I drive the vehicle and what do you mean by this input and what are the types of input that you are going to give or in other words are you going to create every scenario that happens outside on the road here in order to understand the vehicle behavior.

Very important to understand that first that we are not going to build scenarios in this course and that is not what when you develop a vehicle v2. There are a set of standard tests okay, which are available in order to understand the vehicle. In other words, there is an ISO standard which tells you what are the inputs that are required in order to understand the vehicle behavior.

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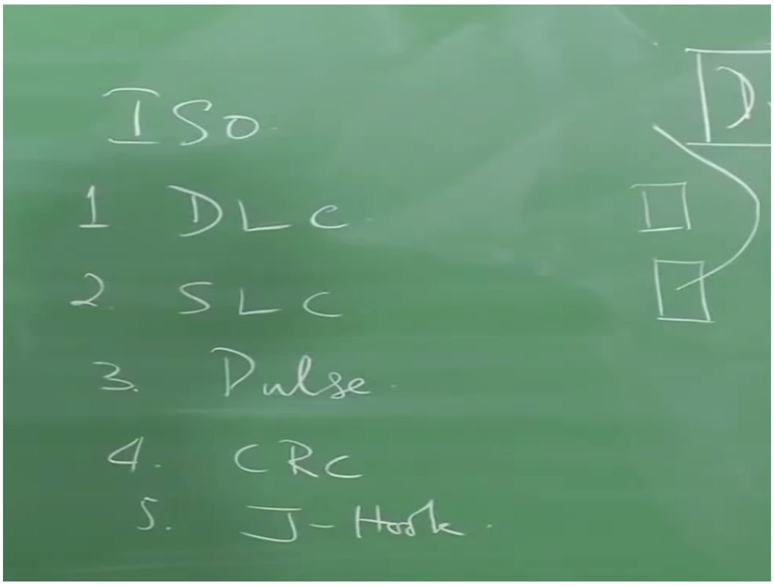

So we have ISO standard for understanding the vehicle behavior. These are called by different names and there are number of them okay. So I am going to list a few of them, not going to complete list here, but we will see that later in the course. So when we come to the input part, we are going to talk about say for example you want to overtake a vehicle in the actual scenario okay.

Suppose you are driving in a highway and you want to overtake a vehicle. Of course, I want to understand how my vehicle is going to behave if I want to overtake a vehicle okay and so what do you do? Suppose the vehicle is going like this and there is a vehicle before you so in order to overtake the vehicle you go okay and then you go back right. So you do what is called as double lane change.

So there is a test called double lane change okay or you can just do a single lane change right. In other words, which to a great extent mimics what happens in reality, but there are other tests which may not exactly mimic, but is used in order to understand the dynamics of the vehicle. They are much more technical. For example, there will be a test, which we will talk about a lot in this course, which is called as the pulse test or pulse steer.

In this test, I am going to give a steering input okay 40 degree change in less than a second okay. So I just change it and then bring it back right this is called a pulse test. You may ask me are you using this anywhere? May not or will not be using it in your day to day driving, but it brings out the dynamics of the vehicle okay. So this is one of the tests that we will be doing or which will be given as an input to this.

In other words, input has been very carefully defined by this ISO standard in order to understand the dynamics of the vehicle okay or to bring out certain scenarios. There is other tests like constant radius cornering or constant radius tests and there are tests okay, which say for example there is a test called J-Hook test and so on which bring out extremity conditions. So in other words, what is that we are going to do or what is usually done?

There are tests, the tests involve either an input through steering or through brake and acceleration. We will mostly be using braking conditions okay. So these conditions, there are number of tests, these tests are given as an input to this mathematical model, which is based on a good old Newton-Euler techniques and so on. Now what are the outputs that we are going to look at?

Okay ultimately as I said I want to look at comfort level, I want to look at safety, this is what I said. The whole ideal of studying vehicle dynamics is to study the safety, economics and so on. Let us take the condition of braking. Let us say that I want to brake a vehicle okay. Suddenly, I see some obstacle and I want to brake the vehicle okay. So I said that I want safety during braking. Actually, what does it mean or how does this output look like?

If I want to be safe then I have to look at braking distance for example. I cannot have a vehicle whose braking distances are large. We will see what typically they are later is large right. If the braking distances are large, then obviously I am not going to satisfy this condition of safety and I may go and crash with that obstacle. So in other words, we are going to look at as outputs okay, quantities which are related to what I said before.

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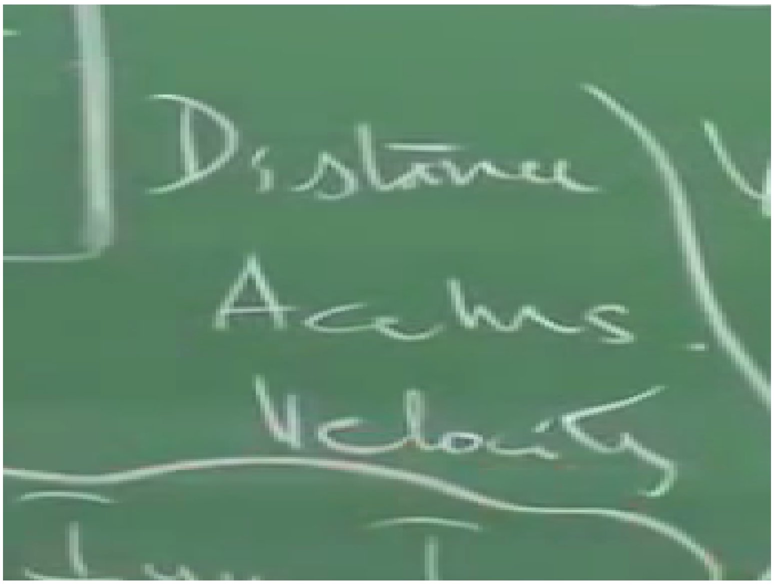

This at least is simple, braking distance okay. So we are going to look at that kind of output distance and there are other outputs that typically what I said is that we are going to go back to Newton. **“Professor - student conversation starts”** So what are the things when you look at Newton’s equation? What are the things that comes to your mind? Lateral and longitudinal dynamics **“Professor - student conversation ends”**.

Yeah so what comes to your mind is accelerations, what comes to your mind is velocity and so on right. So the outputs will now be in terms of these quantities, distances, accelerations, velocities, and so on. There will be other things we will see that later, but all of them are to do with the dynamics clear. Now how is this related to say for example comfort? I may ask you a question okay.

You get acceleration, how do I deduce my comfort levels or in other words what is the effect? So this is the output, response is the output, yes I can understand that if the braking is not happening as the driver wishes it to be, maybe he can jam or press the brakes hard, fine that I understand okay from braking distance. If you want to reduce the velocity or increase the velocity, he either presses the brake pedal all that I can understand okay.

But you are talking about effect of the occupants what is that? You know say for example, I want to be comfortable sitting in the back seat and you know enjoying my ride. So how does this give me or how does this outputs give me that feeling of goodness? So whole lot of research has been done as to how say for example the acceleration levels affect your comfort levels inside the vehicle.

Or in other words, we will map certain of the outputs like for example vertical acceleration okay, lateral acceleration and so on. We will map them into your comfort level by lot of research has been done on this topic, map them into your comfort level okay and tell you what is the effect of the occupation. So it is a large topic, we are going to give a glimpse of this towards the end of the course as to the effect.

The cause and the effect on the occupants clear. So in a nutshell, this is what we are going to look at in this course. We are going to look at first the mathematical model, input, output and so on clear okay. In order to understand the mathematical model itself okay, we will introduce to you or I will introduce to you a certain technical information to write down these equations.

If you remember Newton's equations, on one side we have quantities or Newton-Euler equations if you want to call it you have these quantities on the left hand side or right hand side however you write. On the other side of the equation, you have forces, moments and so on. So we have to understand those as well. So I should add to these lists, the right hand side of the equation which I would call as generalized force, moment and so on okay.

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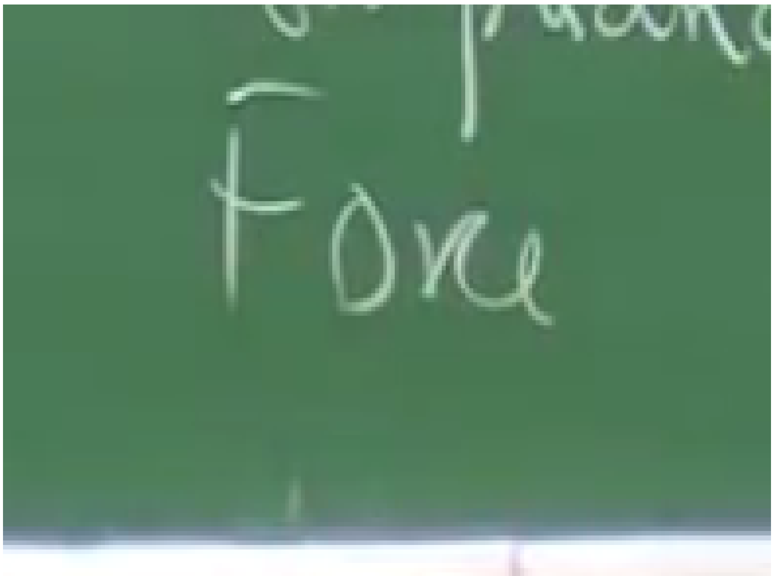

So we also have to understand the source of these forces. How does this force originate? How does it act on the vehicle? How is it transferred to the vehicle? So this is one of things also when we come to the mathematical model becomes important. Just to give you an example, if

I have to brake the vehicle or accelerate the vehicle, then I need a braking force and a traction force alright.

Yeah you can tell me that the braking force emanates when I press the brake pedal, yes of course that is the braking system, but we are not going to look at you know the braking system per se in this course, but ultimately as a vehicle when it brakes, the forces emanate from that interface between the tire and the ground. So we are going to look at actually how the vehicle talks to the road.

How actually the traction is developed? How actually the force is developed? So when you take a turn also, you should look at what generally called as the grips.

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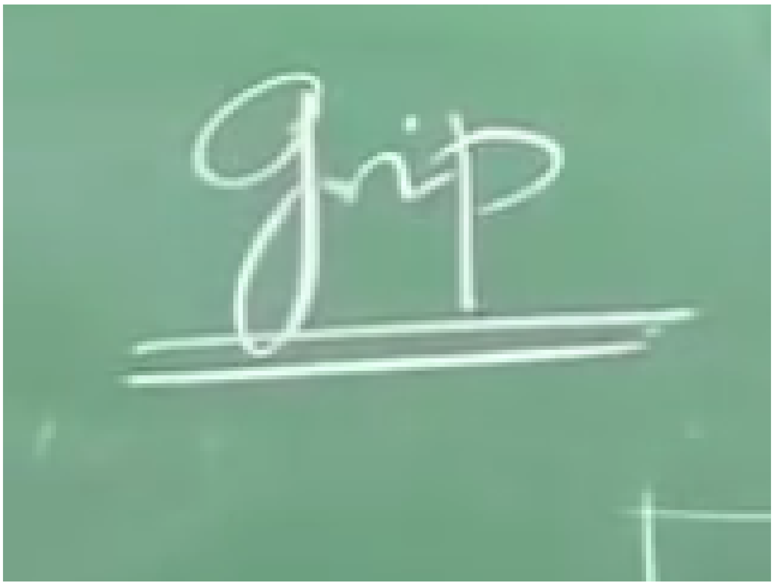

In all these conditions, I have to talk about the grip of the vehicle or grip of the tire okay with the road. So in that process of understanding the mathematical model, we will go into the details of tire mechanics and tire behavior because that forms the basis for one of the quantities on the right hand side. There are other quantities as well.

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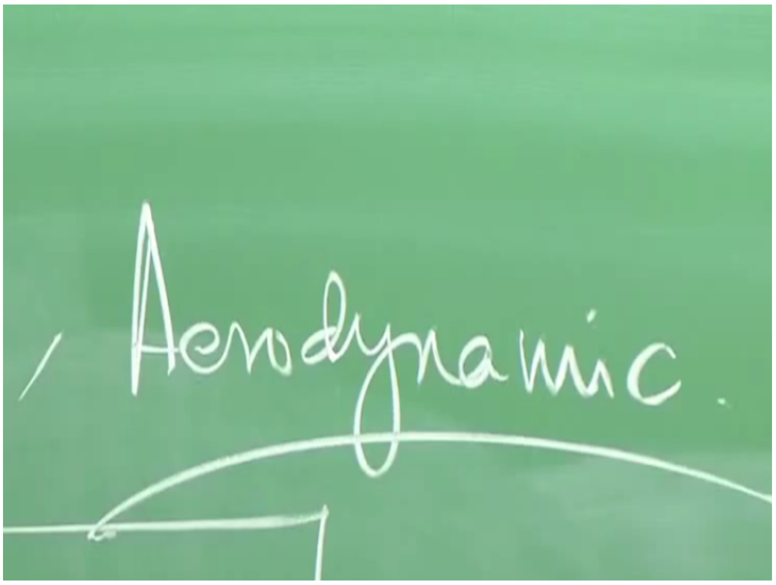

The other quantity or other force, which is important in that mathematical model is aerodynamic forces. So we have to look at the aerodynamic forces, how do they act on the vehicle? And what are the design parameters of the vehicle, which affects aerodynamics? We will follow let say a book at that time I will give you a reference. So we will follow that also in this course okay.

And there will be a short introduction on aerodynamics, the effect of the body okay on the aerodynamic forces okay. So in other words, yes there is I would say an environmental interaction with the vehicle and this is due to various components body of the vehicle and so on. So we are going to look at that because that forms a basis for the vehicle model right okay.

This is we are talking about the equation part of it okay. So the point of view, I do not want you to get confused is at force, is force and input or an output. So you may look at it like that yes okay. Braking force can be an input, but in the equation that is formed okay the force naturally comes and that is why I wrote this along with that equation clear. Any questions? So the view that we are going to take is that we have a mathematical model, we have an input and we have an output okay because of this mathematical model.

And how does the vehicle behave or how is that I convert a vehicle into a mathematical model? So that is the perspective that we are going to look at in this course clear. Okay we are going to introduce of course a number of terminologies. No course is complete if you do not understand the words call it jargons or call a technical terms okay. The course is not complete unless you understand these terms.

So you cannot converse okay or express your ideas if you do not understand the corresponding language of a course. So from that perspective, there will be a lot of new jargons or definitions or terms that we will introduce in this course. Okay how does this jargons look like? Okay let us look at it from a different perspective. So we now know what we are expecting from this course? What is that we are going to do?

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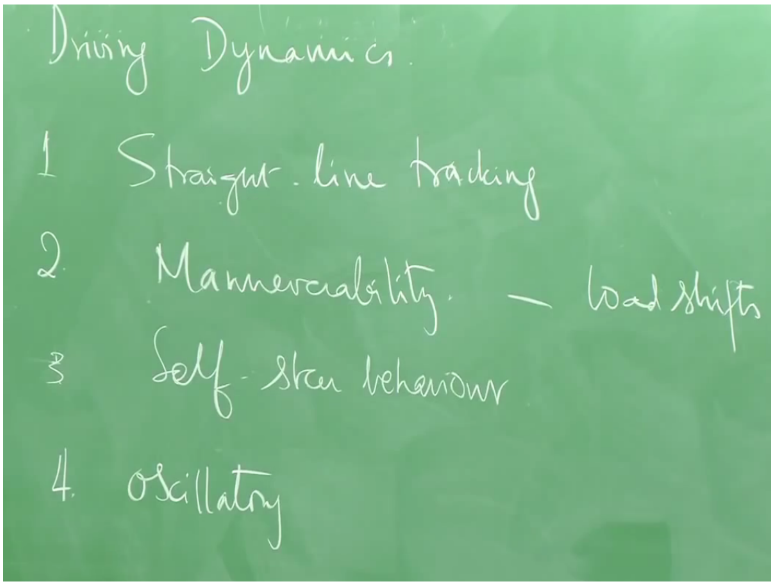

The other way of looking at it also the another perspective is look at the course or look at what we are going to study from 3 different angles. The first angle is what I call as driving dynamics, same thing but termed in a different way, another what I would call ride comfort and the third one is safety okay. So when I say jargon, what are the type of things that we are going to introduce?

So of course when I say driving dynamics, I am going to look at the vehicle in driving dynamics, the first thing that comes is straight-line tracking. Where we are studying we want to study the vehicles interaction with the external atmosphere. We are going to see simple things first. We are looking at maneuverability.

Then we are going to introduce some other jargons. We are going to introduce things like self-steer behavior. Watch out that from the terms which you understand from pure English we are going to terms, which you are not going to make out that easily unless you know the definitions. So self-steer behavior if I am going to define now you would not understand anything.

But we are going to do that later is the difference in the slip angle between the front and the rear tires, does not make sense right now to you okay, but we are going to talk about this okay what is called a slip angle? How is slip angle developed and so on? We are also going to study driving dynamics okay. Since it is dynamics okay and this is a dynamical system or system which is controlled by equations from dynamics.

Immediately you would say that that can be what are called as oscillatory behaviors and does the vehicle also have this oscillatory behavior? If so how does that affect the vehicle? There are lot of very interesting things happen when you give or when you maneuver a vehicle. Things like what is called as load shift. You would have realized that when you take a turn in a vehicle.

You would have realized that okay you are pushed to one side and then you can easily realize that there is going to be load shift okay. In other words, certain of this driving dynamics gives rise to certain effects like for example load shifts, so maneuverability changing gives rise to load shifts okay.

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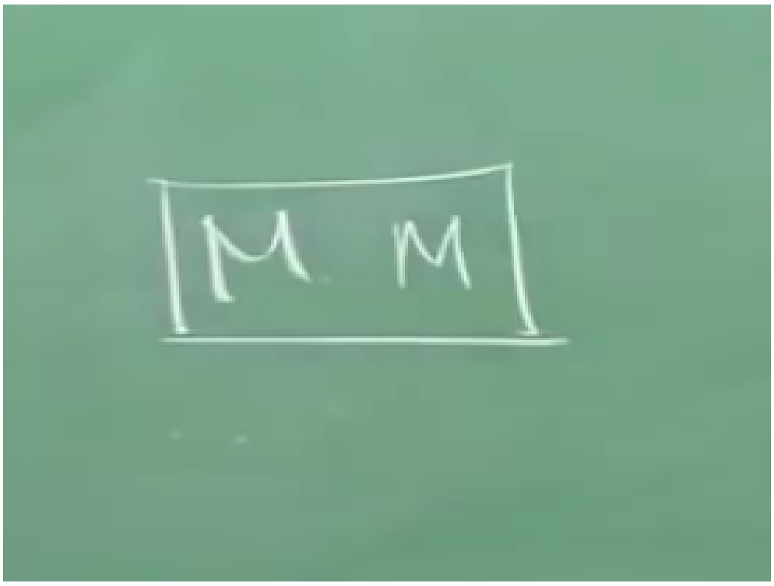

Now one of the things that I want why I am writing, one of the things I want you to realize is that your mathematical model should be able to capture all that driving dynamics okay which I am going to put forth here. So when I say there is a load shift okay, the first thing you have to ask is, is this going to captured by my mathematical model? You will see that mathematical model is a general term.

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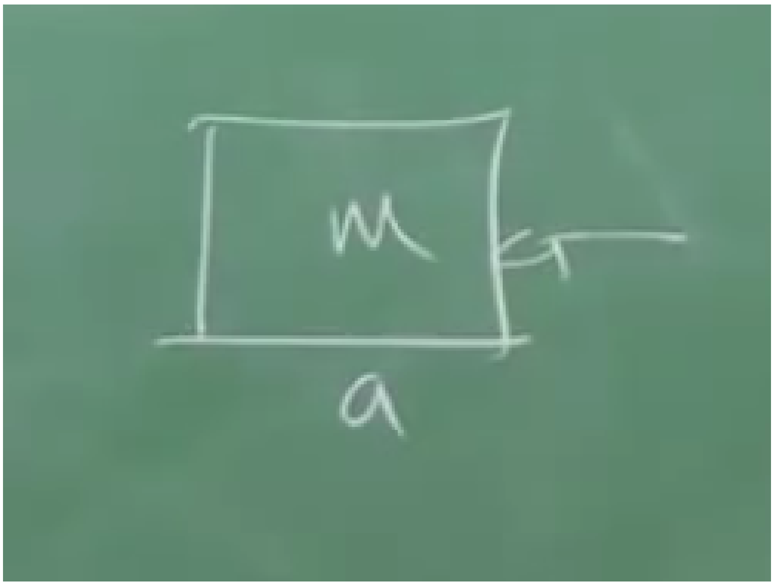

There are simple models, the simplest model you can think of is just vehicle consisting of mass m okay one mass, the vehicle as an acceleration a okay and has a force opposing its motion so a becomes deceleration, will call that s, a we will not call acceleration deceleration every time we just call that depending about positive or negative you can come to your own conclusion.

So you can look at simple mathematical model F=ma right. This does not talk about various driving dynamics. So that is the reason why I have put this. On the other hand, this also does not talk about what happens when the vehicle goes over a bump, goes over a rough road and all these things right. So mathematical model is a very general term okay.

And that you have to understand many of these things in order to understand the limitations or what can be achieved using the mathematical model. So if I just give you a braking force and if I say mass is this one, tell me the deceleration okay simple calculation, back of the envelop you can tell me what is this from this equation okay. Now when I say that the vehicle is taking a turn, I want to know what is the role of the vehicle and so on, this would not work.

So in other words, what is also required is a proper understanding of the physics okay which would be the result of your input and whether your mathematical model will capture that physics okay.

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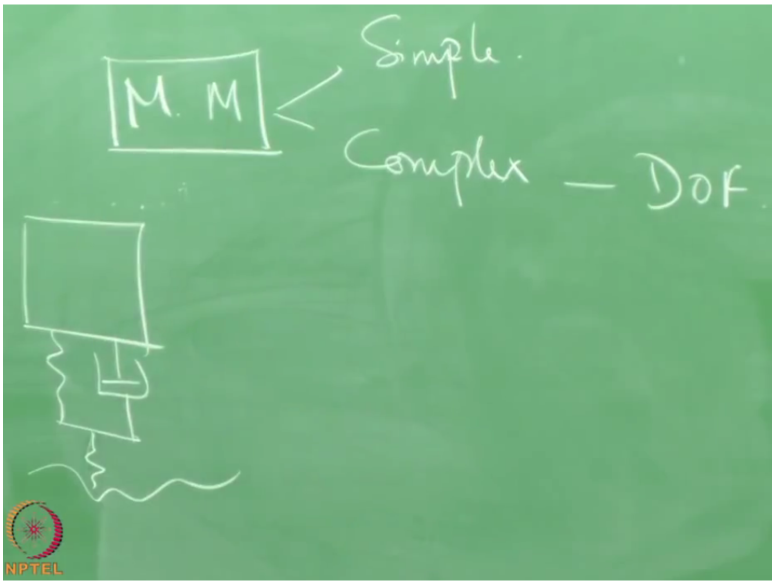

So from that sense mathematical model can be very simple like what we had seen or it can be complex and the complexity is increased as we increase what is called as the degrees of freedom as we increase the degrees of freedom. So that is the reason why we look at driving dynamics, suppose I want to look at oscillatory motion of the vehicle as it goes over a bump okay.

You would immediately reject this and you would go back to your vibration class and say oh this we had studied okay that is the vehicle let me replace all your suspension by a spring okay. Let me replace the damping bla bla bla of the suspension system by a damper okay. So let me say that the tire is just another spring and that the tire goes over a rough road and so on so what did I do?

The same vehicle, okay a different mathematical model or a different view of the vehicle's behavior I have given and the type of degrees of freedom here what I have chosen is different from what I have given here and so on. So the mathematical model in simple terms should capture what you want to analyze in driving dynamics okay. In other words, whether it is a longitudinal dynamics or vertical dynamics or you can say lateral dynamics because it should be able to capture the vehicle.

It is usual practice to start with to D-link the behavior of the vehicle in the longitudinal direction, okay in the vertical direction and in the lateral direction. I can D-link them okay and study them with simple models as if nothing happens in the other directions. So this model quite good maybe you would have done problems in vibration class with this kind of models for the vehicle.

But if I ask you what happens during a cornering behavior you know I am going to say that. So in other words, I will have another model so the models can also bring out the behavior in a particular direction or a particular dynamics clear okay. We will go into some details on the technicalities that have involved before we jump into what is going to be the longitudinal dynamics?

In other words, we are going to have models, which are like this, but much more complex than this okay to study longitudinal dynamics. So the intellectual property right of this whole thing belongs to Newton-Euler and we have to salute him for whatever he has done to us. With that we will stop this class and we will continue in the next class.