Vehicle Dynamics
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Lecture – 27
Subjective and Objective Evaluation of Vehicle Handling and Rollover Prevention

In the last class, we were talking about subjective objective evaluation. We run it a bit fast because we wanted to get an overall picture. We did not go into details of some of the things which may be of interest. You may be wondering for example, what are the type of questions that are asked to expert driver and what is he supposed to know and answer, how does he answer, all these things, the details we just skipped it.

We said that you can refer to the paper and the thesis but let me just take you through a few, at least a few of the questions which was post to these drivers. We said that there were 7 drivers who were asked and one of the key things in this is also the correlation of the answers of the drivers. There are 2 things in this.

One is the correlation of the answers to the drivers and the correlation of the questions itself, you know, the questions require similar response from the driver and whether these questions were similarly responded. So this is also important.

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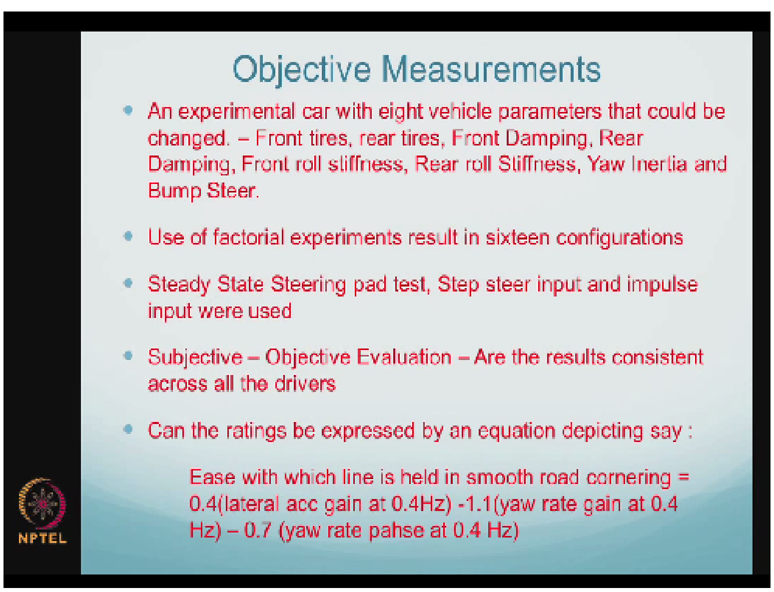

We also said that the experimental car which Chen and Ash used at the Leeds University, they had 8 vehicle parameters, okay and then these 8 vehicle parameters were changed and 16 configurations were arrived at or 16 different cars were the ones which were tested. Of course, Adams model is being used as well in order to get the objective rating and experiments were conducted in order to obtain these ratings as well, okay. So let us now look at what are the type of questions.

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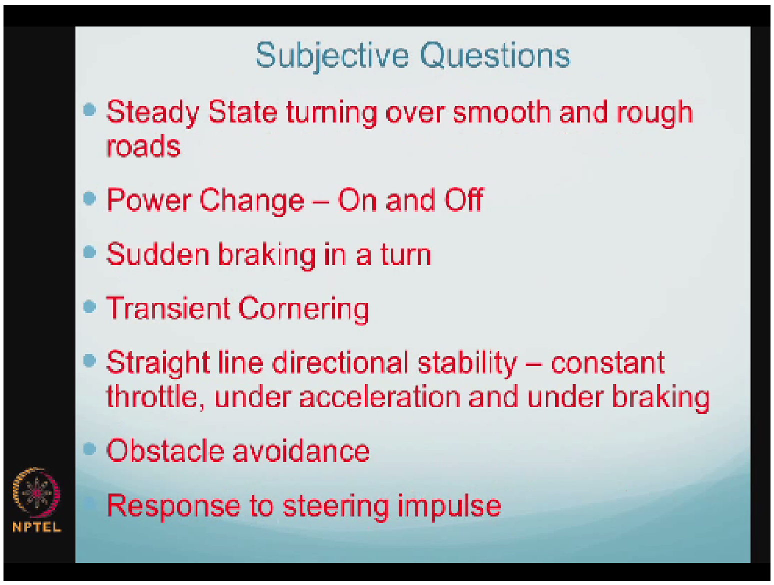

And I am going to just read it out so that you understand. The type of experiments, there are 2 things, one is a number of experiments were done. For example, steady state turning or steady state cornering is an experiment that was done, okay. In a smooth road as well as in a rough road, okay.

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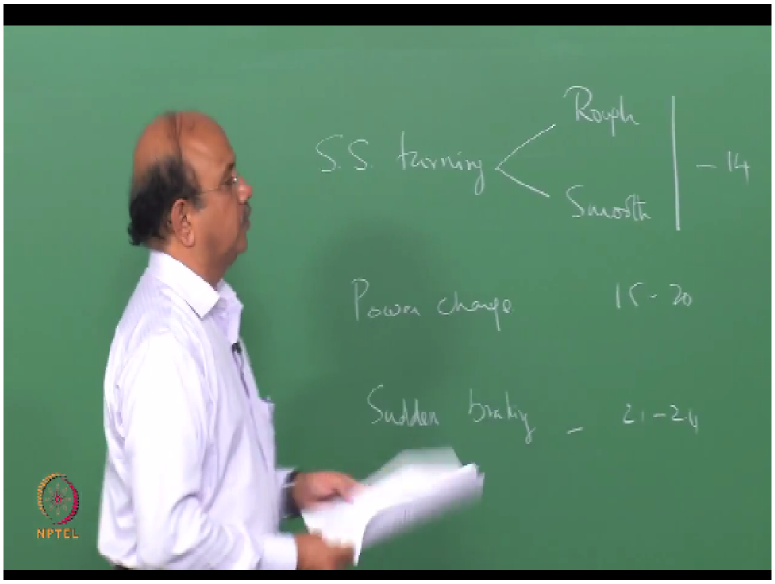

So you have that steady state turning which were run in a rough road and in a smooth road, okay. So there were a set of questions that were asked and in order to determine the cornering behaviour. So for example, the questions is something like this, over smooth roads, progressive behaviour with increasing lateral acceleration, how does this vehicle behave when you increase the lateral acceleration.

Obviously when you say increase in the lateral acceleration, you mean that the speed, okay, the 2 speeds which were chosen and as the speed increases, how does this progressive behaviour with lateral acceleration, how does the driver feel in that. The other thing is that over smooth roads, ease with which this line is held. You know, is it very easy for him to take this turn, hold the line, in other words, hold the path or is it that he had to make constant changes in his, you know, the way he drives and so on.

Then other thing is that, what is the amount of body roll or degrees of body roll, okay, which the driver feels, third one. 4th questions is that, progressive behaviour with decreasing lateral acceleration, okay. So the progressive behaviour of increasing as well as decreasing lateral acceleration, okay and an indication of the feel of available grip, okay and so on. In other words, these are the type of questions that were asked and these were rated as I said before in a 1 to 7 scale of rating, okay.

If you go and look at this paper, see the paper, you see the spread of answers. In other words, it is not that every driver is going to agree, okay on that marks, okay. There are spreads and it was found that a few of them, okay, it is the spread of the answers, in other words, if you take an average as well as the spread of this, you will see for some of them, it was small and some of them, it was large and so on.

In other words, it is not very easy for drivers to agree exactly on every question on these things, okay. So that is why a very detailed statistical analysis was done. In fact, in order to extract information, things like neural network was done and so on. So the first thing is steady state turning and the other as I had said, this involved totally about 14 questions. So this involved about 14 questions.

Then we had this power change as I said on or off, we had already said that power change is going to look at the understeer and the steer characteristics of the car and figure out, this is an exercise when there is a power on, would there be more understeer characteristic, power off would it be less or vice versa. I leave it to you to think about it basically because this involves what, load transfer, okay, and when load transfer happens, what really, whether it is going to be understeer or oversteer.

I would like you to think about this, okay. So this power change involves I think 14, 15 to 20 that is, so 6 questions. Then sudden braking in a turn, okay, so what happens to for example during this case, what happens to your response, what is the role stability, what is the wheel lift and so on. So these were the questions which were asked when sudden braking in a turn, okay. Transient cornering, okay, again there were a number of questions on transient cornering.

So the third one, sudden breaking in a turn, it went from 21 to 24, okay. So than transient cornering, straight-line directional stability and so on. In other words, a total number of questions that were asked were 49. So a very large number of questions were asked. Now it was not that all these questions were relevant, okay, when compared to handling and when compared to subjective objective evaluation.

That is why later out of this 49 questions, a few of them became important. So the first thing is questionnaire was set, these things.

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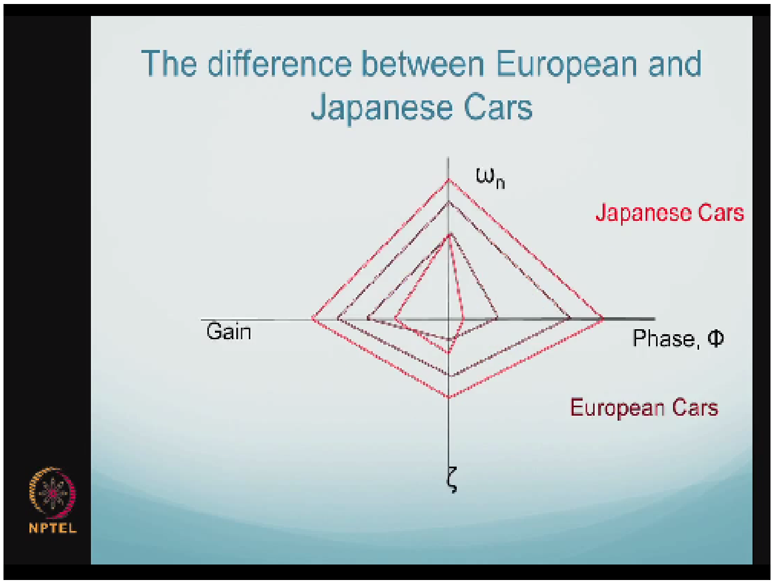

This we had already seen, okay.

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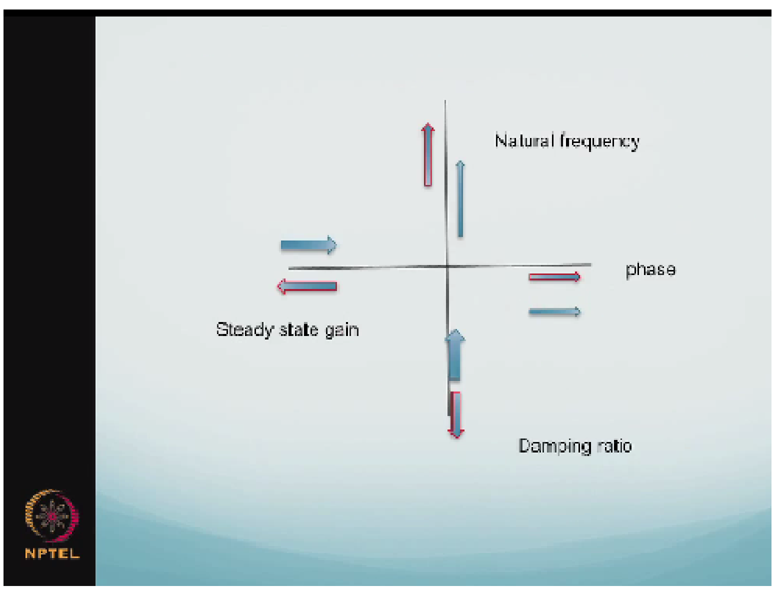

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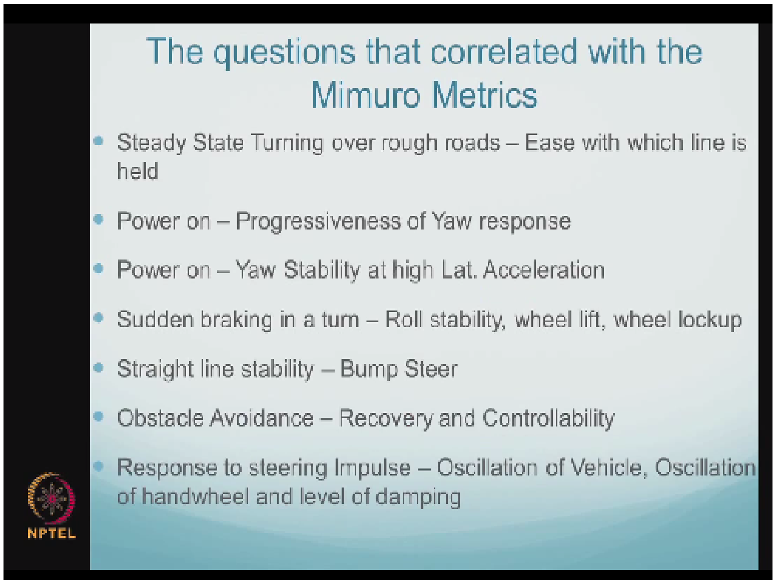

So out of these questions, a few of the, yes. **"Professor - student conversation starts"** The purpose of knowing these tests, there are 2 purposes in this. One is to quantify how good your vehicle is from given technical viewpoint and the other is how, what exactly the user wants but in that case if you, why cannot this subject being used to conditions they would normally face, why they want to put them through test drive. I do not know the user band, may be so high.

No but we make no sense to test them in the scenarios in which they would normally be operating and we could even use a steering, we got whatever to qualify how the performance. Okay, okay. 2 things. One is that if the vehicle performance at the limit is good, because most accidents if you see, it is at the limits. If its limit is good, then handling characteristics of the vehicles is supposed to be good, okay.

More importantly, steering robot, okay, is today used for getting input for the objective metrics, okay. Now here, what are we trying to do. **"Professor - student conversation ends"**. One of the important key things which in my experience we have done a lot of work, we have seen that when it comes to handling, the drivers are very sensitive, okay, very sensitive to changes that take place, right.

That is the reason why, for example, when you have the pressure of driving as you, for example accelerate in a corner, okay and the vehicle feels that acceleration in a corner, okay. Gives you a sort of a good feeling of the car. So in other words, the feeling as you drive the car, is brought out by this subjective evaluation right. Okay, let us put it like this. I have objective ratings, okay, objective parameters, okay.

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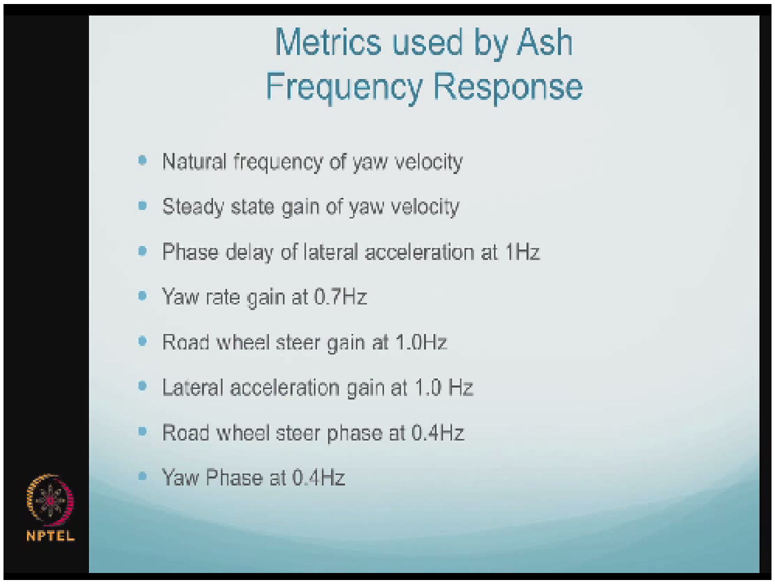

First of all, I do not know. Suppose you remove the subjective drivers. First of all, I do not know what can be this list or what should be this list. Look at the list.

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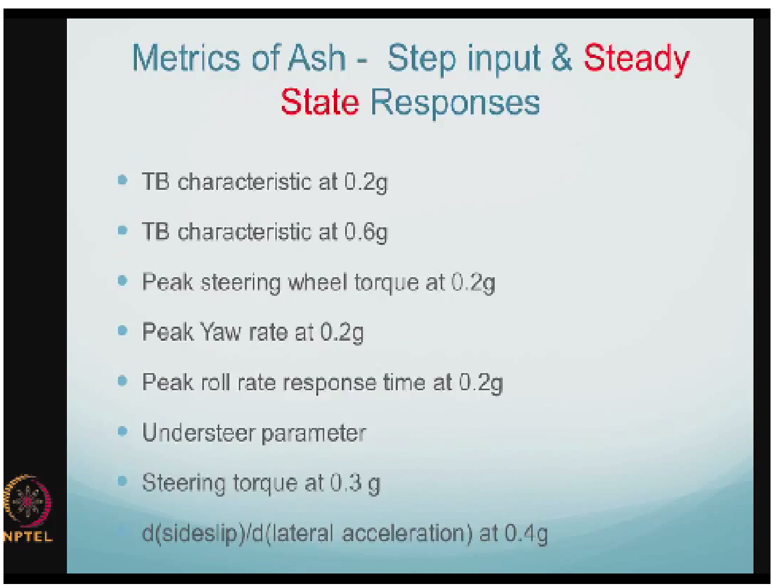

Now there are so many things which we had seen yesterday. So what can be this list in order that I would satisfy a good behaviour of the vehicle, okay. I do not even know it. So that is why I want a subjective to objective correlation, okay and the car is tested at its limit because I do not know now how it can be used, right. I mean, we are not talking about cars being used only at a, say in our roads where you cannot go beyond 40 or in any city road where you cannot go beyond 40 kilometers per hour

We are not testing cars just like that, okay. They are tested for different purposes. For example, there is a city cycle. The city cycle is used in order to find out what is the fuel consumption, okay. For example, our roads, we test the cars for very sharp transient maneuverabilities, okay. So which is also reflected here. So in other words, the city cycle, it has its own use to evaluate the car, specially from a fuel consumption point of view.

But when you want to look at the performance of the car, suppose you take this in a highway, okay and we know in our highway, suddenly there is an obstacle that comes, okay and you do a double lane change under very severe conditions, you are travelling at 120 kilometers, I do not know whether you have driven these highways, Indian highways. Today people drive at 140 kilometers to 160 kilometers per hour.

We know that some of the buses, for example we have done lot of survey on tire life. We know that buses average 105 kilometers per hour, okay. So these speeds are extremely high, extremely high. So at those speeds, okay, we do not know how the vehicle is going to behave. There have been issues when the vehicle touches 110 kilometers per hour, okay. There are countries in which there are restrictions on speeds, United States, okay.

In our country, we do not have most sensors as we do not have restrictions on the speeds, okay. Many countries like Germany, you do not have restrictions on speeds. So you do not know what speeds people are going to drive. So that is why all these things are tested. Simple fact is that, the drivers also do not want surprises, okay. When you change, when you do a transient understeer or transient oversteer, the drivers also do not want surprises. So that is why we do such a subjective rating.

So once I do a subjective and I do a subjective objective correlation, also my design becomes simple. Now if I tell you that my yaw rate gain at 0.7 Hertz, it is important. Then my next goal, which you will do in the next course on our vehicle in the next lab, as to what are the design parameters which are going to have an effect. We have seen with the simple bicycle model, right. But there are other parameters which may have an effect. In a very detailed model, there are other parameters which may have an effect.

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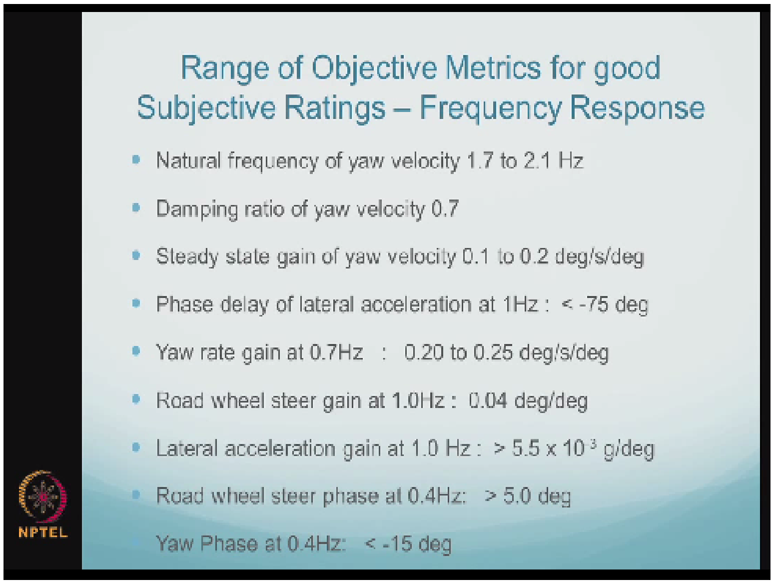

So it becomes easy for me once I have that kind of range which we define, okay. That kind of range which we define, then it becomes easy for me to also design a vehicle, clear. That is why. So what are the important things, how do you design a questionnaire is important, okay. What are the type of questions, relevant questions are you asking, okay.

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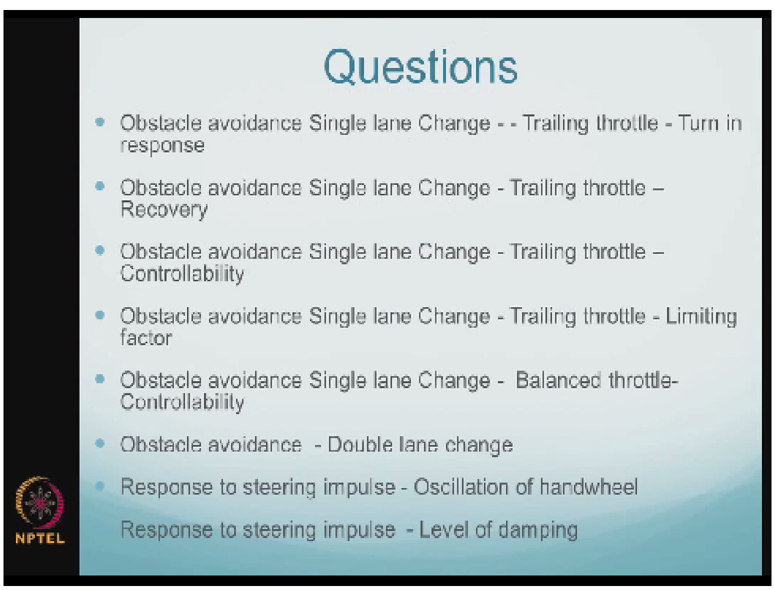

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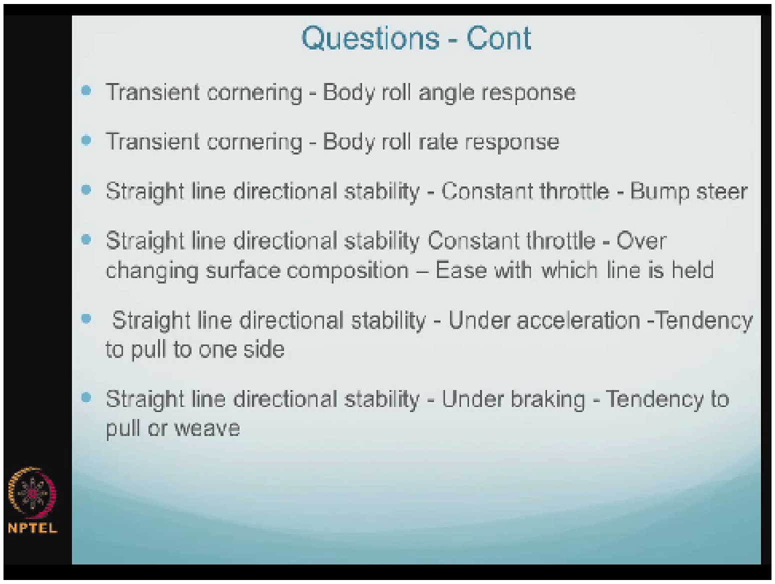

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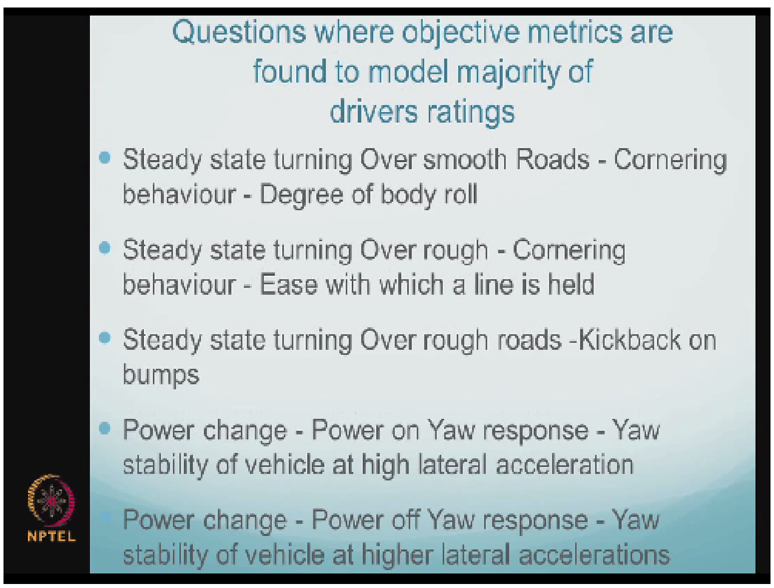

That is why the questions where objective metrics are found to model majority of the driver ratings are given here, okay. Go back and look at the thesis by Ash, you do more about these questions. So from these 49 questions, a few of them become important, okay and tomorrow you want to test a car, it is good to have or to model this or to have a questionnaire, design a questionnaire based on these questions, okay.

So it is a big topic, I do not have time to go into each one of these questions and how it is related and so on, that is why I have given your reference. I would like to move to the next topic, okay but I just want to spend a few minutes on what this subjective rating questions tell you, right. Of course, ultimately when you want to buy a car, you are going to drive it, that is a different thing but this is useful for designers, okay. At least now with the vehicle dynamics course, you also know how to test a car, right.

Yes, okay. We will do a test drive, okay. Post that you are going to buy a car, go and do a test drive and say that I will tell you decision after couple of days. Do not give your cell number to him because he will keep calling you, right. Do not do that. Go and do these tests, okay, fine. We are going to do few tests in the next course on vehicle dynamics lab. We will know more about these things, right. So we will move away from this subject object correlations. We will move to a last topic in lateral dynamics which is rollover.

"Professor - student conversation starts" Sir. Yes. When we try to correlate subjective and objective things, we took only number of (()) (16:36) but it is not… No, no, no, no. I told you, right. I mean the number of plot is the easiest because I have only 4 parameter, okay. That seems to correlate well to a great extent in my opinion. We have also done some tests. It correlates well, okay, except that when the vehicle has a lot more oversteer characteristics, then there is an anomaly.

In other words what we said is that within a limited range, the sentence that as the area of the rhombus increases, it gives a better drive, I mean handling is valid, but then this work, further work after number of, for example it was in 1990, early 1990s. So there were lot more parameters which were included, okay. Now those are the parameters which we had put down sometime back, right and the difficulty as you add parameters, is that I want to now be within that range, then it becomes difficult whether I can have all those parameters within that range.

How will you predict the range because it varies from German to… That is exactly, see that is why this subjective, how will you predict the range. There are 2 things, one is predicting the range, the other is getting the value in a design. Predicting the range is that subjective objective correlate. That is what I been talking. Subjective objective correlation gives you that range, okay, clear. **"Professor - student conversation ends"**.

So in other words that is why drivers are asked to drive, look at their answers, then what are those cars which they have said very good, what are those ranges and so on, you know. That is why you did or people did in the Leeds University did a factorial experiment, okay. So this range is obtained from that correlation. There are number of ways in which they have obtained this correlation, okay.

So range is different from design, then you have to go and design a car whose, for example natural frequency of yaw is between these 2, 1.7 and 2.1, okay. So this is applicable to a range of say up to SUV, right. But may not be applicable for say trucks type of, okay. So this range is for the vehicles tested which is sort of sedan, SUV type of vehicles, this range is valid. Your question is well taken.

So that is why if you are working in a car company, you would like to have your own these numbers, okay. So that you can fine tune it. So this will be very useful for you to fine tune your vehicle. **"Professor - student conversation starts"** Sir today I want to design a car and I want to predict my range. You cannot predict the range. See this you can, when you design a car, you will get values for these things.

You will get the values. The range is predicted as I keep telling between subjective objective correlation. Sir which is the subjective way, we did not ask any numbers that is just it is like out of cars when you turn things like that. Yes. So there what we did was, we asked to rate it as 1 to 7, okay. In fact, that is why this paper, I do not have much time, 980226SAE, there is a table, say figure 4 rather, okay.

Figure 4, you get effect of objective metrics on subjective ratings. It is completely given there, okay. Go and have a look at it. For example, effect on subjective ratings is in the y axis and you see that a very many number of objective metrics are given in the x axis, okay. **"Professor - student conversation ends"**.

So when you change this parameters, say for example, a natural frequency of yaw at 0.7 yaw or yaw gain at 0.7, what is the effect on subjective rating is obtained, okay, and he had also defined whether there is a uniform agreement or the drivers are unequivocally said that this particular parameter is important and so on, right. So that is how this is arrived at. Change it, for example, I mean in simple words, I change the configuration.

Say let us take one thing, I change the natural frequency, okay let us forget about the rest of them. Just as an example, okay. Very good statistics is involved but let us forget it for a minute. Just to make you understand, I know that students, you will be wondering why we are doing these things. So let us forget about everything.

I will say natural frequency. I am going to take say 3 cars or 4 cars, okay, whose natural frequency yaw varies from 1.6, okay, 1.8, 2 and 2.4. Let us says that I take these cars and I give it to the drivers, okay and as a number of questions which were at listed, okay. How does it behave in a turn, whether you are going to hold it, you know are you losing a grip and so on and so forth and I am going to ask them a number of questions.

Now then if I consistently get that drivers say that your car which is 1.6, okay, is not good or his ratings for the questions are low for 1.6 and becomes high for 1.8 and 2 and again low for 2.4, okay, right. Then I would say that look this range, consistently if they say it and there is a statistical significance. There are number of statistical significance test, go through this thesis, then you would see that with 95% confidence, you know there are what is called as R squared values in statistics and so on.

Forget about all that jargons. Just say that these 2 values, okay, consistently people say it is good, then I would say that look if the natural frequency, that yaw is between these 2, people say that it is a good car and so you should keep it like that, okay. Now we cannot change, okay. Let us say that I change similarly damping and so on. I keep changing one by one and I want to find out each factor, that is one way, but I cannot do that because there are so many factors, I cannot do.

So we do a factorial experiment to understand, okay, the interactions between the drivers feel and this and arrive at a set of values, clear. So once you arrive at it, you go and start working in your design, okay. Now so natural frequency of yaw, how is this going to be related. The first thing I will do is to go to a bicycle model. You already know the formula for it, okay. So you look at your vehicle. So where do I stand, what is my natural frequency at yaw, okay.

Simple the first cut, okay, maybe 2 degree of freedom or 3 degree of freedom, where do I stand, yes. Looks like it is fine, okay. Like that whatever is possible for me to get, okay, yaw velocity gain or a lateral acceleration gain, okay, phase and so on. All these things I have simple formula and first I will check, okay, what are the parameters, may be the mass of the vehicle will have an effect, CG location may have an effect, moment of inertia may have an effect, lateral compliance may have an effect, so many things may have an effect on these things, okay.

Then my job as designer is to optimise this and see that my vehicle lies in those ranges, that is a challenge. It is a good optimisation problem which you will do that in the next semester. I assure you that we are going to do a complete sensitivity parametric analysis, okay. We will take a car, we will change various parameters, we will list down, okay, various parameters and then you are going to change them and see how these parameters are getting affected.

So you can come to a very optimise car, okay. So in other words if you produce this car then and give it to this ratings of the drivers who are very important, okay, then you will get good ratings from that, that is the fundamental basis, yes. **"Professor - student conversation starts"** Sir, at someone to identify what these parameters are, that is probably the tougher job because even now you are not sure of whatever…Absolutely, that is too good PHDs, that is why I took that in this course, too good PHDs were done, a lot of work, okay.

In my opinions, this is an exhaustive work that is done, right. That is the, you know, 2 good PHDs from Leeds and that is what they had done but the problem is, it is not one-to-one correspondence. It is not that for that one question, there is one objective parameter. It is not like that. That is why this statistical base I keep on telling that that, that becomes important. Like you have said whatever the number of guys had done, was invalid in European car or something. Whatever these guys have done, why not we valid in our setting. Yes, correct.

If you are not, if you are in that, I would say, range, okay, this will be valid. That is why I said that mostly if it is a sedan, okay, or SUV, this would be valid, okay. So yes, the validity has to be checked, we are not questioning that but generally because of the range that was done, okay, this likely to be valid, okay. This is not something as a design rule we are saying. That is why we are giving a range, around this value, looks correct, looks valid.

Even when the value, the metrics is absent, okay, we will be sure that… Yes, correct. So that is where, again I want you to go through the thesis, we will do that, you know, in the next semester in another course, okay. We will go into details. So we are only scratching the surface. In this whole course, we are only scratching the surface. Vehicle dynamics is I would say huge topic, okay.

The questions which are still not answered is, I said that there have been some answers, I am not convinced that every metric has been answered from a very, I would say, use again the word, from a very objective fashion. **"Professor - student conversation ends"**. In other words, some of them you may know that the response of the vehicle is in that frequency range and so the phase becomes important and so on. But for some of them, you do not even know.

Say for example, why is it at 0.4, 0.6. If you go back and look at it, the list of, for example, metrics which they have studied, okay, which is given in the table 2 in this paper. So you would see that the metric you studied at say for example 214 meters per second plus or minus 2 and 4 meters per second and that the peak lateral acceleration response time is taken at 2 and 6 meters per second squared lateral acceleration and so on, okay.

So in fact, the others themselves agree that this kind of, you know, I wrote down a formula, why is it that it is 1.1 multiplied by something minus 0.5 multiplied by something plus, that is still not clear, right. So that is why it is purely 2 datasets connected by statistics, okay. This is just a parameter identification, okay. Some have meaning, some do not have meaning, okay. I do not know why it is 1.1, say if you look at. I mean just like that I have given from.

I do not know why it is -1.1 into yaw rate gain at 0.4 Hz, I do not know. You know that is this, that is what the statistics throws out at you. Regression analysis throws out okay and that is the value. If you ask me why 0.7, it is just a statistical output, that is all I know. I do not know more than that, why -0.7 into this, I do not know more than that, okay. So in other words, subjective objective evaluation is still in the realm of statistics, okay. It is still in the realm of statistics.

You are correlating it through statistical means, clear, okay. It is a challenge to produce a good car and you learn, okay. That is why when many of this car companies have a huge data bank, okay. So let us shift to the next topic. I know it is an interesting topic because it actually impacts design of the vehicle itself as I said vehicle dynamics, we are scratching the surface. It is a huge topic, extremely interesting, I know that there is so much of interest to the students.

It is an extremely interesting topic, we cannot complete all the things, maybe you need a couple of more course on advance vehicle dynamics. In fact, I am guilty of not covering many things connected with vehicle dynamics, for example, a lot more vibration aspects and we are not covering the effect of suspension and steering and so on. There is no time because of the limited about 35 hours of lecture we, let us at least get a view of because it is an introductory course, get a view of what happens, okay.

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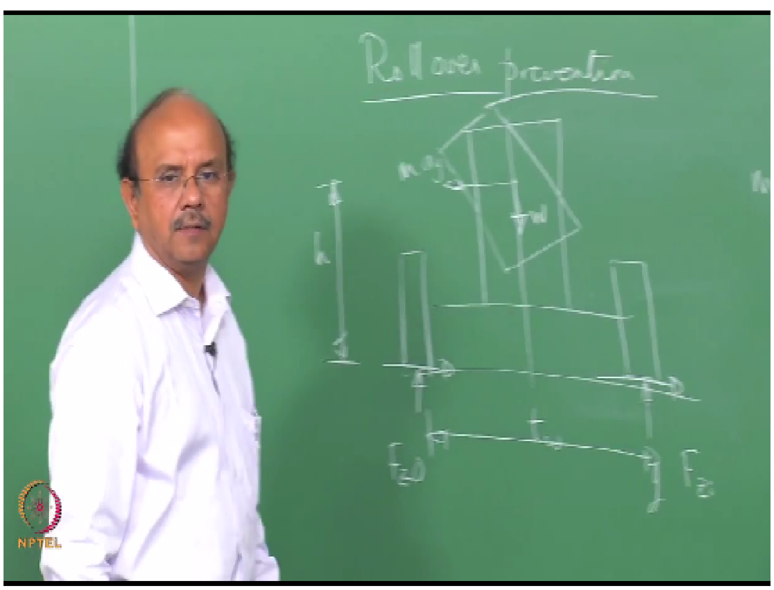

Let us get to the next topic which is rollover before we follow or we go to vertical dynamics. We are still a lot more to cover in vehicle dynamics as far as the vertical dynamics is concerned and so we will go to rollover. Rollover is a very important topic, okay, starting from SUV onwards. It seems, you would have seen lot of accidents in SUVs, sports utility vehicles, okay, where the vehicle has in no would have rolled over on the sides and you would have seen huge trucks, okay, tractor-trailers or some of them, okay.

There rollovers you would have seen it a number of times. You will be surprised to know that reason statistics shows that in United States, 15,000 vehicles rollover a year, okay. There is lot of them, okay. In our country, we have had cases where there are a number of rollovers. In fact, we had looked at some of the cases where there are rollovers of huge trucks which take cars, okay, which are manufactured, say around Chennai, there huge vehicles whose takeover, which take the cars, right.

And usually the loss is upward of 5 million rupees, okay, because of the cars that are involved. Unfortunately, in this country, we still do not have a law on how this kind of tractor-trailers are designed. In fact, what is the height and what simple ratio which we will see in a minute, you know these ratios are not followed and so on, okay. So there is a lot of scope to work on rollover and in recent times, control strategies are being used for rollover prevention.

As I said again we will not have time to go into the control strategies for rollover prevention but let us quickly understand what we mean by rollover. The simplest analysis is what I would call as a steady-state analysis where we considered the vehicle to be rigid, okay and sitting, say for example, very approximate diagram and let us say that is the center of gravity location.

Let us say that these are the centripetal forces that are required, okay in order that the vehicle takes a turn, right and that is the corresponding d'Alembert's force, okay, or the centrifugal force, okay, which is mV square/r or I would call that as m*ay, okay. Now of course there are reactions at the front and the rear, okay, and we call that as the track with, let us say that that is the track which I would call as tw, okay.

And of course the weight w acts there. Obviously you see the roll, you know, as the vehicle takes a turn. Let us say that this is the outer tire and that is the inner tire, just call that outer tire and inner tire and the f that is acting here, Fz at outer and Fz at inner. Let us define, I am defining it. Let us define that vehicle rolls over or we say that vehicle has rolled over once this F is at inner.

How is it going to rollover, I am going to take now, what am I doing, I am going to take a turn to the right. Now I am taking a turn to the right, okay. Where will it will turn over, which side, to the left, right. So I assume that the rollover condition has achieved when I lose contact of the inner tire with the road, okay. This is the condition which I must, I am assuming, right. So let us just calculate what should be the critical ay in order that this lift of the inner tire takes place.

Let me call that distance as h, okay. Now take moments about this outer tire, okay and tell me what should be this ay.

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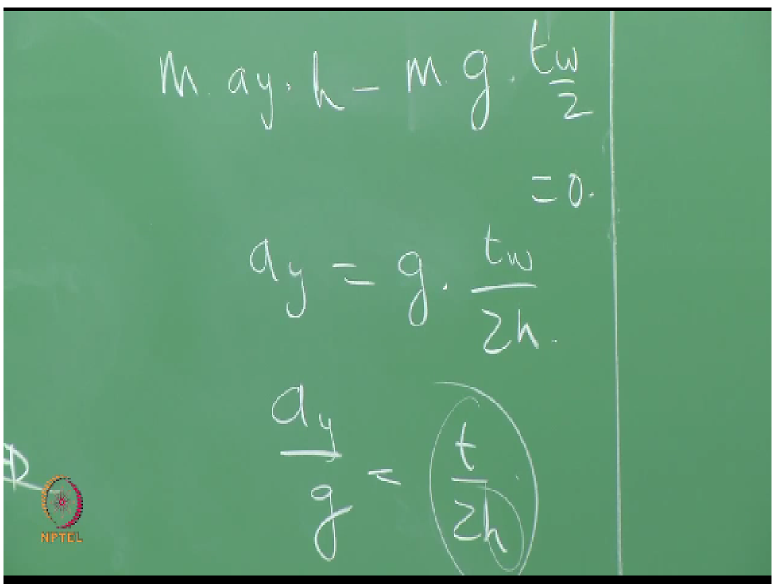

M*ay*h-w which is m*g*tw/2=0. We talked about steady state, we are not introducing the time derivatives, okay. **"Professor - student conversation starts"** (()) (37:09) rollover is 0. No this Fz inner, that is what I told you, this is not, this is nothing here there, okay. **"Professor - student conversation ends"**. So ay=g*tw/2h, this is a very famous ratio, t/2h ratio as it is called or ay/g, usually expressed as the simplest formula, okay, =t/2h.

The first thing that our commercial vehicle guys who carry those lovely cars have to do is to check what is the t/2h ratios. You will be surprised; we have done this calculation. You will be surprised to know that this is 0.22 0.23 g, in other words, t/2h is what, 0.22, 0.23, very very low. So that is the level at which, okay, that acceleration levels at which this will rollover. In A typical car, would be about 0.7, 0.8 and if you look at a the formula one cars, it will be more than 1.5, very high, okay. So the very first thing, first equation that you look at is what is called as the t/2h ratio. There are 2 things that we left here. There are a number of factors, the number of factors which would now change, t and h.

What is the assumption that we have made, we assume that this whole thing is rigid, not true. Actually the vehicle, the body what is called as the sprung mass is actually going to roll, right. There is a roll center, we have seen that and the vehicle is going to roll. So as it rolls, say in other words, as it rolls, okay, about the road center, so the center of gravity location is going to change.

So one is that h is going to be affected by the roll and hence due to the suspension and so on, okay. The other factor, and the roll is also, this is one of them. The roll is also due to the stiffness of the tire. The tire stiffness is also going to have an effect, okay. In other words, you can imagine that Fz in the inner is going to go to 0, okay. The whole of F, the Fz that is the normal force, will be transferred to this tire.

"Professor - student conversation starts" Because of this suspension roll, even t should be affected. Yes, I am coming. We will do one by one, okay. Both of them are going to be affected, okay. There are number of factors which are going to affect both, right. I know I am very happy that you are so involved but we have to go step by step, right, okay, yes. So that is also, the roll also is affected. **"Professor - student conversation ends"**.

There are 2 rolls here. One is the roll of the unsprung mass, which is basically due to the tire stiffness because of which there will be, let us say that, let us look at the suspension system or just axle system, okay, which is a rigid axle system which is there in most of the commercial vehicles. Because of this, this is going to be affected and the second one is that because on top of it, it is going to set this our sprung mass, okay and that sprung mass is now affected by the roll stiffness.

So in other words, there are factors which affect this. There are factors which affect t, okay. There are factors which affect t. T is affected by the kinematics in compliance of the suspension system. For example, it is affected straightaway even without going into the details of kinematics in compliant system, is affected by the tire lateral stiffness, okay, straightaway tire lateral stiffness. It is affected by the camber change, okay. How does this camber change and so on.

It is even affected by the torque that is produced due to the gyroscopic effects. So a number of factors affect this and this, which we will list in our next class, okay and so usually, if you design a vehicle, if this factor is t/2h= say 0.8, okay, this factory usually is, the actual factor is less by about 25%, okay. Number of these things are going to have an effect. This is going to be less by about 25%. So there are at least 4 factors which have an effect.

The major effect, maybe even 25-30% you know and so on. The major effect is because of this roll. So my first job here, right now, is to find out what is this roll and how that affects this h.

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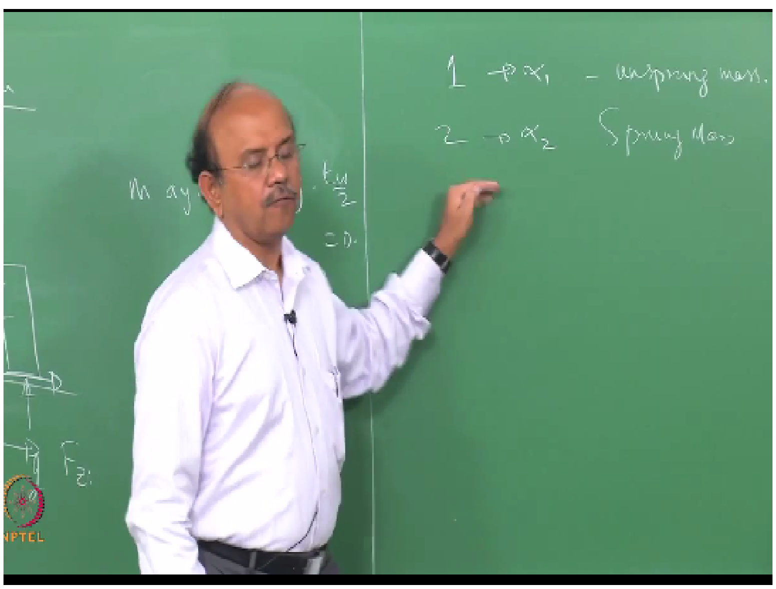

So let me consider 2 of this roll. Roll simply means that there is going to be an angle, okay, 2 of them. One, I would call as alpha 1, we are going to follow for this derivation, the reference is that Road Vehicle Dynamics by George Rill, Road Vehicle Dynamics, which is very simple derivation which takes into account of this. And if you want slightly more detailed, I will give you one more reference, again due to, okay which may be next class.

I will give you that reference, I do not have it right now. So these are the couple of references which talks about this, but one of the things which we have not done here is that we have not considered actually the dynamic effects. In other words, I have to write down a differential equation based on phi double dot, i.e. phi double dot and so on. That we have not done, you know that is the next step.

The more interesting part is, okay, let us just finish this, I will come to this. Okay, one is this alpha 1, the roll of the unsprung mass and alpha 2 which is the roll due to the sprung mass, okay. WE will do this, we will do the detailed derivation in the next class and finish this topic. I just want to tell you that what we are doing is actually not dynamics, even when I include these 2, we are not doing dynamics, okay.

So we have to do dynamics. In other words, we have to understand the dynamic behaviour in roll and that becomes very important in order to design, okay, control systems for preventing roll, okay. There have been number of papers and thesis on how to write down these equations. In fact, it goes back to the 1950s, write down these equations and then the recent attempt has been to rewrite the equations in state space and use a number of standard controls strategies, okay.

So we will talk about alpha 1 alpha 2 and its effect on this parameter in the next class, right, okay. So any questions. We will stop and we will continue in the next class.