Modelling and Simulation of Dynamic System
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Lecture – 33
Simulation of Plantar Mechanisms

I welcome you all in this lecture on simulation of plantar mechanisms, which is a sub module for the course on modeling and simulation of dynamic systems through, which you are going through. There are many plantar mechanisms, which we come across and the most popular and most basic one is the four-bar mechanism and in this lecture today we will be seeing how can we simulate a 4 bar mechanism.

Now, there can be many ways of doing the simulation using simulation for the four-bar mechanism and the method could be say we can write the conventional expressions for the four-bar mechanism okay and then we simulate by writing say C or C++ codes or we can draw say the bond graph model for four-bar mechanism and then we can do the simulation that is generate the system equations for that four-bar mechanism.

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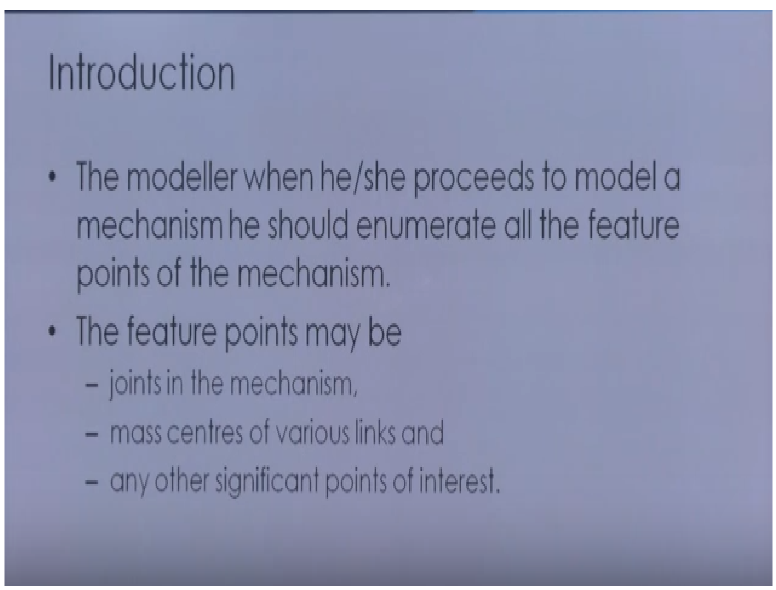

Then, we can go for the simulation, but here what I am going to discuss today is that is simulating using the MATLAB okay, so MATLAB yes now when we talk about the simulation of the mechanism now you see mechanism is made of many links and joints okay, so when we are talking about simulation of the mechanism then we are interested in seeing how much these joints rotates or where the link points moves, how the link point moves.

So, here basically what we are interested in that seeing the location of the points when the mechanism has got emotion and these points feature points maybe as I said joints in the mechanism, it could be mass center of various links or any other significant point of interest okay.

So this it could be like that, say if I am talking about a plantar rowboat and I want to say simulate it, then my interest could be say seeing how by what amount the individual joints of the rowboat rotates and where my tip is going okay, so I am interested in knowing the Cartesian tip coordinates okay, so this could be my aim of simulation. Now here in this lecture I am going to discuss how can we create a model in Simscape and using its Multibody features okay.

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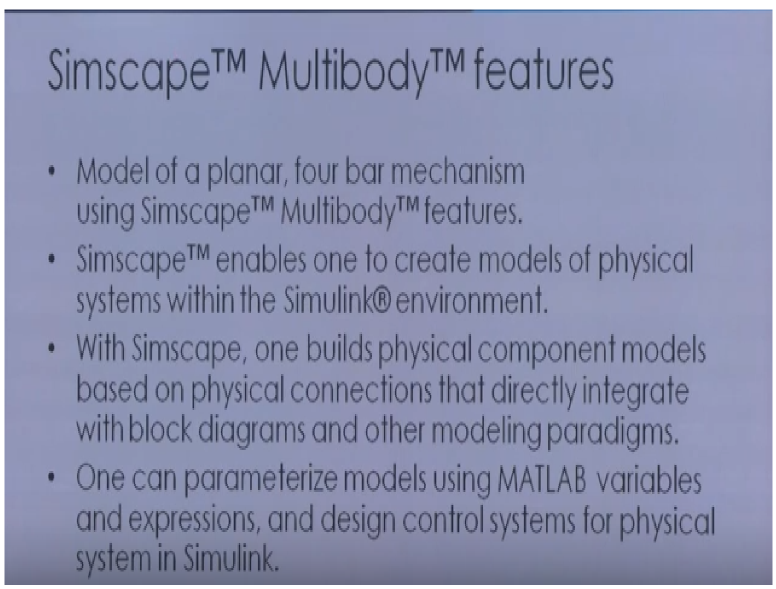

Now here, we will be modeling the plantar four-bar mechanism using Simscape Multibody features. As I said the Simscape is basically enables one to create model of physical system within the Simulink environment. We have already seen a simulation using the Simulink in our earlier lectures and with Simscape one builds physical component model based on the physical connection that directly integrate with block diagram and other modeling paradigms okay.

One can parameterize model using MATLAB variables and expressions and design control system for the physical system in the Simulink, so this is what we can do in the Simscape. Let us take as I said here I will be discussing that how can we simulate a four-bar mechanism okay, so the four-bar mechanism as all of us know consists of four linkages connected through the 4 revolute joints okay.

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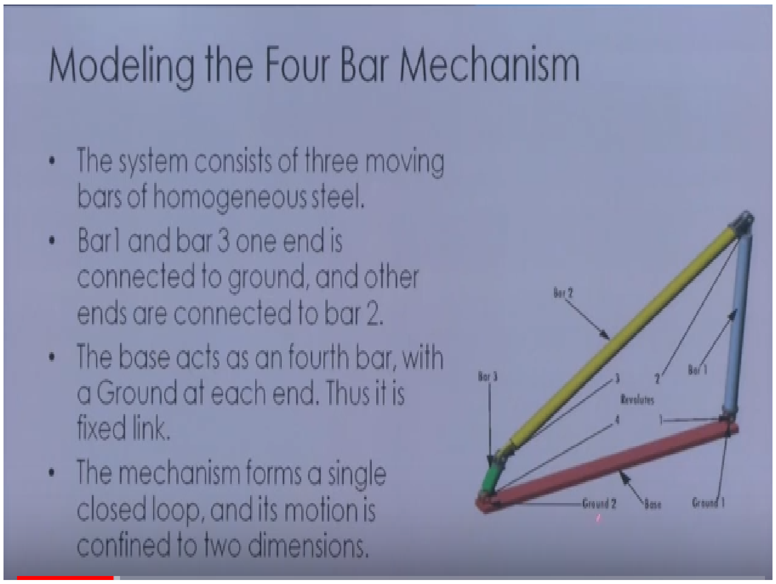

So here this link, which you are seeing, this is the base or what we can call it as the ground link and then we have the bar 1,bar 2 and bar 3, so these 3 are the movable links okay and these are connected through each other through the revolute joint here, so the first revolute joint is between bar 1 and ground. Similarly second revolute joint is between bar 2 and bar 1, the 3 revolute joint is between bar 2 and bar 3 and the fourth revolute joint is between bar 3 and the ground okay.

So, the system consists of three moving bars of homogeneous steel let us take and bar 1 and bar 3, one end is connected to the ground and other end is connected to the bar 2 as we have seen. The base excess the fourth bar with ground and this is the fixed link okay and as you can see that this mechanism forms a single closed loop and its motion is confined in two dimension only.

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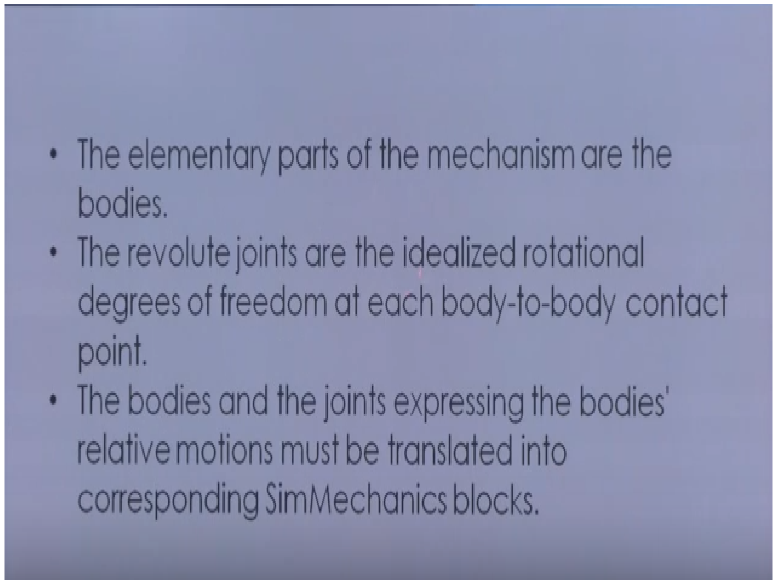

Now the elementary part of the mechanism are the bodies here, the revolute joints are the idealized rotational degree of freedom at each body to body connection point and the bodies and the joints expressing the bodies relative motion must be translated into the corresponding same mechanics block okay, so this is how if you do we can do that. Now before we move first let us see how many degrees of freedom the four-bar mechanism has okay.

So, the students in general say that since there are 4 revolute joints, it has got the four degrees of freedom, but this concept is wrong okay. For open kinematic chain, 4 revolute joints means four-degree of freedom, but as we have seen that this is a closed chain, so here that concept is not valid okay, so let us try to derive that how many degrees of freedom the four-bar mechanism has okay, so here you see that there are 3 moving bars and that are constrained to move in a plane.

Now each bar has got 2 translational and one rotational degree of freedom, so if a bar is in space say if a bar is in space, it has got the three-degree of freedom that is it can move in X direction, it can move in Y direction and it can rotate about Z axis, so the bar has got three degrees of freedom.

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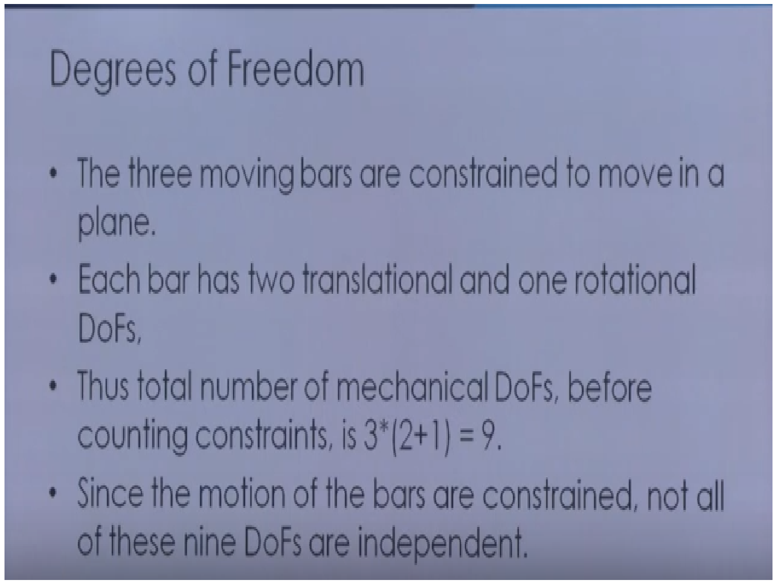

Now the total number of mechanical degree of freedom before counting constraint here is the three- degree of freedom okay for the 3 bars, 2 partition and 1 rotational okay, so total we are going to have the 9 degrees of freedom, total number of mechanical degrees of freedom before counting the constraint is 9.

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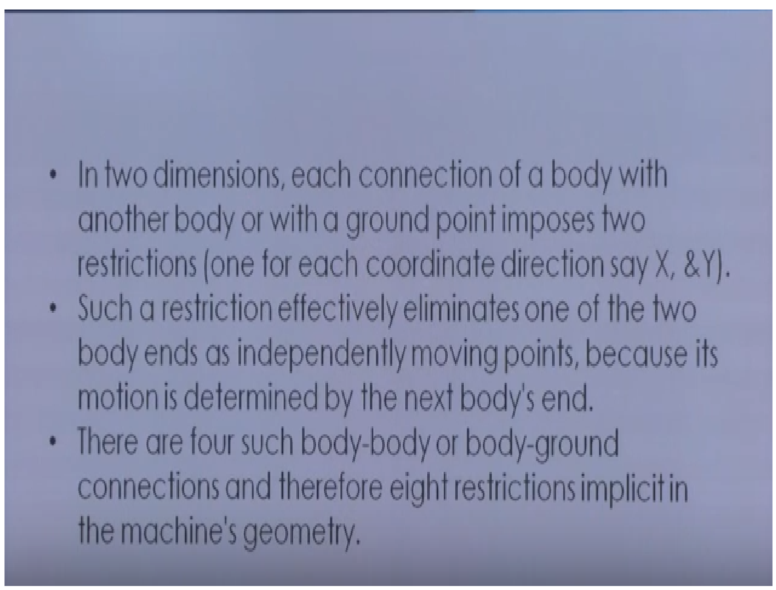

Now, since the motion of the bar are constrained not all of these 9 degrees of freedom are independent and you see that in 2 dimensions is connection of a body with another body or with a ground point imposes 2 restrictions okay, because the coordinate if we are going to connect say this to another link, this coordinate is going to common in this body, as well as in this body okay.

So with one connection, basically we are losing the two-degrees of freedom, s 2 mechanical degrees of freedom we losing, so with 4 connections, we are losing a 8-degree of freedom, so the total degrees of freedom will be 9 - 8 that is 1, that is a 4 bar mechanism has essentially got one degrees of freedom and that is what is explained through these slides okay.

So, such a restriction effectively eliminates one of the 2 bodies hence and independently moving points because its motion is determined by the next body N okay, so since there are 4 such body ground connections, therefore 8 restrictions are implicit, so the effective degrees of freedom are going to be 9-8=1, all right, so thus we can say that a 4-bar mechanism has got 1 degrees of freedom.

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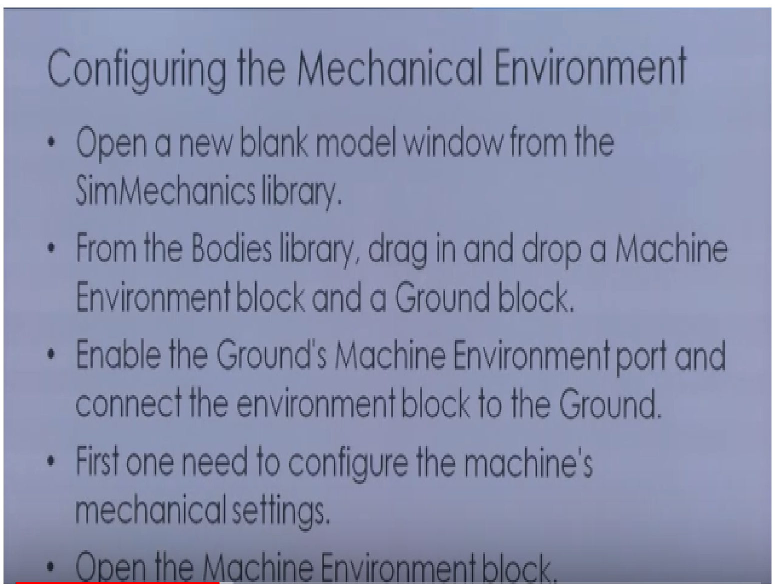

Now before we move configuring the mechanical environment, we need to configure the mechanical environment in the Simscape okay so to do that what we do is that we open a new blank model window from the SimMechanics library and from the bodies library drag and drop the machine environment block and the ground block, then we enable the ground machine environment port and connect the environment block to the ground.

First one need to configure the machine mechanical setting so for that we need to go to the open the machine environment block. so this is the machine environment block and here you can see that this is the block dialog box that appears and here we have the parameters, we specify parameters, we specify constraint, we specify the linearization is to be done and we specify the visualization here okay.

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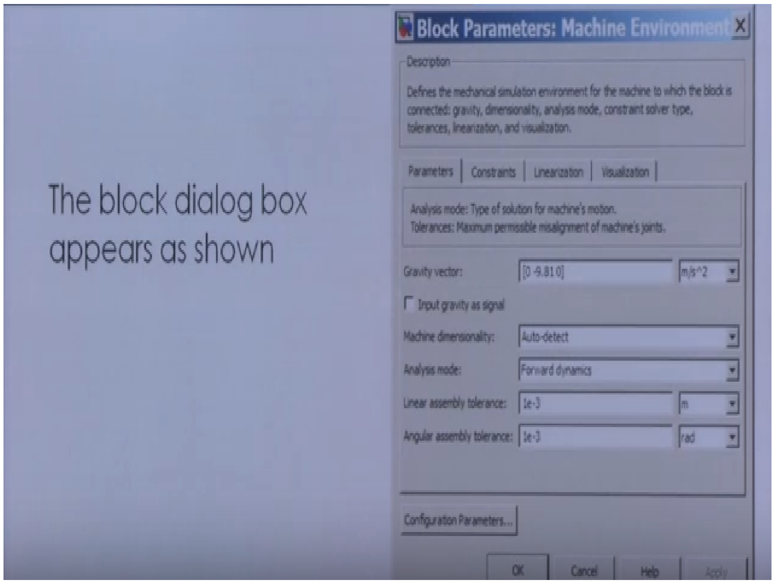

The gravity vector is specified here, the gravity is taken minus in the download Y direction, so we have -9.81 here then machine dimensionality is auto-detect, analysis mode is forward dynamics and we provide the tolerances for linear assembly, as well as the angular assembly, so this is how this dialog box appears for the setting of the environment dialog box okay.

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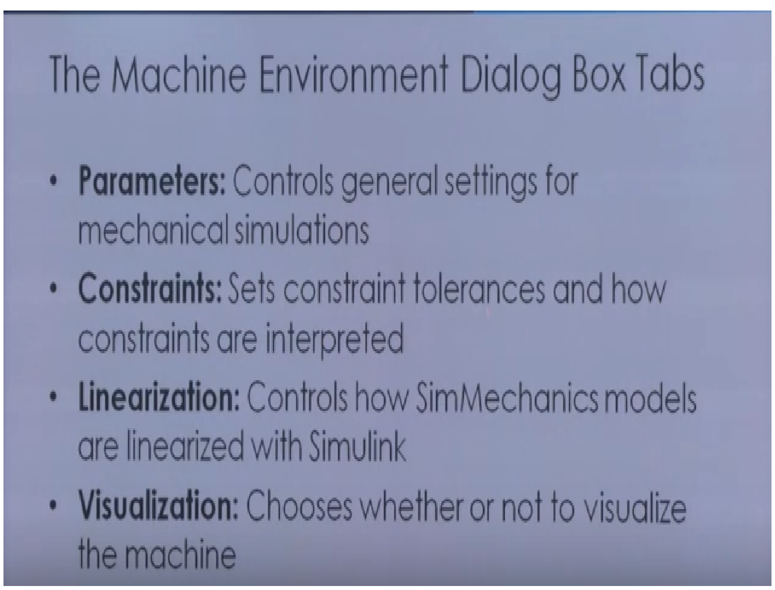

So, the parameter as I said it contains general setting for the mechanical simulations, constraints, set constraint tolerance and how constraints are interpreted then we have the linearization block, it controls how SimMechanics models are linearized with Simulink and then we have visualization, choose whether or not to visualize the machine.

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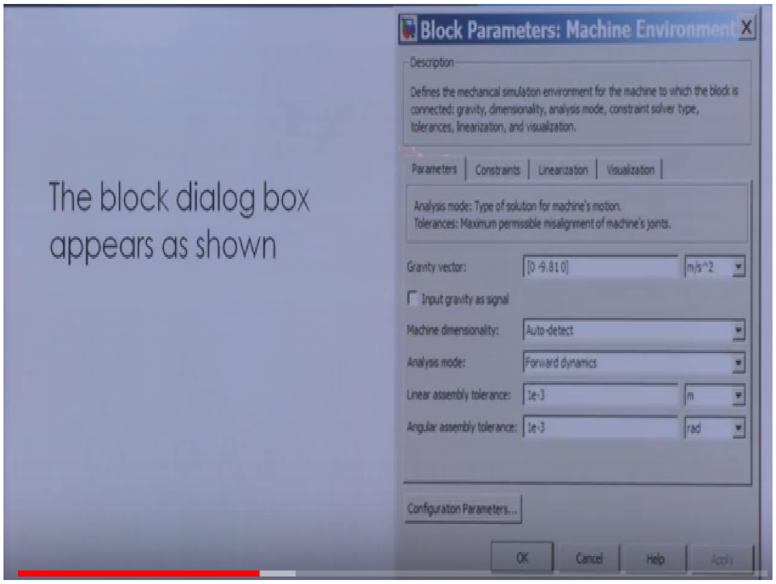

So, this is the explanation of what we have seen in the 4 blocks here,4 tabs, parameter constraints linearization and visualization okay. Now some important features of the Machine environment dialog box, tabs, the gravity vector field will specify the magnitude and direction of the gravitational acceleration and as it sets the vertical or up-down direction, linear and angular assembly toleration feeds are also set here.

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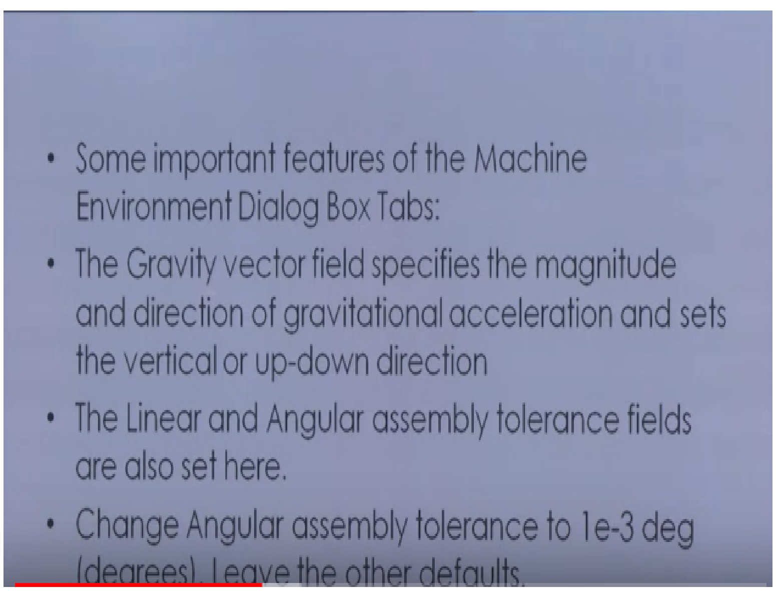

The angular assembly tolerance is set to 1 exponential -3 degree and other fields are left as the default, then for starting visualization to visualize the bodies as you build on the model go to the SimMechanics node of the configuration parameter dialog box okay and select the display machine after updating the diagram checkbox okay, if you want to animate the simulation latter. Now when you run the model select the show animation during simulation check box as well.

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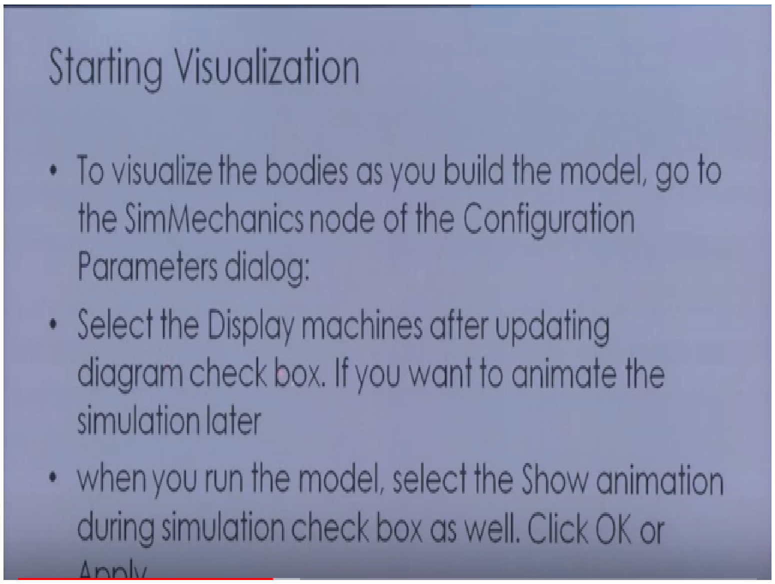

Click ok or apply, then of course we can select update diagram from the edit menu and then visualization window will open, then the menu will come, select body geometric then ellipsoid and as you add change bodies in your model, you can update the display in your window at any time by updating your diagram. Now next is setting up the block diagram, now in this setup you create bodies, position them, connect them to joints and then configure the body and joint properties.

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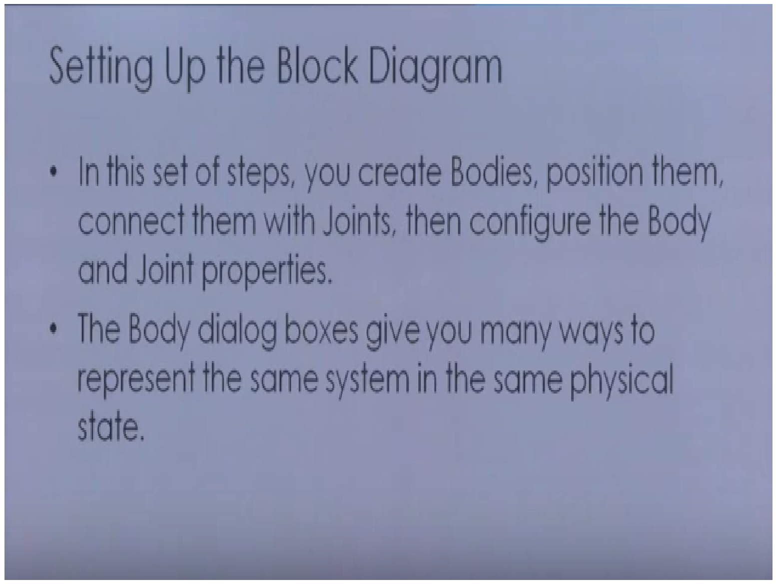

The body dialog box gives you many ways to represent the same system in the same physical state, so we can also do the mat file data entry, the geometric and mass properties will need to specify for the grounds and bodies in this model are listed in the tables of the configuring, the ground and the joints and configuring the bodies okay.

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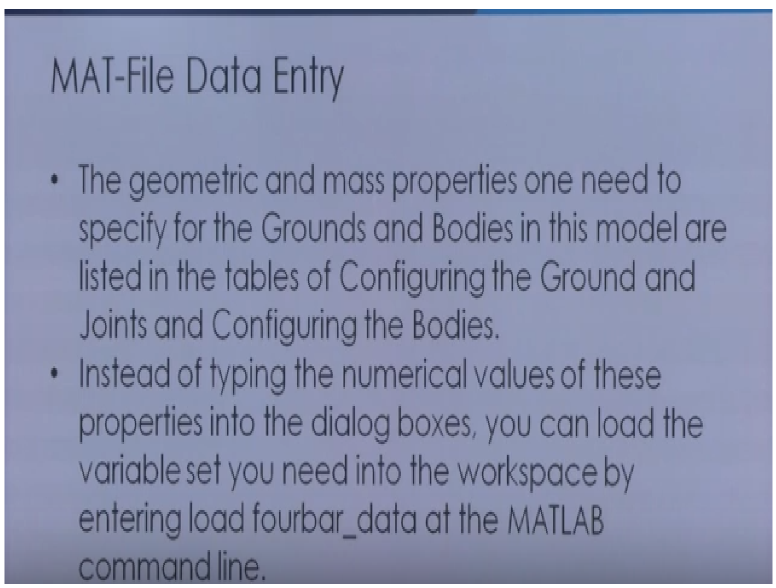

Instead of typing the numerical values of these properties in the dialog box, you can load the variable set you need to the workspace by entering say some four-bar data in the MATLAB command line, so this way we can load the parameters directly rather than typing them individually in the dialog box. Now the variable name for each property is given in the table, just enter the appropriate variable name in the appropriate field as you come to them in the dialog box.

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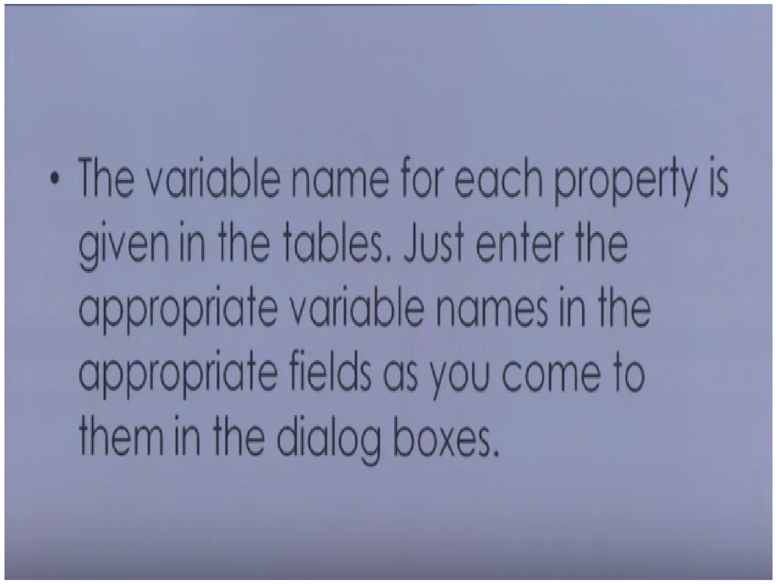

Then it will pick up the values, now block diagram set up. Your model already has one environment block and one ground block, which we have done earlier then assemble the full model with these steps. Again, we go to the block library, open the body library, drag and drop another ground block and the three body blocks into the new model window and then close the body's library.

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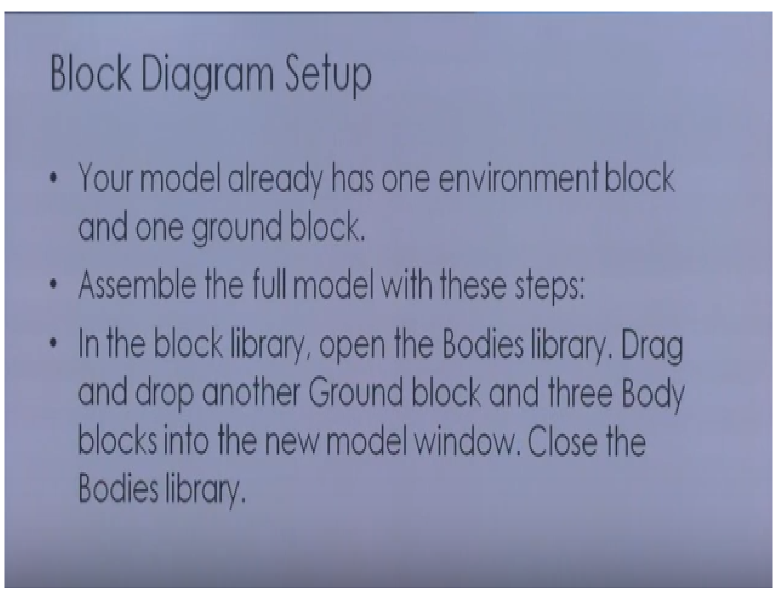

Because we had to get one ground block for the other end and for the 3 body blocks for the 3 linkages, now from the joint library, we drag and drop the 4 revolute blocks into the model window and rotate and connect the blocks in the pattern shown or with an equivalent block diagram topology.

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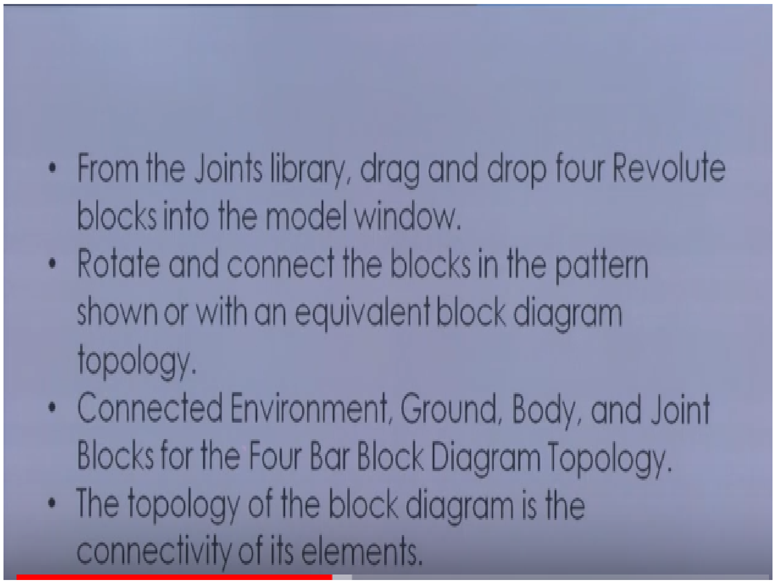

Now connected environment, ground, body and joint blocks for the four-bar block diagram topology okay and the topology of the block diagram is the connectivity of its elements, so this is how this looks like you can see here is the ground one, then you have the bar 1 and between ground 1 and bar 1 is the revolute joint okay and here we specify the B and F that is the base and the follower okay and here in the bar 1 you can see that there is a coordinate system one at one end and the coordinate system 2 at the other end.

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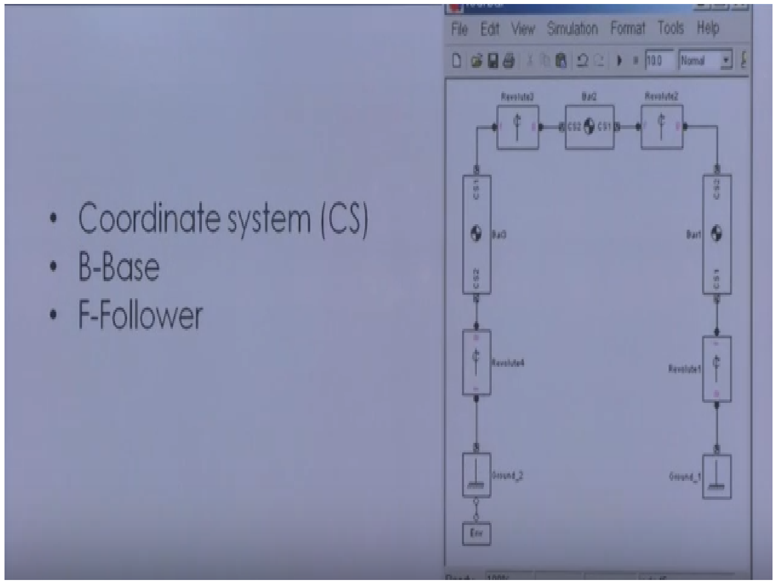

Similarly, we have between bar 1 and bar 2, we have the revolute joint 2, between bar 2 and bar 3 we have the revolute joint 3 and between bar 3 and the ground 2, we have the revolute joint 4, okay so this way we can set up the block. Now, the elements are the bodies and the ground is connected by the joints, unlike the model of modeling and simulating a simple machine, the four-bar mechanism is a closed-loop mechanism.

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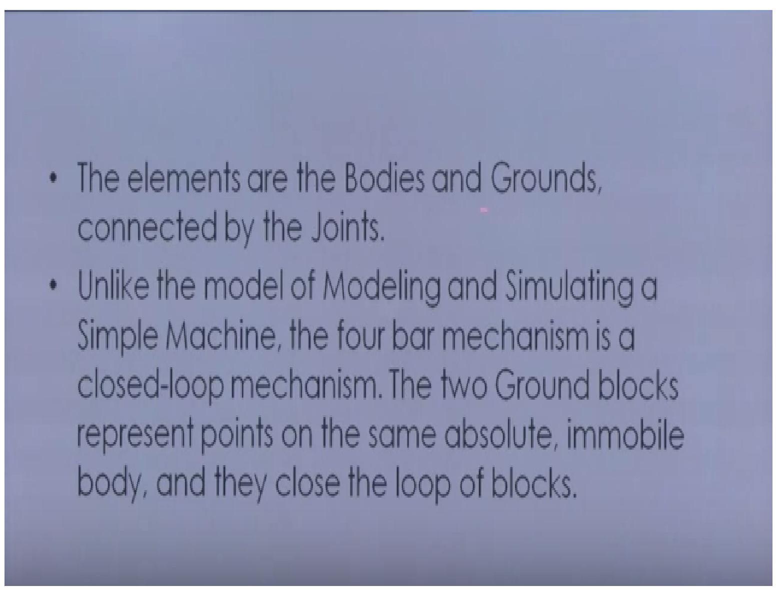

I have discussed earlier itself and the 2 ground blocks represents the point on the same absolute immobile body and they close the loop of the blocks now to maintain consistent body motion direction make sure that the body coordinate system, CS which I have just talked both pairs on each body follow the sequence say CS1-CS2,CS1-CS2 for each bar moving from ground 1 to ground 2 that is from right to left as it has been shown here okay.

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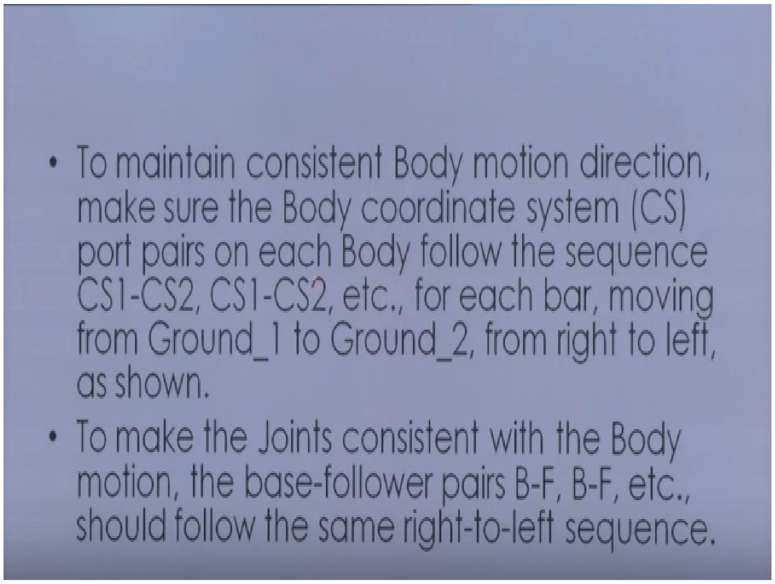

From right to left we have the CS1-CS2,CS1-CS2,CS1-CS2, this way it is made okay and then to make the joint consistent with the body motion the base follower pair that is B-F,B-F, etc. should follow the same right to left sequence as I told you here that is this is base follower, then we have based-follower, base-follower, base-follower, so the same sequence has to be followed moving from right to left, then configuring the ground and joint.

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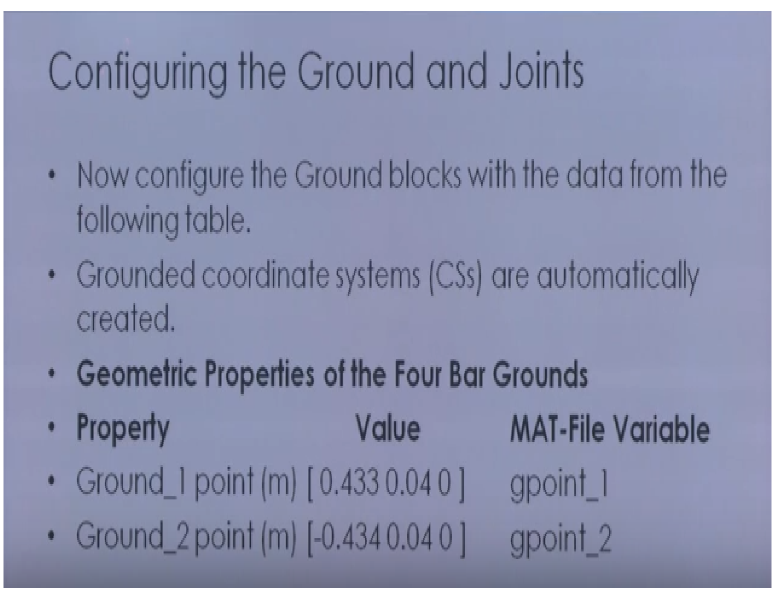

So we have to configure first the ground and joint, so configure the ground block with the data from the following table grounded coordinate systems are automatically created okay, so the geometric properties for the four-bar ground can be given say property ground, 1 point ground, 2 point, we are specifying essentially the X and Y coordinate here, so this is XY coordinate, this is XY coordinate for the first ground and for the second ground.

We can specify some MAT file variable if we have to pick up the value from the file directly. The base of the mechanism has these measurements the base one is a base is horizontal with the length of say 86.7 centimeter, so ground 1 represent the ground point, which is 43.3 centimeter to the right of the word coordinate system origin and ground to represent the ground point, which is 43.4 centimeter to the left of the word coordinate system origin okay.

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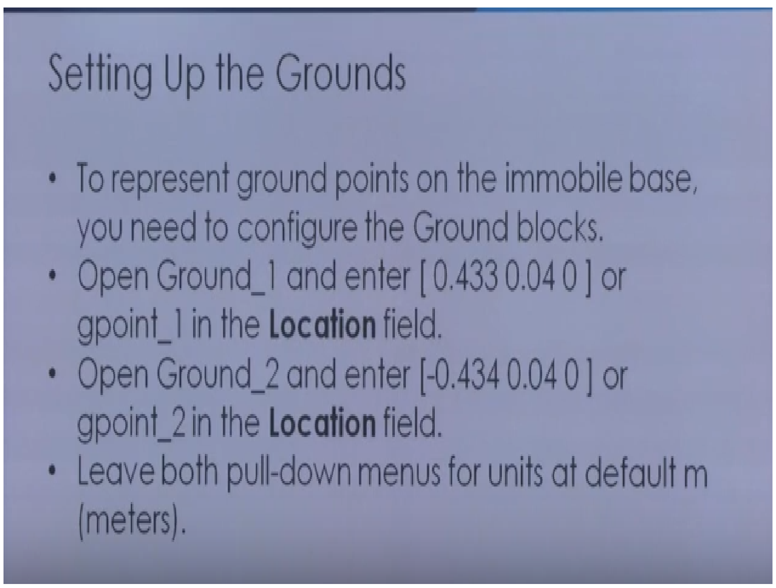

The bottom revolute are 4 centimeter above the origin that is why here I am specifying this by 0.04, this is point 0.04 and this is 0.433 this is 0.134, so this is how it is specified. Then setting up the grounds, now to represent ground point in a immobile base, you need to configure the ground block, this we have already done.

Open ground 1 and enter this data okay in the location field and open ground 2 and enter this X and say Y data okay on ground G2 in the location field and leave both pull down menus for the units at default meters, so this way we have specified the joint location for the 2 ground points, so this is how it appears block parameter ground 1, so here I am specifying say X coordinate and here I am specifying say the Y1 and here is for the ground 2, here I am specifying the X and Y here okay.

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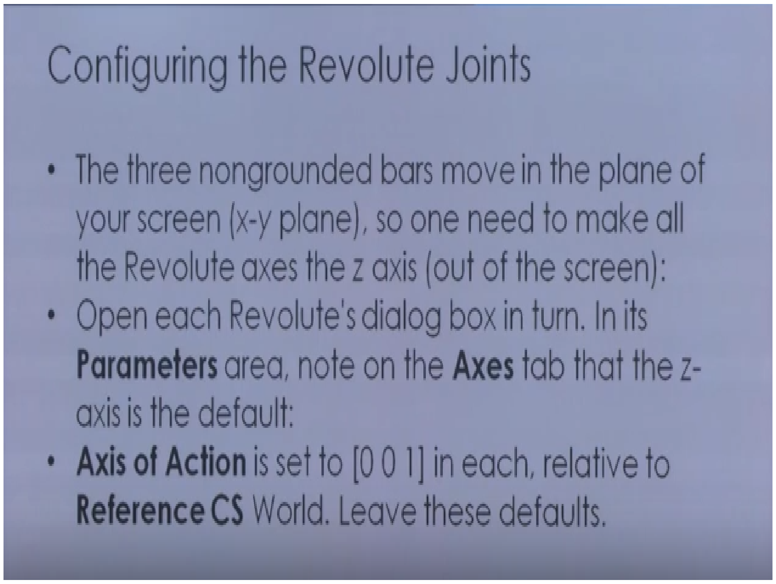

So this is how it is done here is the default unit meters, then after configuring the ground joint between ground and the bar, next is configure the revolute joints. Now we have the three non grounded bar moves in the plane of your screen, so one need to make all the revolute axes the Z axis, now also open each revolute dialog box in turn and its parameter area note on the access tab that is the Z axis in the default.

Now axis of action is set to 001 okay here this 1 basically indicates that it is rotation about the Z axis okay in each related to the reference coordinate system word, leave these defaults. Now a revolute block contains only one primitive joint, a single revolute degrees of freedom, so the primitive is automatically revolute its name within the block is R1 that is revolute 1 and leave this revolute joint block defaults and ignore the advanced tab.

The body coordinate system and base follower joint directionally should be set up as shown in the block diagram, which we have seen previously, ground, body and joint blocks for the four bar. Now in the connection parameter area that the default joint directionally for each revolute automatically follows the right to left sequence of the grounded and the body coordinate systems.

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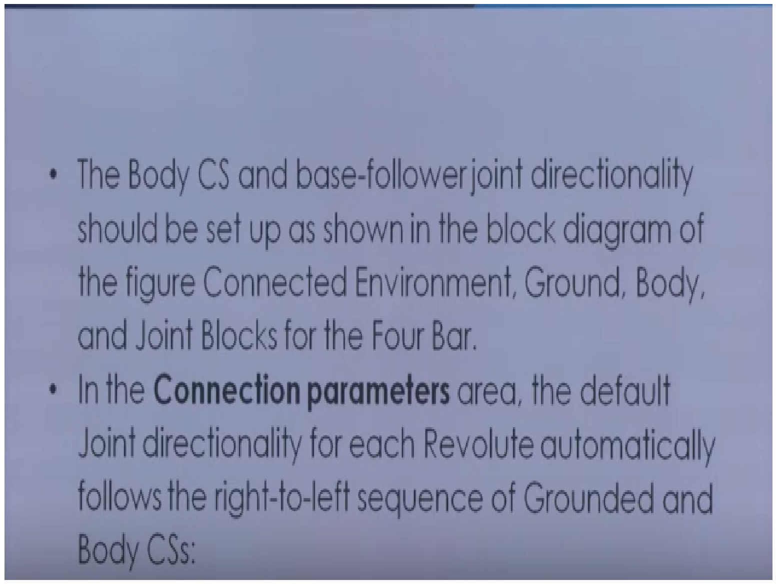

So this is how what we have set up and this is how we specified for revolute 1 say this is my revolute 1, so this is based to follower B2 and this is between ground 1 and CS1 of bar 1, so this is how we specify revolute 1. Likewise, we specify revolute 2 that is this is revolute 2 base to follower okay so CS2 of bar 1, so you can see here this is CS2 of bar 1 and this is CS1 of bar 2 okay and CS1 of bar 2.

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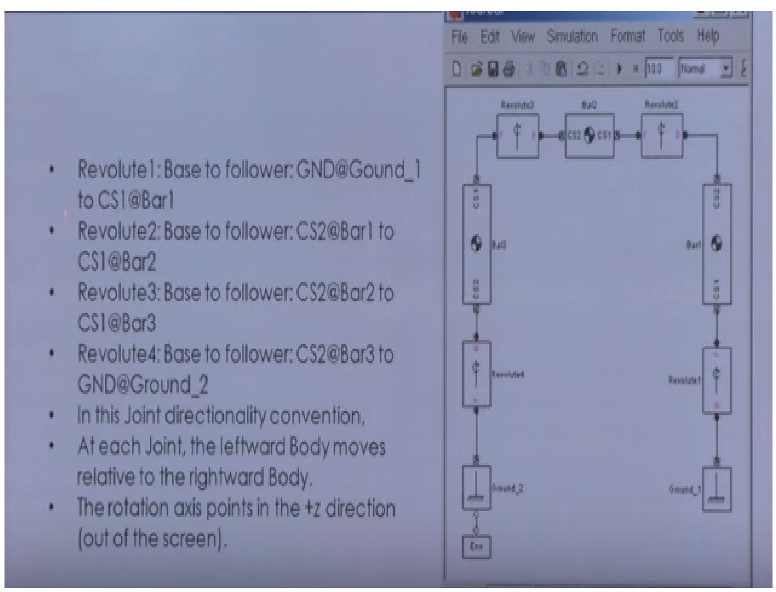

Likewise I can specify revolute 3 and revolute 4 okay and this way we can do that and each joint, the leftward body moves relative to the rightward body and the rotation axis points in the positive Z direction, which is out of the plane of this screen. Now looking at the mechanism from the front of the figure a four-bar mechanism, the positive rotational sense is counterclockwise okay.

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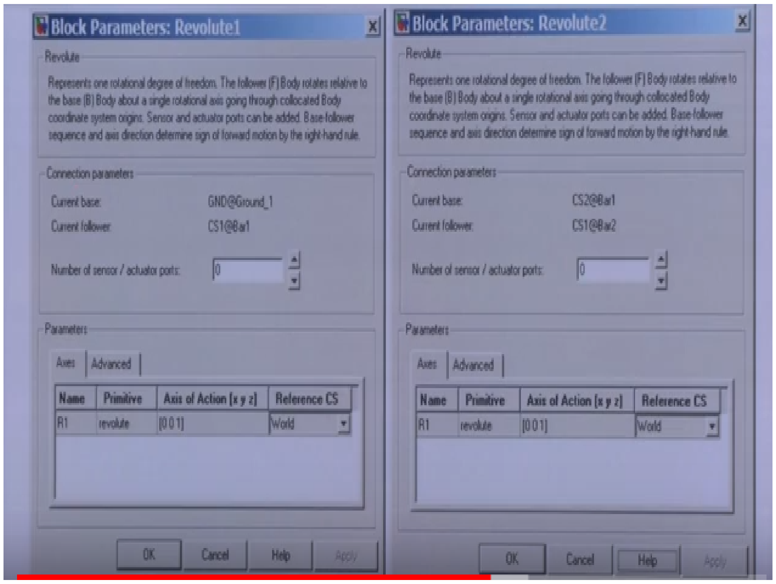

All joint sensor and actuator data are interpreted in this sense only, so this is how we specify the block parameter for the different joints say revolute 1 and revolute 2, so here we specify the current base ground one and the follower is CS1 of bar 1 okay and here now we are not specifying the number of sensor actuated ports.

Here is the specification for the revolute 1, R1, the primitive revolute, axis of rotation 0011 because it is rotation about Z axis and the reference coordinate system is the word, likewise I can specify for the revolute 2 and likewise we can specify for revolute 3 and for the revolute 4 joints okay, so this way we can specify all the four revolute joints okay and after specifying the joints, we specify the bodies okay that is we configure the bodies.

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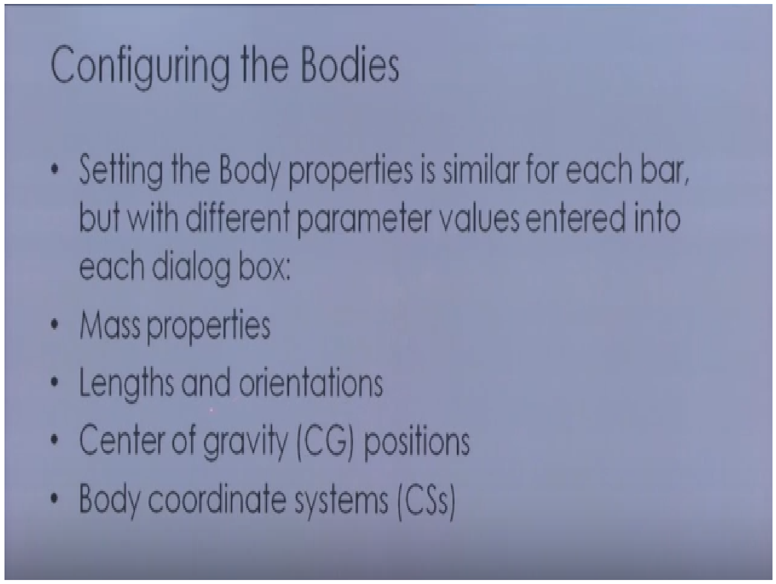

Now setting the body properties is similar for each bar, but with different parameter values in turn into each dialog box and what all parameter values we need to enter is the mass properties, we need to enter the length and orientation, we need to enter the center of gravity positions and we need to enter the body coordinate systems okay.

So these four parameters we need to specify for the each bodies, so here we specify the body coordinate system origin on the bars in relative coordinate okay and the components of the displacement vector for each body coordinate system origin continued to be oriented with respect to the word axis and the rotation of each bodies CG coordinate system access also with respect to the word axis of course in the Euler XYZ convention okay.

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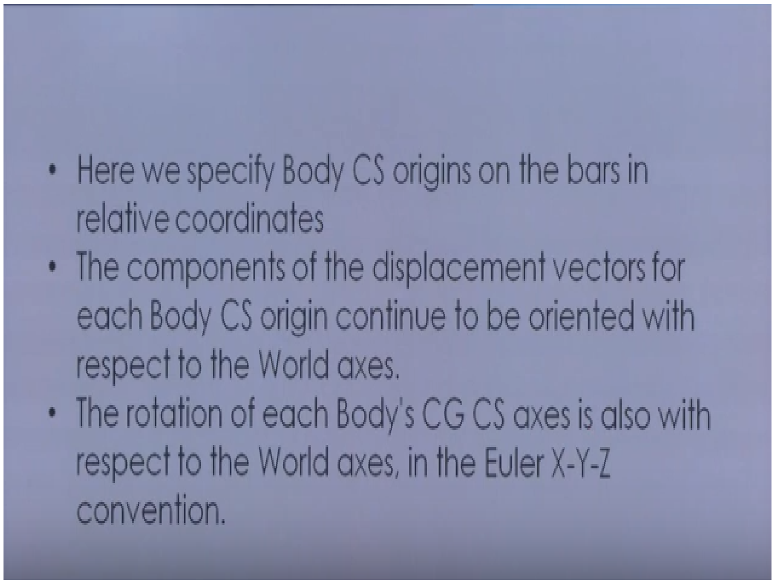

If you want to understand what is Euler X-Y-Z convention, please refer to any of the say dynamics book or the book on robotics on how the body orientations are represented in X-Y-Z convention. Here the Euler X-Y-Z convention okay. In case of Euler, the orientations are represented in the rotating frame, so this is what we want to say specify for bar 1 mass and body coordinate system data say MKS unit.

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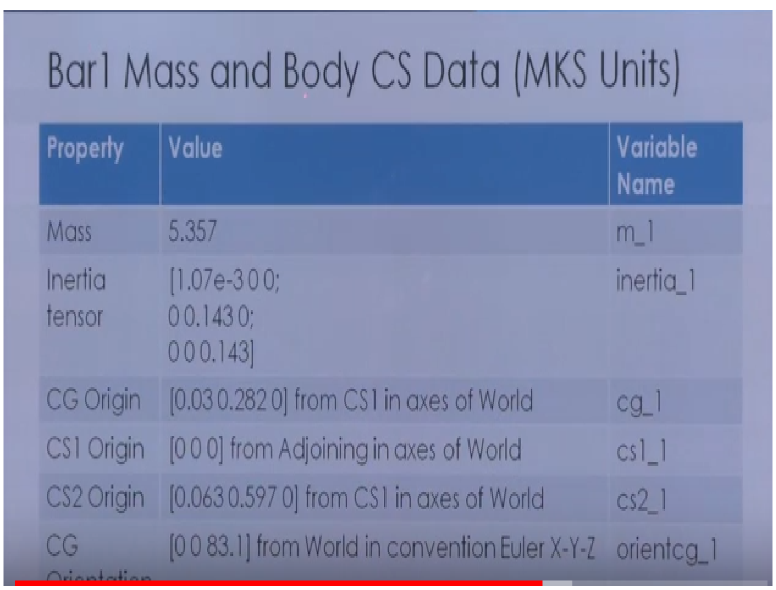

Property	Value	Variable Name
Mass	5.357	m_1
Inertia tensor	[1.07e-3 0 0; 0 0.143 0; 0 0 0.143]	inertia_1
CG Origin	[0.03 0.282 0] from CS1 in axes of World	cg_1
CS1 Origin	[0 0 0] from Adjoining in axes of World	cs1_1
CS2 Origin	[0.063 0.597 0] from CS1 in axes of World	cs2_1
CG Orientation	[0 0 83.1] from World in convention Euler X-Y-Z	orientcg_1

So I specify the mass, I specify the inertia of course here it is a say we are talking about the principal axis, so I am specifying just IXX, IYY and IZZ then the CG origin, I specified the XY coordinate, CS1 origin here and CS2 origin and the CG orientation from the word in convention

Euler XYZ, so this way we are specifying all right here we can give the some variable names also, here is for the bar 2 mass and body CS data, so say bar 2 mass.

Then inertia tension for the body bar 2, the CG origin location here, the CS1 original location from the adjoining in axis and CS2 origin location with respect to CS1 and then the CG orientation okay, so this again is specified likewise I specify for bar 3. Now these parameters can be inserted in the dialog box also, let us see how we configure the dialog box for entering those parameters.

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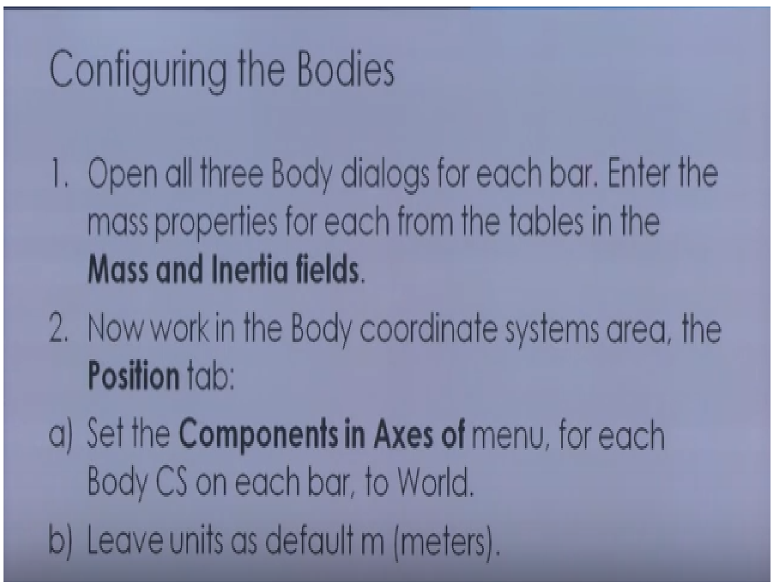

So configuring the bodies, open all the three-body dialogues for each bar, enter the mass properties for each from the tables in the mass and inertia field and then work in the body coordinate system area, the position tab, set the component in axis menu for each body CS on each bar to the word and leave the units as the default meters okay, then set the body CS property for each body CS on each bar from the data of the preceding table.

Enter the body CS origin position data for CG CS1,CS2 on each bar from the table said the translated from origin menu entries for each body CS, body CS on each bar according to the value of the tables and then select the orientation, then orientation vector has to be selected, choose word for relative CS in each case and leave the other fields, actual value, so this is what how we specify the block parameter for bar 1.

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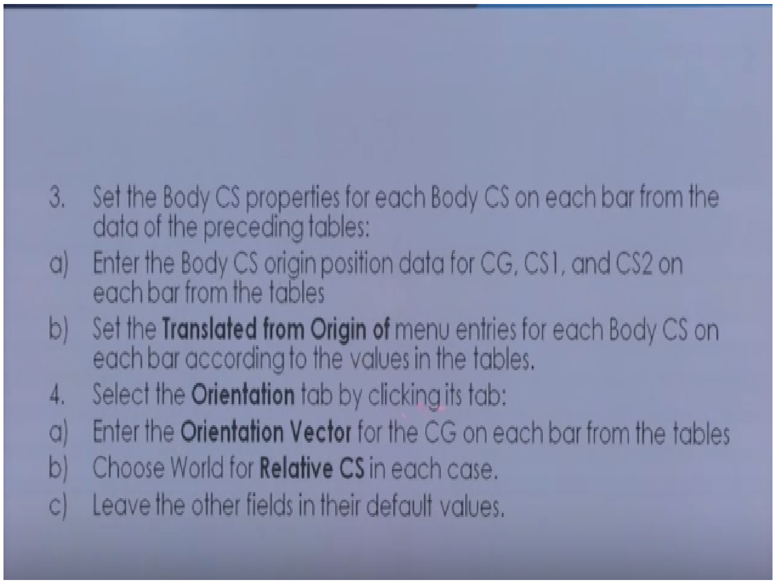

So this figure is same figure, which essentially shows the connection and here this is my bar 1 okay, so bar 1 for bar 1, I enter the mass properties here, the mass and here this is how the inertias are entered, you have the units here kg and kg meter square, then here we show the position, show ports whether these ports are to be shown or not then port site, the name CG CS1, CS2 and these are the same values which we have seen there in the table.

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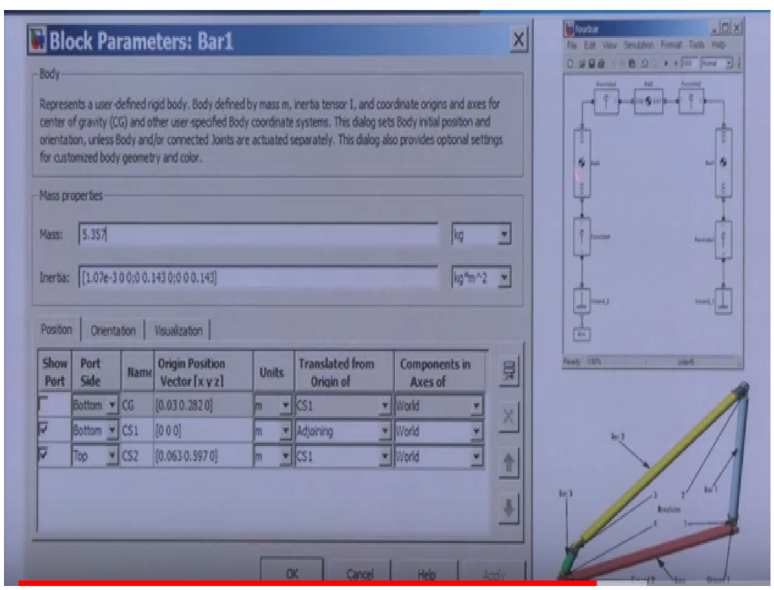

Then units translated from origin of whether it is CS1 adjoining or CS1 and component in axis of word, so this is how we specify for bar 1 okay, so likewise I specify for say bar 2 and I specify for bar 3, okay so the 3 bars mass and inertial properties, as well as location of the various coordinate system and the CGs are done, then we can go for the visualizing the bodies and here we can see that this is how we can visualize, so this is my bar 1,bar 2 and this is my bar 3.

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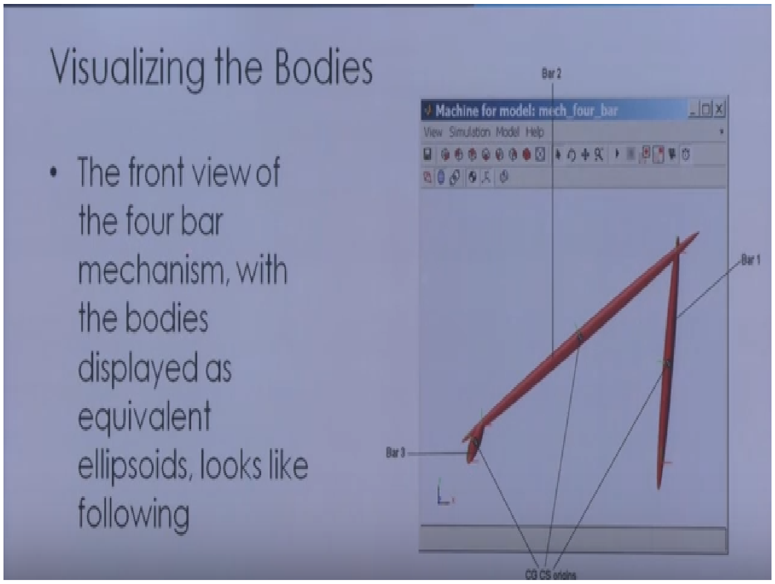

The ground is not shown as the bar here, but these two ends are fixed on the ground okay, so the front view of the four-bar mechanism with the body displays the equivalent ellipsoid looks like this one so this way we can create the four-bar mechanism. Then let us to simulate we need to put the sensing motion and running of the model, so we can finish building of model by setting initial condition and inserting the census.

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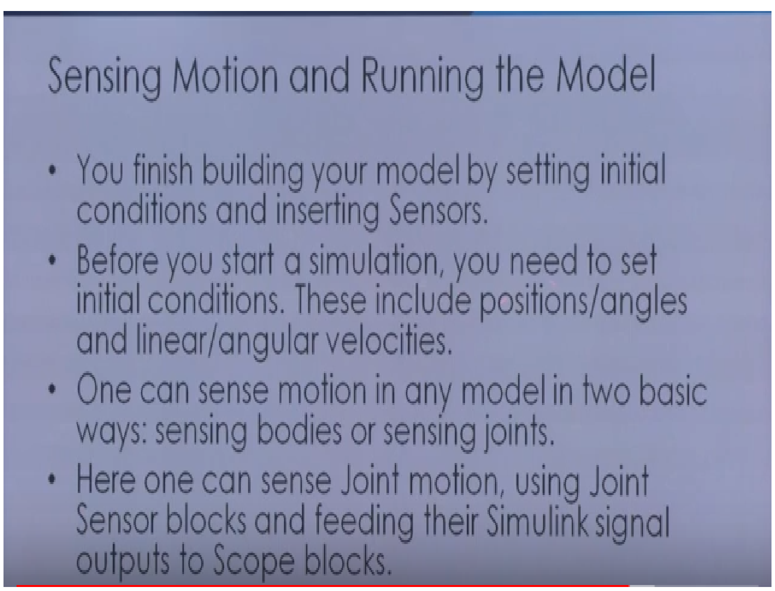

So why we need to insert the sensor because we want to measure the joint angles okay by what amount the joints have turned that we need to measure so for that we need to insert the sensors, so before you start simulation you need to set initial conditions these includes position and angles and the linear and angular velocities.

One can sense motion in any model in 2 basic ways sensing bodies or sensing the joints. Here one can sense joint motion using the joint sensor block and feeding their simulation signal output to the scope block of the Simulink, then you can see that. So here connecting the joint sensor, so here you can see that I am connecting a joint sensor to revolute joint say 3, which is joint sensor 1 and again another joint sensor to the revolute joint 2.

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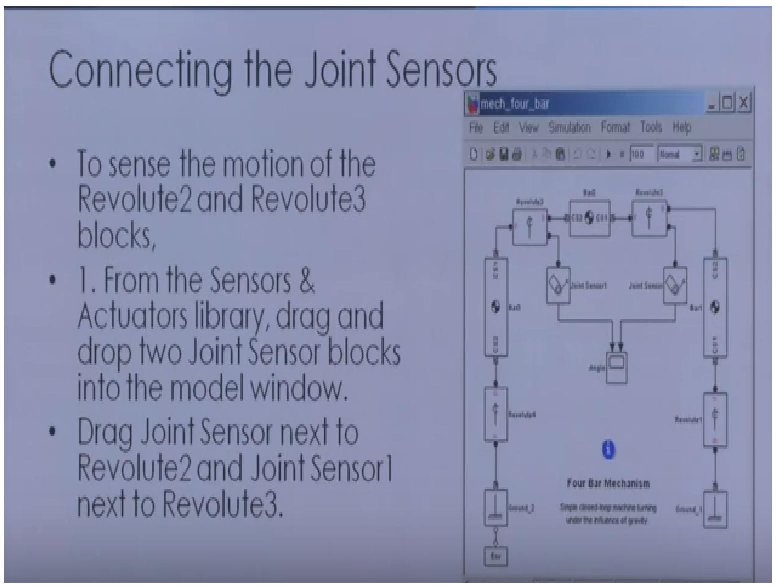

I am connecting this to the scope in order to see the angle okay, so to sense the motion of the revolute 2 and 3 blocks from the sensor actuator library, drag and drop to joint sensor block into the model window and drag joint sensor next to the revolute 2 and joint sensor 1 next to the revolute 3, so this is my joint sensor 1 and this is my joint sensor 2 and then before one can attach the joint sensor block to a revolute block.

You need to create a new open round connection port on the revolute okay, then only you can connect, so open revolute 2 dialog box and then connection parameter area in the middle adjust the spinner menu, number of sensor actuator port to value 1 and then click ok that one port will be created. Now connection port appears on the revolute 2 and then you can connect that to the joint sensor.

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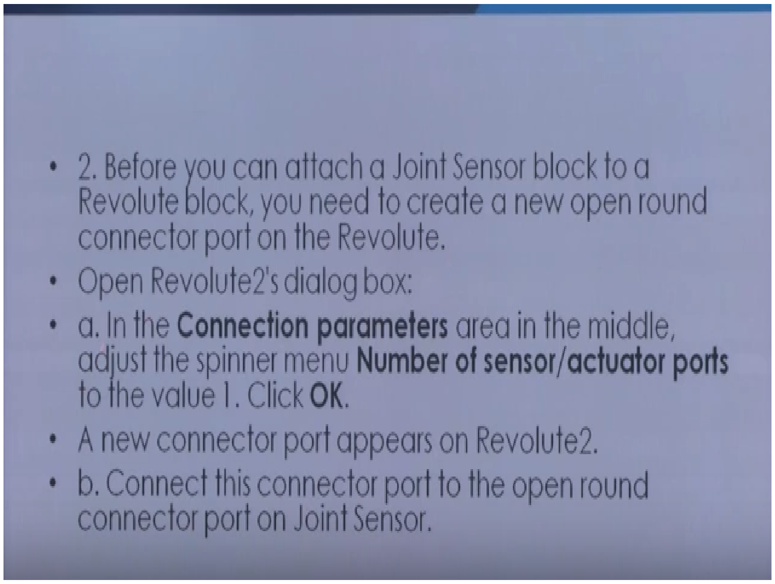

Now we can repeat the same instant for the revolute joint 3 also and create one connection port on the revolute 3 and connect this port to the joint sensor 1. So it is this connection port basically, which I am talking about, so you have to create this port and then connect the joint sensor here, create this port and connect the joint sensor here, so this way you can do that okay, then the graphical plot of the joint motion with a scope block, which is our ultimate aim.

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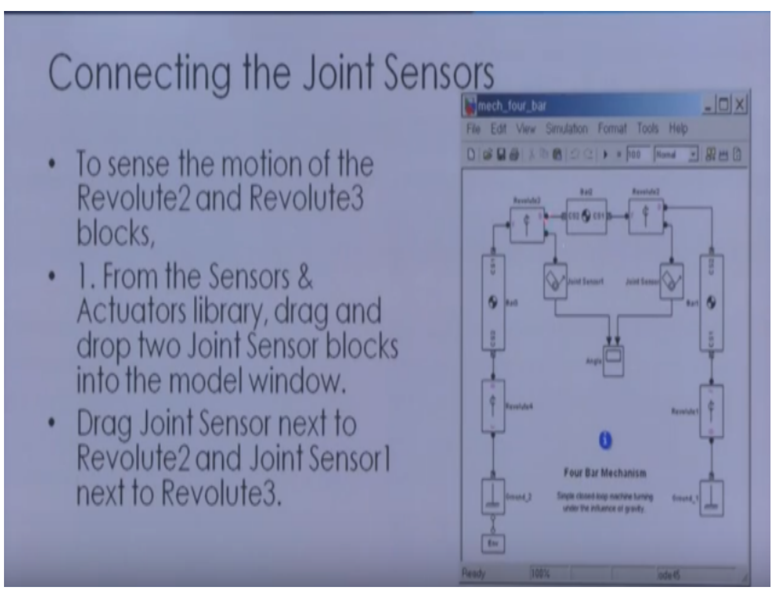

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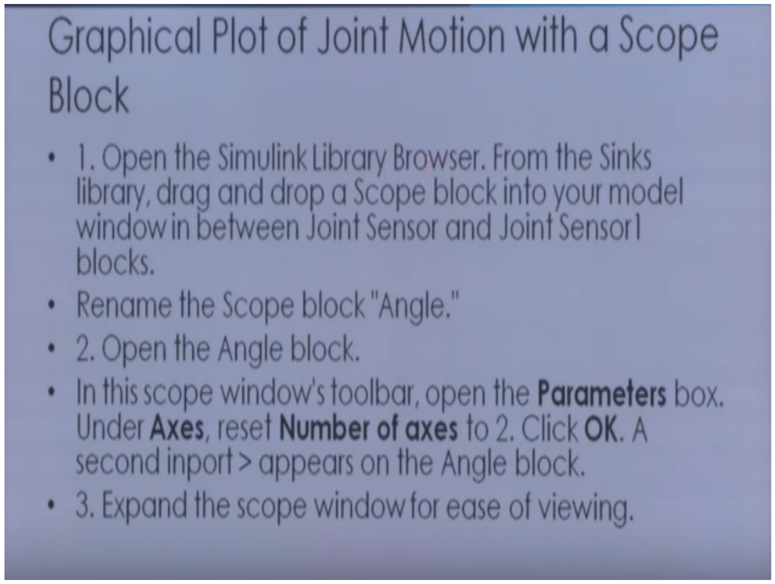

So to do that what we can do the open the Simulink library browser and from the sinks library, drag and drop the scope block into your model window in between the joint sensor and joint sensor 1 block here so this is what we put here from the Simulink library and rename the scope block as angle and then we can open the angle block and in this scope, windows toolbar.

Open the parameter box, under axis reset the number of axis because we have 2 axis that is we want to measure the joint rotation of the second and the third revolute joint, so I set the number of access to 2, click okay and then second input appears to the angle blocks. Expand the scope window for ease of view okay and then connect the joint sensor and the joint sensor 1 block output to the angle block and open the joint sensor and the joint sensor 1.

The measurement area connected to the primitive is set to R1 in both blocks indicating the first and only primitive revolute inside revolute 2 and revolute 3 to which each sensor can be connected and second select the angle checkbox in order to measure the angle okay and then we can after that we can configure and run the simulation.

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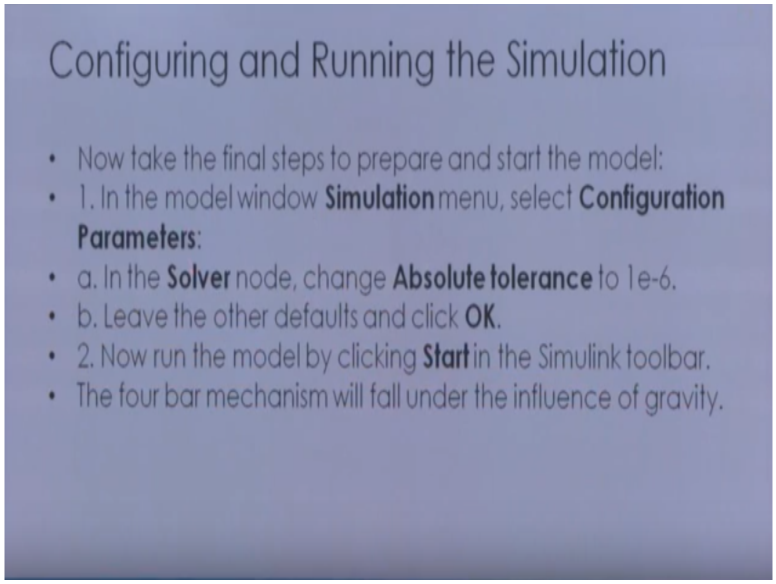

So take the final step to prepare and start the model in the model window simulation below select configuration parameter in the solver node, change absolute tolerance, we have to give some tolerance, leave the other values to default and now run the model by clicking start in the Simulink toolbar and the four-bar mechanism will fall under the influence of gravity initially and then what will happen, you will see that for this, this is the simulation how it looks like.

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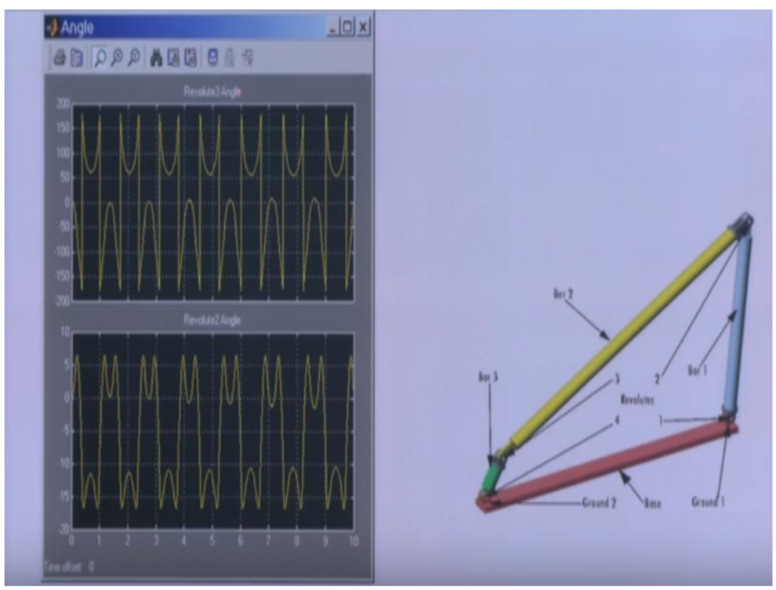

Here is the revolute angle 2 that the revolute 2 angle and here is the revolute 3 angle, so this is how you are going to see this for this four-bar mechanism okay and we can observe certain things from this simulation and these things are that the mechanism starts from rates with the initial velocities at 0, thus the initial state of the forward system is just the geometric start that you set up in the immediately preceding section.

We have done that and setting up of the block diagram, now the assembly at the first fall over the right and then revolute 2 angle decreases and then what happens your bar 3 turns out whereon and bar 2 and bar 1 turns back to the left and the revolute 2 angle reverse in the direction, so we can see that this first goes like this then comes and then it goes up okay and the revolute 3 sweeps through complete turn, angles are met in the interval of -180 to +180 and exhibit discontinuities.

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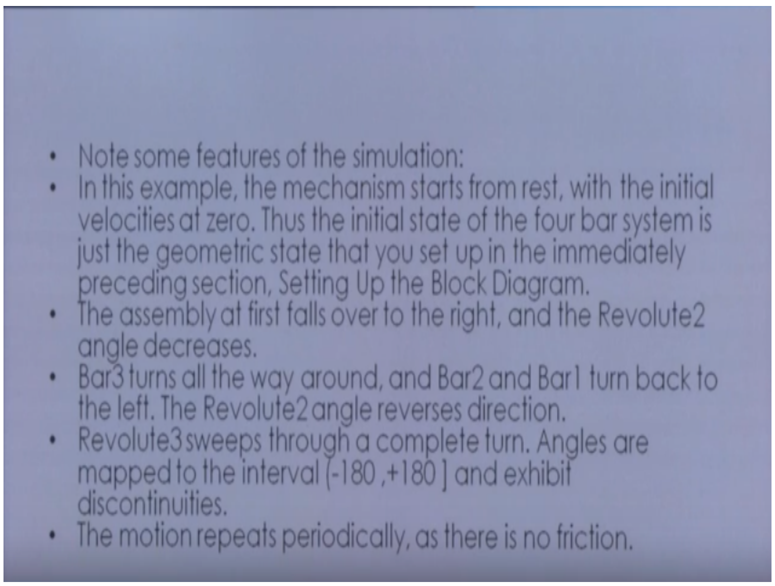

The motion repeats periodically as there is no friction, so there is no decaying of the angle and since we have not modeled the friction okay, so this way we can simulate the four-bar mechanism all right and I will ask you to go to the Sim scape and repeat the same exercise to see that you can do that and you can simulate the other inversions of the 4 bar mechanism also okay.

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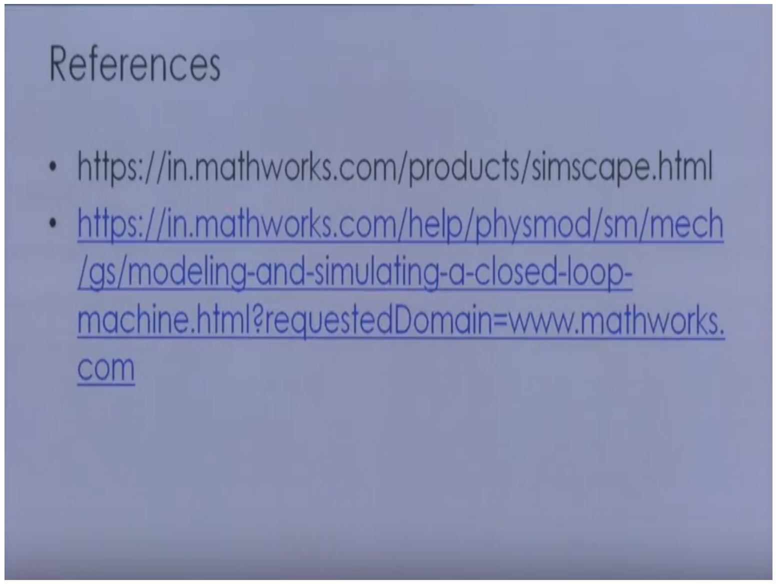

So this is all if you want to have a look at for the help, please look at the math work website, where you will find out further help about creating of the model for the mechanism okay, thank you.