Rocket Propulsion

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Lecture No. #03

Rotational Frame of Reference and Oribital Velocities

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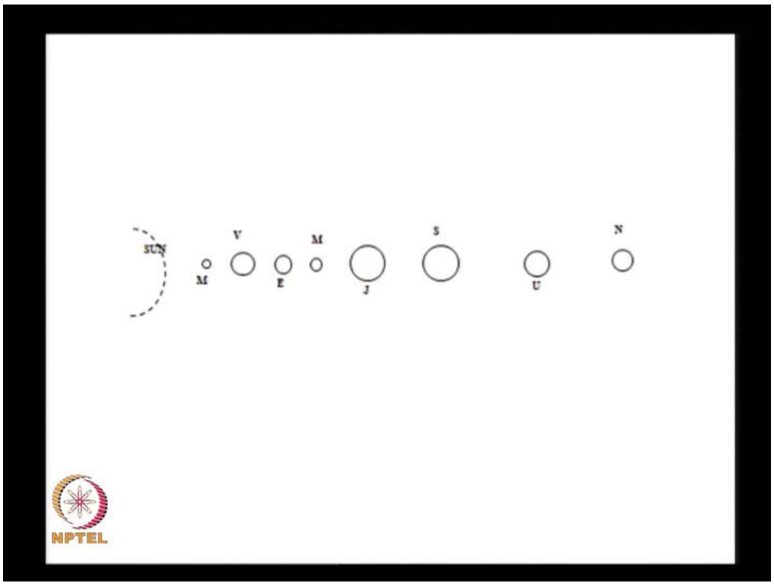

Good morning in today's class we will address the orbital requirements of satellites and therefore, what rocket should be doing. You know in last the class just to refresh ourselves on what we learnt we told ourselves there are something like eight planets revolving round the sun. We said these planets consisted of Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune. We also told ourselves that is there was one planet called Pluto which is no longer considered to be a planet because it is not dense. Having said that you know there is lot of interest in exploring the different planets and I will take two examples

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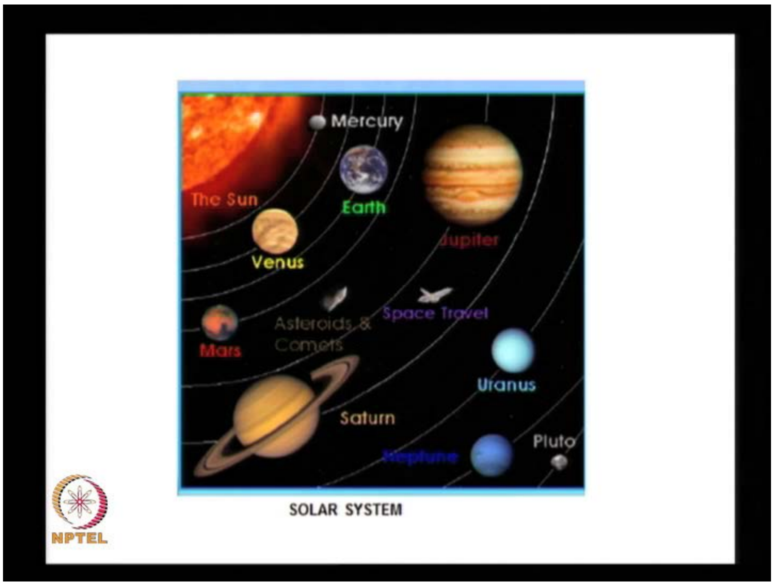

The first example is one or let us say this is again the repeat of what I just now told you may be your centrally the sun which is shown in red there you have about it may be mercury as after that may be Venus then earth and the different planets see inbetween you also see some asteroids which we talked about it in the last class I will I will precisely come back to this point a little later,

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But having said that you knowwe had alaunch vehicle known as new horizon launch; that means, it is a rocket which goes and finds out what is happening in the Kuiper belt beyond Pluto you know if you take the time taken to go to Pluto this was launched in January2006 it is supposed to reach there in another 4 or 5 years something like it takes something like almostten years to reach Pluto and what does it consists of it consists of series of rocket one about the other and the purpose of this course at the end this course of we should able to size up our orbit we must be able to put things in rocket such that we can achieve as specific mission and that is where I showed

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New Horizon Spacecraft

And thenext slide shows may be something like a space craft which this particular rocket launches and it goes round and round the planet what what we are interested in therefore, this goes and looks at the Kuiper belt that is beyond Pluto

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The next slide I show here the a launch which took place some three days back it was on august 52011 it was an atlas centaure rocket this again from U S it is supposed to have something known as a Juno mission this is supposed to go and look at Jupiter you know as per Greek mythology Ithink we must have some general understanding you know Jupiter supposed to be a god and his wife is known as Juno therefore, they have named it as Juno mission and again we will have to be able to find a rocket which will meet such missions and that is what this course is all about

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Planet	Mass(kg)	Diameter(km)
1. Mercury	3.302×10^{23}	4,880
2. Venus	4.869×10^{24}	12,104
3. Earth	5.974×10^{24}	12,756
4. Mars	6.419×10^{23}	6,805
5. Jupiter	1.899×10^{27}	142,984
6. Saturn	5.685×10^{26}	120,536
7. Uranus	8.683×10^{25}	51,118
8. Neptune	1.024×10^{26}	49,528

Having said that in the last class we also looked at the different planets we looked at the mass of the different planets the diameter the distance from the sun and so on. One thing we must keep in mind is the earth's mass is around 5.974 into 10 to the power 24 kilograms and its diameter is 12756 the smallest planet is our mercury which is 1.3 diameter of the earth and the largest we said is Jupiter which is quite quite considerably big planet right having said that we also plot in terms of moon we said that the earth moon is smaller than mercury in size and there are 31 moons which are available in solar system of the milky way galaxy having said that

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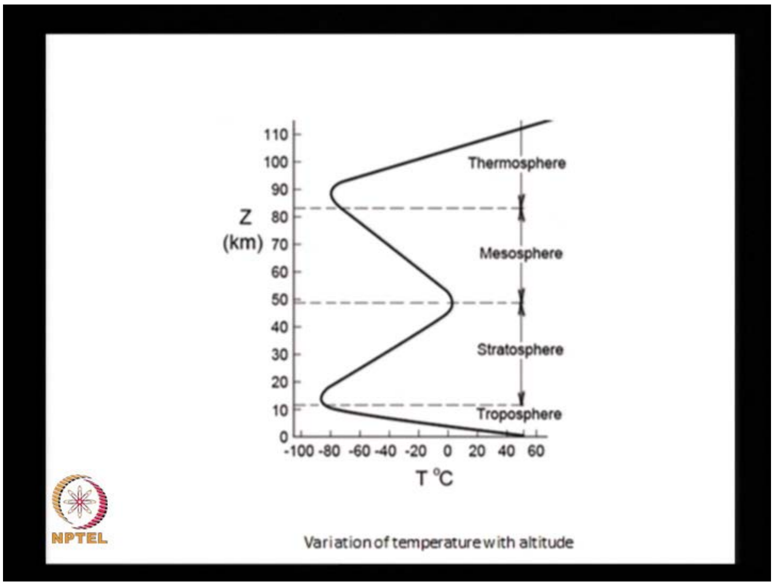

We also plot in terms of atmospheric because Iasked a question what is the difference between an rocket and an aeroplane and other vehicles you all told me a rocket is something which flies in vacuum it really not vacuum anything which goes in space is what we called as a rocket and we talked in terms of the temperature variations above the surface of the earth the y axis here shows altitude the temperature is shown on the x axis we told ourselves because the earth gets heated by the sun the layer of air above the earth gets heated and therefore, the temperature drops from a high value of around 40 degree centigrade atthe surface of the earth to a low value around minus 60 to 80 degree centigrade at a height of around around10kilometres

and at that height you know that is the height around which an aeroplane flies may be a jet aircraft flies at altitude between 8 and 10kilometres above this height again the temperature drops and it drop I amsorry the temperature increases, that means in the troposphere just above the surface of the earth the temperature drops and after some particular height between 10 and 15kilometres above that the temperature increases again the increase is because the ozone gas which is available there absorbs the heat energy.

But then you keep on going on higher and higher altitudes, say around 50kilometres beyond that you know the amount of air available is very small therefore, there is nothing really to absorb the heat and therefore the temperature begins to raise again. Whereas, when you go to extremely high values around 80 85kilometres and so on, the individual atoms like oxygen atom combines with oxygen molecule to give out heat and again the temperature increases, but then the pressure monotonically falls and in thermosphere there is hardly any pressure therefore, the concept of temperature no longer holds good.

It is the individual molecules which are in high temperature or which are moving at high velocity whereas, there is no continuum we cannot even talk of temperature it is a fictitious temperature and therefore when we talk of rockets it goes through the troposphere stratosphere mesosphere into the thermosphere and further is where the rocket flies.

I think this must be clear to each one of us is there any any confusion between let us say why the temperature decreases above the surface of the earth the place where an aircraft flies is around 8 to 10kilometres where the temperature is around minus 45 to minus 50 degree centigrade then you have the stratosphere mesosphere where the temperature again increases a and the thethethetemperature again decreases in the stratosphere the temperature increases because of ozone a aaozone absorbs heat radiation mesosphere not much gas there in the thermosphere we have no no continuum and the individual atoms and molecules react toliberate heat and you have something which is not continuum we say molecular region right is it clear oris there any question now let us go ahead what else we we do in last class

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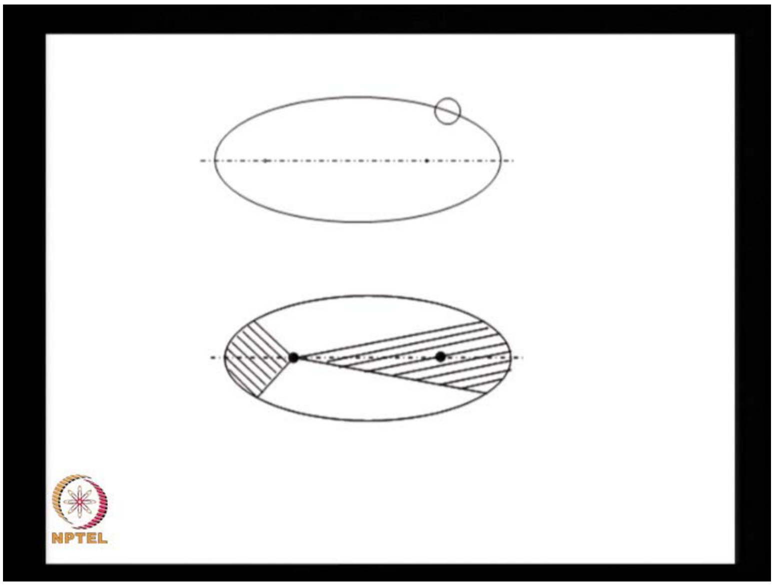

We told ourselves well all planets move in elliptical paths and they trace out the equal areas in equal time and,

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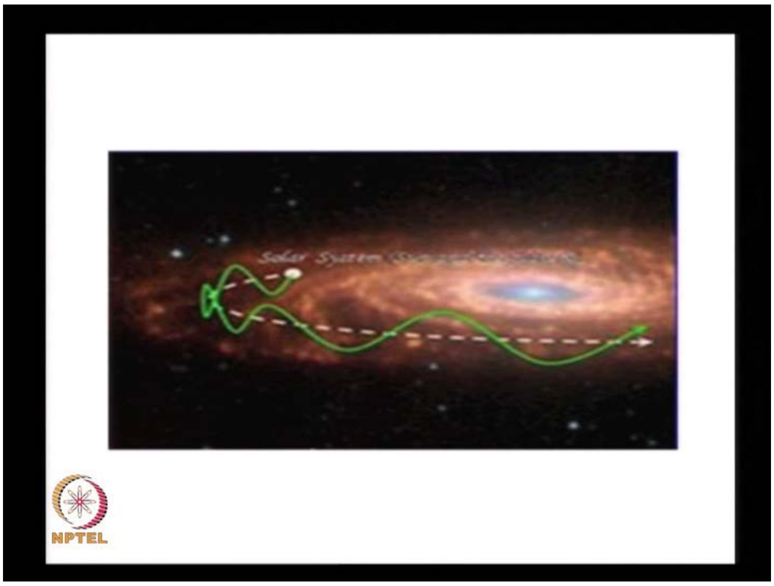

And butyou know if you see the newspapers and science magazine over the last two three months they keep telling us know the orbits elliptical, but above the ellipse there are undulations which are there and you see the green colours shows the real orbits,

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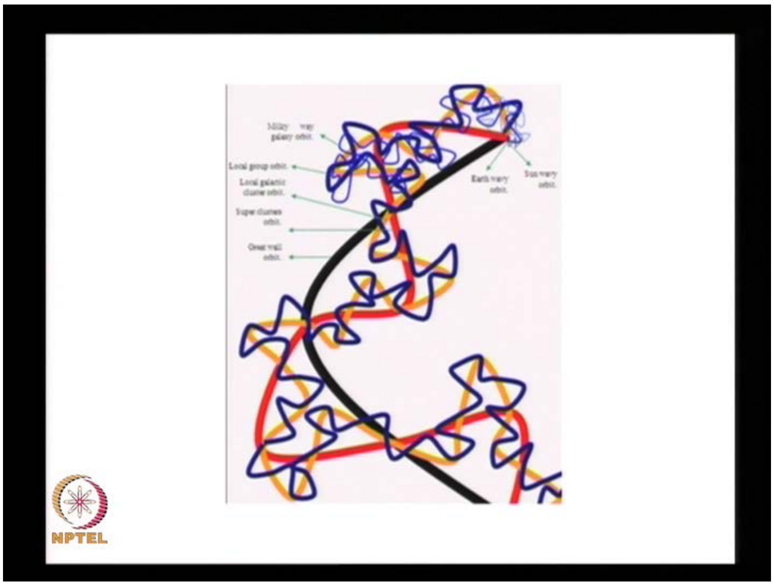

Butthen there is something still more confusing even within the undulations there are further undulations like turbulence which is available therefore, if somebody is talking of turbulence well even the motions of the planets around the sun looks to be turbulent to me, but then in any way you know grosslyit is all elliptical path

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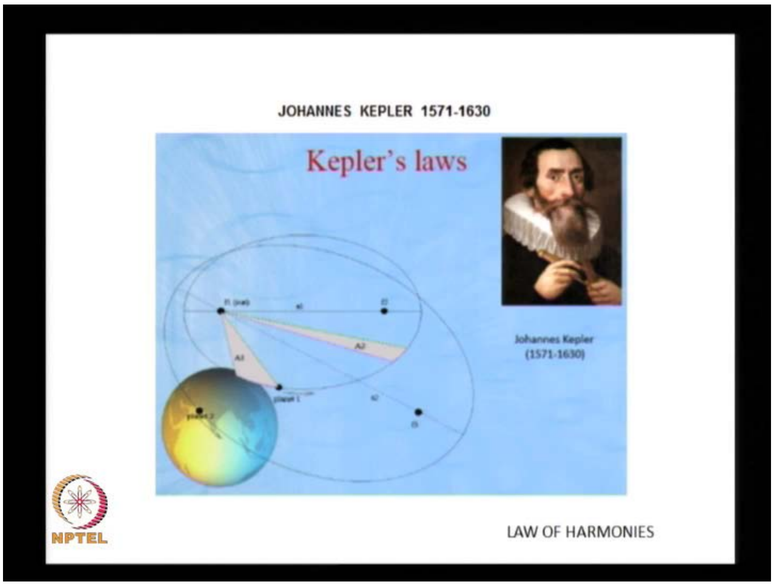

And we have Kepler we talked in terms of Johanneskepler in the last class we told ourselves what did kepler tell tell there are three laws one is all planets move in smooth elliptical orbit the second we said they trace equal areas in equal amount of time in this figure the sun is at one of the focus and therefore, you see the focus on the left hand side around which those white patches show equal areas in equal time and the third law which is law of harmonies we said that the time period t divided by R namely, t to the power 2 t square divided by R cube is the same for all the 8 planets. Therefore you have very very well or synchronized motion of the planets around the sun and therefore, this this is useful or this was useful for for Newton to be able to formulate the t universal law for gravitation.

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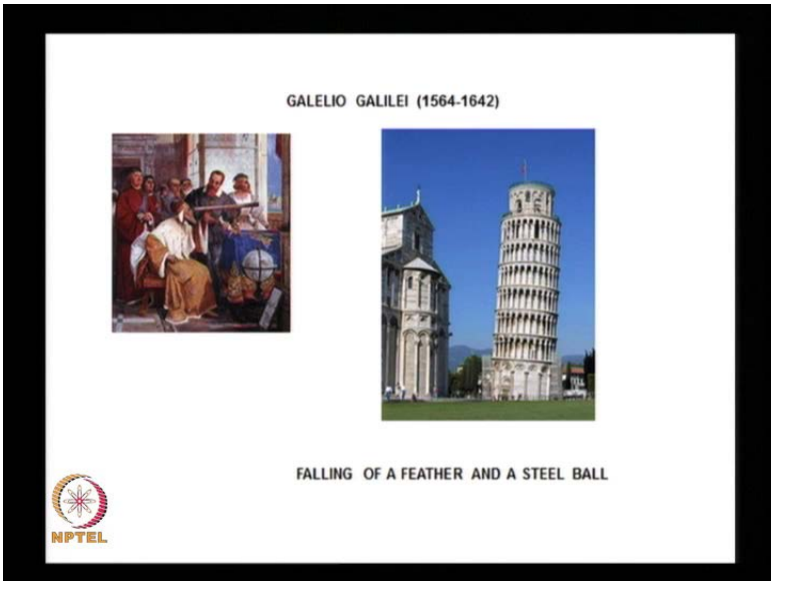

How did we go to it, before Newton that means let let us go back here we told ourselves Johannes kepler was in the period 1570 to 1630 afterwards comes Galileo Galilee around around the same time little bit later and what did he do he was also interested in looking at the planets you see him on the left hand side gazing at the planets and he is supposed to have done an experiment in which a feather and a steel ball fall together in in a place which is evacuated or vacuum and he finds that the time taken is the same and Newton did no experiments.

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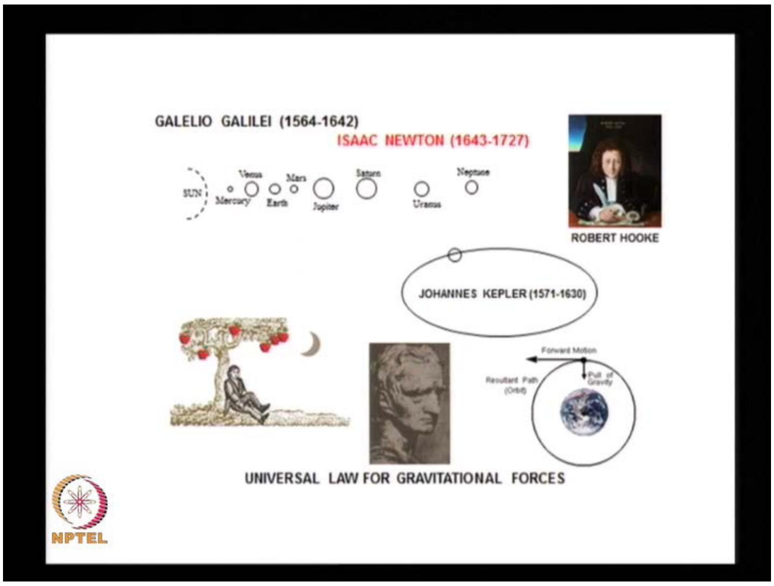

He just relied on these observations and what did Newton do well he saw it is stated that he sees an apple falling from a tree he uses the information which Johannes kepler gathered mainly you have elliptical motion you have equal areas you have t square by R cube is a constant and then he says well and there was this person Robert Hooke you have all read about hookes law in in mechanics stress upon strain and Hooke also was doing the same thing at precisely the same time and Newton put everything together and he said well an apple gets attracted by earth because earth is a large mass just like the Sun attracts the different planets therefore, he formulates that universal law of gravity gravitational forces planets fall freely onto the Sun that means, planets are freely falling bodies just like a stone falling on the Earth

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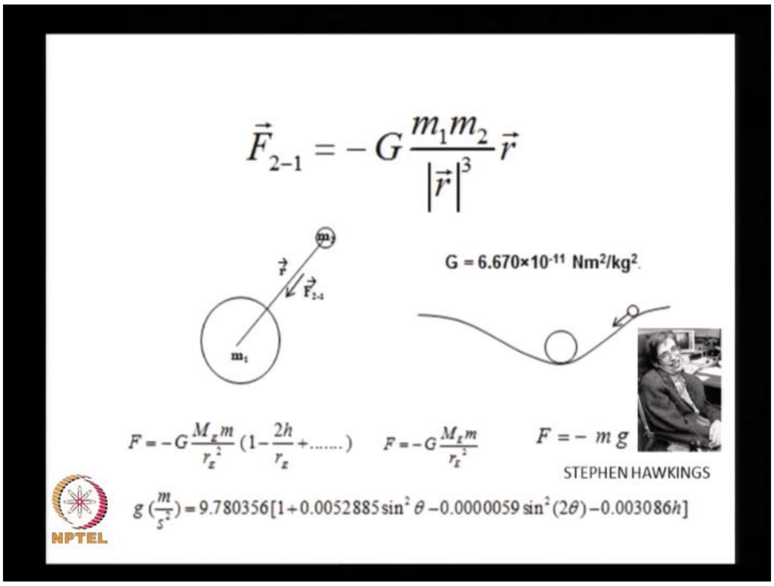

Therefore, what we telling in last class again we said this states that if I have a heavy mass m_1 as shown over here and then I have a light mass m_2 which is at a distance R away then I have the attraction force with which the heavy body attracts the lighter body is given by F is equal to G into m_1m_2 by R square. This is the universal law for gravitation, we said G has units of Newton meter square by kilogram square the unit is 6.670 into 10 to the power minus 11 with this we should be able to do problems. But then we were not clear and how this gravity force comes what is this gravitational field it comes from mode from different areas from physics we must be able to understand why gravitational field exists it is still not proven, but these are very powerful minds like Stephen hawking we said he was a physicist who is looking into the different mechanisms. We had different people looking at the laws, but still not clear we just told ourselves if I stretch something if I put a heavy mass the heavy mass and I put a light mass the heavy mass may be pulls down the stretch rubber and therefore, the light mass rolls towards it and that is what we say is a field. And we went further we expanded the value of the universal law G m_1 m_2 by R square in terms of let us say the heavy mass being the earth and R being the radius of the earth plus the altitude R e plus h and we found that F is equal to minus m G.

And but you know the gravitational field is not constant all along the surface of the Earth because Earth is little bit chubby in shape it is not a pure sphere and therefore you find that with the angle of inclination or the latitude and the height the gravity or the acceleration due to gravity G keeps changing. Therefore, we have F is equal to G m_1 m_2 by R square or in the gravitational field of a particular planet if g can be expressed in terms of let us say a unit the unit comes out to be meter per second square which people all all of us loosely call as acceleration due to gravity there cannot be acceleration due to gravity it is a field therefore G is the field expressed in meter per second square this is what we did in the last class

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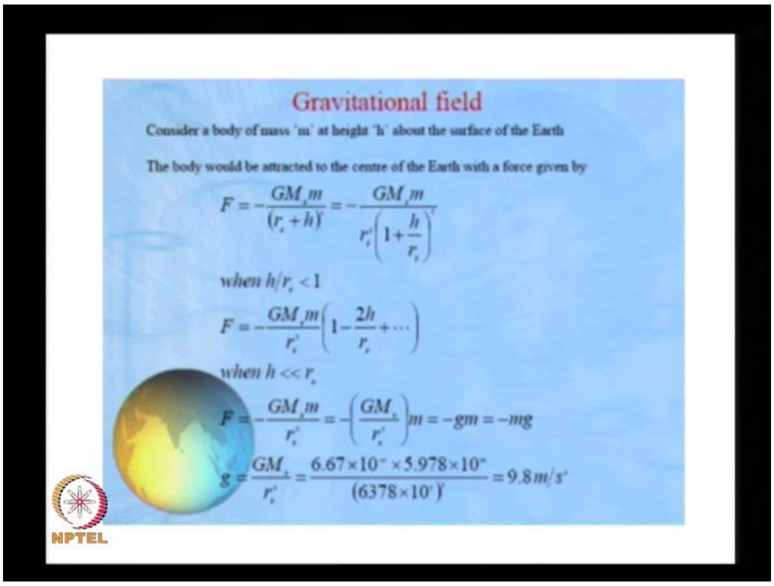

Let let us progress further here I just expanded it out for our information F is equal to Gm e that is mass of earth radius of earth R e and h and when we did this we found F is equal to minus mg and we got the value of g, as 9.8 meter per second square this also we derived in the last class.

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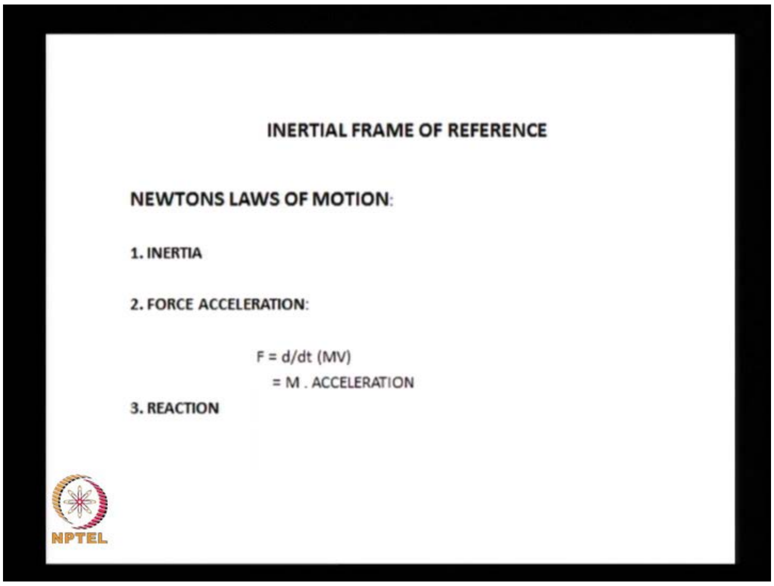

Having said that we have to keep something in mind we we define what we called as inertial frame of reference what did we say all of us are moving the earth is rotating all the galaxies are moving sun is also moving therefore, how do we define motion in space this was a problem for us. Therefore we said either the object must be stationery or I must be absolutely stationery then I can see the motion of an object or if I move at constant velocity then the change in motion of the body is independent of my constant velocity.

Therefore, we define inertial frame of reference as a frame of reference which is either stationery or it moves at constant linear velocity therefore, based on these linear frame of reference we talk in terms of Newton's laws of motion which is precisely what we have been talking all along namely inertia or body continues to remain in a state of rest or of uniform motion unless it is forced otherwise by an external force makes sense.

We say the second law of Newton we say rate of momentum is proportional to force or force is equal to rate of change of momentum F is equal to d by d tof m v you expand it out you take constant mass outside you have d by d tof v which is acceleration. Therefore, second law of Newton can be expressed either as between force and change of momentum or between mass and acceleration or we say acceleration from second law goes inversely as the mass of the body and directly as the force on a body.

We will be using these these laws and the third law says that actions and reactions are equal and opposite, but mind you the important qualification is inertial frame of references. These laws are valid only in the frame of references is inertial and this important for all of us supposing I want to say I want to find the temperature distribution in a rotor in a machine; therefore, I am looking at the blade the blade is rotating to be able to find the temperature of a blade I am I will be sitting on the blade and monitoring the temperature but I am rotating; that rotating body need not be an inertial frame of references. Therefore the momentum equation for a rotating body need not follow the Newton's laws; that means, I will have another equation to describe it and I come come back to this

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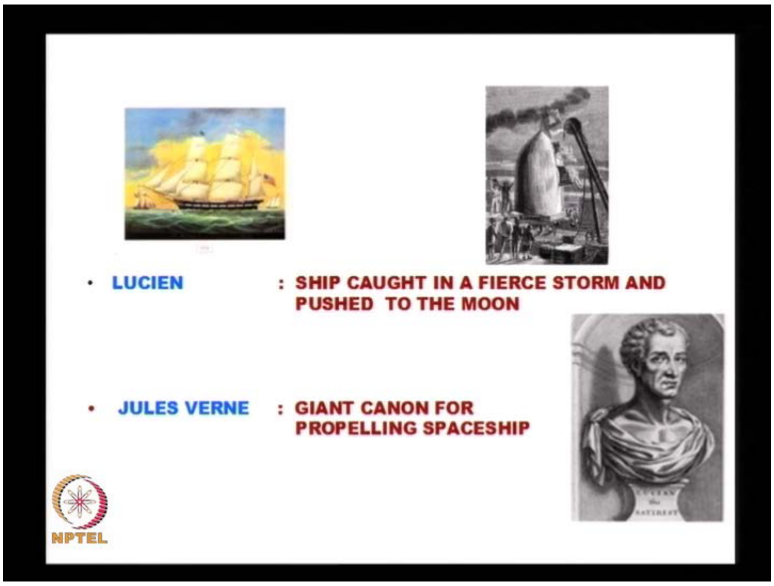

Now let let me just get get into this last last slide of what we did in the last class. We told ourselves, well to be able put anything in space you need to give a force Lucien before the birth birth of Christ around 40 AD or 40 B CI think what he said is a ship is thereon the sea there is a giant storm which pushes the ship into moon he wanted to go to moon. But when we looked at Julie Jules Verne who who was a popular science fiction author he said well now well why not have a capsule which is contained in the barrel of a canon and you push it through, but you know such things are not possible as we shall see a little later.

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And therefore, the last part which we did in the class was we talked in terms of asteroids which are there which which are lose bodies which are available in space and one such asteroid missed the space station around two months back space station is a satellite which is in low earth orbit and it is used for scientific experiments and you know whenever they see some asteroids they go and correct the position of the space station slightly move it away such that the asteroid does not hit the satellite and that is where you know you have these misses you know these are all bodies in space

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which hit each other, but something which was disturbing and which we talked in the last class was you know this I took from The Hindu this was this came in February this year you know it is said that by April on April13 2036 one asteroid the name of that asteroid is apophasis is supposed to hit the earth. And if this asteroid comes and hits the earth well it is reminiscence,

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that the picture on the right side shows an asteroid hitting the earth and the asteroid gets rapidly heated due to friction it explodes and forms a blast wave severe wind and extremely high temperatures that might be the end of civilization itself. Andinfact6 million years ago the extinction of dinosaurs was because one asteroid came and hit the earth. Therefore, the question is people have been always wondering how to make sure that if an asteroid is going to come and hit the earth how do I deflect it. Therefore, one of the things which are talked of is, well I have something like a like a heavy satellite which I put near to the asteroid and now the asteroid has a certain mass and I I because of the force the asteroid slightly shifts away and I can shift it away from the earth and this is known as a space tug may be we will design a space tug in the next class.

Having said that I think this is all what we covered and we set the pace to continue further.

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What did we say in the frame of reference which is inertial I know the equations I know Newton's law but if I were to consider an orbiting that shows the earth something revolving round the earth as it were the bottom picture shows the inside satellite going around the earth it keeps on encircling the earth we find these are all you know that boy there he through a stone into orbit it keeps on rotating round and round the earth. Now, what is the frame of reference here the frame of reference may be if I were to consider

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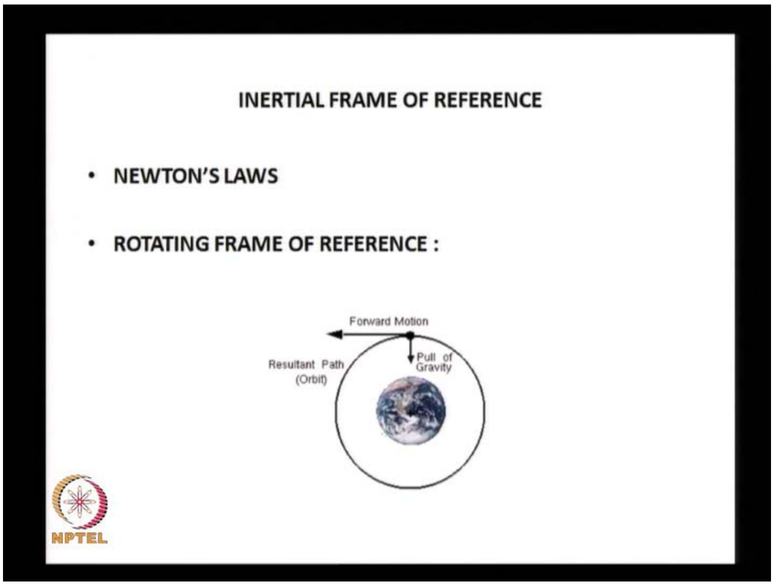

a bit a particular the pull of gravity attracts it and causes it to fall freely while the forward orbital velocity component shifts it away from falling onto the earth and the body gets into a circular orbit now for me the frame of reference cannot be supposing I am standing here and looking at it and see it going round and round I find it difficult to describe that sphere if I were to sit on the sphere then I know I am here and I see everybody else going some other motion. Therefore, I would like to get back and ask a question can I can I get out of this inertial frame of reference and describe the motion around earth taking body.

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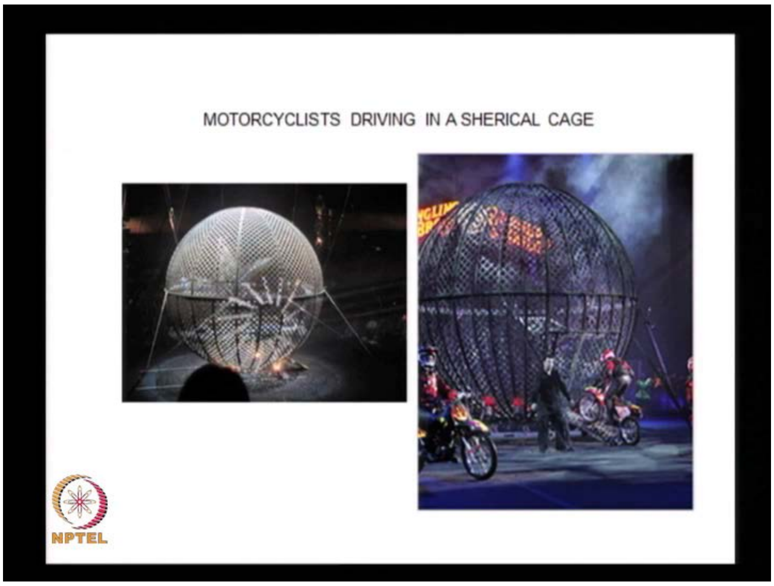

Let me put in this way, let us take an example all of us go to this circuses and you know one of the things which is shown in a circus is you have something like likea spherical cage know a loosely cage a motor cyclist gets in and he goes round and round it all of us have seen it right how howhow does he support himself how what is the principle by which he is on what he does not fall down and if I were to consider myself sitting along with the cyclist and I want to describe my motion and that is how a satellite is there. I Iwouldlike Iwould I would like to know what is what is the type of forces which are acting on me and for this to be able correctly describe the motion of bodies as they are rotating we say it is a non-inertial frame it is not something which is moving at constant velocity or which is stationery, but in the frame of reference or something which is darken there I say well it is rotating and I that I called as x dot I would like to be able to find out the forces or rather describe the motion in the in the frame of reference of a rotating body.

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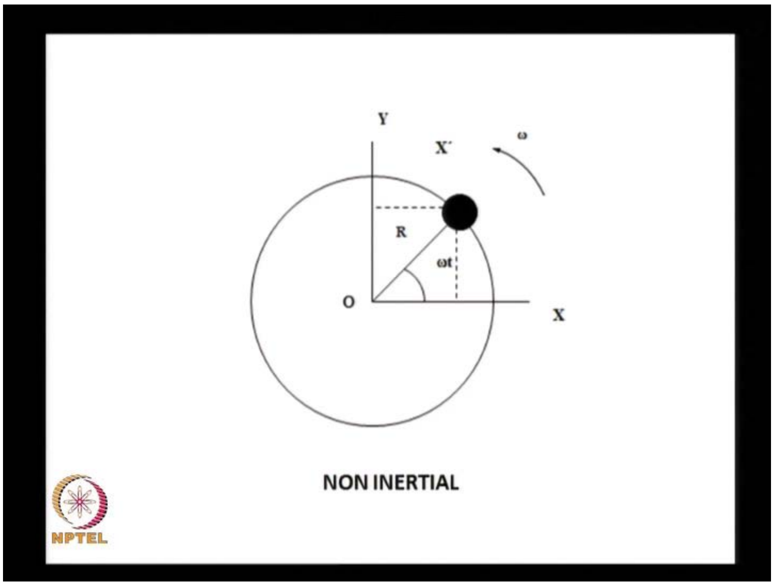

This is what will be doing in today's class and along with that we will be able to find out what we mean by orbit. Therefore, let us comeback III seize with the slide show let let us get back to lecture.

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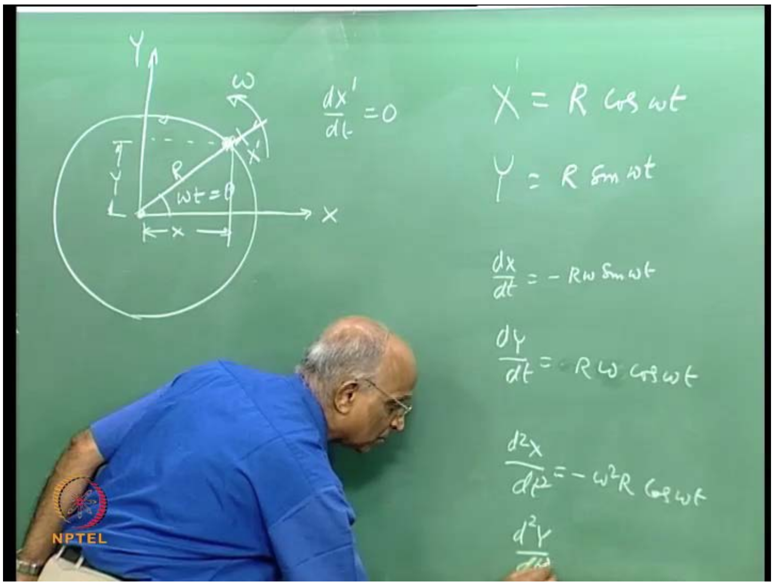

Therefore, what is it I am telling I have something like an orbiting something is orbiting over here may be I have the centre over here let us say a ball is going round and round this is the rotating frame of reference I am interested in finding out the equation of motion with respect to the rotating frame of reference is there something more I have to do. My question is as long as I considered myself to be stationery I said inertial frame of references is the Newton's laws of motions are ok, but if or if I move at constant velocity the inertial frame of reference is there what is the change when I use a rotating frame of reference I want us to be very clear because I think I must make make myself absolutely clear on this the perspective is not that I am standing here and we told ourselves when I stand on earth I assume I am moving at constant velocity then I am in a inertial frame of reference I am I am not looking at the body from the inertial frame of reference but I want to look at the body which I call as x dot which is a rotational frame of reference. In other words I also sit on this body and I now I ask myself can I describe my motion properly. Let let me say instead of me standing here and watching this this mass go round I tell myself well I am on this body and I want to describe my motion properly. In other words you know my motion around x I am on this body therefore, with respect to the body my motion is d x by d t is equal to equal to 0 right. There is no no change but how do I describe this motion well let us come back let us say that I move with a velocity angular velocity omega and let us say at time t at this particular point omega t is equal to theta I start over here at a time duration t I have reached this particular point and therefore, I can write this is my x coordinate this is my y coordinate this I call as x dot which I have just written excuse me. Therefore, I write now x prime is equal to if the radius of the of the circle around which it is going is capital R I can write x prime is equal to R cos omega t this is x over here y is equal to R sin omega t right.

That is the x component of radius is x cos theta and the y component of the radius is y R r sin theta and theta is equal to omega t therefore, I differentiate it I get d x by d t is equal to minus R omega sin omega t and I get d y by d t is equal to R that is R omega into cos e omega t. I take I further instead of taking the velocity along x and along y I want to find the acceleration x and y I get d two x by d t square is equal to minus again it becomes minus omega squared R omega comes here omega square R cos omega t and the second equation I get is d two y by d t squared is equal to minus omega squared R into sin omega t.

In other words when a body is rotating I find I can describe the acceleration along x it is pointed it is minus it is in this direction equal to minus omega square R cos omega t

Ihave acceleration in this direction is equal to minus omega squared R sin omega t and the net acceleration

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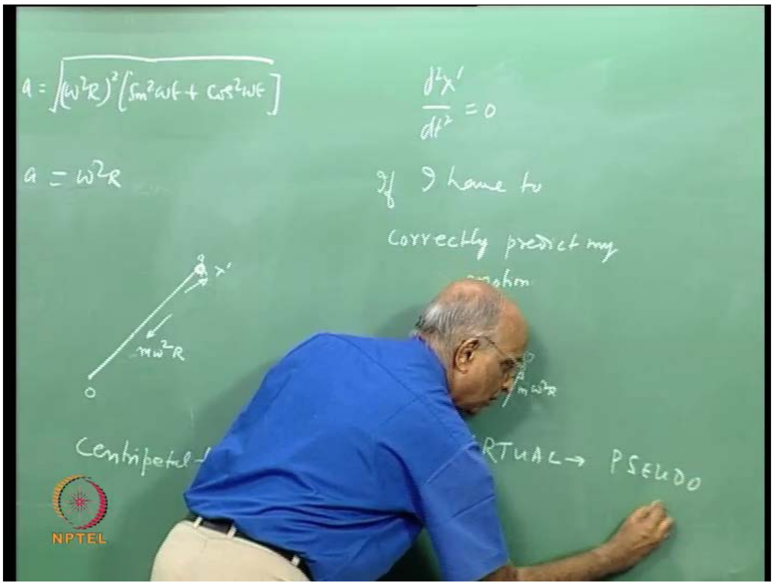

If were to write I get the net acceleration a is equal to under root of these two namely omega square R the whole squared into sin square omega t plus cos square omega t which is one and therefore this is equal to omega squared R is the acceleration. That means when something is rotating I have a net acceleration which is along the radius pointing towards o because this in this direction this is in this direction this is the direction in which it is rotating and therefore, I have a net acceleration over here.

Now from second law we know if something rotating and have an acceleration I have for this particular body which is rotating I have a force in this direction equal to minus m omega square I I did not take the value because I am III say that the force in this direction towards the centre this is the body which is rotating and therefore, I have a force equal to mass into acceleration is equal to m omega square R.

What is the name of this force cannot be (( )) it is a force which is acting now my question was; what is this force this force is known as centripetal force.

This is all what we can say, we are we are considering a body which is rotating I say that there is a net force which act towards the canter and this force is equal to m omega squared R. What is this point? I say I am sitting on this body in the perspective of this particular body my x dot is 0 therefore when x dot is 0 d x prime by d t is equal to 0 therefore let us go back and write write the equation here. We therefore know that d two x bar by d t squared is equal to 0 right, but then you find acceleration of the body in the frame of reference of the body is zero, but then I find hey I am talking of a force which is available to me therefore, if I have to describe my motion correctly therefore, let me put it if I have to I have to correctly sort of predict my motion, what should I do? It is necessary for me to put a force on the body equal to minus omega square R to be able to in that case only this will be 0because I find there is an acceleration which is coming of force in this direction for me to be stationery I must put a force in this direction and this is what I call it it cannot be real right I am putting a force on the body. Therefore, it is something which is virtual or which we call as a pseudo force and why do I have to put this force to be able to correctly describe the motion of the body when in the context of the body itself because I am sitting go the body and if I say that I am not moving I that is only possible when I put a motion like this such that the centripetal force and this pseudo force are same and this pseudo force is what we call as centrifugal force. Let me let me just repeat whatever I have said in in short all what we were saying is in a in an inertial frame of reference Newton's laws are valid. Now I consider a frame of reference which is not which is not a inertial frame, but it is a rotating frame now I am looking at the motion from the perspective of the body which means is I am sitting on the body if I am sitting on the body and I am rotating then

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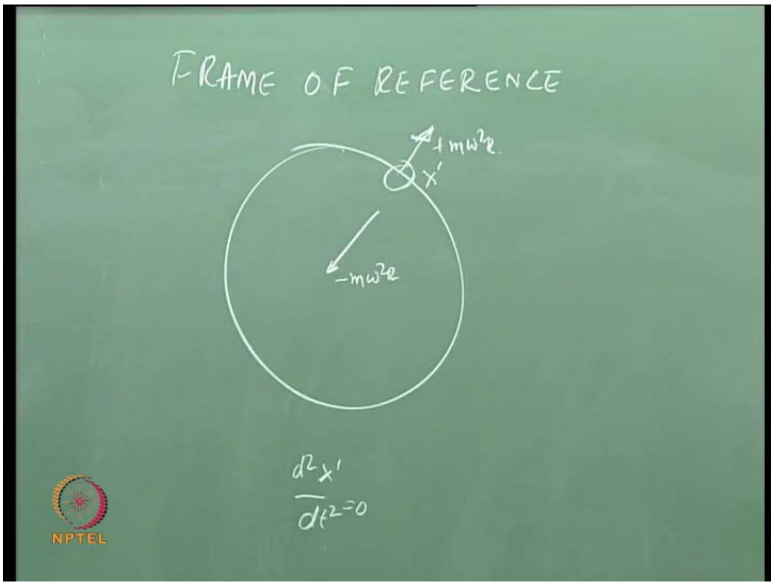

in that case to be able to correctly define my my coordinate or with respect to me if I want to define it is necessary to be able to Igo round Iconsider this it is necessary for me to put a pseudo force to be able to correctly describe my body, because I find that d two my position x dot by d t square is equal to 0.

In other words I have a centripetal force minus omega square R and Ihave to put a force equal to plus m omega square R to be able to correctly determine my motion, but which we call as a pseudo force is not a real force, but it helps me to find out the forces in a non-inertial frame of references. See this we will keep on encountering, whenever we use these code you know we use fluid code to determine some some gas motion or gas mixture. We must be very clear we might have written it for an inertial frame of reference if I have a body which is sort of going on side and which is rotating I could have some other force therefore, frame of reference is extremely important in any problem like we have considered.

Therefore now, let let me let me summarise what I have been telling you so that we go back and start finding out what are the velocities in orbit and what we want to do. All what I have been telling is well I consider a body which is rotating

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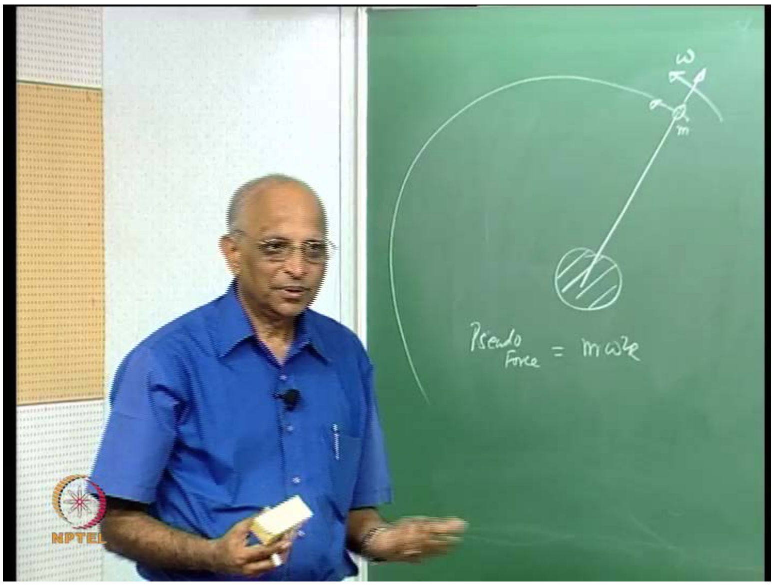

And I tell myself if I am looking at the rotating frame of reference, it is necessary for me to put a pseudo force which I call as a centrifugal which I call as centrifugal force equal to m omega square into R where m is the mass of the body. Therefore let us come back to this problem, let us consider earth to be here let us consider a satellite or some, body of mass m going round earth as it were. Now, Iwant to find out the motion of this particular body. Therefore, all what I say is well let it rotate with an angular velocity omega then the the pseudo force is equal to pseudo force which we call as centrifugal force is equal to m omega square R which is acting in this direction.

But what balance is this pseudo force what what would be balancing let say this object is going round the earth what will be balancing this pseudo force?

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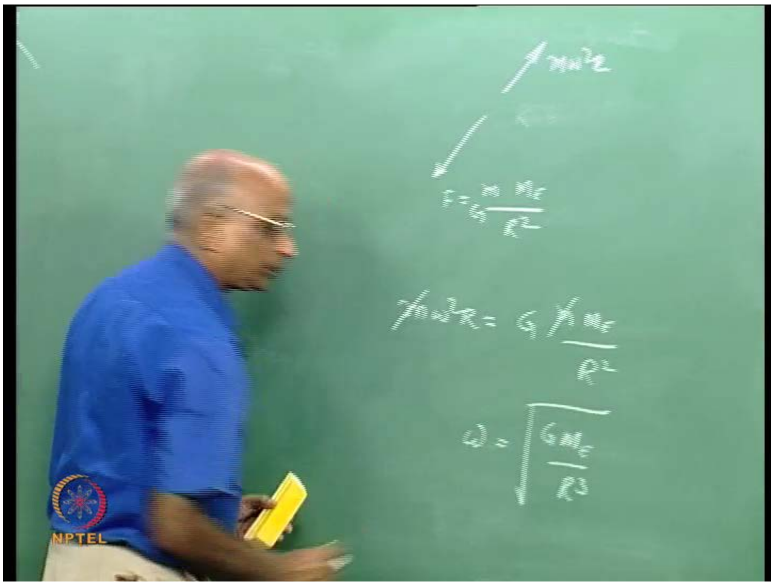

Gravity, how would you tell, what will you say, how how you would we describe it. You are telling me that the gravitational forces balance the pseudo force. In other words all what I am saying is pseudo acts in this direction equal to m omega square R.

And what is the force in this direction the gravitational force which is given by universal law for gravitation is equal to the mass of the body mass of the earth divided by R square into the gravitational constant.

Now we are saying some body is rotating round this therefore, I take the force balance and what is a force balance I have the pseudo force or centrifugal force m omega square R is equal to G into m mass of the earth divided by the distance from the centre of earth to this particular body R square. And now I find out my my my angular velocity m and m cancels you find that irrespective of mass of body the value of the angular velocity is the same and I get is equal to G m e by R cubed and this is what gives us the angular velocity of rotation of a body around the anything. If I were to go consider instead of the earth I say I am go around the sun say I go round the sun and let us write the equation for it.

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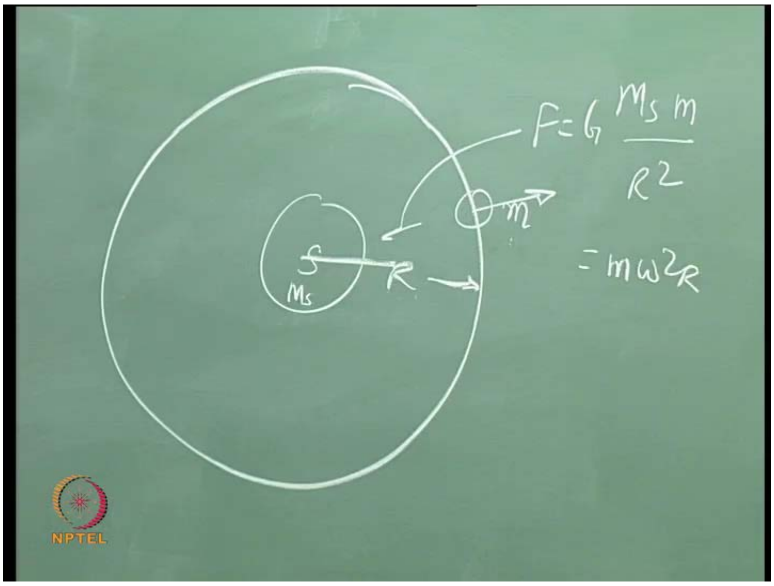

We tell ourselves well I have the sun over here I have a body going round the sun at a distance R from the centre of the sun this my body mass let us say small m this is the mass of the sun m s the distance is R. Then for exactly the same thing I have the gravity force that is F is equal to mass of the sun into G into mass of the body into R square and I have the pseudo force here which is equal to excuse me m omega square R right. Therefore, I get the angular velocity as equal to G into mass of the planet into distance from the canter of the planet this could be a mission around moon we have the angular velocity and once I know the angular velocity I need the velocity of orbit therefore, orbital velocity.

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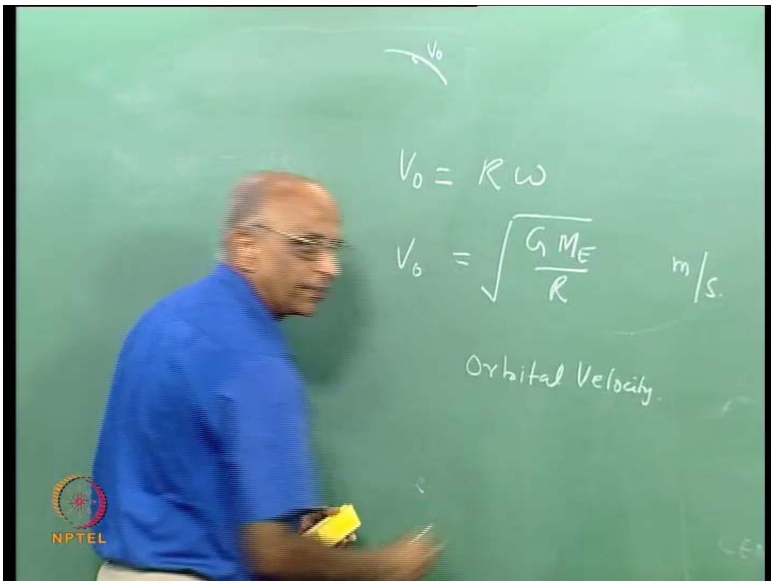

Whatis the velocity with which it is rotating v 0 v 0 is equal to what R omegawhich is equal to Iputthe value of R here and what is the value IgetR becomes R squared inside; that means, Iget R square over here into R cubed and therefore Iget, so many metres per second.This is how we calculate the orbital velocity of anybody like moon is going around the earth we know the mass of the moon we know the mass of the earth we know the distance between center of moon and center of earth we know the speed at which the moon istravelling which we call as orbitalvelocity.

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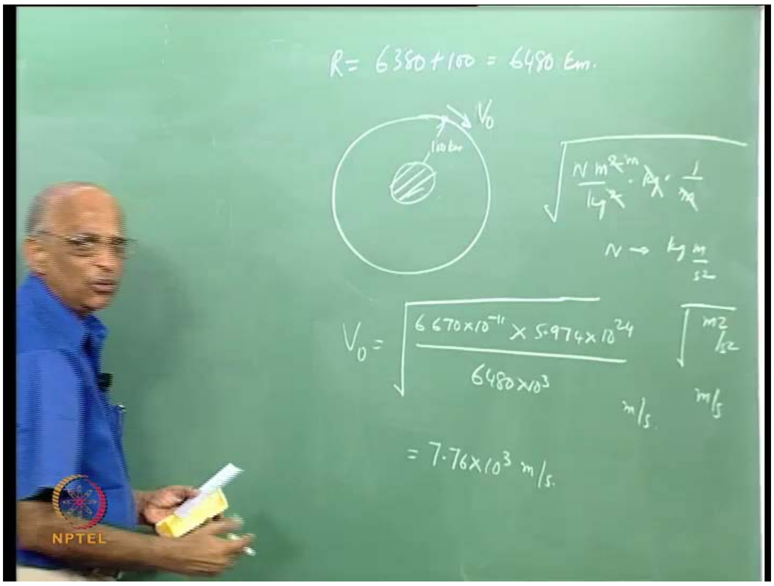

Let us do a simple example to illustrate this. Let us find out the velocity of a body or let us say a space craft or something which let us say we say this is the earth as it were, somethingis rotating round the earth at a height let us say of 100 kilometreabove the earth. Iwant to find out velocity of the orbit v 0.Therefore how do I,Ijust make use of this equation Ihave v 0 is equal to under root G we said was equal to 6.670 10to the power minus 11.Whatwas the unit Newton meter square by kilogram square into the mass of the earth the mass of the earth was 5.974 into 10 to the power 24 k g multiplied k g divided by the R we saidhundred kilometre above the surface of the earth therefore, R is equal to the radius of the earth is 6380 kilometre plus 100kilometreswhich is equal to 6480 kilometres into 10 to the power 3 meters 1 over meter square 1 over meter, its meter,this is under root therefore, what am Ileft I am left with kilogram,kilogram meter Newton is equal to kilogram meter per second square therefore, this becomes under root meter square by second square and the unit is meter per second so much meter per square is the orbital velocity.

Andthis if you calculate will come out to be about 7.76 into 10 to the power 3meter per second or 7.76kilometres per second this is typically the velocity of a body orbiting the earth at a distance of 100 at a height of 100 kilometers. Thisis how we calculate the orbital velocity let us go a little bit further.Whatdo we find from this?

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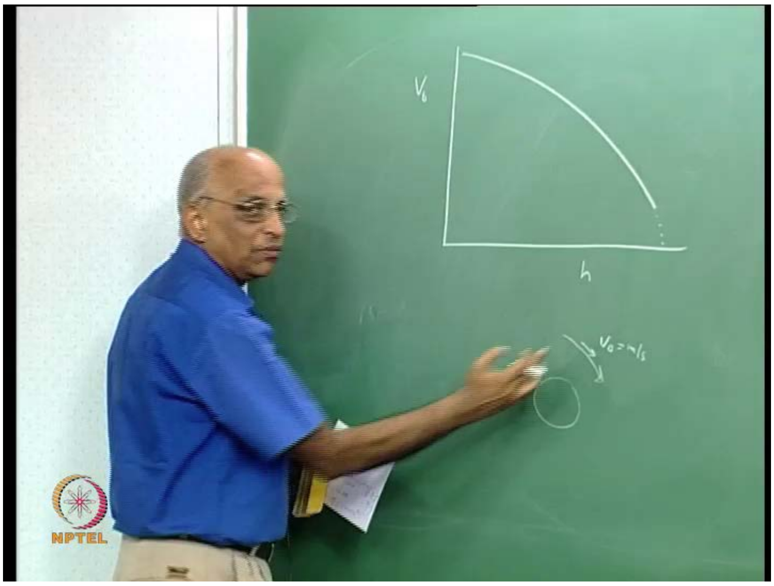

Wefind that as the height above the earth increases the value of orbital velocity will keep coming down when I reach infinite height the orbital velocity is really 0 rightin other words whenever we are considering any planet a body orbiting around the planet Ican calculate the velocity v 0 in meters per second or the orbital velocity of the rotating body.Wetalk in terms of INSAT spacecraft whichis going round the earth and therefore we say well, it is at this height and therefore it is rotating at this particular speed.WellIthink Iwill I will stop here, in the next class what we do is we will go into some details of may besee you find that the orbital velocity keeps falling you would like to understand that as the height of the body increases Imust give more velocity to the body to reach that height, therefore where whereis have I what is the total velocity which is required for arotating body and then we will go into some more details of different orbits and then fix what are the requirementsfor a rocket to be able to put some space craft into different orbit that is what I want to do.Thank you