Satellite Communication Systems
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Lecture - 04
Orbit – 03

Welcome back, we will continue our discussion on Orbit. We have a seen till now, different types of Orbits and the velocity the Orbital height and the time period of the Orbit how they are related and what is called Geosynchronous Orbit, Geostationary Orbit and other different types of Orbit. Also from the observer at the earth which is we call an Earth Station; which direction is in the satellite that is the look angle to the satellite the Azimuth alleviation how to calculate the distance from the observer to the satellite which is very important for us. Thus that will give us delay of the signal from observer to the satellite to reach or the other way. Similarly how the satellite is visible at what angle and from the satellite what angle the earth arc or the earth surface how much is visible, some of the calculation quick calculation we have done.

Now, let us try to see, that how do we raise the Orbit or reach to the Geosynchronous we had seen that Geosynchronous or Geostationary Orbit is quite advantageous particularly those who are in India or linear equated, for them it is very good because elevation angle is quite high the disturbances from the local reflections or multi path are really low. So, that is quite advantageous. Though other types of satellites different Orbits are also available. So, let us try to see the how this Orbit is reached and by different types of launchers we just try to see some of the pictures of the launchers. So, let us go back and see the basic planes of the Orbit.

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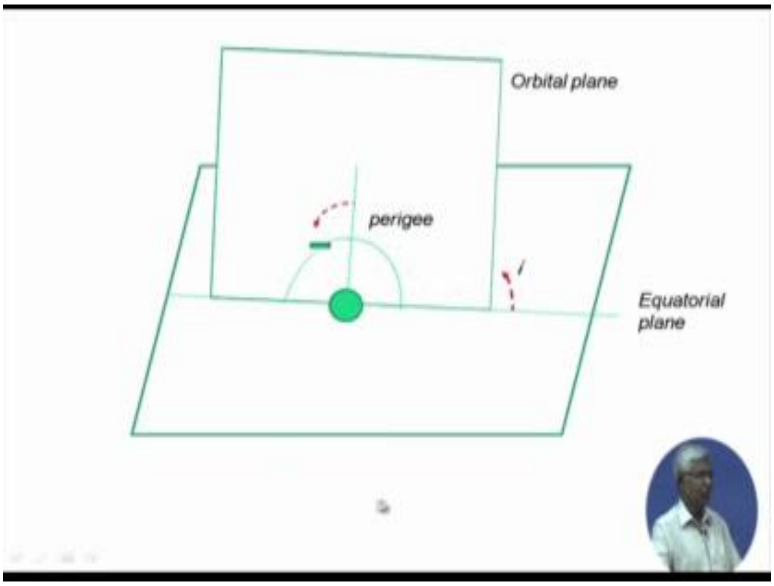

This is the, let say, this is the earth and this is the equatorial plane and for generalization let us say that satellite is Orbiting in a different plane than the equatorial plane and that Orbital plane is making a intimation with the equatorial plane is the perigee and then may be apogee below.

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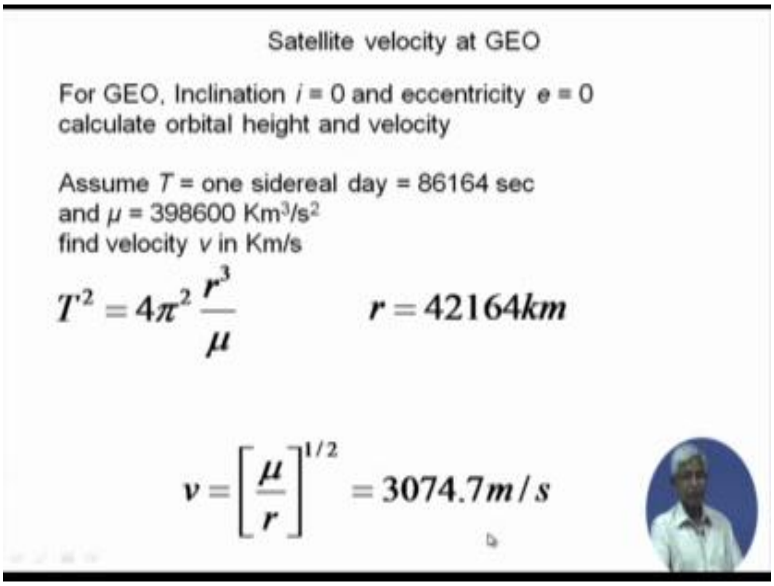

So, this is the position for GEO the satellite velocity at GEO that is what we will calculate, that is Geostationary Orbit. The inclination what you have seen just now is 0, that means, the Orbital plane and the Equatorial plane are same and the same plane and the eccentricity of the Orbit is 0. So, there is Apogee is equal to Perigee.

So, in with these 2 conditions let us calculate Orbital height and velocity in the Circular Orbit time period is one sidereal day we have seen it is 86164 second and that constant mu is 3.983 to the minus 5 or 398600 kilo meter cube per second square. In this circular Orbit that is at GEO, What is the Velocity? To calculate that you remember that T 2 that is arbitral period square in this case sidereal T 2 is equal to 4 pi 2 r cube by mu.

And from these by putting the values of sidereal day and mu pi is a constant we get r is equal to 42164 kilo meter. So, putting this r for calculation of Velocity we get Velocity is 3074.7 meter per second, that is roughly about 3 kilo meters per second. If you recollect our initial calculation just rough calculation relating is a 40000 kilometer velocity is a of the order of 3 kilo meter per second is coming here. Remember this number at this velocity the satellite moves continuously in Geostationary Orbit.

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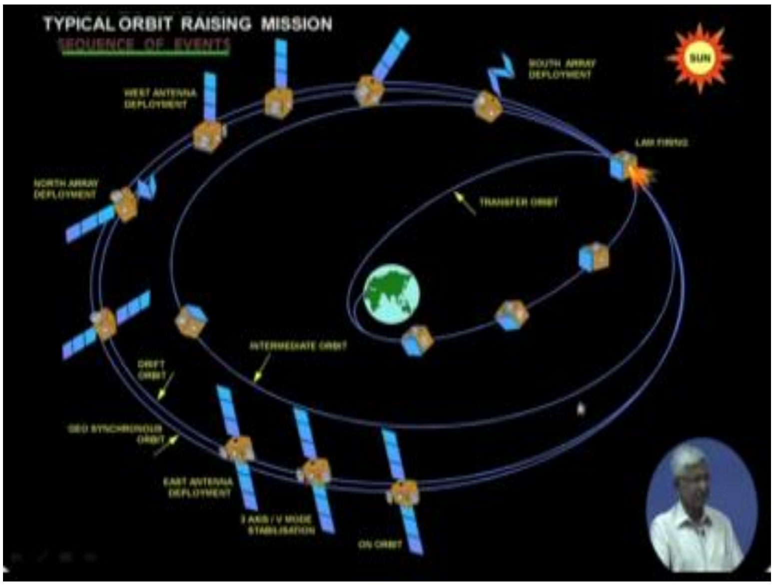

Now, let us go back to the that particular picture we have seen this earlier that from earth some location a launcher has launched a satellite and launcher has gone out ejected the satellite, satellite looks like a cube here, packed condition and it is put in a particular Orbit which is here named as a Transfer Orbit. Now we will term it as Geostationary transfer Orbit GTO, but right now it is a Transfer Orbit. So, satellite will move in this Orbit looks like ellipse it is a Elliptical Orbit, where perigee is near earth and apogee is far away from earth, and then there is some rocket firing rocket is already there in the satellite is called LAM here Liquid Apogee Motor firing at apogee it is getting fired.

So, as a liquid fuel, so liquid LAM firing, with that it gives some incremental velocity; it has in the Transfer Orbit at apogee it has some velocity, I give some incremental velocity to that. So, that the perigee changes apogee remains same. You know that calculation in the Orbit Elliptical Orbit at apogee N P T. So, by changing firing the velocity here and changing this velocity I can change the apogee and perigee height here it shows, that slowly the apogee is at changed a sorry perigee is at changed and whole thing is made circular, and during this process it start deploying the other preference of the satellite, that is Solar panel deployment and Antenna deployment etcetera goes on. So, this is called arbitrary rising.

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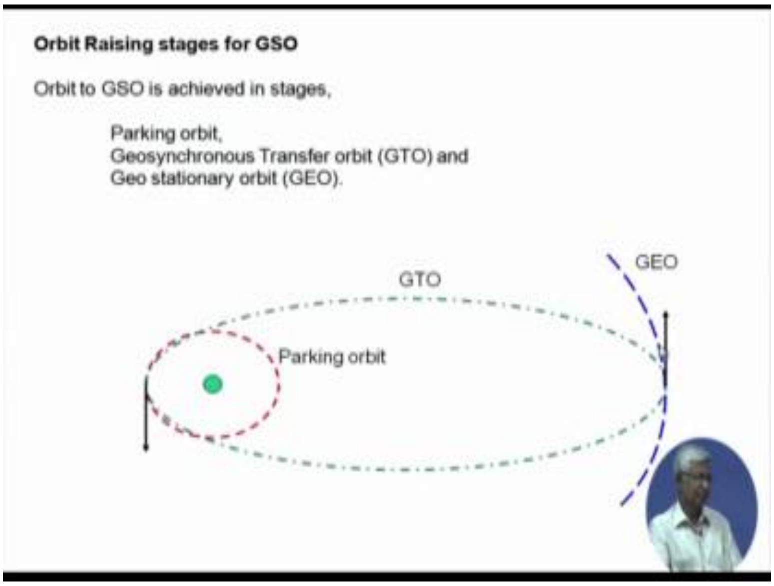

Let us do some quick calculation, how much is that incremental velocity. Generally it is done it is put in the parking Orbit which is circular Orbit and then it is Geosynchronous Transfer Orbit GTO and then it is a Geostationary Orbit. In some cases the parking Orbit is avoided directly the launcher placed it into GTO or in SAT launchers they place the insert satellite and GTO will see all these things. So, parking Orbit is generally a suppose to be a circular Orbit which is near to earth is low earth Orbit and then it is fired and it is put in a GTO Geosynchronous Transfer Orbit means apogee is at GEO and perigee is at parking Orbit and then here the tester or apogee motors are fired. So, that incremental velocity puts into GEO Orbit. So, let us try to do some quick calculation of that.

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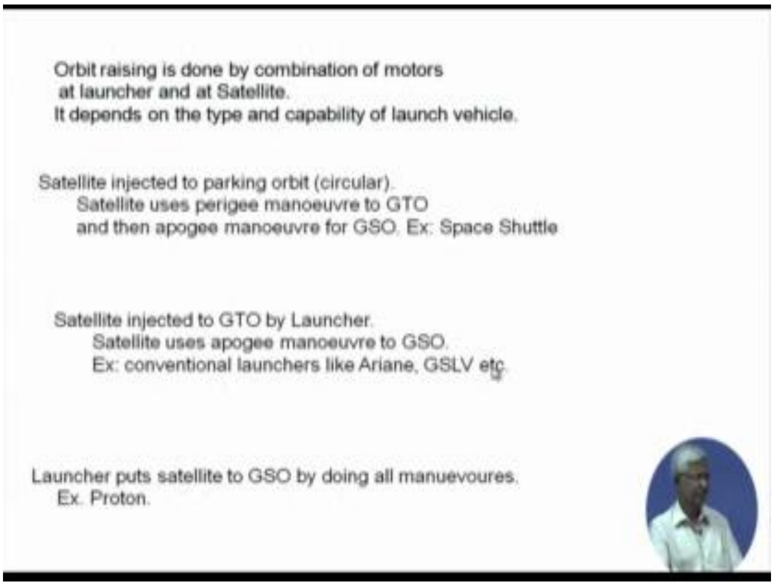

This Orbit raising done by the combination of motors and at the launchers and at satellites, it depends on the type and capability of launch vehicle. Injecting into parking Orbit satellite uses perigee maneuver to GTO if shown that diagram and layer, and then apogee maneuver to GSO space shuttle is one of the example which does it this way. Directly the launcher, launch the satellite into GTO Orbit which is done by launchers like GSLV that is Indian Geosynchronous Launch Vehicle or Arianne that is European launch Vehicle. These are conventional way directly put into GTO Orbit and directly into GSO Orbit is also possible, rush in rocket proton can do that one. So, depends on the rockets capability how it can do will do some simple calculation.

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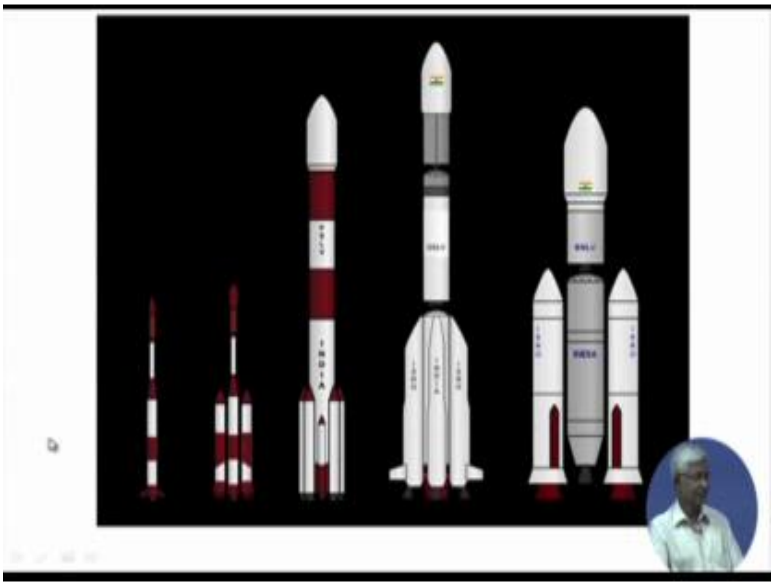

Of course there is pictures on Indian rockets, this is called S L V satellite launch vehicle small rocket earlier days then with 2 small appended rockets attach to a S L V is called augmented SLV augmented satellite launch vehicle. Then this is called P S L V Polar Satellite Launch Vehicle much larger. This is what cause of Indian Space Research Organization. It puts the satellites and normal put in the nose cone it puts in the polar Orbit that is the Orbit is around the pole for different purpose it is used for remote sensing satellites normally it is like that.

Then GSLV GEO geosynchronous launch vehicle bigger than this, you can see the height and here also in the nose cone put the satellite insets (Refer Time: 09:42) launched with this. And sometimes the ISRO people they call it G SAT because it launch by GSLV we call it satellite they call it the satellite they call it g sat, satellites are inside this nose cone, and then the later versions of GSLV which is not yet launched you can have much bigger satellite. Right now this can take roughly of the order of two ton type of satellite this can take I was told that it can take about the will be able to take about the 5 tons weight of the satellite and P S L V can take about one ton of the satellite roughly , you can go to the ISRO site get more details, but one interesting thing why I am showing you the picture is you can see there are stages colors you can see at least here you can see very differently very clearly that is this is a separate rocket, this piece is separate rocket they are integrated together Why? that is the question.

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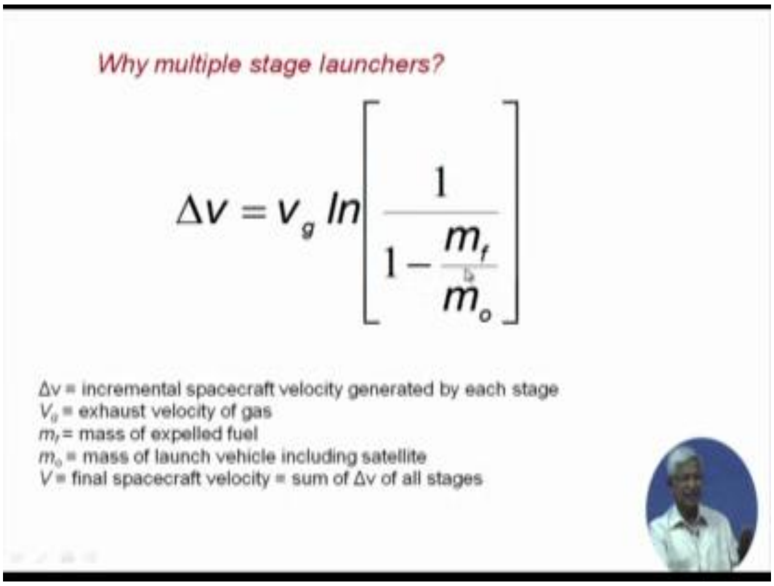

Why multiple stage? That incremental velocity delta v is equal to the velocity of the gas, velocity of the exhaust velocity of the gas and natural algorithm of 1 by 1 minus m f by m 0, this is the mass of the fuel which is inject, which is exited and this the mass of the container plus the fuel, I mean remaining fuel. There is m f is the mass of the expelled fuel and m 0 is the mass of launch vehicle including the satellite and remaining fuel. To get delta v higher and higher you have to make the denominator as small as possible therefore, this should be as near to as one as possible, but this m f is getting a exhausted there is m 0 is nothing, but the container weight which is the dead weight is full goes of the dead weight remains some deduction is there, but dead weight remains. So, it is better how do you make these 2 near to one. So, after some fuel exhausted I remove some part of the dead weight that is the trick. That is how it is summation of many dead weights, summation of many segments of the rocket. So, one segment of the rocket fuel is exhausted that portions of the container also is exited out. So, therefore, the remaining thing is again quite high near to 1 that is a trick.

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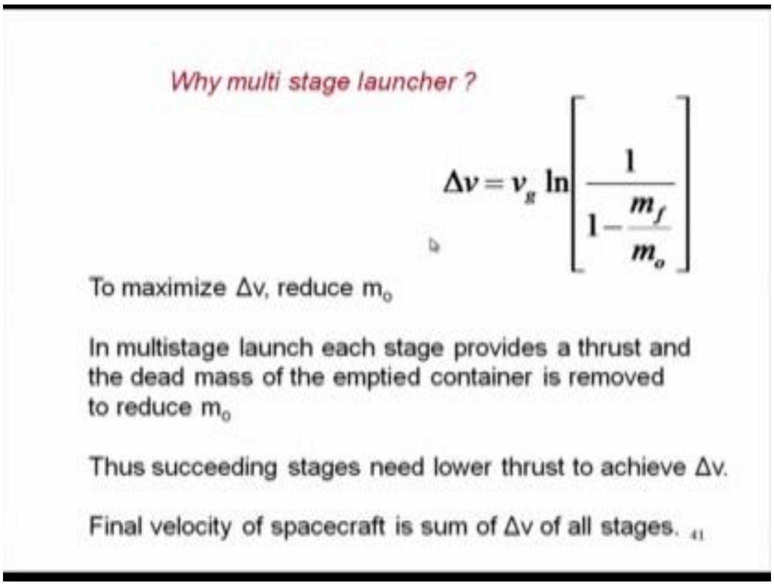

To maximize the delta v we reduce m 0 in multistage launch each stage provides a thrust and the dead mass of the emptied container is removed to reduce m 0. Thus succeeding stages need the lower thrust to achieve delta v and the final velocity some of all the stages of delta v what we get is the multi stage now.

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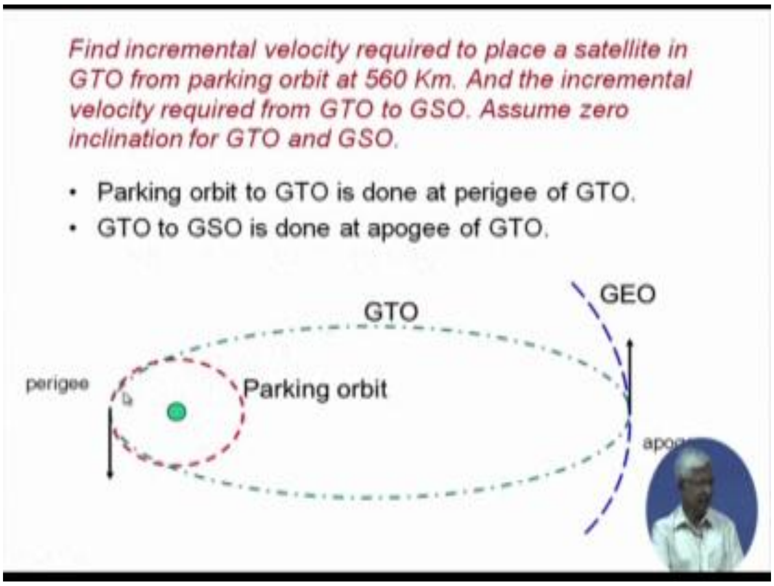

Now, let us go back that is just a additional knowledge you gather lets go back to our calculation of what should be the incremental velocity required to place a satellite in GTO from the parking Orbit and let us define the Orbit size as height as 560 kilo meter and incremental velocity required from GTO to GSO. When I say GTO it is apogee at Geosynchronous Orbit Geostationary Orbit the apogee is known perigee is known here. So, GTO to GSO and of course, for simplicity let us assume that it is on the equatorial flow. So, inclination GTO and GSO is 0.

This is very generalized calculation in real case for Indian launcher we have seen that directly from GTO to GSO. Please keep you calculators ready and do the calculation. Though I am going to show step by step, but do not just blindly follow you must do your calculation parking Orbit to GTO is done at perigee of GTO and GTO GSO is done apogee of GTO it is pictorially shown here. Initially it is put in to a circular Orbit and then at perigee it is fired. So, this elliptical Orbit is attained an apogee it is fired. So, that Geostationary Orbit is attained.

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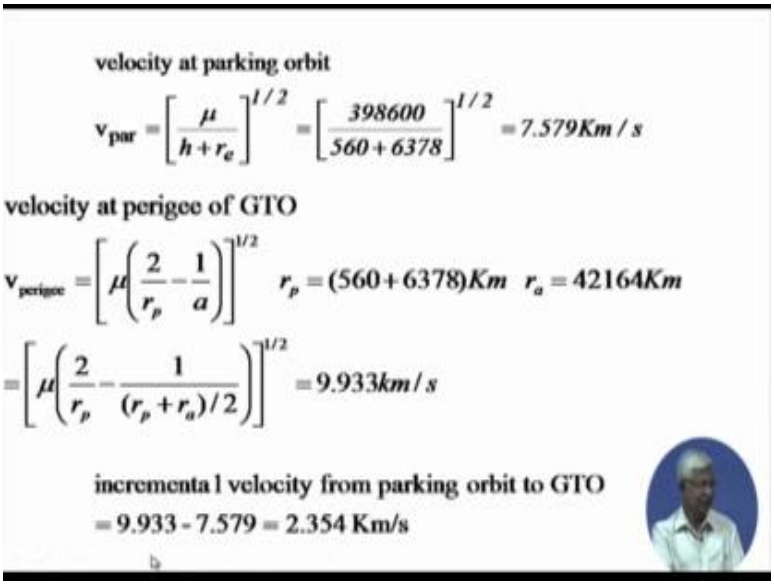

So, velocity of the parking Orbit is u by h plus r e, that Orbital height and the radius of the earth in this case Orbital height is 560 kilo meters radius of the earth we just assume 6378 and mu value is known. So, it comes out to be 5.6 roughly kilo meters per second this after decimal numbers do not worry you need not calculate let me make some small here and there and then this roughly about seven and half kilo meter per second. That is at the circular Orbit that is parking Orbit at 560 kilometer Orbital height. Now to create the ellipse with the perigee of GTO is equal to 560 and apogee of GTO as Geostationary Orbit we fire at water. So, the velocity at perigee of that particular elliptical Orbit you will put r p here the r p value is the same as this and the semi major axis is the r a plus r p where r a is Geostationary Orbit.

So, with that i plus r p by 2 and with that you get where r a is this you get the perigee velocity roughly about 10 kilo meters per second. So, when it is moving at parking Orbit you have to give difference of these 2 to get into that elliptical Orbit. Incremental velocity from parking Orbit to GTO is 2.3 kilo meters per second.

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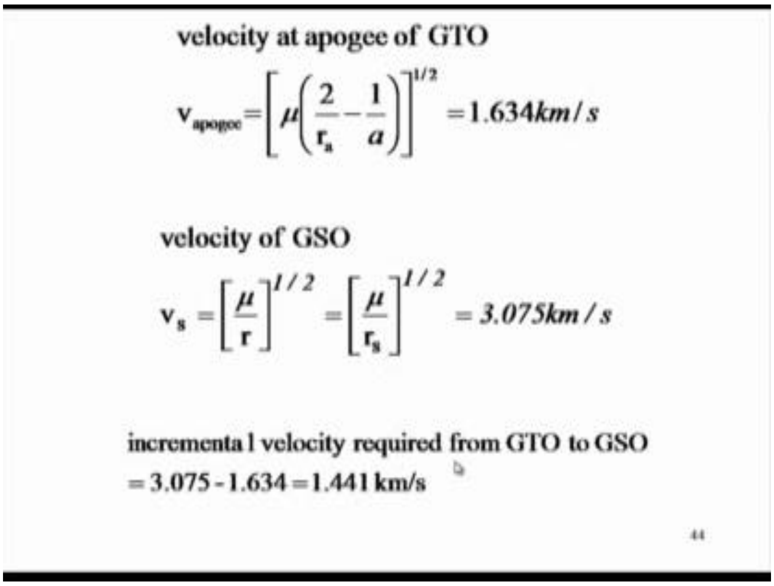

And then velocity at apogee of that particular elliptical Orbit you can put r a and velocity will be 1.6 kilo meters per second. Whereas, at GSO we have calculate earlier the velocity is supposed to be 3 kilo meters per second. So, this difference is you applied and the incremental velocity from GTO to GSO is 1.4 kilo meters per second simple calculation, but you must try to do it yourself. Decimal numbers do not get much for it is just approximately give you a feel that only this much thrust has to be given. So, the fuel expense is not much at apogee if you try to do.

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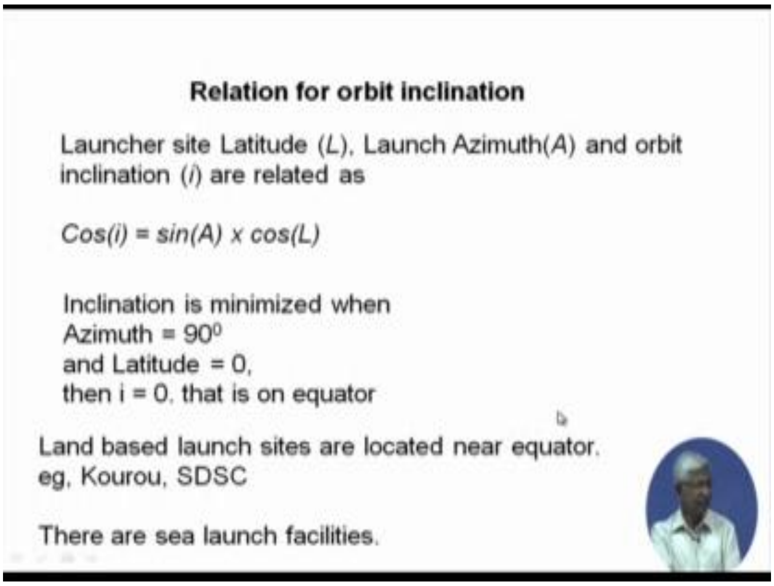

But then we have assumed certain things that the GTO and GSO are all same inclination 0 to equatorial plane, but in real life it does not happen that is the launching site at certain latitude the azimuth of the launch. It is having some angle and Orbital inclination they are related with this expression that is cos of inclination is equal to sine of the launch azimuth in to cos of the site latitude. So, you can see that when the azimuth is 90 degree and when the latitude is at 0 degree that is the equator the inclination is 0. So, you can attend the equatorial plane Orbit, but in real life on equator you may not have some launch sites particularly the in India that is Chattis Dhawan space center which is near Madras in place called Sriharikota slightly north of madras which is; obviously, linear to equator, but not at equator.

Similarly, at South America there is a place called Kourou from where European launches takes place. It is also very near to equator nor at equator. So, there will be some inclination from this launch sites and that is to be corrected to put into the 0 inclination. People try to put sea launch facilities also it is available around the world. So, that to make that i equal to 0 the correction has to be applied, you can see this particular picture where this is the Orbital equatorial plane or which our Orbit should come, but right now the Orbit based on our inclination based on latitude sorry based on azimuth and (Refer Time: 19:10) now this is having some inclined plane. So, the velocity on this inclined plane is this and velocity we have to achieve v s that is synchronous Orbit and Geostationary Orbit is this.

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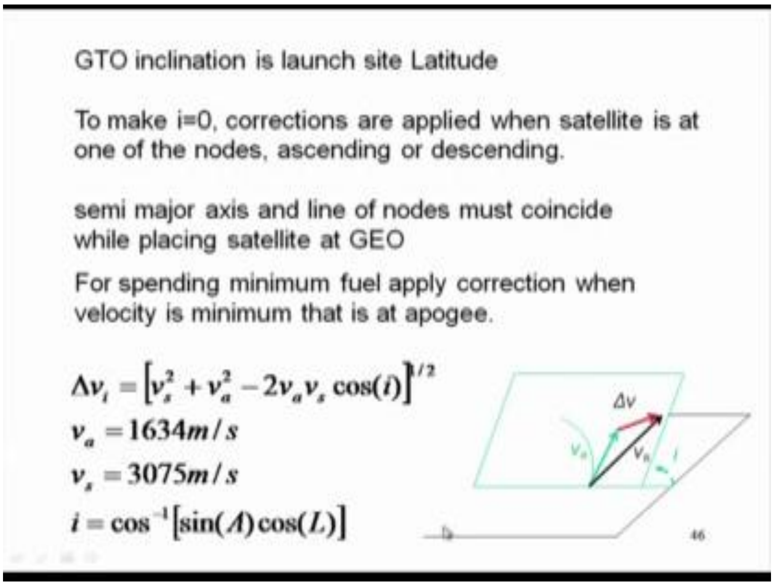

So, you can form a triangle and you can find out delta v that is required which equal to v s square plus v s square minus 2 times cos of v a into vs. So, for spending minimum fuel the correction the velocity has to be minimum that at apogee, at apogee. So, at apogee this thing is fired. So, delta v i is equal to these expression as i just now told and we have calculated that v a and v s for that particular problem and the i can be found out from the azimuth and the l.

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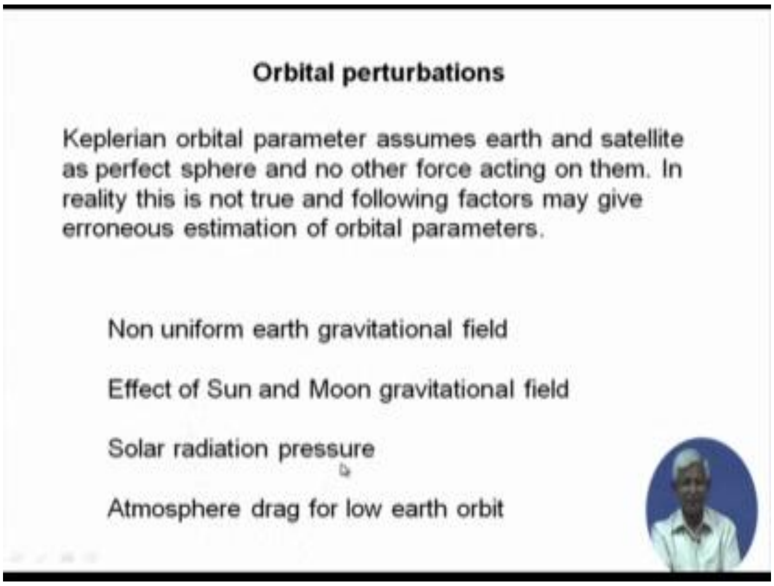

And you can calculate with some numbers, we will try to give some assignments this is on this I am looking to the calculations let us see.

Now, that is briefly about raising the Orbit into different Orbital plane and adjusting the arbitrary playing for GSO, but then once you put the satellite into GSO there are certain arbitrary part of machine basis is that all these things we are assuming that in the whole world in the universe we have only 2 bodies that is earth and the satellite which forces are acting on each other and earth is sphere satellite is also a sphere and the center of mass is at center of this sphere those steps of assumptions we have done, but real life it is not like that we large natural bodies like sun and moon and other things. So, your Orbit will be perturbed.

So, let us look at the perturbation effect. Just for assisted Keplerian Orbital parameter assumes that earth and satellite as perfect sphere and no other force acting on them in reality is not true and that may give erroneous estimation of the Orbital parameter. So, non uniform all of them is non uniform earth gravitational field which is non uniform even quickly intuitively say that there is lot of ocean body and land mass which are not informally distributed. Then there is a effect of sun and moon their gravitational field then there is a solar radiation pressure solar radiation is putting some pressure on the surface of the satellite which has solar balance and if it is lower earth Orbit you will have atmospheric drag which is flow down the Orbit this is some of them.

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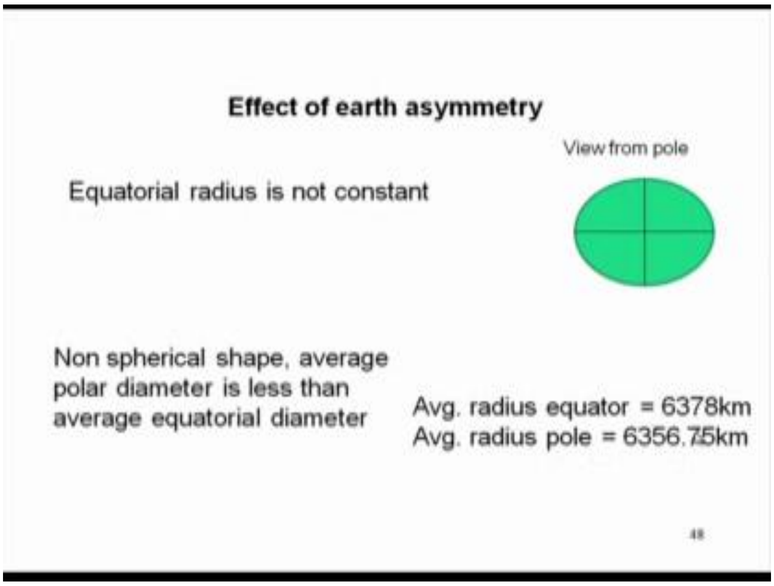

Let us look at the very briefly Equatorial radius is not always constant, its slightly positive at the equator now non spherical shape the average polar diameter is less than the equatorial diameter, taken from some books that is the average Equatorial radius is 6378, other one is 6356 at the pole it is different that is what is important.

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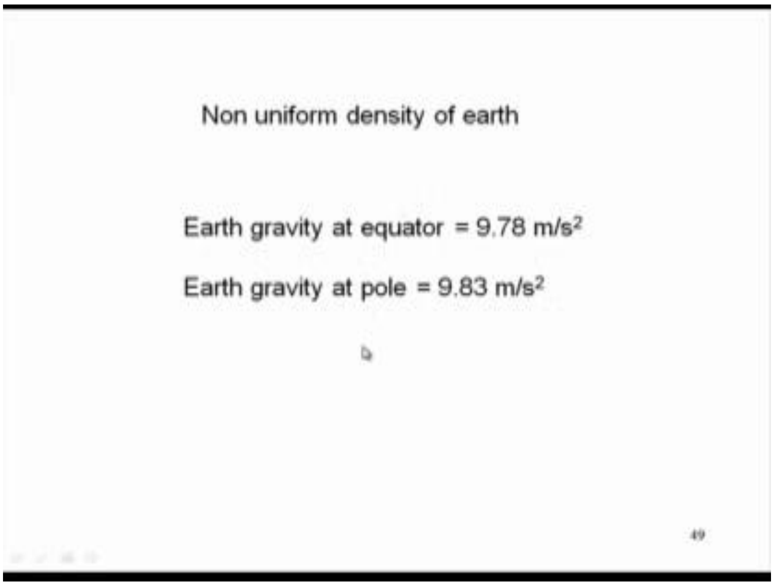

Then earth gravity at the equator is 9.78 meter per second square at pole is 9.83 meter per second taken from some books all this things that is non uniform that is important.

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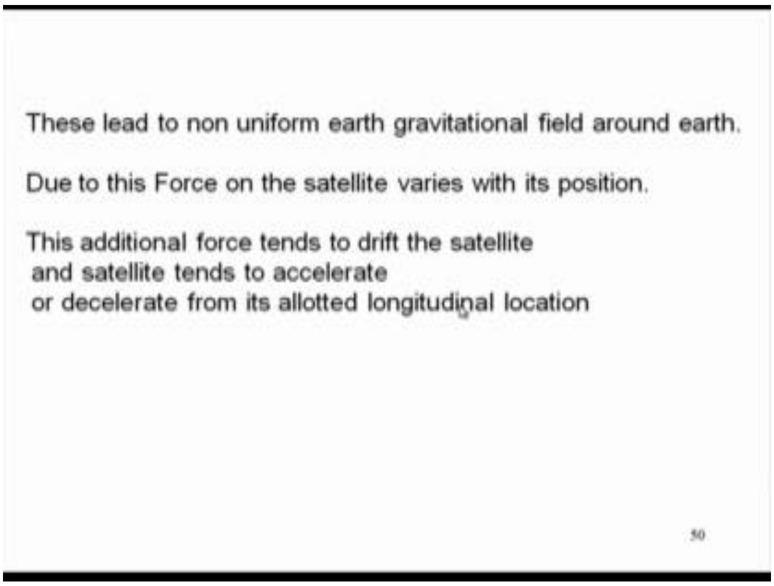

So, therefore, it leads to non uniform earth gravitational field around the earth and due to this force on the satellite varies on its satellite position. So, this additional force trend to drift the satellite from the intended location and either accelerate or decelerate.

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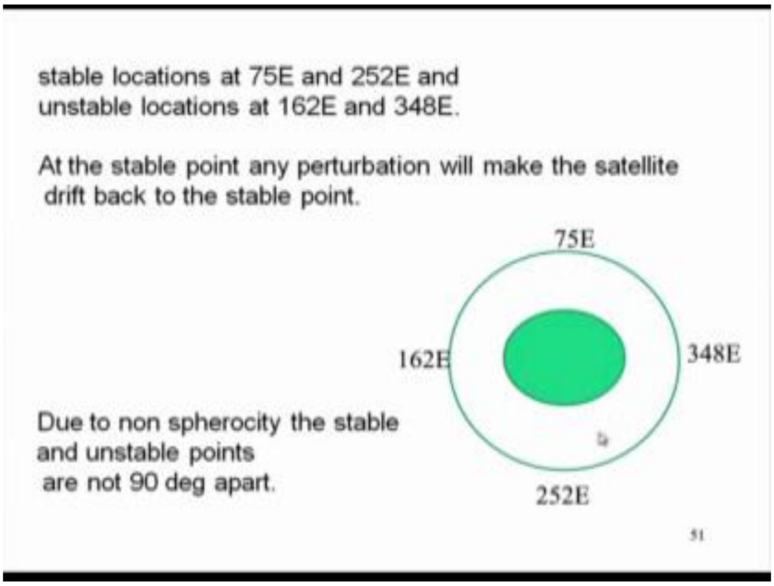

Which was found out by lot of experimentation and resonance that there are certain stable locations and there are certain unstable location. Now this stable locations are 75 degree east fortunately India center is almost like that I mean the same longitude and opposite side there is 252 degree east and unstable position is 162 degree and 348 degree east.

Now, at stable point if there is any perturbation happens, it will make the satellite to drift back to the stable point in site it moves, but at unstable point if it try to drift, one more thing you can point you can see that these are not exactly 90 degree apart because is not a sphere earth is not a sphere it is not 90 degree apart.

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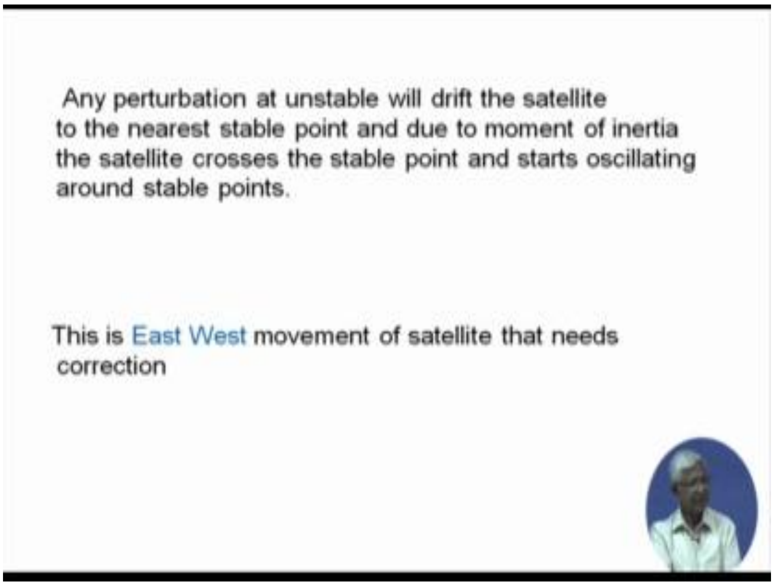

So, any perturbation at unstable point will drift it towards the stable point and oscillator on it due to inertia. These movements are on the equatorial plane. So, it is called East West movement of the satellite that has to be corrected keep it in the position.

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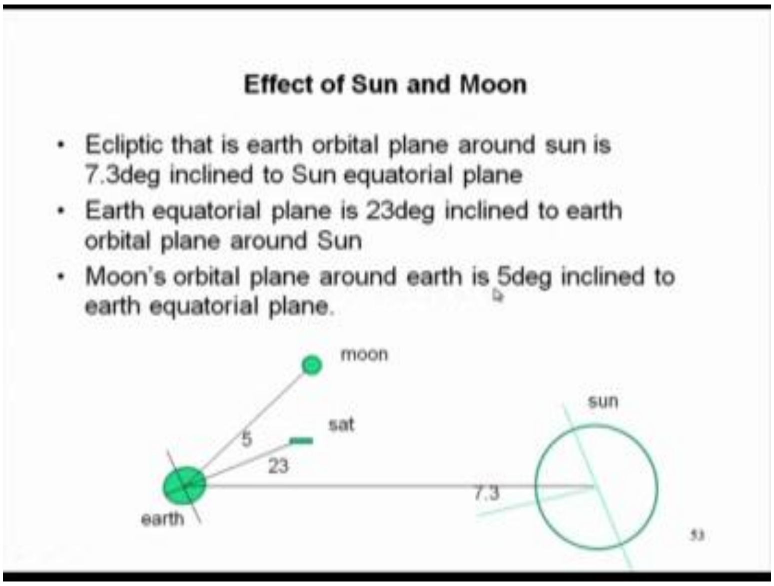

Now, let us look at Sun and Moon, Earth is Orbiting around the sun on a plane which is not the plane of the on which sun revolves, which is making some 7.3 degree angle similarly earth equatorial plane and earth Orbital plane around the sun are 23 degree roughly the satellite is on the equatorial plane Geostationary satellite moon creates a 5 degree estimation with the equatorial plane of the earth and based on their position that is moon sun and earth there will be some force acting on the satellite you can see that the force acting on the satellite can move the satellite north word or south word this is called North South movement.

What is said is listed here ecliptic plane is the that is earth Orbital plane is around sun is 7.3 degree earth equatorial plane is 23 degree inclined to earth equatorial plane around the sun moons Orbital plane around the earth is 5 degree inclined to the earth equatorial plane.

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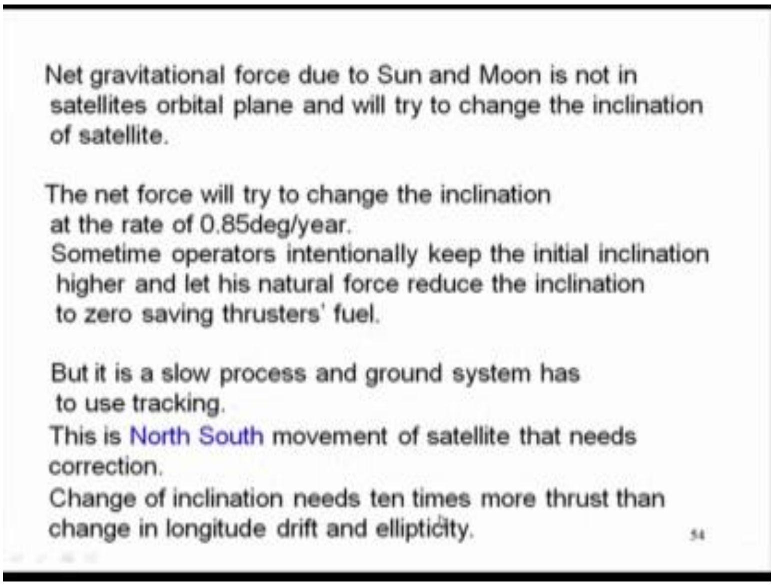

So, Net gravitation force due to sun and moon is not on the satellite Orbital plane. So, it will change the inclination of satellite that net force is roughly about point 8 degree per year. So, operators they keep initial inclination higher. So, that automatically slowly because it is a very small number slowly it gets adjusted to save the fuel otherwise you correct it. This is called north south movement that needs to be corrected and change in the inclination needs ten times more thrust that is north south correction needs more fuel than east west correction.

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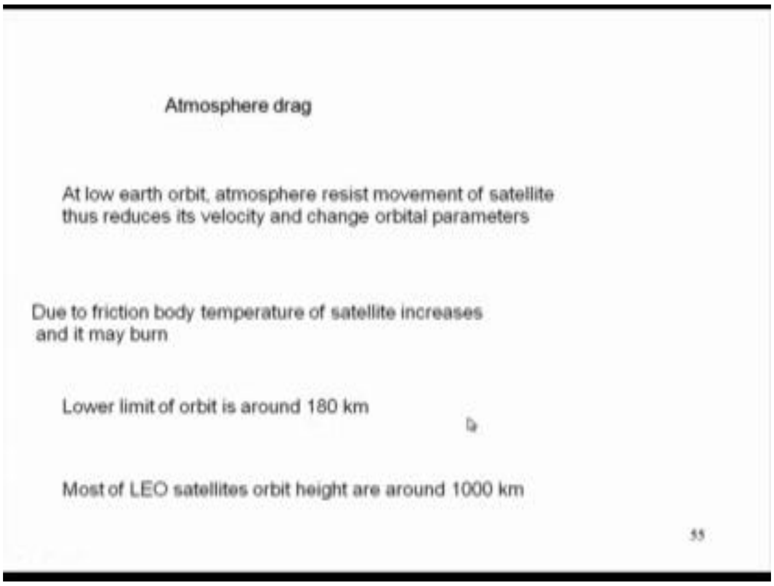

Other things are atmospheric drags for its low earth Orbit atmosphere resist the movement of the satellite that reduce its velocity in the Orbital plane and due to friction the body temperatures are slightly increases it may burn normally satellites are launched above 180 kilometers they are not brought below 180 kilometers. These are just rough number is not a very precious number its atmosphere density is different at different places different time and most of the new satellite Orbit is 1000 kilo meter of the earth.

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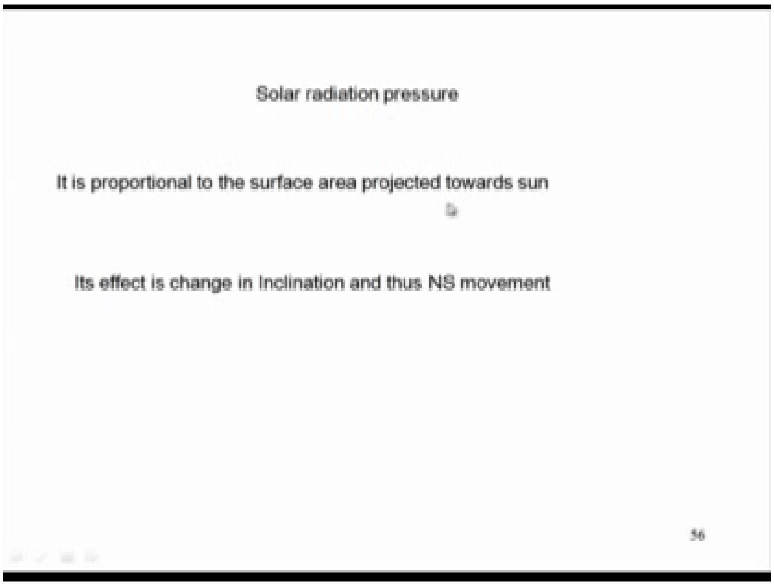

There is the solar radiation pressure which is proportional to the surface area projected towards the sun its effect also in make the non (Refer Time: 27:01).

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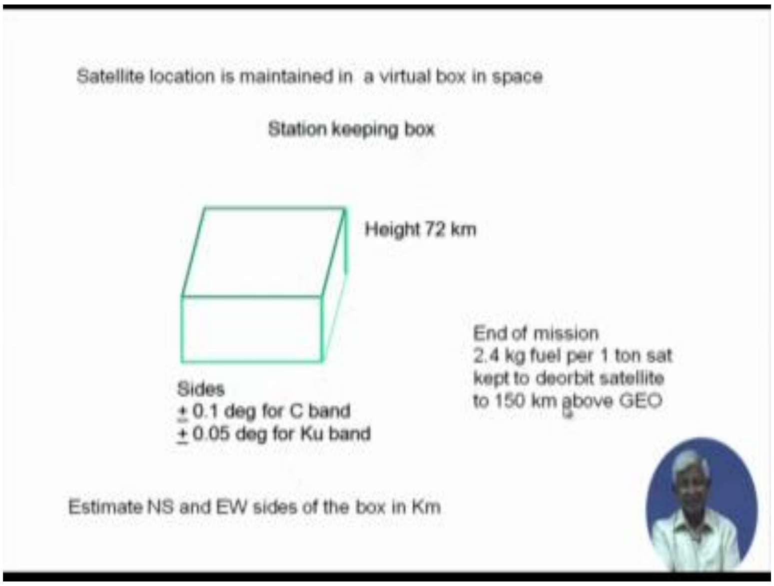

So, with all these things the operator they think a virtual imaginary box which is called Station Keeping box which is the height of 72 kilo meters and sides from the center of the earth it is about the point plus minus 0.1 degree for c band plus minus 0.05 degree for k band. This is at operational arrangement, but creates a virtual boundary on which satellite is allowed to drift and when reaches the boundary onboard satellite there are some rockets which are fired the thrusters which are fired to bring it back within this box which is called Station Keeping box.

So, you can estimate for this degree how many kilo meters it will be for different and different type of band. At the end of the mission that is when fuels are exhausted then it is moved away from GEO Orbit 150 kilo meter that is when we say satellite dies, actually satellite never die this actually electronics are always alive only fuel is exhausted. So, some fuels are kept to move it out are called de Orbiting the satellite.

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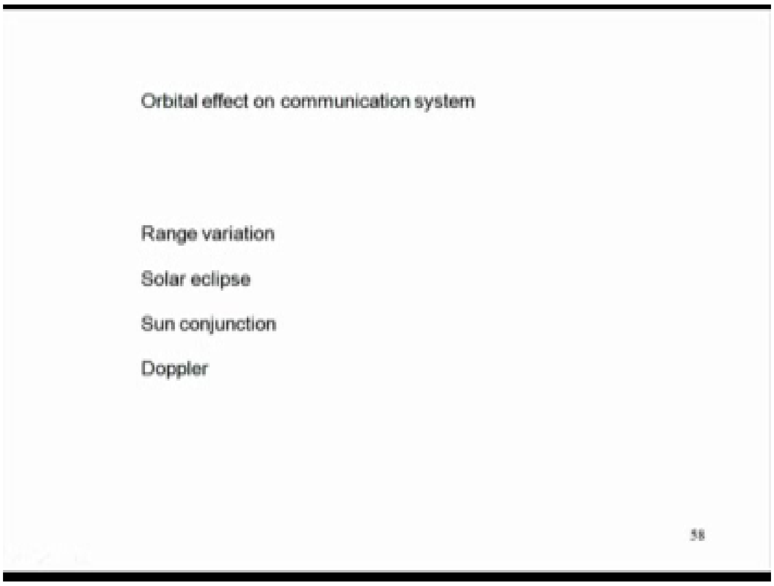

So, we will we have that how the arbitrary moves and perturbation. We stop here to continue in the next session - Further effect of the Orbit on communication system.

Thank you.