Introduction to Flight
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Introduction to International Standard Atmosphere (ISA)
Lecture 01.2

So, welcome to today's presentation, in which we will cover planet atmosphere, the topic of this course or the title of this course is Introduction to Flight.

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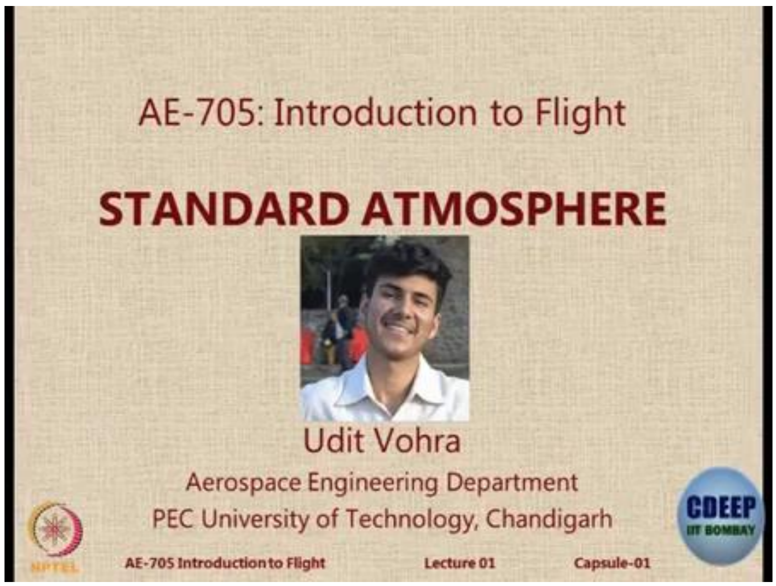

And in general, flight cannot take place unless we have an atmosphere, right. So therefore, it is very important for us to study the atmosphere in which flight takes place, especially at the altitudes at which the aircraft fly. So, I introduce you Udit yesterday, are you in the class, Udit? So, Udit Vohra was a summer intern, he is the one who has made this presentation. So, the layout of presentation is to first give you an idea about the atmosphere around the Earth.

We then talk about some standards, there are various standard atmospheres and then when you talk about Aerospace Engineering or in general aviation, it is interesting that there are many many different altitudes which are defined. So, we will see all the different altitudes, we then go ahead little bit of calculations, look at two magical equations that help us capture the essence of the atmosphere.

And then some operational information which is not available in textbooks so easily. And finally, we have some idea about how weather around the atmosphere that we live in strongly affects the operation of the aircraft, the nature of the presentation that I have made is such that it is not easy to get this information from textbooks.

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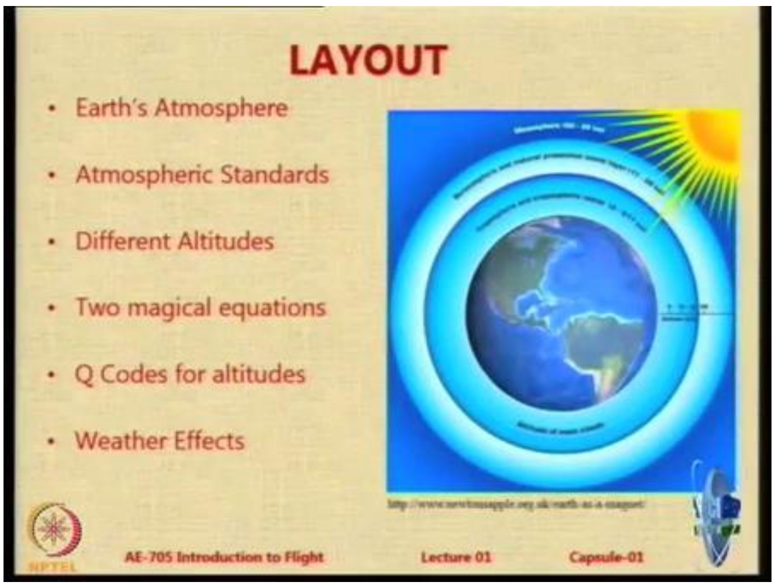

So, as part of your self-study, you are expected to go through the standard textbook, the book by Anderson, which has a chapter on atmosphere but the best book available today in Aerospace Engineering to study atmosphere is written by the first Head of Department of Aerospace Engineering from IIT Bombay. Professor S K Ojha his book has been published by AIAA American Institute of Aeronautics and Astronautics and it is a best seller book.

And that book is the best book for studying about atmosphere, we have copies of the book available in departmental library as well as in the institute library. So, I will urge you to refer to that book after you see this presentation. The presentation alone will not allow or not enable you to completely understand, this is just like an initial material.

So let us see how it looks like. So, essentially, our atmosphere is in separate layers, but these layers are not homogeneous all over the earth okay, there is no a line there which says above this is Mesosphere and below this is Stratosphere, this is just a general demarkation, but the properties of the air are quite different in these individual layers. So to understand what these layers are, and to understand what the specialties are, I thought I will just screen a video.

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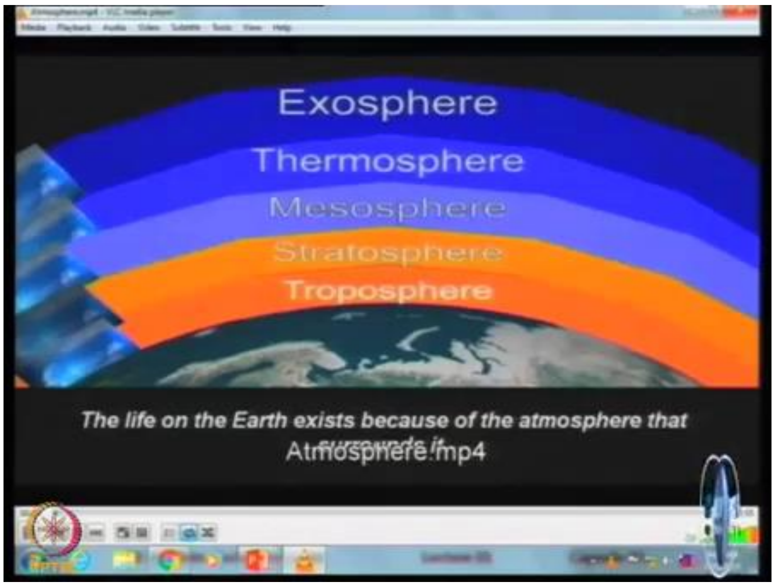
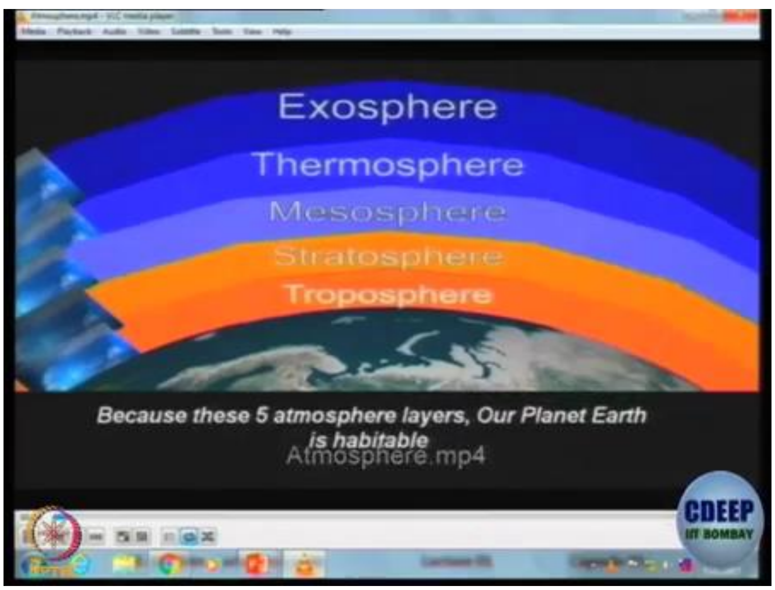
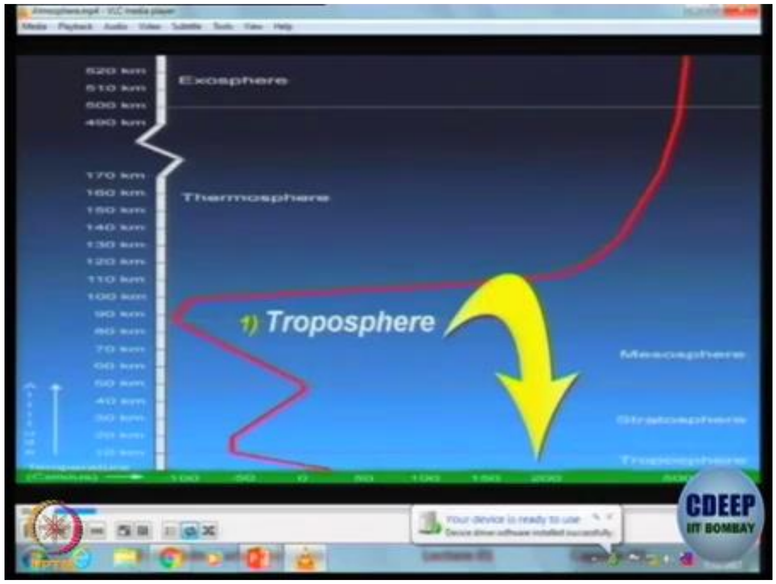
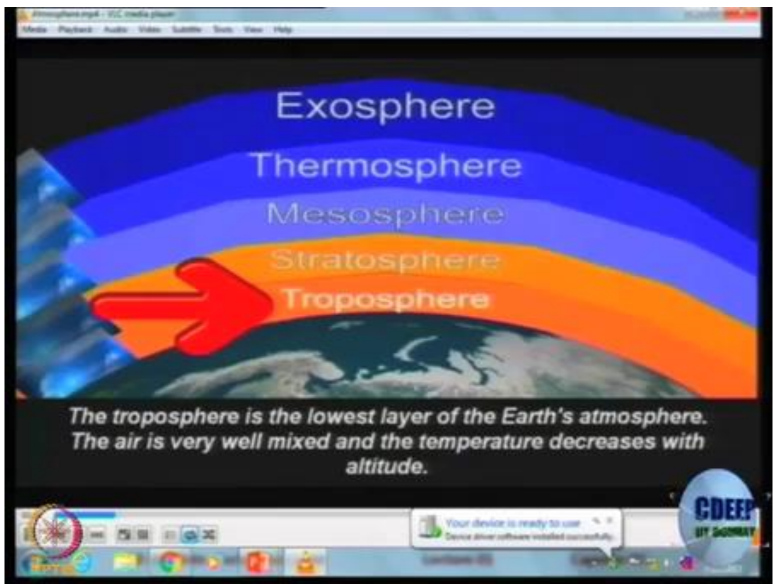
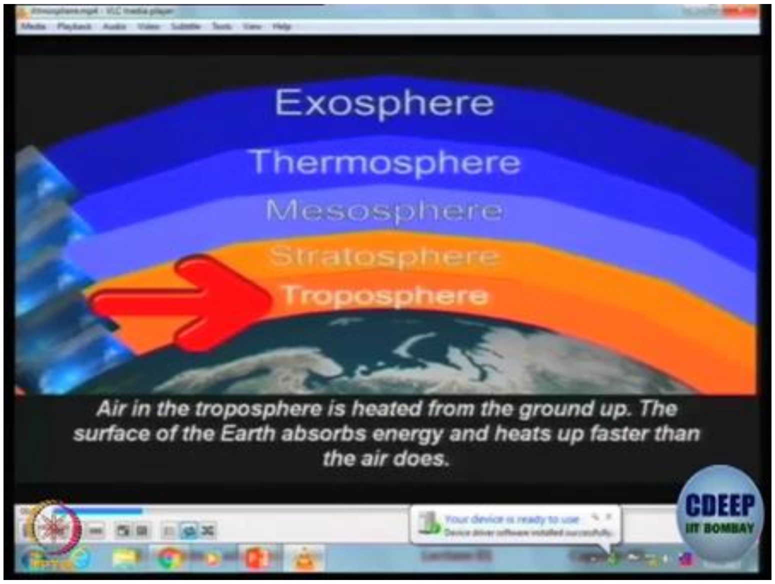


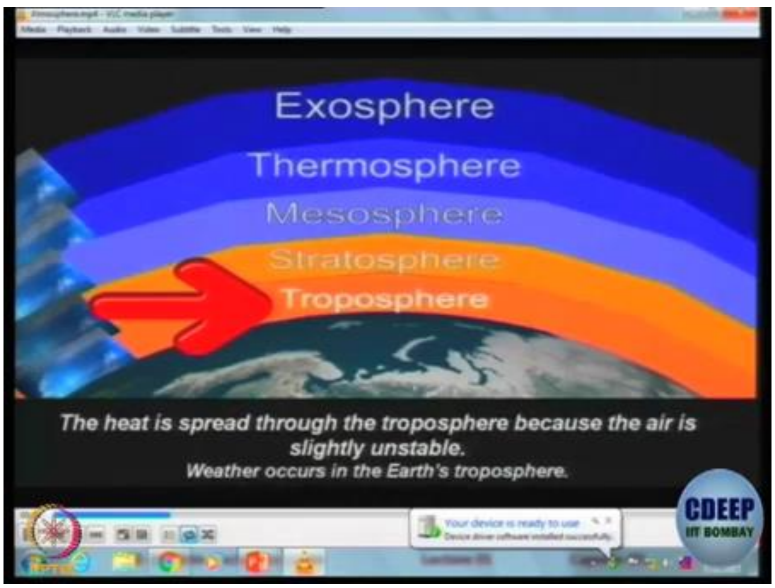


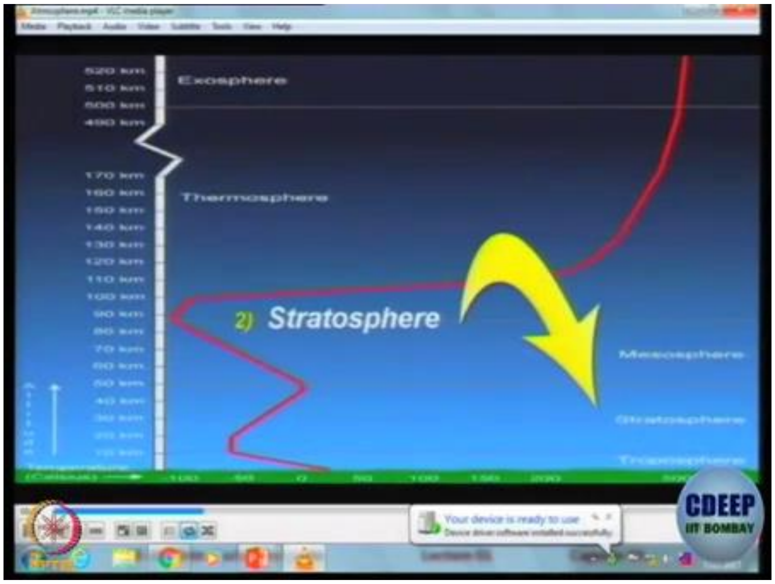




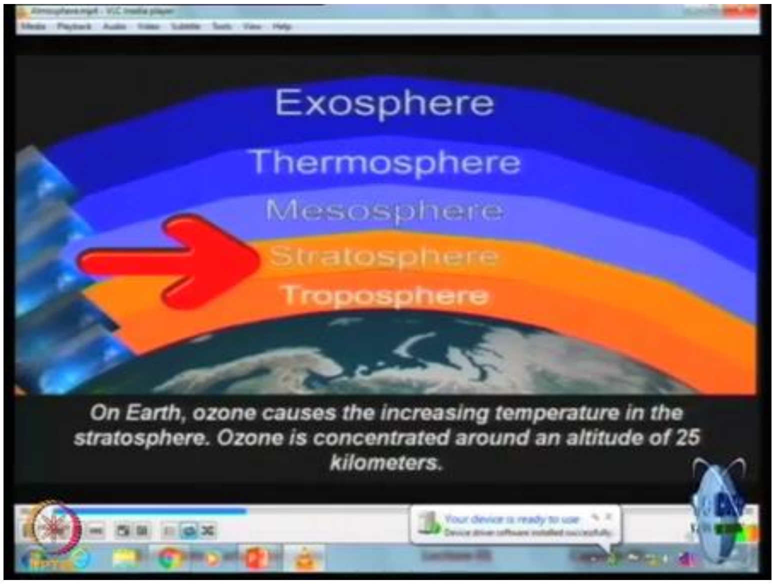
So, we live on earth because of atmosphere, because it contains oxygen that we need, if you do not have the atmosphere we cannot live. The bottom most layer is Troposphere, because of the mixing of the air there is heat transfer and hence temperature falls with altitude, so as we go up the Troposphere, temperature will reduce and reduce linearly.

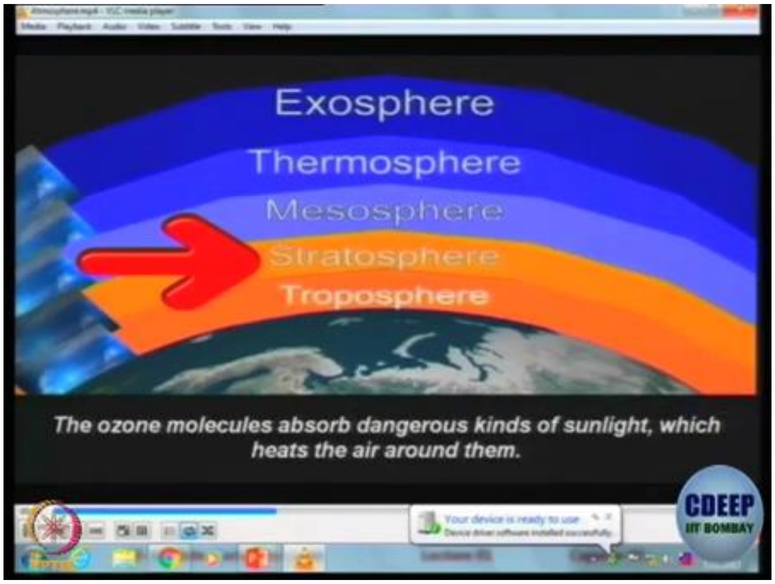

Exosphere
Thermosphere
Mesosphere
Stratosphere
Troposphere
Air in the troposphere is heated from the ground up. The surface of the Earth absorbs energy and heats up faster than the air does.
CDEEP
IIT BOMBAY

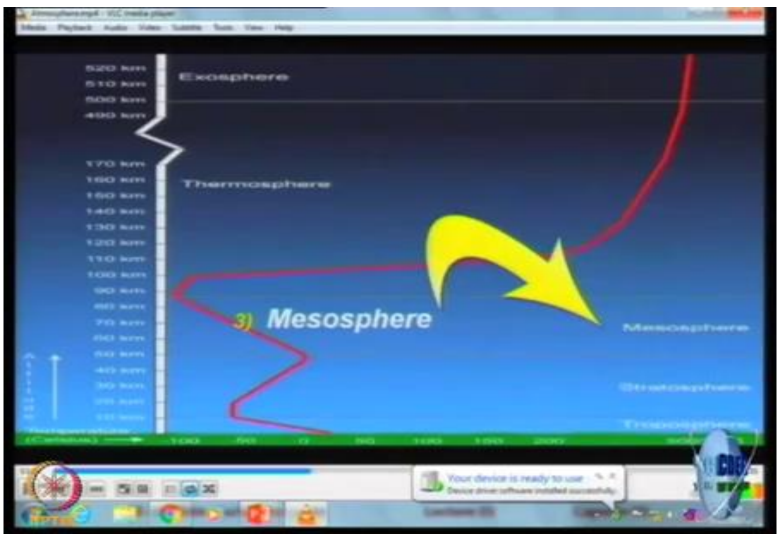

Exosphere
Thermosphere
Mesosphere
Stratosphere
Troposphere
The heat is spread through the troposphere because the air is slightly unstable.
Weather occurs in the Earth's troposphere.
CDEEP
IIT BOMBAY



The next level is stratosphere, here the opposite happens and the reason for that is ozone, ozone layer that is present in Stratosphere is the reason for this heating up, because ozone absorbs that heat and also it retains it.

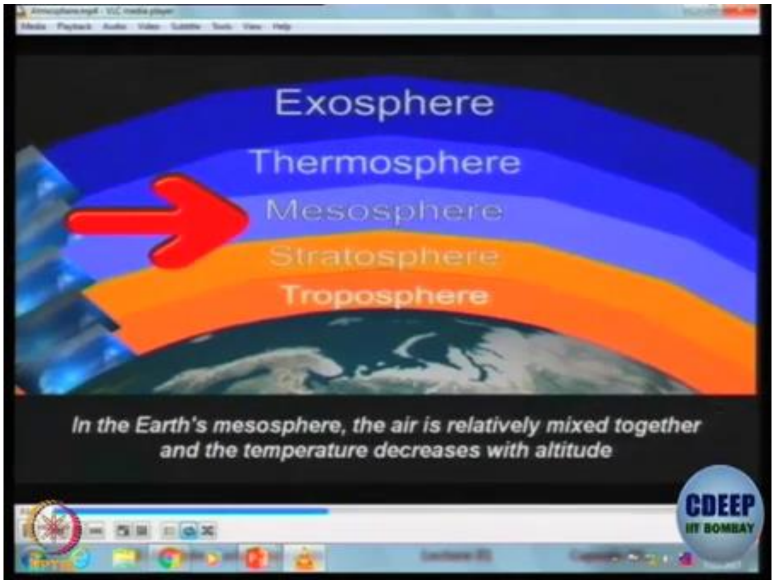






Above that we have Mesosphere, so Mesosphere once again, you come up with mixing like we have in the Troposphere.

So, now the temperature is going to change but it is the coldest area in the atmosphere normally, you can have up to minus 90 degrees centigrade. And fortunately, this is a place where meteors are normally consume otherwise they would be hitting us regularly.


Exosphere
Thermosphere
Mesosphere
Stratosphere
Troposphere
In the Earth's mesosphere, the air is relatively mixed together and the temperature decreases with altitude
CDEEP
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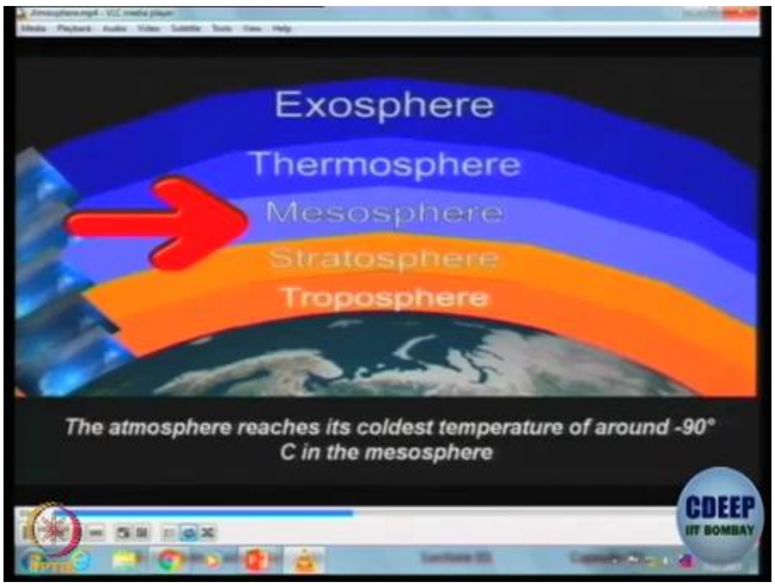
Exosphere
Thermosphere
Mesosphere
Stratosphere
Troposphere
The atmosphere reaches its coldest temperature of around -90° C in the mesosphere
CDEEP
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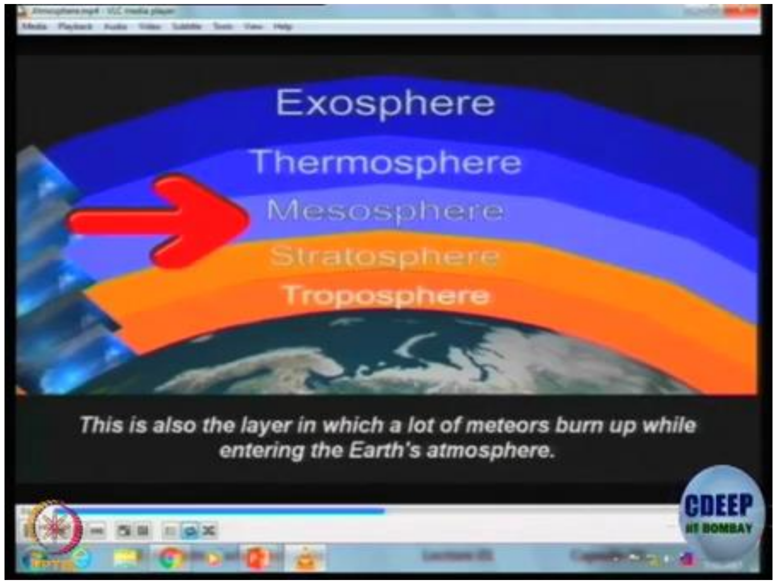
Exosphere
Thermosphere
Mesosphere
Stratosphere
Troposphere
This is also the layer in which a lot of meteors burn up while entering the Earth's atmosphere.
CDEEP
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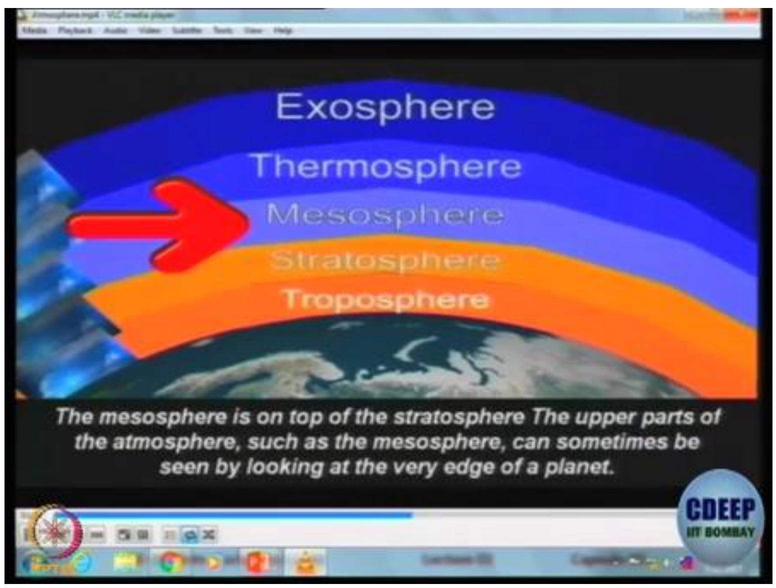
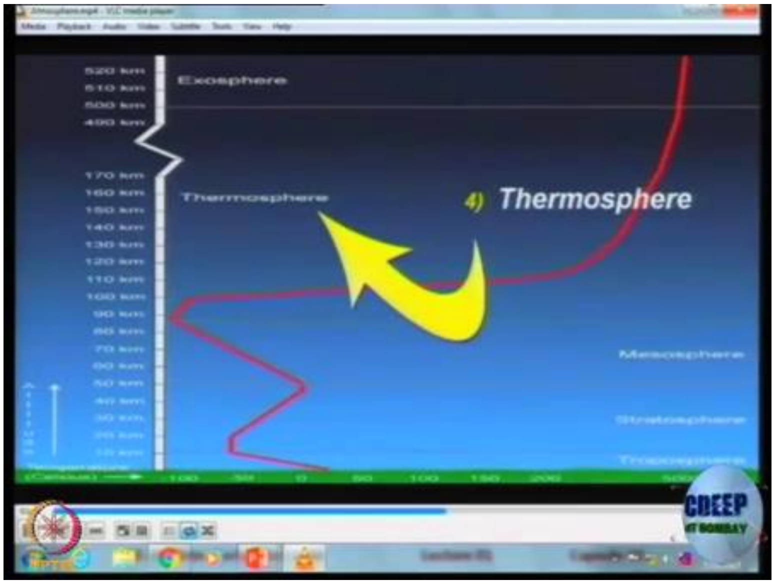
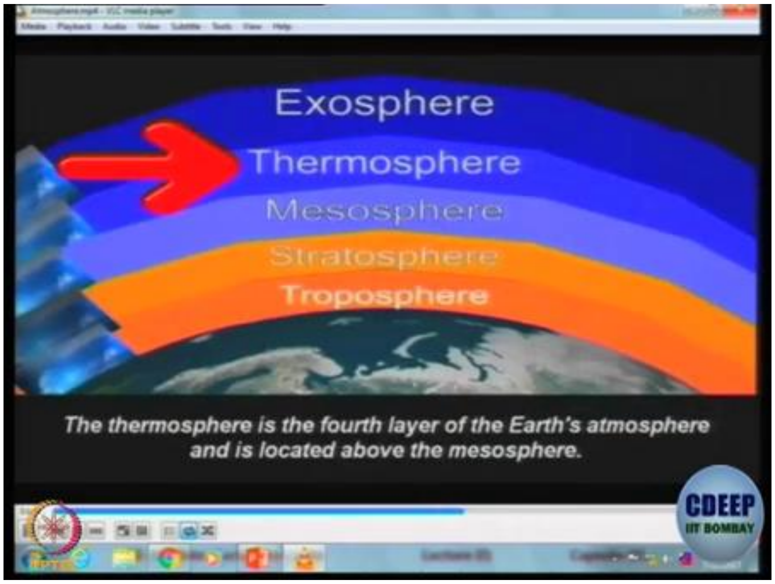
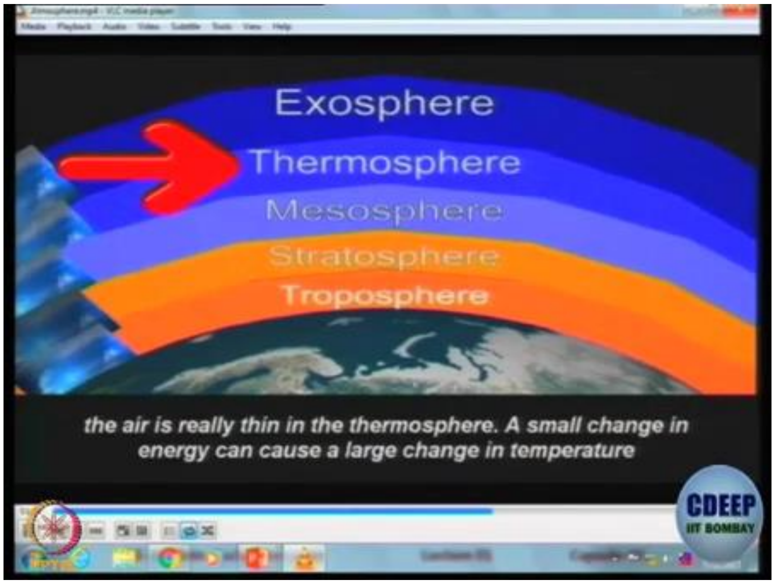

Exosphere
Thermosphere
Mesosphere
Stratosphere
Troposphere
The mesosphere is on top of the stratosphere The upper parts of the atmosphere, such as the mesosphere, can sometimes be seen by looking at the very edge of a planet.
CDEEP
IIT BOMBAY

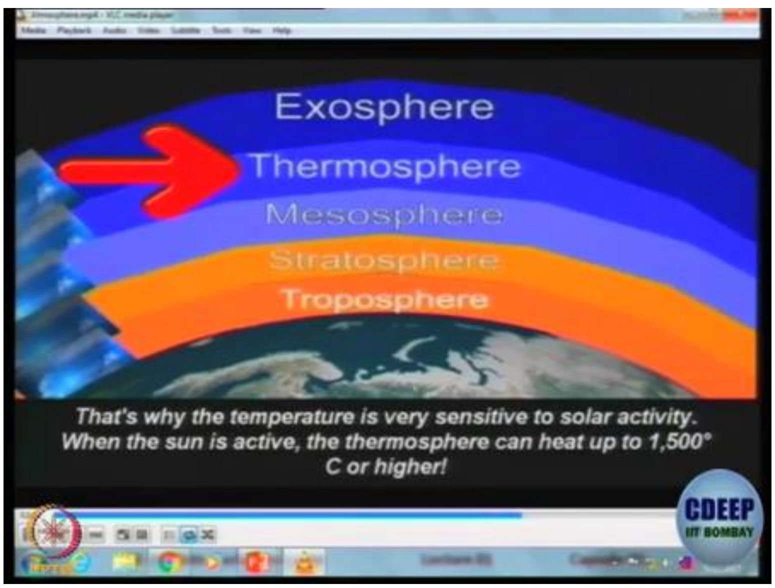


The next one is Thermosphere, by the name Thermo it means hot or heat, temperature in Thermosphere can be as high as 1500 degrees Celsius, so imagine from minus 90 to 1500 degrees in a very small height, because a very small change in the energy as you can see cause a change in the temperature.

So, this is a place where most of the items will melt, so when spacecraft enter the earth this is where normally they get melted or consume but some of them are able to still go through because the layer is quite thin




Exosphere
Thermosphere
Mesosphere
Stratosphere
Troposphere
the air is really thin in the thermosphere. A small change in energy can cause a large change in temperature
CDEEP
IIT BOMBAY


Exosphere
Thermosphere
Mesosphere
Stratosphere
Troposphere
That's why the temperature is very sensitive to solar activity. When the sun is active, the thermosphere can heat up to 1,500° C or higher!
CDEEP
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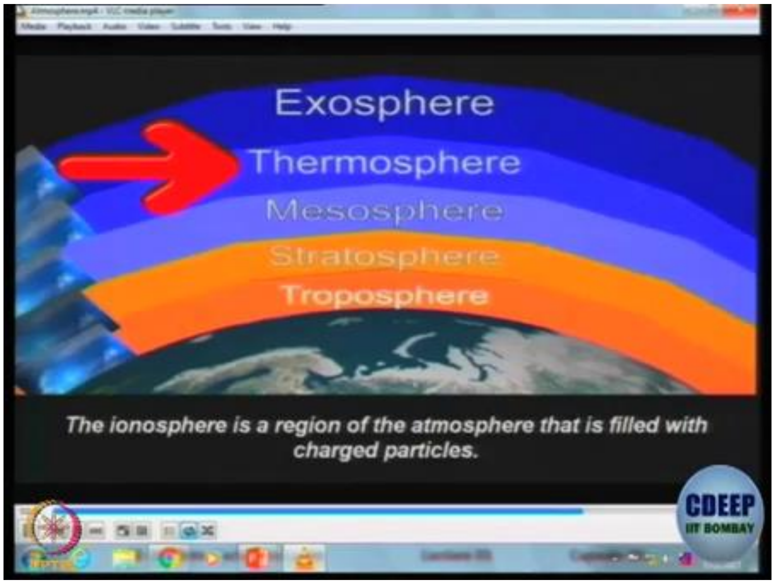

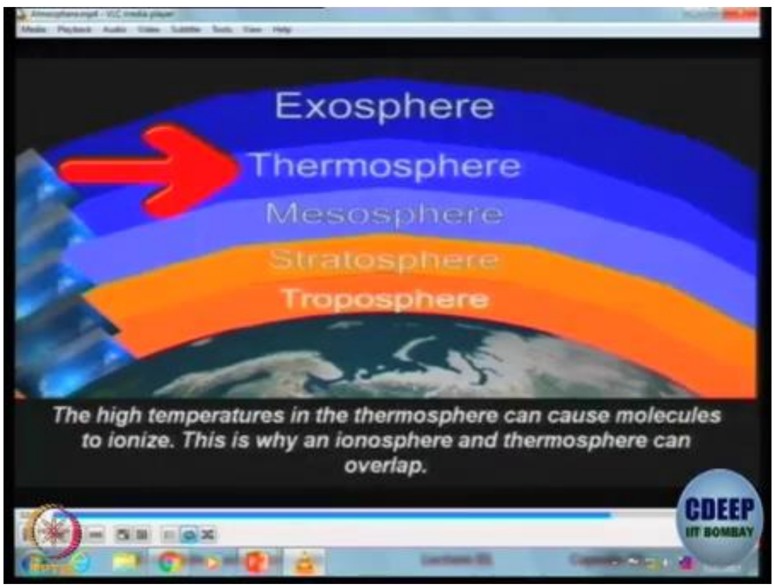

and then we have the Ionosphere where the air is in Ionospheric particle, these are charged particles, and because they are charged particles, it's very difficult to find the distinguishing. Outside that is Exosphere and then it goes up to outer space. So, demarkation is not really possible.

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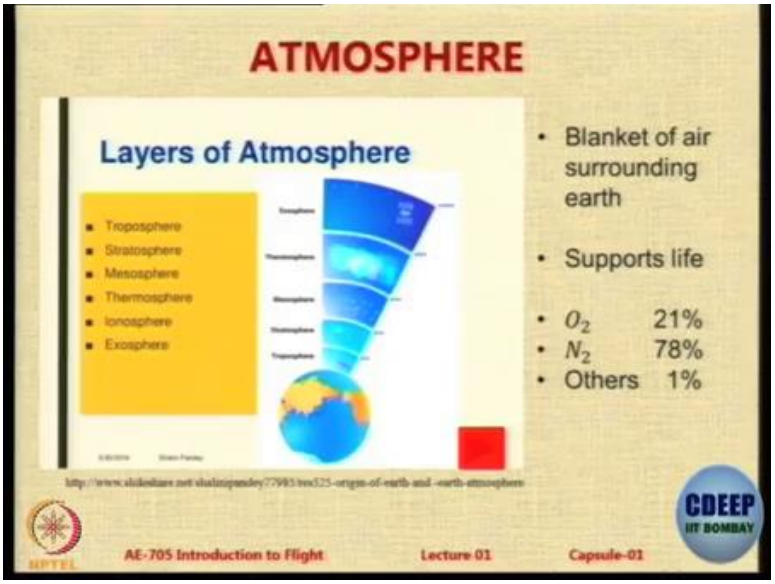

So summing up atmosphere is a blanket of air that surrounds the earth and it supports life on earth predominantly, the atmosphere that we live in that is the troposphere contains oxygen around one fifth, nitrogen around three fifths and then everything else okay, right.

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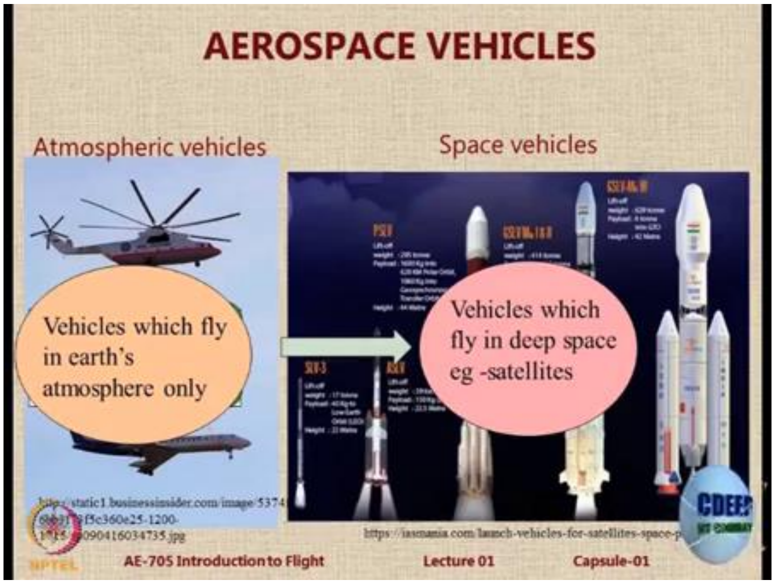

Let us look at generally aerospace vehicles. There are two basic kinds, one kind is the vehicles that operate in our atmosphere, atmosphere as we know and this atmosphere basically is the lower atmosphere.

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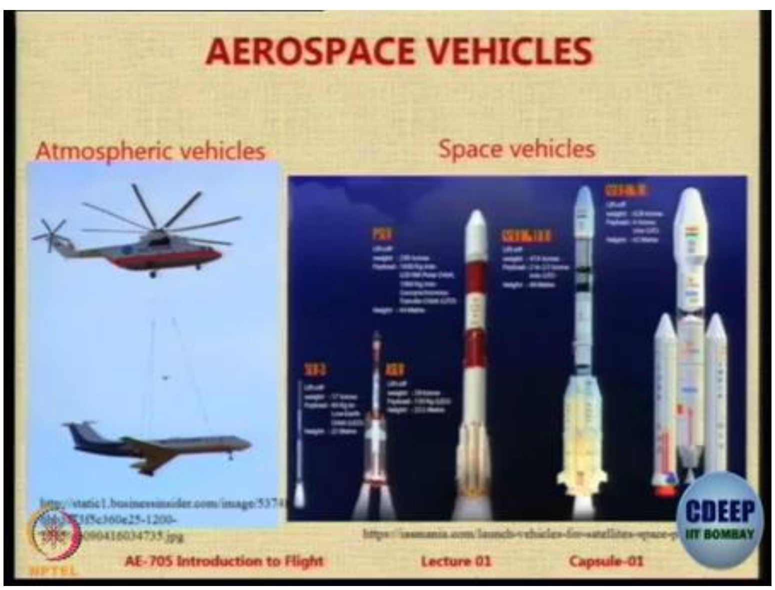

So, there could be helicopters, there could be fixed wing aircraft and there could be helicopters carrying aircraft. In the outer space, beyond about 100 kilometers we start looking at space vehicles. So broadly speaking, upto 100 kilometers from earth broadly speaking could be considered as part of the atmosphere, although aircraft never fly beyond 20-22 kilometers except for a few exceptions.

So can you tell me which are the aircraft that have flown beyond 20 kilometer altitude? Raise your hands if you know the answer, Yes. MiG 25, Yes, I am sure you know it because of your experience in the armed forces and what else? Where are you from? Are you from the Indian Air Force? Good. So MiG 25 is one example up to what height does it fly? 25 kilometers okay, anything? Yes. What height does it fly?

65,000 ft or so. That is right. You two reconnaissance aircraft also, okay. And any other aircraft that you know? How about Concorde? The Concorde also flies at a height of around 60,000 feet or I should say used to fly it does not fly anymore. But for these exceptions, everyone is generally below around 15 kilometers 12, 13 kilometers okay, there is a reason for that, which we will understand when we go to a lecture down the line.

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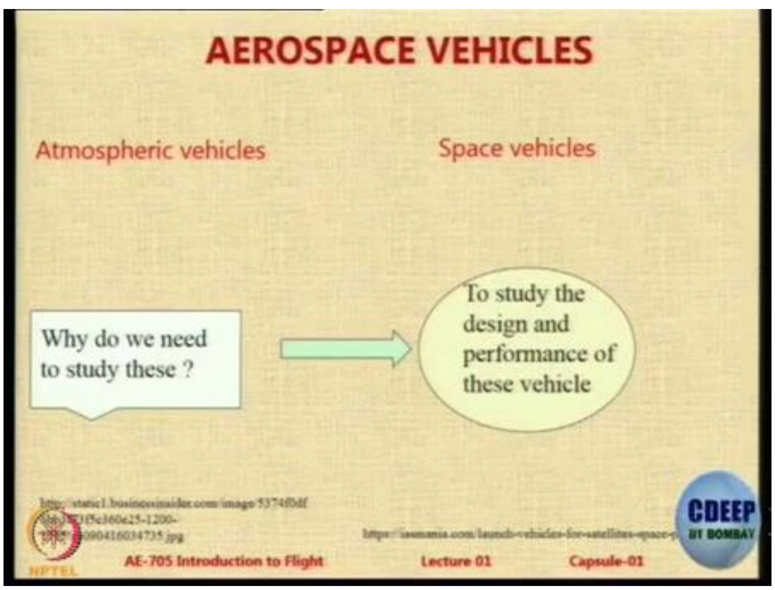

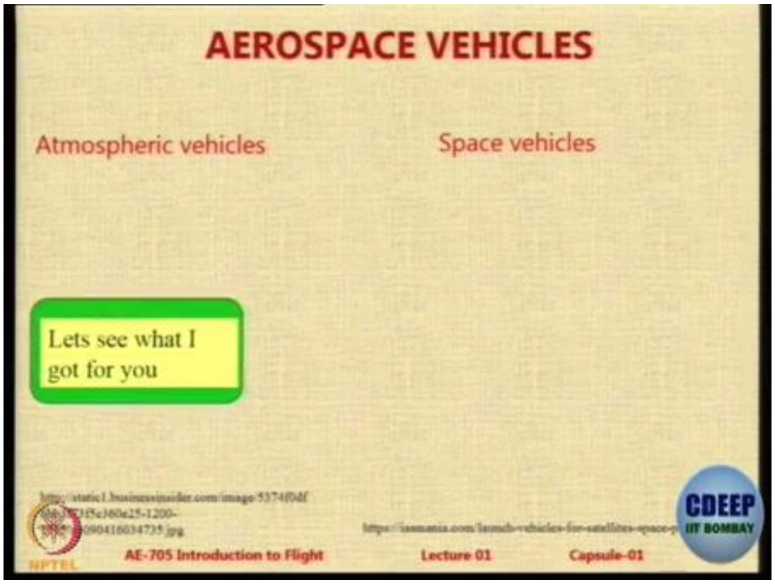

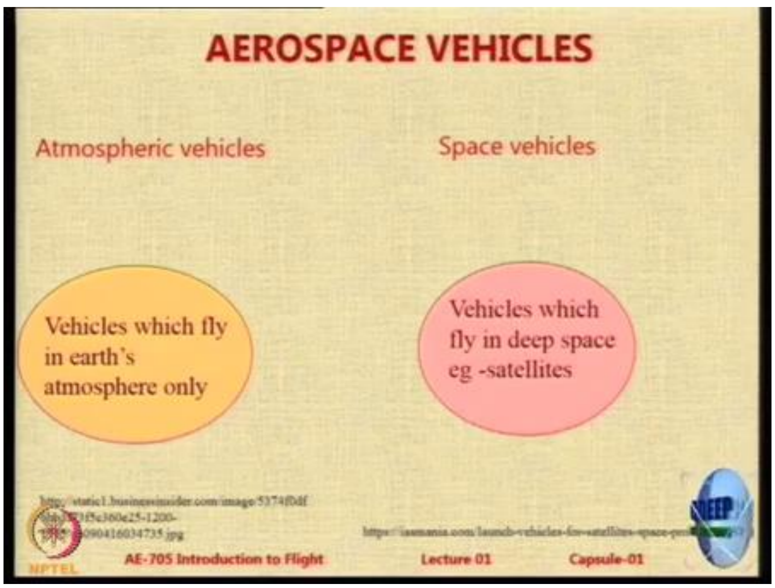

So, our concern is basically about atmospheric vehicles, we study these vehicles, because we need to study and design and study the performance of the space vehicles. So, that is why although we live only in the atmosphere, which is below us, we actually have to be concerned about the vehicles that fly both within our atmosphere and also vehicles which go into deep space. All right.

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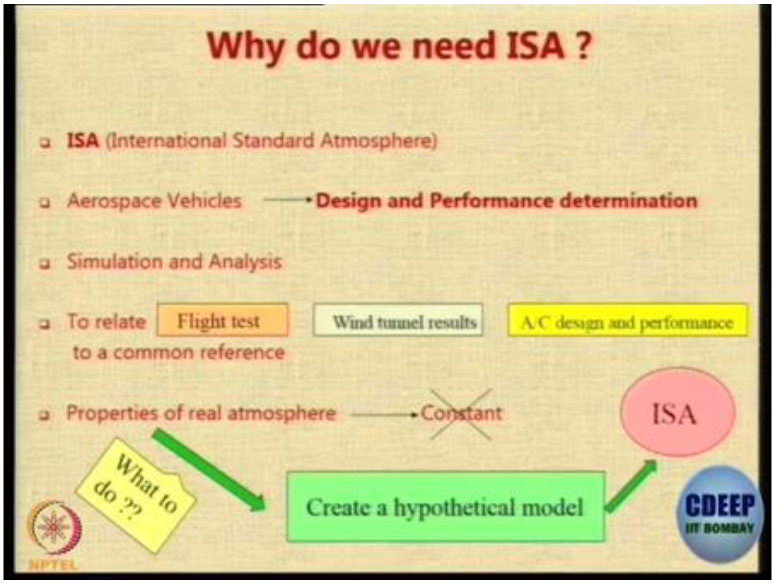

So, the question is, there is something called as the International Standard Atmosphere we have to understand what is the need for us to define an atmosphere like this, remember, I mentioned to you that the atmosphere does not have that beautiful layer structure that I showed you in the slide, it is only a representation of the average values. So, the aerospace community follows a standard atmosphere internationally and therefore, it is called as the ISA. Now, when we design aerospace vehicles, our task is to also determine their performance and capabilities.

And you know that the performance of an aircraft will change if you look at a different atmosphere. So, an aircraft that flies at some Mach number in an atmosphere, where temperature is say 10 degrees centigrade will not have the same performance when temperature is 20 degrees centigrade. So, the same aircraft in Russia and in India will not have the same performance. I know this because when I did the performance calculations for MiG 27.

I found that MiG 27 can fly up to Mach number 1.7 at a height of 10 kilometers when it is flown in Russia, but in India in Nashik, we were never able to get Mach number 1.7 and initially there was a conflict with the customer saying that your aircraft is deficient. The manual says Mach 1.7 clean, that means without any armament and where your flight testing only shows lesser Mach number. So, we were able to convince by calculations that the difference is because of atmosphere and atmosphere in Siberia at 10 kilometer is different from that in India and hence the performance of the aircraft can change.

So, if you do not do normalization, then you have these problems. So, when we do simulation, analysis etc . we need some kind of a normalization and we want to relate these three things, flight test happens in the real atmosphere, wind tunnel test happen in the laboratory or in the test area in a different atmosphere and the aircraft performance and design is quoted in the manual for some other conditions. So, to have a match between them or to have a common reference, all data is reduced to the ISA conditions, so that there is uniformity, okay.

And the reason for that is the properties of the atmosphere are not constant they are different from place to place, country to country, season to season in the same place, okay. So, what to do to handle these problems? The solution is to create something hypothetical which everybody has to follow and that hypothetical atmosphere is called as the international standard atmosphere, it is absolutely hypothetical. There may not be any place in the world, where the temperature profile may follow what is given in ISA, there may not be and there need not be, as long as you understand and you know what the variation is expected to be, as long as I understand and they understand we are on the same page.

So, for uniformity across the board, we define a theoretical atmosphere. Now, many people say that the ISA is modeled around the temperature in Northern America, somewhat true, but not exactly true okay, right.

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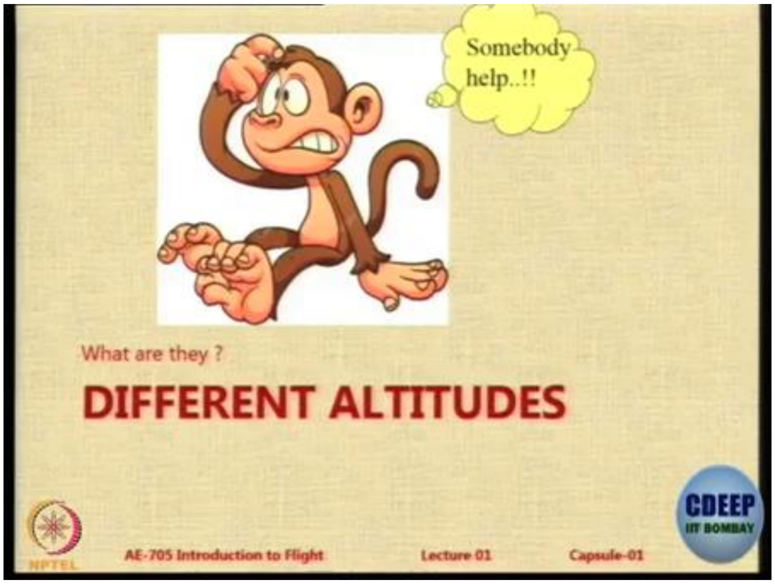

So, now, we come to the altitudes. Interestingly, altitude when I say you may say okay, there is only one altitude, but I'll show you in aerospace, there are actually six altitudes which are define, okay.

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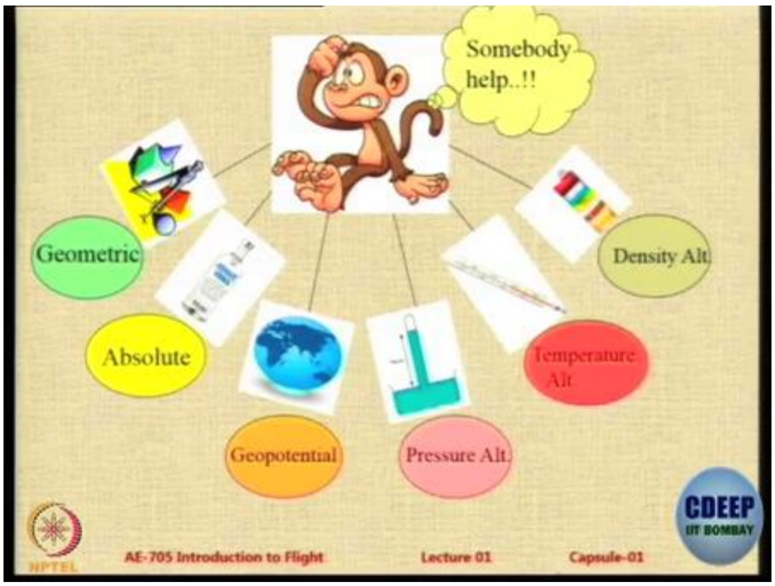

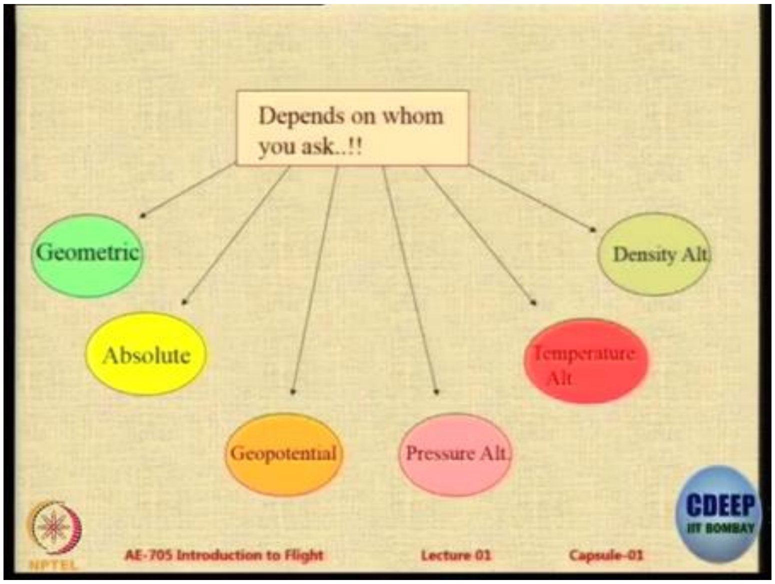

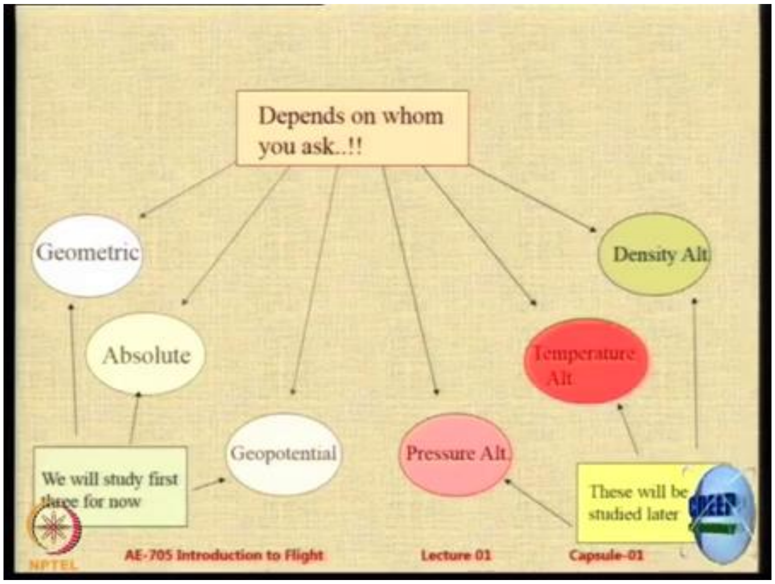

And today, what we will do is, we will look only at the three altitudes, depending on whom you ask the air traffic controller, the pilot, the person on the ground, the meteorologist, the aircraft designer, the performance engineer, there could be different answers for the altitude. So, what we will do is these three the first three, these are the ones we will study now, Geometric, Absolute and Geopotential we try to understand the difference and these three, we will do it later because these, these three actually come from only the operational point of view, they do not come from that theoretical calculation point of view, pressure, altitude and, temperature altitude and density altitude are actually relevant only when you do flight testing or operations.

So, we will come to that later, first let us do the simple theoretical part, right.

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Now, the altitude that the pilot reads is called as the indicated altitude okay, it may not be the true altitude or the correct altitude because the instrument can have errors right, any instrument which works on a sensor can have errors. So, the altitude that the pilot reads may not be the correct altitude for all you know, the pilot may read zero altitude at 10 kilometer because the altimeter is jammed it happens sometimes.

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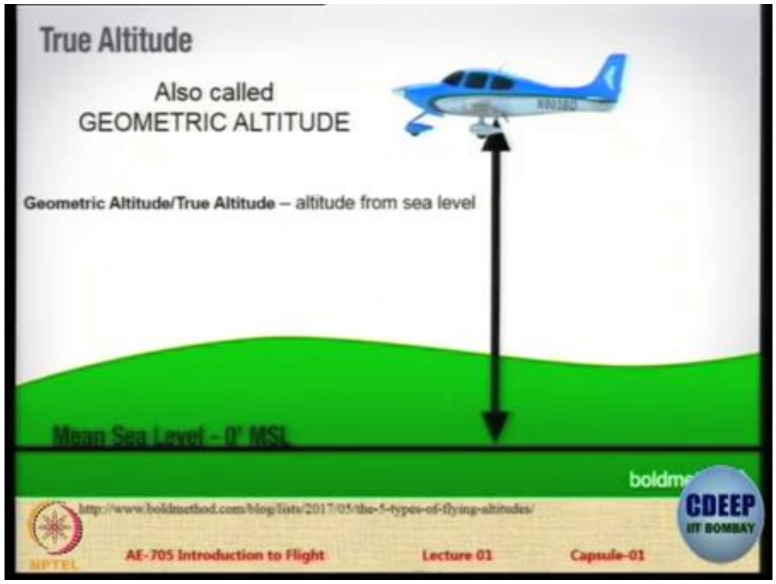

So, let us start, the first altitude is the true altitude or the actual altitude or the geometric altitude and that is, there is a theoretical place called a mean sea level. Again, it is theoretical because even the sea level is different at different places. So, you do not have only one uniform sea in the world. But we have defined one mean sea level. The mean sea level at Amsterdam is different from the mean sea level at Mumbai, but okay, at Mumbai there is a mean sea level from that height at what height you are operating that is the geometric altitude or true altitude.

So, this altitude is the one that we most commonly refer, when I say an aircraft is cruising at an altitude of 10 kilometers. If I do not say anything else, I mean this altitude. So, this is the most basic one, if no information is given, assume this is the information, Yes. Very good question. We will answer this question when we come to those Q values, that is the exact purpose of this question, the mean sea level is different. So, you may take off from zero, height of thousand meters above mean sea level in Mumbai, and you may come to some height and then the height maybe 200 meters above mean sea level because the sea has gone down.

So to answer this question, I will come to the Q value, very good question. Okay, any other question if you have like this, I will be very happy, alright. So, this is the simplest one, yes.

That is another interesting question. Even the mean sea level may change from season to season at a simple place, okay. So, what we do is, we define one particular average value for the mean sea level at that time, we plus or minus some values and that so once that number is decided, it is communicated for example, Mumbai, it is 14 meters above mean sea level. It does not mean that always it is 14 meters, during high tide, during low tide, during some seasonal thing it can change, but the average is 14 meters above mean sea level.

The interesting thing is if all the users are following the same reference, then there is no confusion. If my altimeter is set to Mumbai as 14 meters at sea level and you are the air traffic controller and your instrument also is set to the same value, when we talk if our references is same then there is no doubt, okay, it may actually be at some level, how does it matter? Both of us know that it is at this. The problem is when you talk of mean sea level from something and I talk from something and that is how confusions come, I will talk about it when we come later on.

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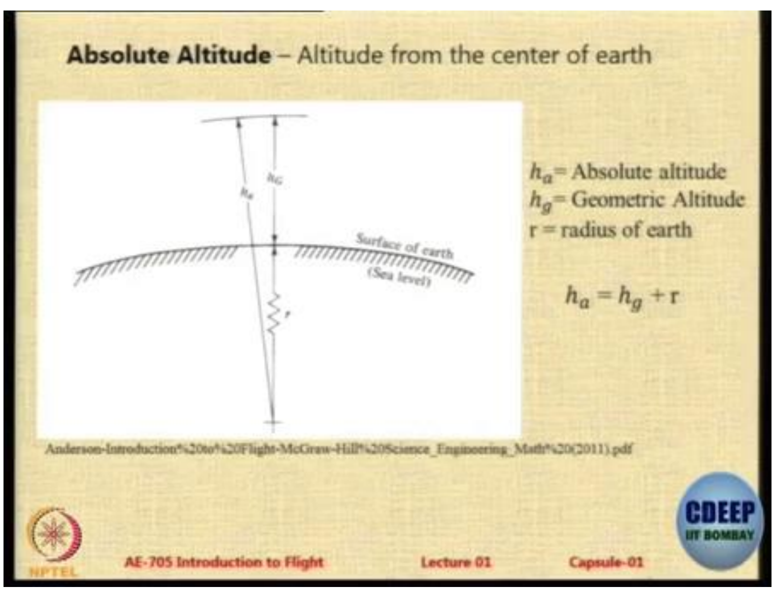

Then, when we have one more altitude called absolute altitude. So, now we say that the earth also has got its own curvature and radius. As you know, earth is oblate spheroid, not even symmetric. So to avoid confusion, and when we look at operation of spacecraft or high altitude vehicles much much beyond aircraft, then we define something called as an absolute altitude which is equal to the height above the surface of the earth.

Now, there is no sea level, is the surface of the earth plus the radius of the earth at that point. So, it is h a absolute altitude.

$$h_a = h_g + r$$

Where, $h_a = absoolute\ altitude$

$h_g = geometric\ altitude$

$r = radius\ of\ earth$

Obviously, this is used mainly when you are interested in looking at you know, when you want to look at the absolute value and the third one is very interesting, this is geopotential altitude because even the value of g, that is the acceleration due to gravity it does not remain the same in the entire space.

So, up to 10, 12 kilometers there may be hardly any variation. So you can ignore, but when you look at spacecraft going to Mars or outside then there is a huge change. So, when you look at the variation of the gravity into consideration, then you define something called as H geopotential which is equal to radius of the earth R into the height above the ground divide by the absolute altitude R plus HG okay, so, this way, we take care of the value of g, where g is, g is taken care in the calculations. Okay. So this is only in the case of space vehicles. We never normally bother about these, we do not worry about these for the atmospheric vehicles.

$$h_{geopotential} = \frac{r * h_g}{r + h_g}$$

Where, $h_{geopotential} = Geopotential\ altitude$

$h_g = height\ above\ the\ ground$

$r = radius\ of\ earth$

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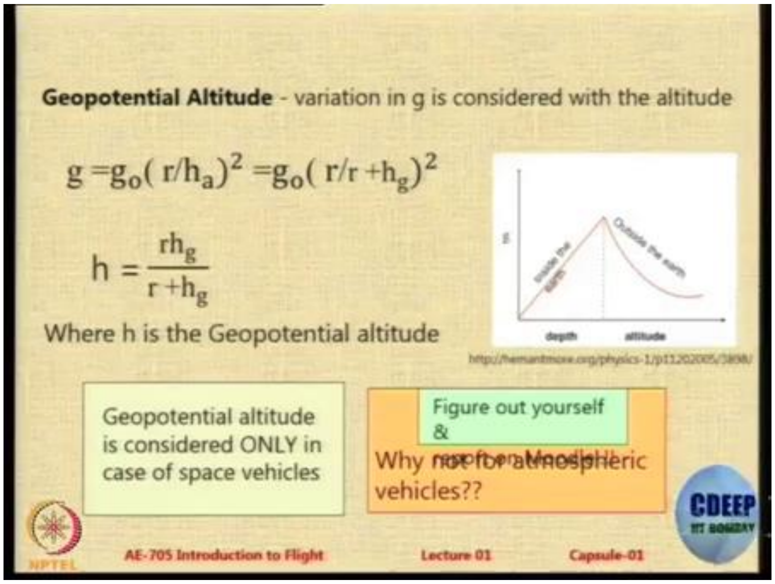

So, why is it so that the geopotential altitude is of consequence only in the case of space vehicles and not in the case of other vehicles? We do not want to answer this question. We want to give this as a question where you can post it in Moodle, okay. So I am expecting some people to post the answer in Moodle, start a new discussion saying, 'Why is geopotential altitude not considered for aircraft vehicles in general?'. Quote your answer and mention your source, we are not looking at opinions, we are looking at reliable information, all right.

We proceed now to some simple mathematical calculation about the properties of atmosphere and to do that, we use what is called as the hydrostatic equation. So, this is our atmosphere, this is the typical variation of atmosphere.

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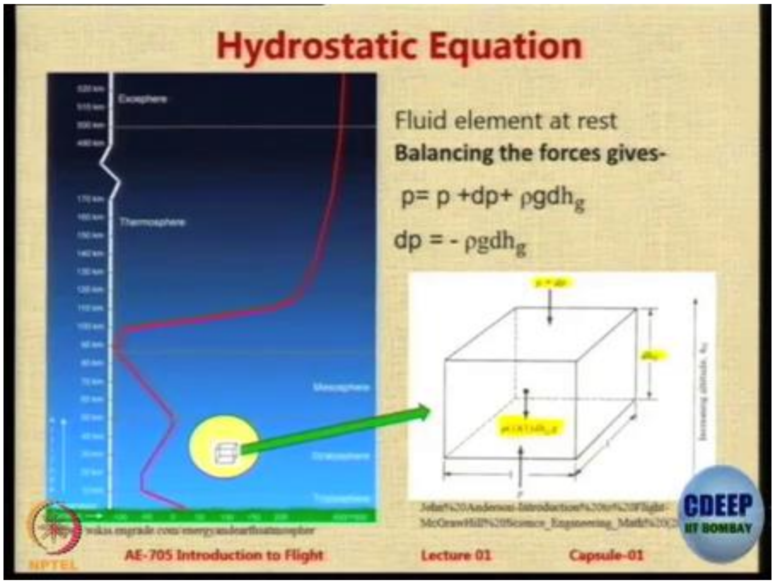

So, assume that at some place in the atmosphere, it may not be only Stratosphere it could be anywhere, just look at some, focus at some particular place, look at a small element. And now, let us assume that this element is at rest okay, we are ignoring the effect of wind, etc, we are saying that because of the temperature variations with the altitude, under no wind condition, there is a small element of fluid which is at rest. So, just zoom into that particular element. And now for simplicity you can assume, not necessary, but you can assume that this is now a cube of unit dimension, unit dimension will be only the bottom, the height is not unit, the height is some dhg a small value dhg.

Now, because this particular now, we assume that there is a variation in the pressure from bottom to top, so, we assume that the pressure acting on the bottom surface is P and the pressure acting at top surface would be that P plus some Delta P, it could be positive, it could be negative we do not know. Under all conditions, this element is still at rest, if it is moving up or down, left or right then it is not valid, because then you have to bring in F is equal to ma and invoke the dynamics of this particle, which is what we do when we study the properties of atmosphere in the dynamic mode, but that is beyond the scope of this course.

So, right now, our chap is stationary. So, the force acting on the bottom is the pressure into the area right. So, if you balance the forces, we will get that the bottom pressure P is equal to P plus dP from the top plus the mass of this particular element which will be rho into g into dhg and because it is stationary they are equal. So, using this you can get very easily that dP is equal to minus rho dhg. Therefore, if the height change is positive, if hg is positive, pressure is reducing.

$$P = (P + dP) + \rho * g * dh_g$$

Where, $P = pressure\ at\ the\ bottom\ surface$

$(P + dP) = pressure\ at\ the\ top\ surface$

$\rho = density\ of\ air$

$g = gravitational\ acceleration$

$dh_g = height\ variation$

$$dP = -\rho * g * dh_g$$

Now, does this consider, is it true for any altitude? What do you say? Is this formula true for any altitude in the atmosphere? Do you agree? No. So, where is it not valid? No, but if I assume that there is a fluid particle at rest at any point, then is this formula only for Stratosphere or Ionosphere or Mesosphere? So, now, if you say, if you say that this formula is true only in those conditions where g is assumed constant, I accept it, I accept it. So, let us assume that g is constant because we are not talking about outer space.

Let us say, can we say that at least up Exosphere it is constant? What happens above that we do not know because the G is changing, right? So, if you assume G to be constant, what about rho, the density? The density of the air, let it change, the value of dP will be numerically different depending on density. So, it does not, there is no restriction on this formula except in that situation where the particle is moving or where density, the value of g is not assumed constant. So that means it is applicable almost anywhere in the atmosphere. But for the same height change in Ionosphere, there may be a different pressure change because the value of rho may not be the same, even if g is constant.

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