Introduction to Flight
Professor Rajkumar S. Pant
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Lecture No 46
Climbing Flight and Ceiling

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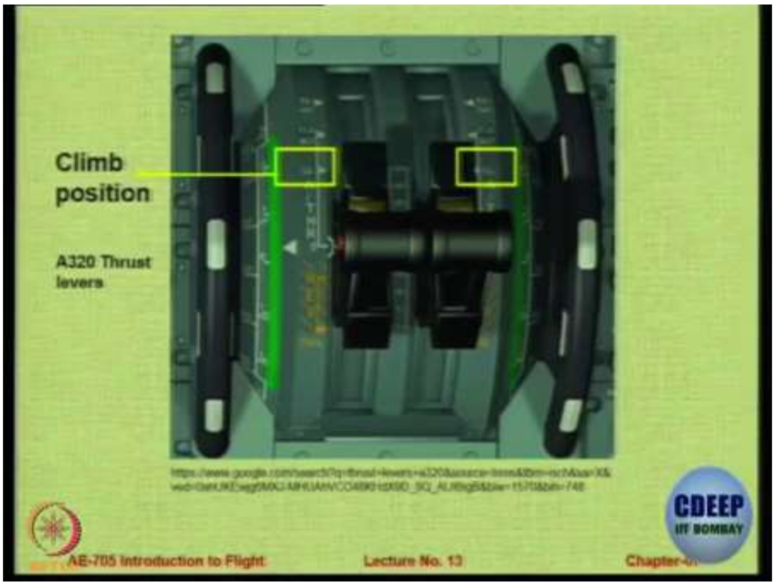

So much about Gliding, now let us go to Climbing. Climbing flight is a flight… so in the throttle of the aircraft you have a position called as a climb position this is the throttle of the air craft just to give some idea these two on the right and left are basically the trimming wheels. They are use to trim the aircraft so that the pilot can fly hands free so they are just the trim tyres and other things to ensure that the net moment is zero and these two are the throttles, so throttles you have you can see there is a reverse position which is marked in yellow color which is back and then you have climb position then you have cruise position and etc etc okay.

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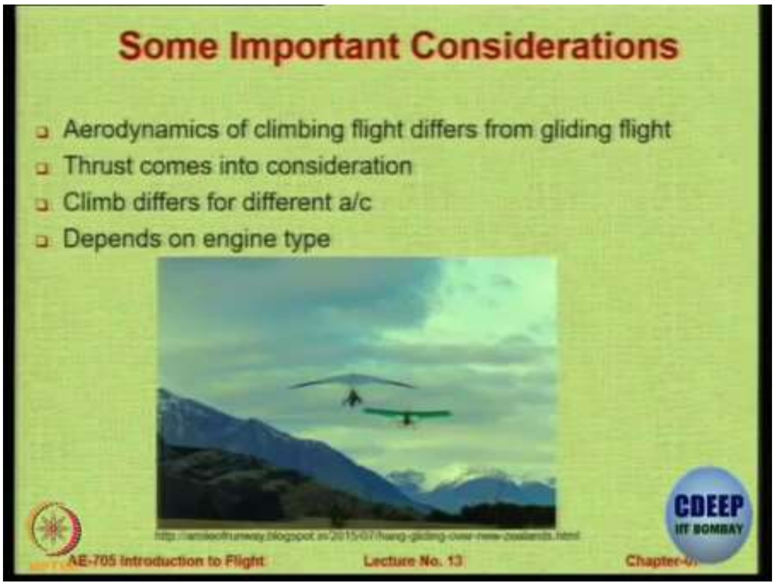

So that means this is A320, so we have to be careful first thing should be that some people say climbing is basically reverse of gliding, in gliding you are coming down and in climbing you are going up but that is not true, that is not true. Because is one case the gravity is acting in your favour, in other case you are going against gravity so you require thrust force to overcome. The thrust comes into play when we go into climbing yeah that is important thing and for different aircraft there are different climb speeds and different front climb positions okay. You can see picture you have a hand glider and a normal aircraft and you see there are differences in the way they are climbing. So it depends upon the engine type okay.

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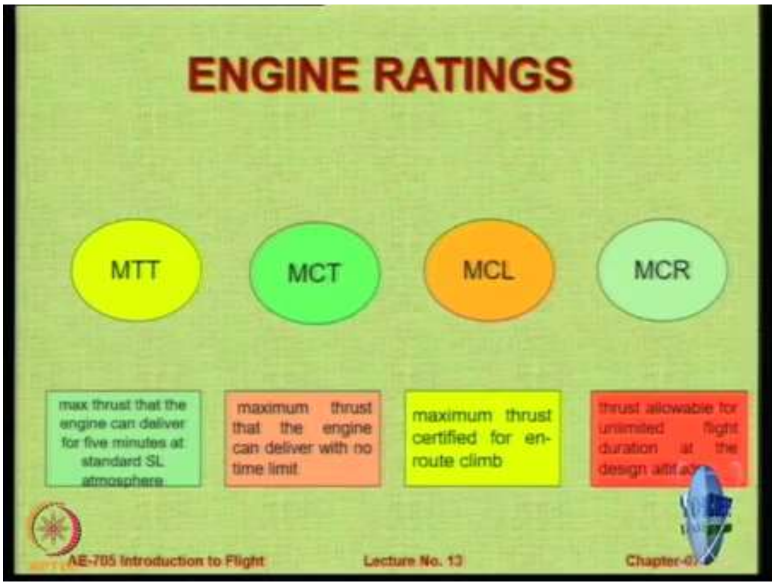

So when you fly an aircraft actually there are four possible ratings ok, So the first one is called as MTT and that is basically the maximum thrust that an engine can basically deliver for 5 minutes that is the max thrust condition it is called as max thrust condition, during this particular condition you are actually getting a huge amount of thrust so therefore there is a time limit after that engine life will be reduced, then you have maximum continuous rating, max continuous this you can give as much as time you want this engine is certifies to work nonstop for many many many hours at that rating. Then what you have is called as max climb rating ok, so certified for enroute climb, so climb is also of many types we will see that. And then you have max cruise rating that is the thrust allowable for the unlimited fly duration at the design altitude. The MCT is at any altitude but MCR is at cruising altitude, so these are the four ratings of the engine

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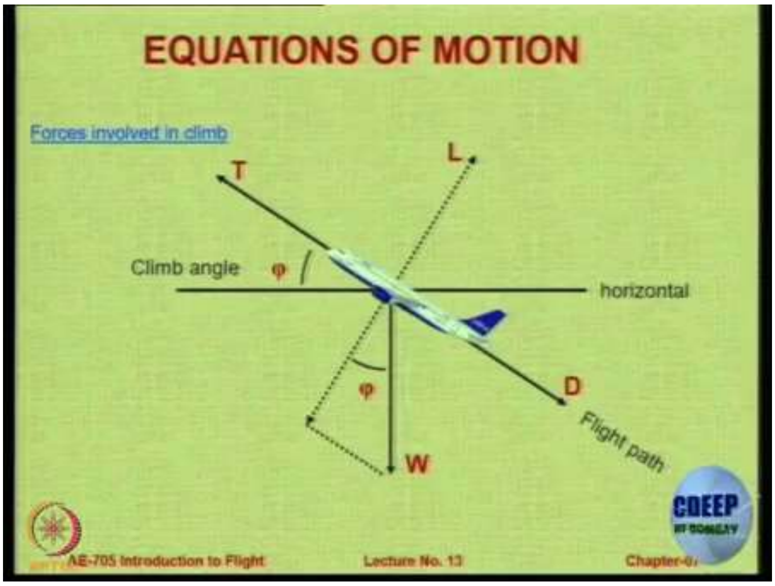

Now let us see the equations of motions we first have a reference line and then we have a climb so obviously we have thrust and drag along the flight path we have weight normal towards the earth center resolving you get the lift and if you are flying at angle phi, then you can look at the four forces. So here we have very interesting observation but before that let me ask you the aircraft is climbing so do you do you think lift is more than weight? It is climbing it is going up okay you think lift is more than weight, that is wrong, that is a misconception actually lift will be less than weight during climbing. So why is that so? Because there is thrust which gives you upward force not lift. In short if you have lift equal to weight it will not climb properly see.

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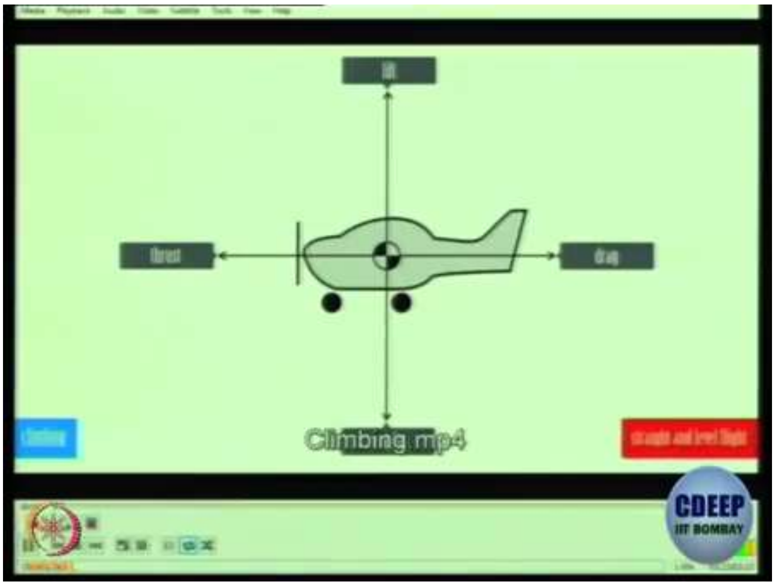

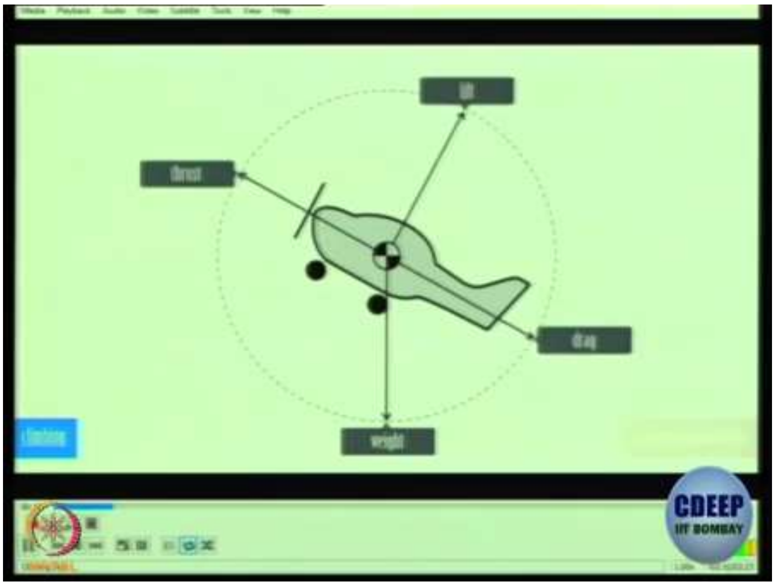
lift
thrust
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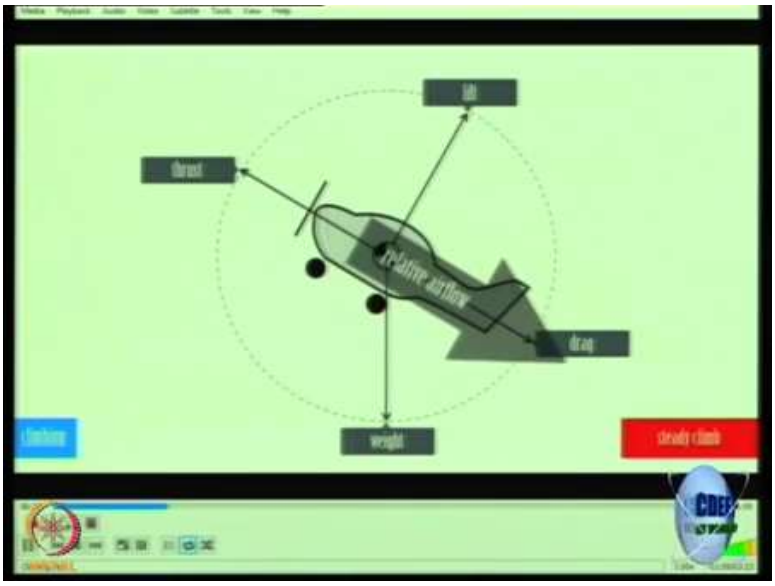
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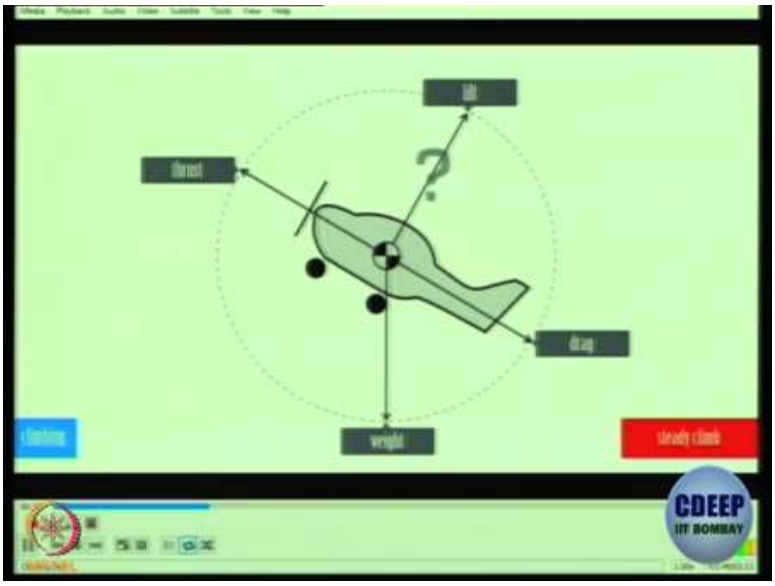
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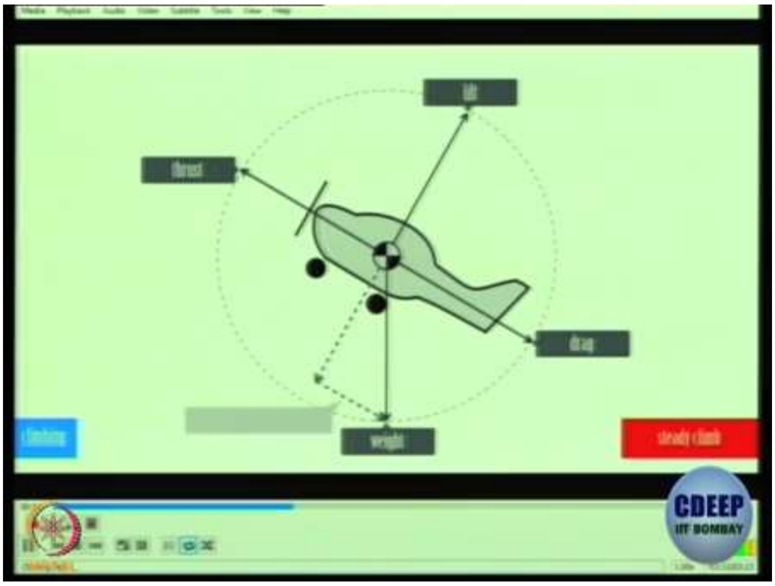
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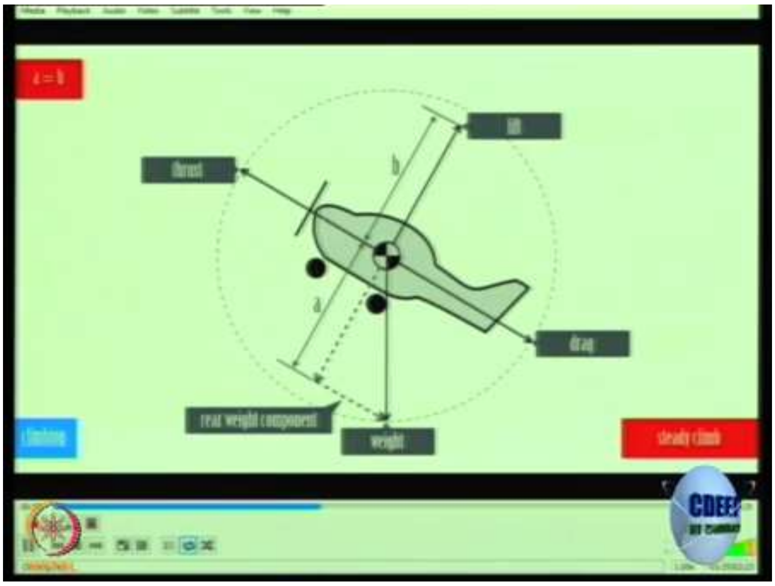
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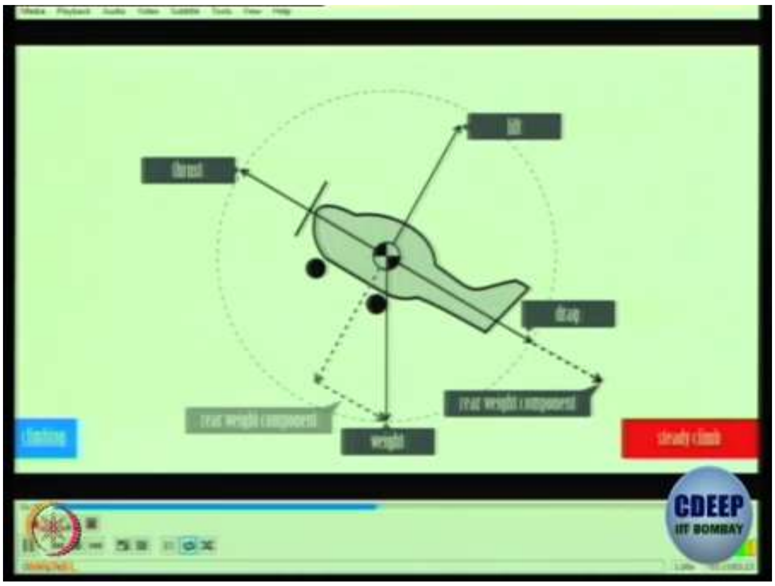
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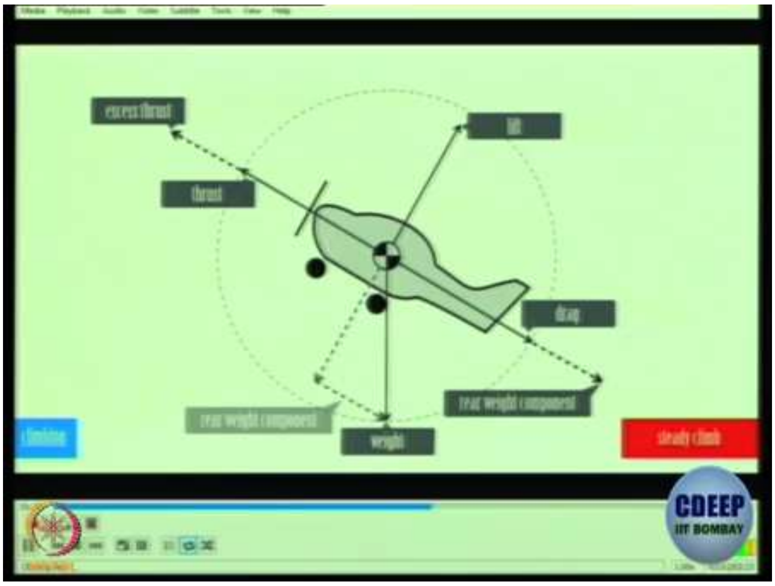
excess thrust
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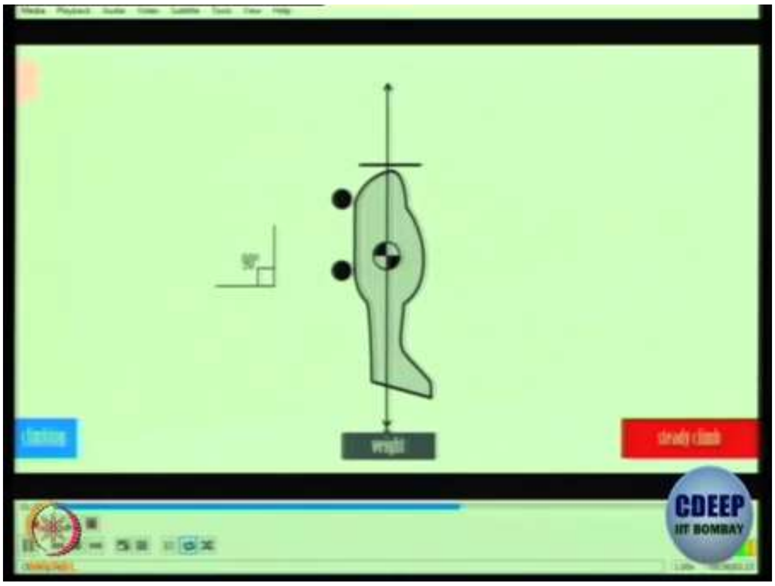
90°
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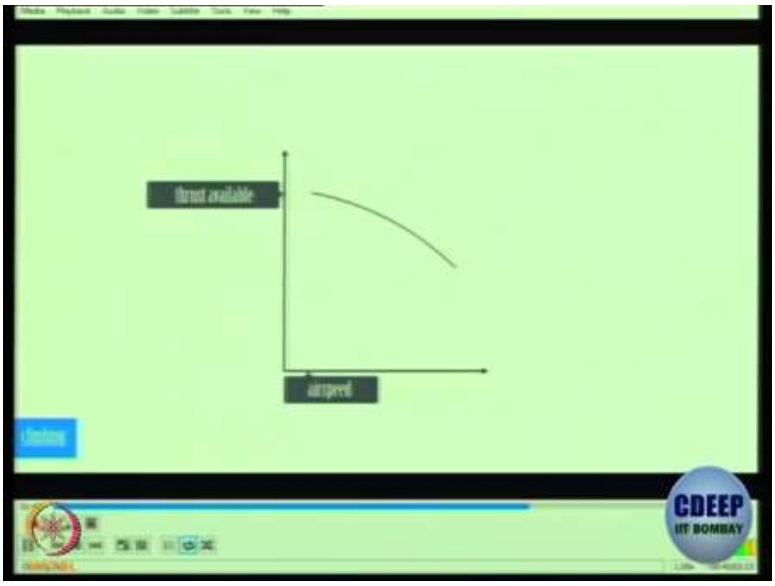
thrust available
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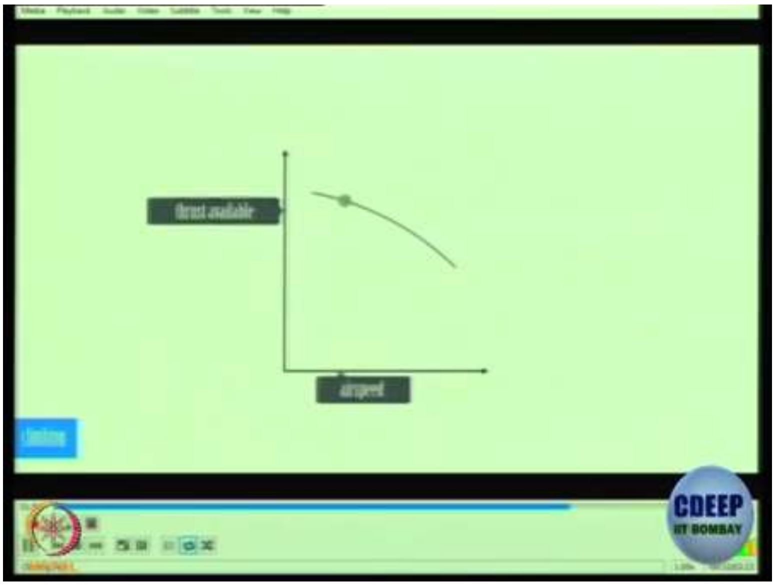
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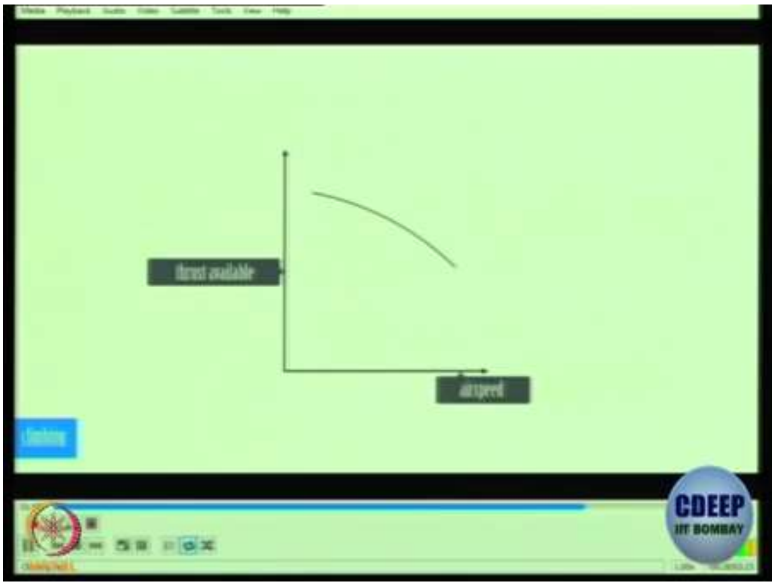
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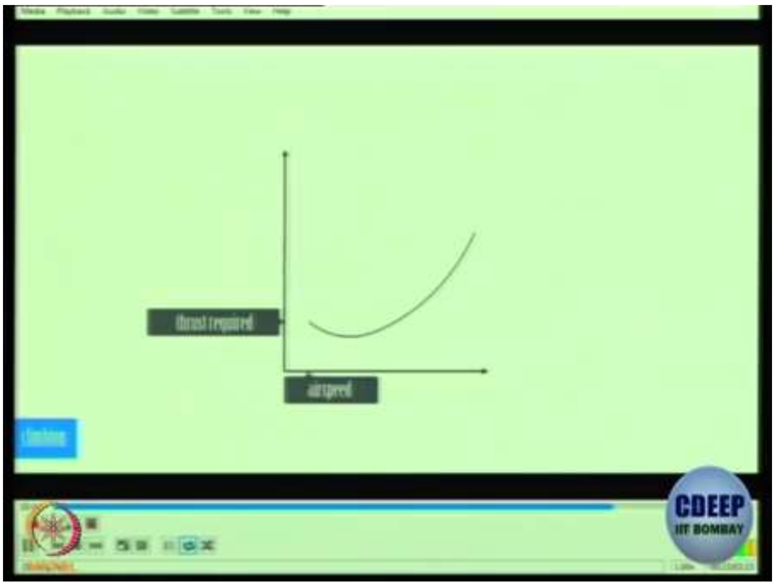
thrust required
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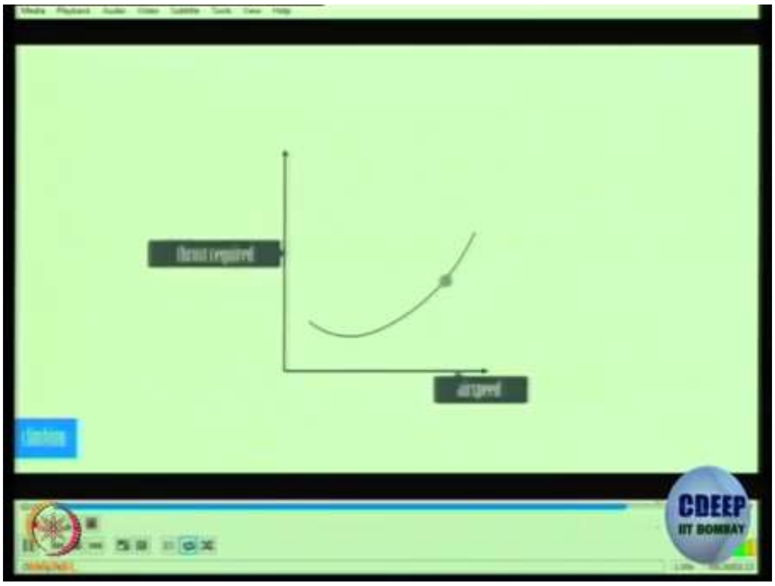
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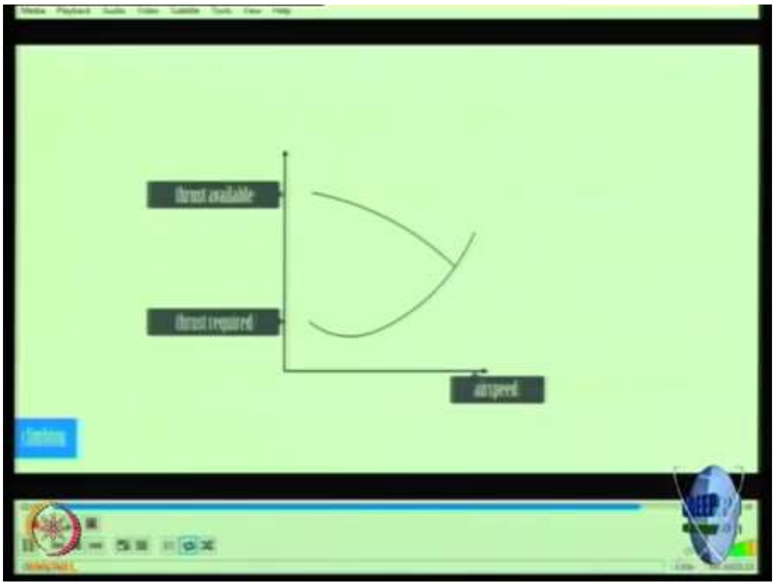
thrust available
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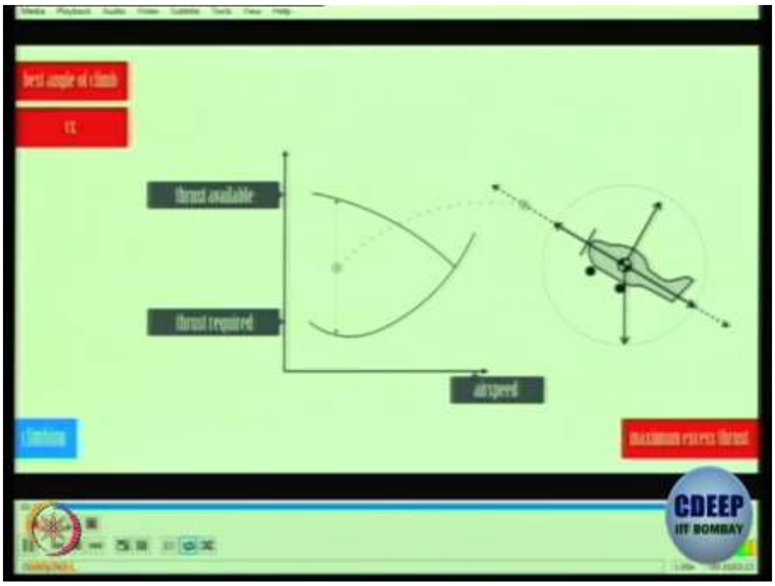
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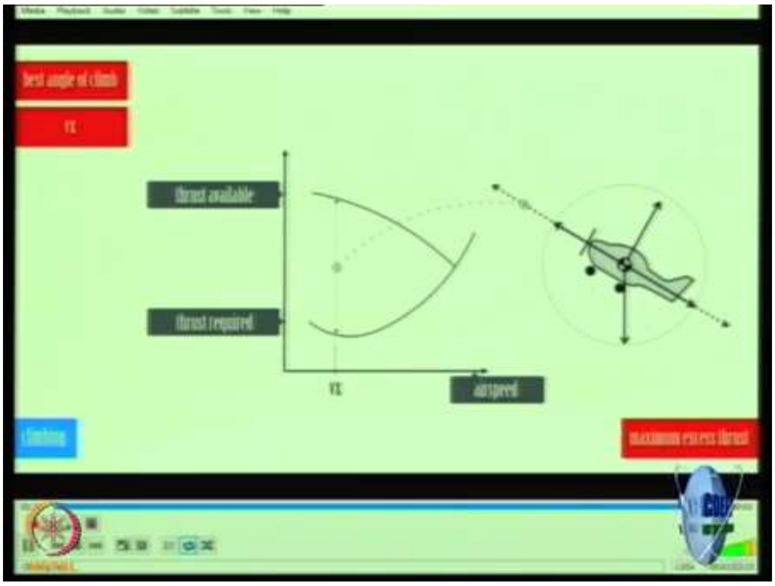

Video: Lift drag thrust and weight are all balanced. What you see here is of course a simplified representation of the 9 forces which are in equilibrium.

Professor: This one we know this is a level flight.

Video: In steady climb the airplane is also in the state of equilibrium. Thrust and Drag act in line in relative air flow along the airplanes flight path whereas lift acts at right angle to relative air flow, weight acts down towards the center of the earth. The common misconception is that lift increase in a climb, in steady climb where the forces are in equilibrium to right moves backwards. So weight may be resolved into 2 vectors, weight component that opposes lift and the rear weight component. Lift is slightly reduced because the opposing weight component is also reduced at the expense of the rear weight component, the rear weight component acts in same direction of drag therefore it contributes to drag.

So to maintain the equilibrium and steady climb thrust must increase. This is called Excess thrust. Are you still not convinced that lift is smaller in climb. Imagine that this airplane is capable to climbing at the ultimate 90 degree angle of climb now you can say how it becomes about the excess thrust not lift. An airplane will achieve its best angle of climb in excess thrust is the greatest. This curve represents thrust available against air speed in level flight. The faster you wish to fly less effective the propeller is so the less thrust is able to generate.

Professor: This is for turboprop and piston prop only.

The thrust required curve suggest generally you need more thrust if you wish to fly faster. Comparing the two curve the greatest difference between the thrust required and thrust available is the maximum excess thrust which happens to be your best angle of climb air speed.

Professor: Ok, so remember Vx is the speed which is the best angle of climb speed so Vx is the best angle of climb speed that correspond to the location where you have maximum gap between thrust available and thrust required okay. So therefore interestingly lift is going to be less than weight in climb contrary to what we normally expect $L = W cos\emptyset$ and $\emptyset$ being non zero small number but non zero means L is going to less than W and T will be more than D because that excess thrust has to be created to overcome the rearward weight component alright.

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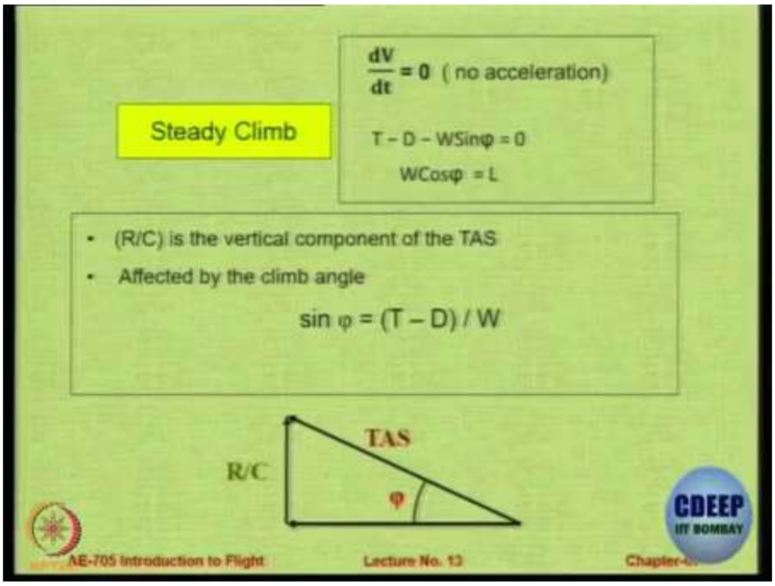

So when you say steady climb again we mean constant speed okay and what else no change in angle of climb. So it is constant angle constant speed that is called as Steady Climb. So there will be no $\frac{dV}{dt}$ no acceleration along the path, so resolving the forces you can get a very simple idea that, the rate of climb will be actually $\frac{dh}{dt}$, the vertical component of TAS and that will be function of climb angle okay. That will be $sin\emptyset$ so $\frac{T-D}{W}$ so if you want to have a better $\emptyset$ other thing remaining same either you have more thrust, less drag, lower weight. So weight is something that is fixed so we cannot touch it that much. You cannot throw passenger away or you cannot say I will dump the fuel and climb better may be you can in emergency but in general W is constant D will be function of aircraft configuration yeah it change with flaps and landing gear etc. So mostly what you can do is control T minus D okay. So the rate of climb will be basically true air speed into $sin\emptyset$ that will be $\frac{dh}{dt}$ so remember ROC or RIC will be

$\frac{dh}{dt} = sin\emptyset$ where V is the speed during climb okay.

So let us see R/C by definition is basically true air speed into $\frac{T-D}{W}$. So the rate of climb will increase, when either TAS increases that means if you fly at faster speed and you are going to climb you will be able to go into a better speed or if you have more excess thrust or if you have lower weight it is very obvious. Now this we have already seen in video, this is how drag will be equal to thrust in case of level flight here drag is going to be less than thrust, thrust has to be excess. So you can say that this is the drag on the aircraft there is one velocity at which drag is minimum and that corresponds to if you remember C_{D_0} equals to C_{D_i} okay when the two powers are equal. The thrust for jet engine remain almost constant actually it changes slightly but you can consider it constant. So therefore… and for piston engine aircraft it is going to come down.

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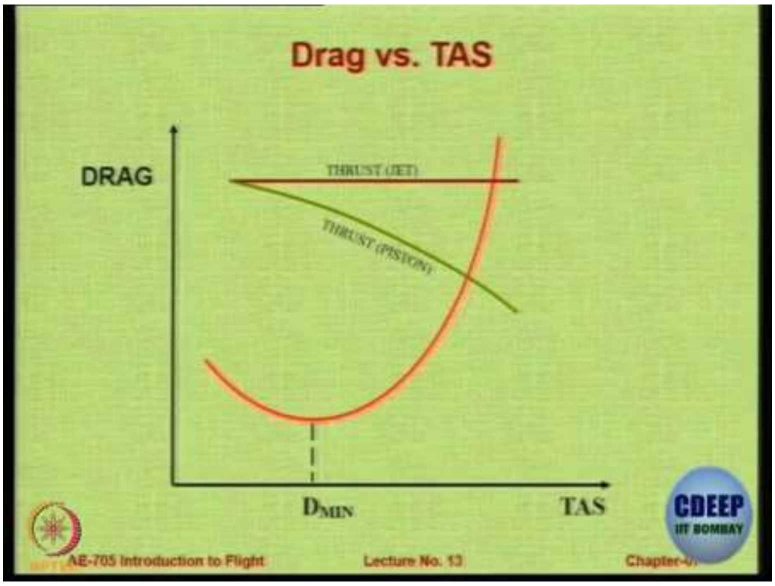

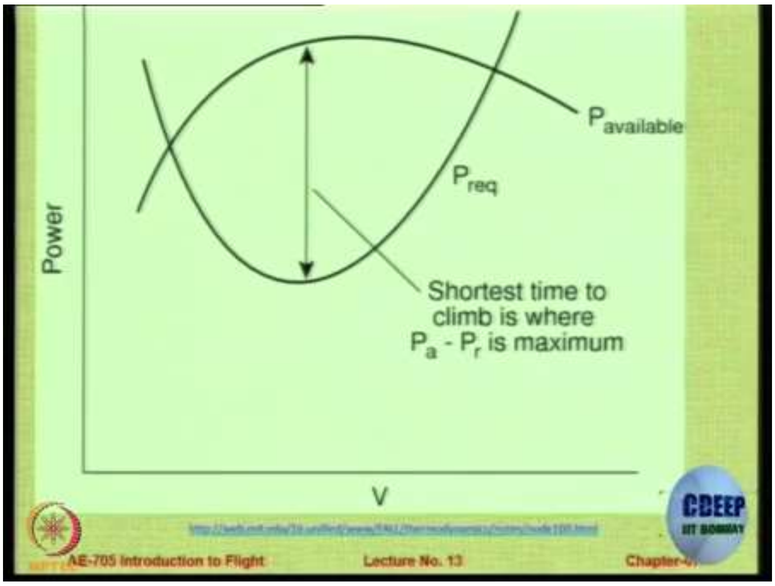

So the red line is true for both the aircraft the numerical value may be different but that does not depend upon aircraft type the shape is same, the shape of the thrust with the jet or thrust with piston changes ok, so therefore the shortest time to climb is where the… now here we come to power because now we are looking at time that was rate now this is time. So if you want to go for time to height then you look at the power available versus power required which is nothing but P into V okay.

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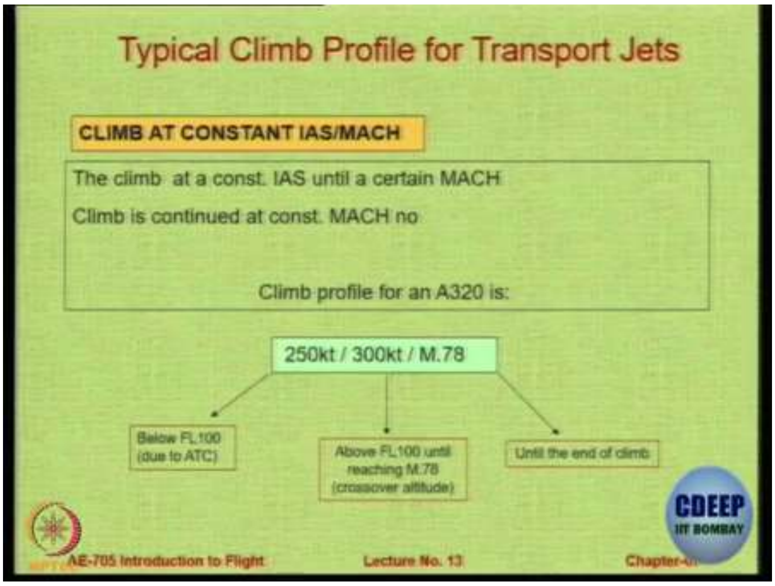

So now the way in which a transport aircraft climb is a very different from what you think it does not go up it follows a particular sequence. So the first step is called as constant IAS climb and then you have a constant Mach climb let us see, so up to a particular Mach number typically 0.8 or so the pilot is requested to climb at a constant indicated air speed and then once you reach that Mach number then the pilot is asked to maintain a constant Mach number and change the speed accordingly. So for a A320 this is given climb profile 250 knots 300 knots 0.78 the 250 knots is below flight level 100 or below 10000 feet because of the air traffic control restrictions you are asked to fly at a constant speed of 250 knots above flight level 100 till you reach the height at which your Mach number reading is 0.78 you are allowed to fly at 300 knots and then when you reach M equal to 0.78 you are asked to maintain same Mach number till you reach end of climb or you reach the cruising altitude.

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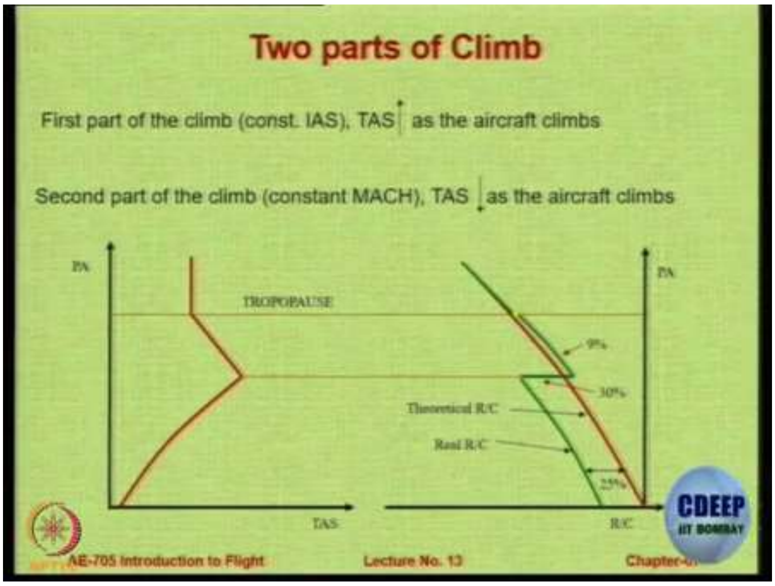

So this is the climb profile now why do we do it, because of the atmosphere. So on the left hand side we have a curve which is power available versus true air speed. And it follows this particular sequence due to change in the temperature and there is an effect on the thrust. On the right hand side we have two lines, one is the red line which is theoretical line for rate of climb. And then we have green line which is the real aircraft rate of climb or the actual ROC. So typically what we do is up to that particular kink altitude you fly at a constant speed and then you proceed to constant Mach number okay. So first part of climb constant IAS second part TAS reduces it is a constant Mach number climb.

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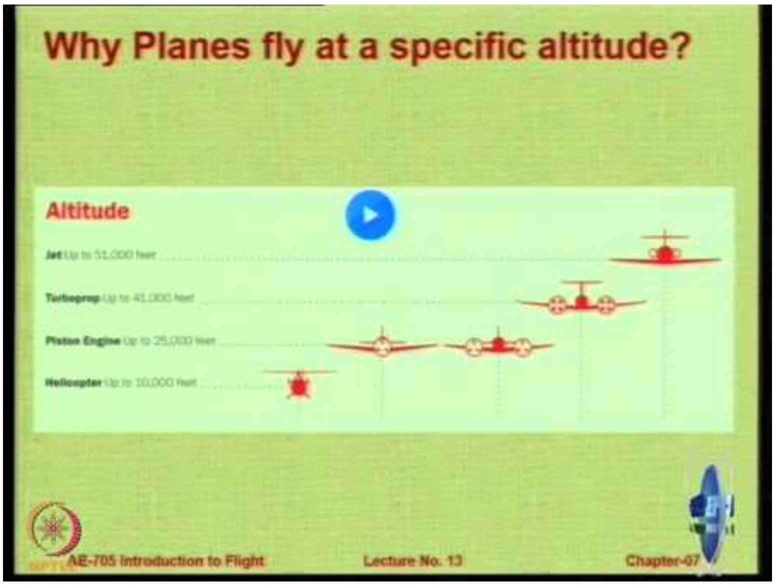

Now many people ask a question that why it is so aircraft fly at a particular height. For example if you look at helicopter we do not normally go beyond 10000 feet unless you have a special requirement like upgrading in Siachin or any other high altitude requirement. Piston engine aircraft generally do not go beyond 25000 feet, turboprops 41000, jets can go to higher they do not normally go beyond 36-40 thousand but they can go up to 51000 if required. So why is it so, that they fly at different altitudes. So that is explained in this short video.

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THERE'S LESS
AIR UP THERE
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THERE ARE FAR FEWER MOLECULES AT 30,000 FEET (9 KM)
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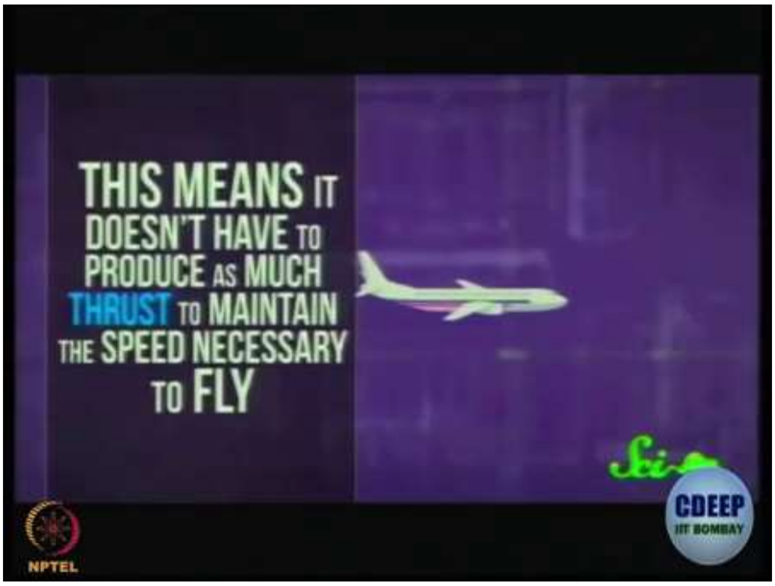
THIS MEANS IT DOESN'T HAVE TO PRODUCE AS MUCH THRUST TO MAINTAIN THE SPEED NECESSARY TO FLY
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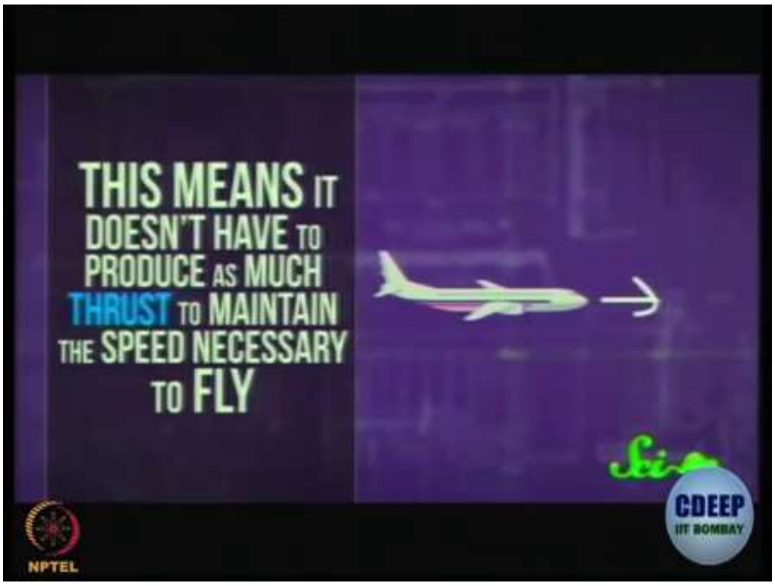
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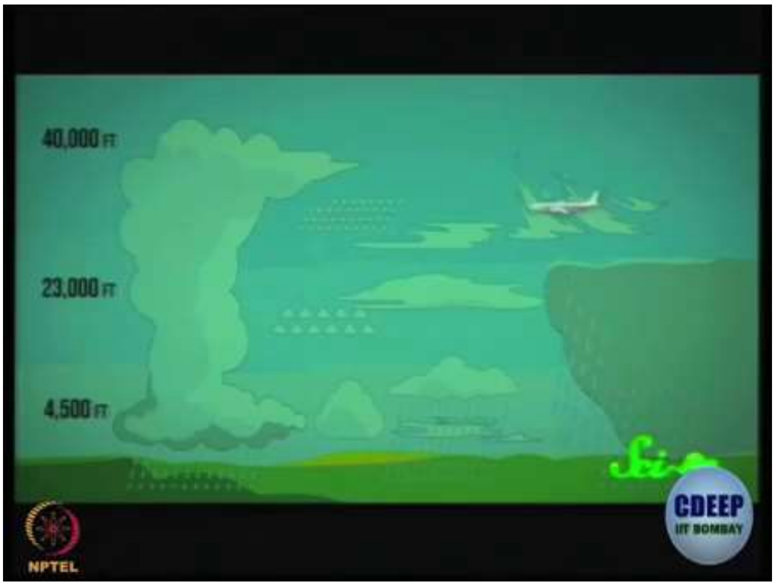
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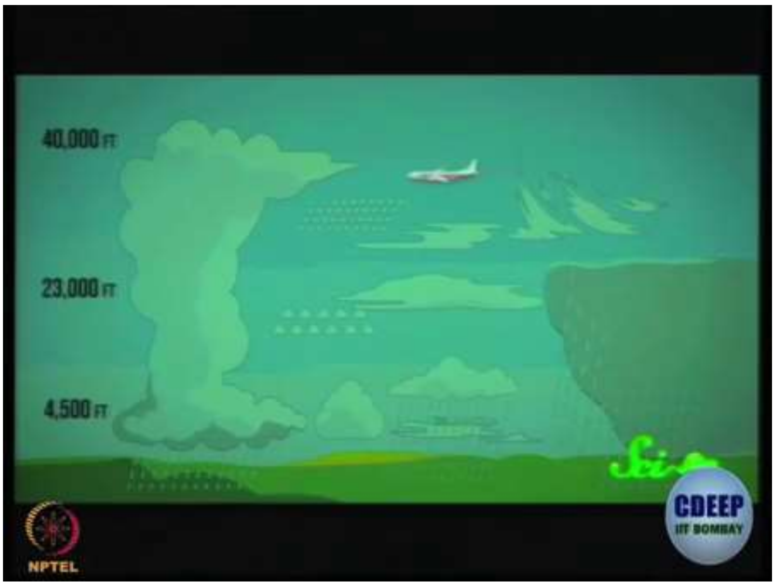
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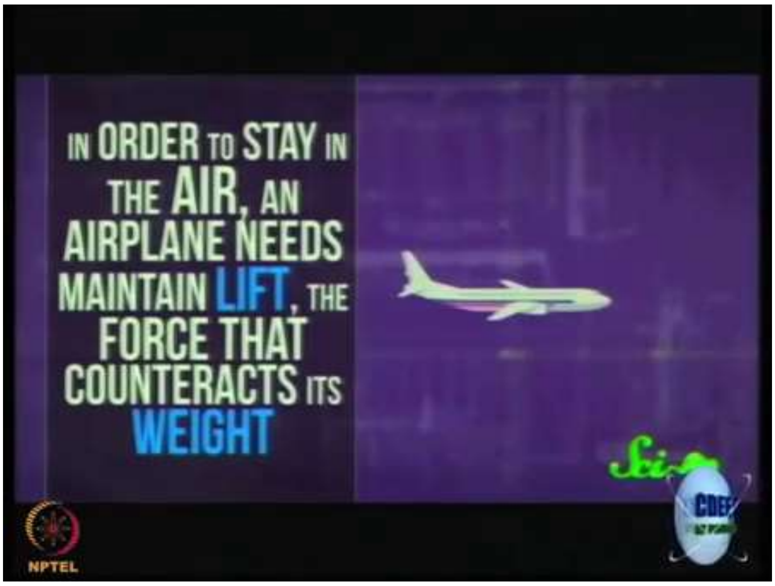
IN ORDER TO STAY IN THE AIR, AN AIRPLANE NEEDS MAINTAIN LIFT, THE FORCE THAT COUNTERACTS ITS WEIGHT
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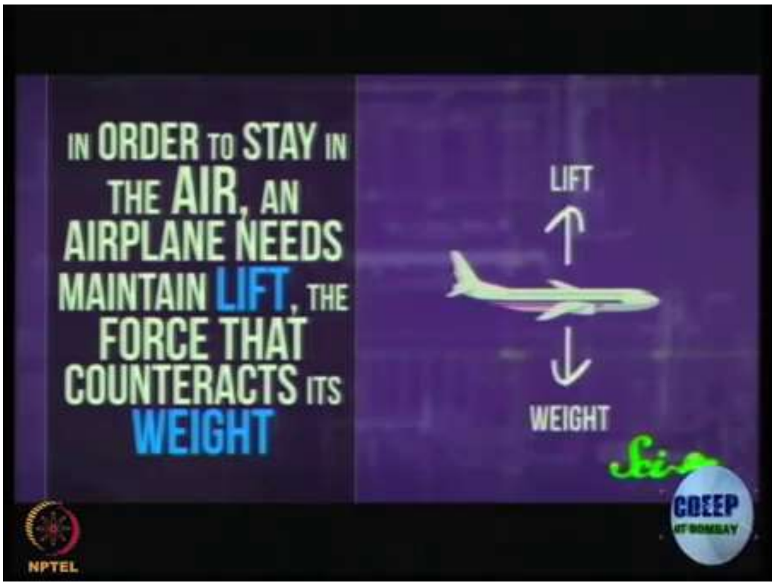
IN ORDER TO STAY IN THE AIR, AN AIRPLANE NEEDS MAINTAIN LIFT, THE FORCE THAT COUNTERACTS ITS WEIGHT
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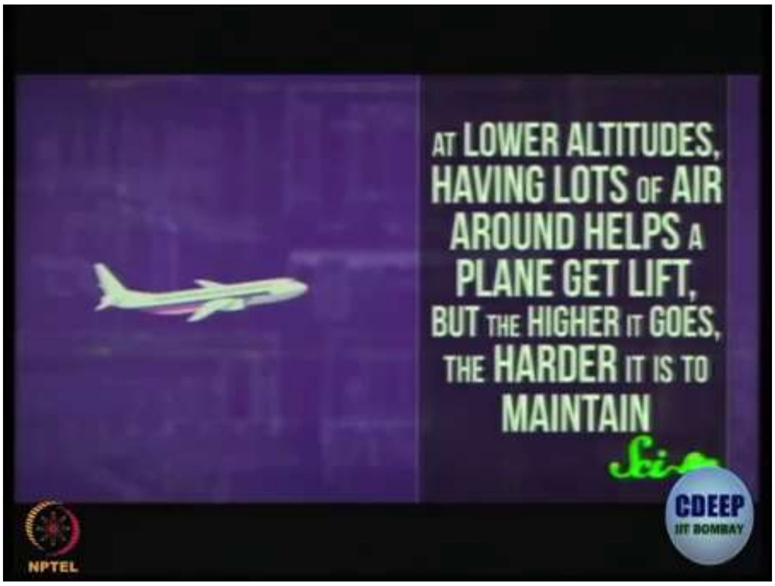
AT LOWER ALTITUDES, HAVING LOTS OF AIR AROUND HELPS A PLANE GET LIFT, BUT THE HIGHER IT GOES, THE HARDER IT IS TO MAINTAIN
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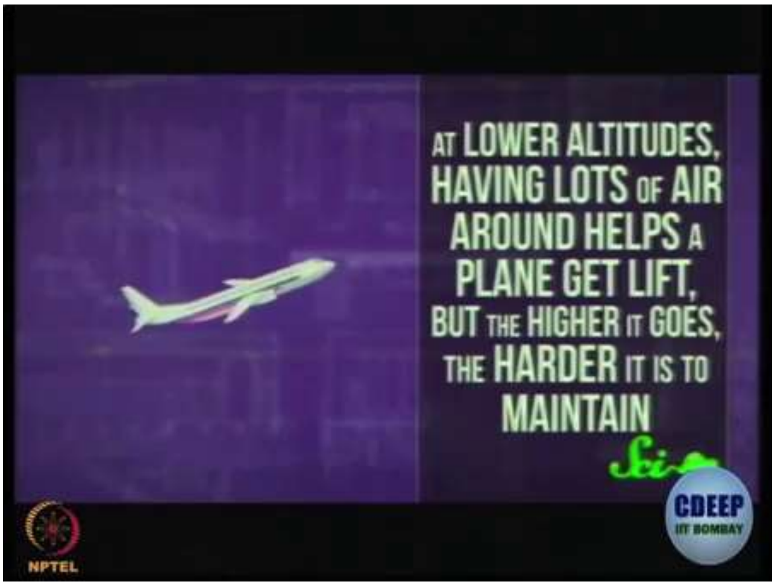
AT LOWER ALTITUDES, HAVING LOTS OF AIR AROUND HELPS A PLANE GET LIFT, BUT THE HIGHER IT GOES, THE HARDER IT IS TO MAINTAIN
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TO BURN STUFF YOU NEED OXYGEN
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IIT BOMBAY
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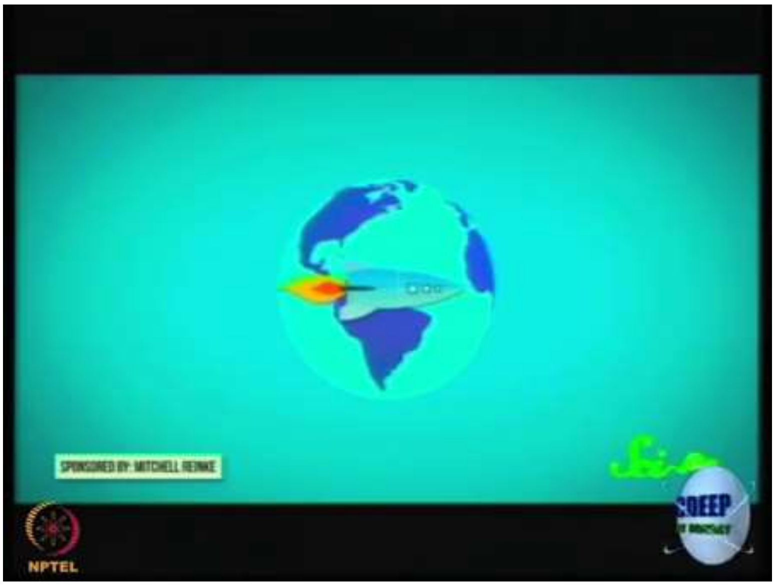
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Video: we travel by air we are way up there. The average cruising altitude of commercial jet is 7 and half to 11 kilometers. In other terms it is at least as far as the average distance between you and the nearest Starbucks at any given moment and the vertical terms well that is a long way down, the good news is that the plane starts to fall it has a long time to figure out how to stop falling. We have been flying that high ever since the development of the Jet Engine in mid-1950's.

The jets were designed to fly at these high altitudes because there is less air up there that is what the engineers, passengers, and airlines all prefer. Basically there are far few air molecules at say 30000 feet or at 9 kilometers above the sea level. So the plane is literally running in the fewer molecules it means it does not have to produce as much thrust in order to maintain speed necessary to fly. So it can travel more efficiently which is what the airlines want, what the passengers want that it should not feel like they are flying in air at all, and flying at higher altitudes means being able to fly over at least some of the weather patterns in air currents that older less powerful propeller planes often had to fly through.

So flying higher usually means more comfortable flight. But there are some trade offs efficiency and comfort in order to stay in the air an airplane needs to maintain lift the force that counteracts its weight. At lower altitudes having a lots of air around helps a plane get lift, but the higher it goes the harder it is to maintain, So engineers has to find the way to generate more lift in other ways like making planes with dihedral wings. Jets cannot fly too high though in order to like continue working jet engine needs to burns fuel that is an important part of the process and the burnt stuff you need oxygen. So burnt have to stay at altitude where there are still enough oxygen to mix with the jet fuel and allows combustion to happen. To get any higher your aircraft would have to pack canister of air to mix with the fuel and once you do that you are not an airplane any more you are basically a rocket. So engineers has done the math and found the optimal height for efficient travel and designed plane to operate best at that height. Yeah engineers, thanks a lot, probably use to perspective when we travel by air we are way up there. The average cruising altitude of commercial jet is 7 and half to…

Professor: Okay very fast, after all it is a jet aircraft so he wants to go at high speed. So let us break down what he says into bits and pieces which we can understand. First thing he says is planes fly at high altitude because the density of air is less so therefore at given speed it will encounter lower drag and therefore if thrust can be produced the amount of thrust needed will be less, but as you go higher up even the thrust available will also change because the same mechanism also comes into play for thrust productions. You need more air you need more oxygen therefore you need more air so if you have rarer molecules air you have rarer oxygen. So there is a sweet spot there is a place something 36000 feet to 45000 feet where in it is the most optimal drag reductions and thrust availability are in sync and that is the kind of altitude at which most aircraft powered with jet engine would like to fly. Turboprops and Piston props are worse hit with density change, so therefore they would like to fly a lower altitude their optimal altitudes tends to be 25000 to 40000 feet okay.

So one reason is they said jokingly that if you are at high altitude you can have a longer glide if an engine fails that is not the reason why they glide so high. So it is basically a function of what is optimal from the point of view of fuel consumption and efficiency alright.

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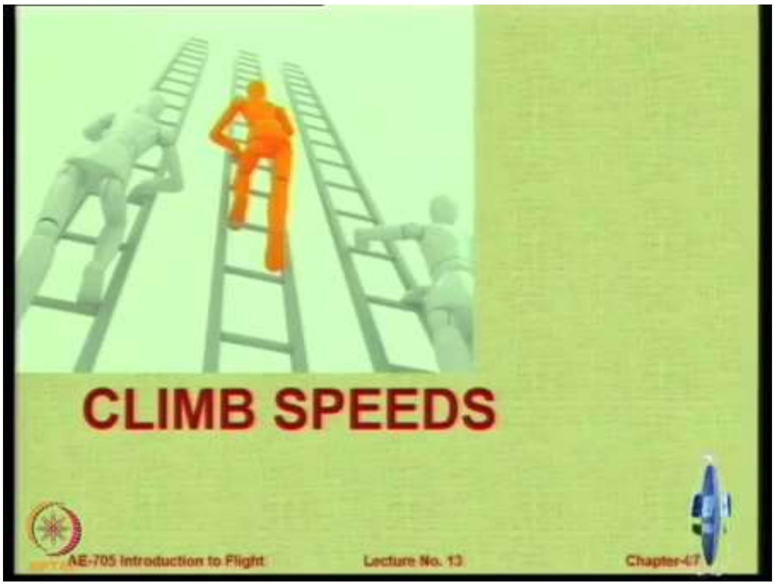

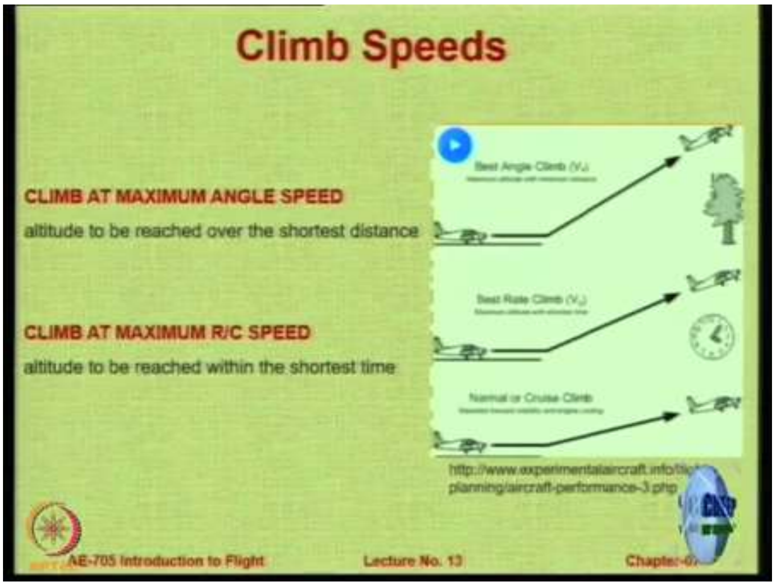

Similarly now let us look at the climb speeds, so this is a slightly interesting part there are various types of speed in climbs one of them is what we have seen that is the Vx ok, the other is the rate of climb. So one of them corresponds to what is the best angle for you to climb the other is the one who gives you the best rate of climb dh by dt and these speeds are called as Vx and Vy, and then we have a normal or cruise climb okay.

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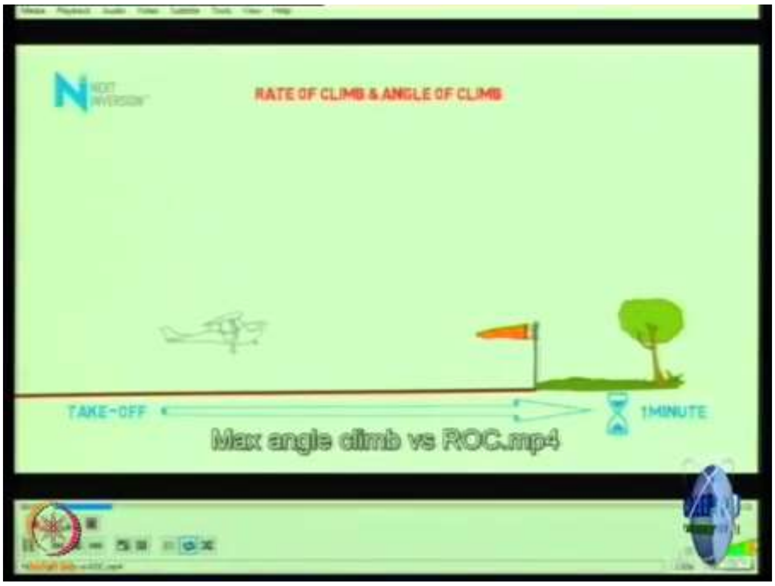
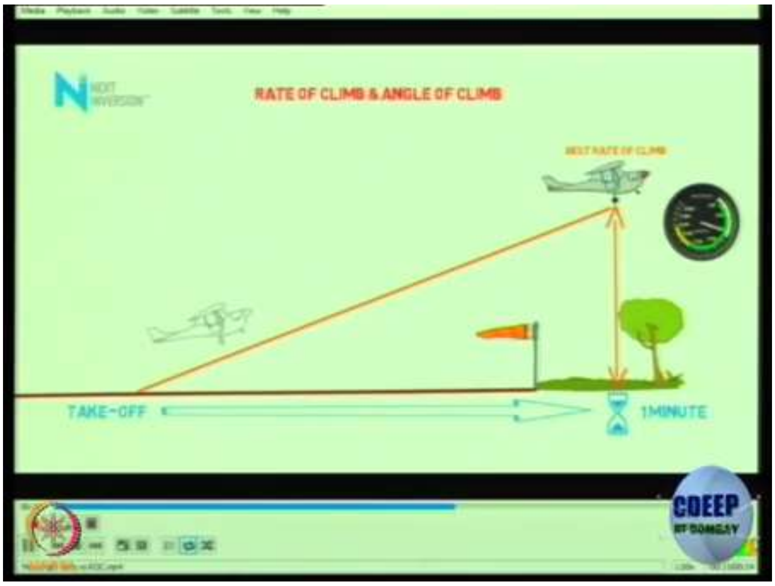
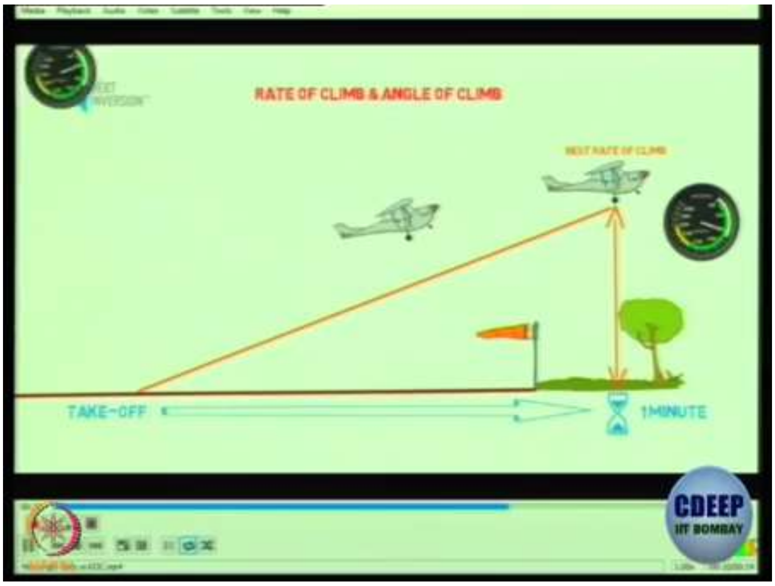



RATE OF CLIMB & ANGLE OF CLIMB
TAKE-OFF
1MINUTE
CDEEP
IIT BOMBAY


RATE OF CLIMB & ANGLE OF CLIMB
BEST RATE OF CLIMB
TAKE-OFF
1MINUTE
CDEEP


RATE OF CLIMB & ANGLE OF CLIMB
BEST RATE OF CLIMB
TAKE-OFF
1MINUTE
CDEEP
IIT BOMBAY

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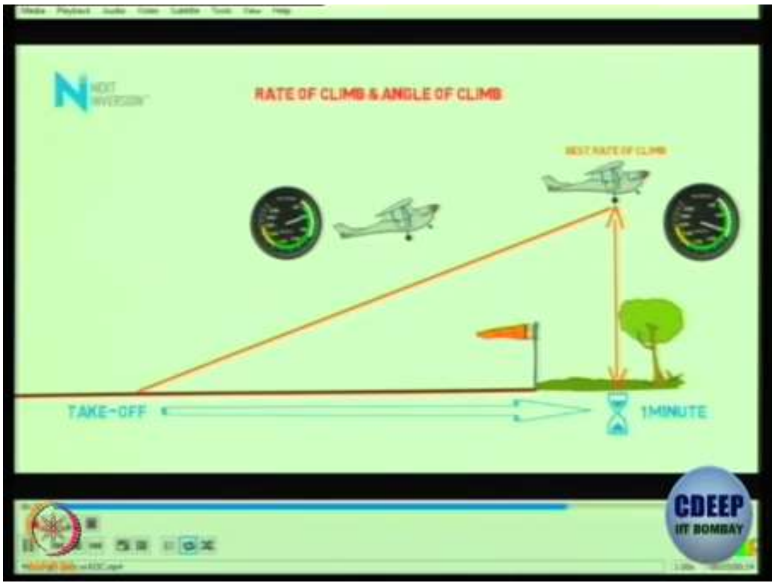

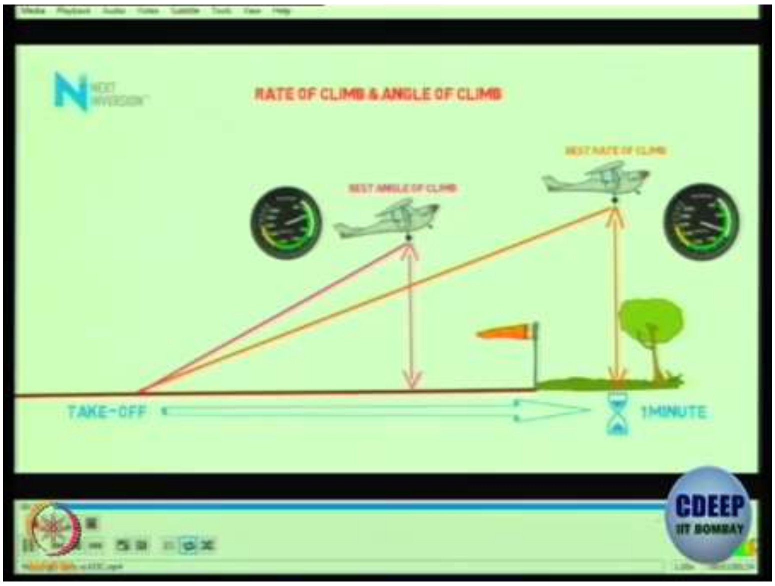

So now you see the max angle of climb, so this is basically here you are interested in knowing what would be the rate of climb? So you are concerned about dh by dt here. The other thing that you are interested in knowing is what would be the angle at with I should climb? So that I can have a best angle of climb. So they are both different and there is reasoning for that. So, if you want to clear the obstacle height at smallest possible distance you need to fly at maximum angle speed, because you want to reach a height at shortest horizontal distance but if you want to reach the altitude of your intension in the shortest possible time then you have to go at the speed which corresponds to the maximum rate of climb.

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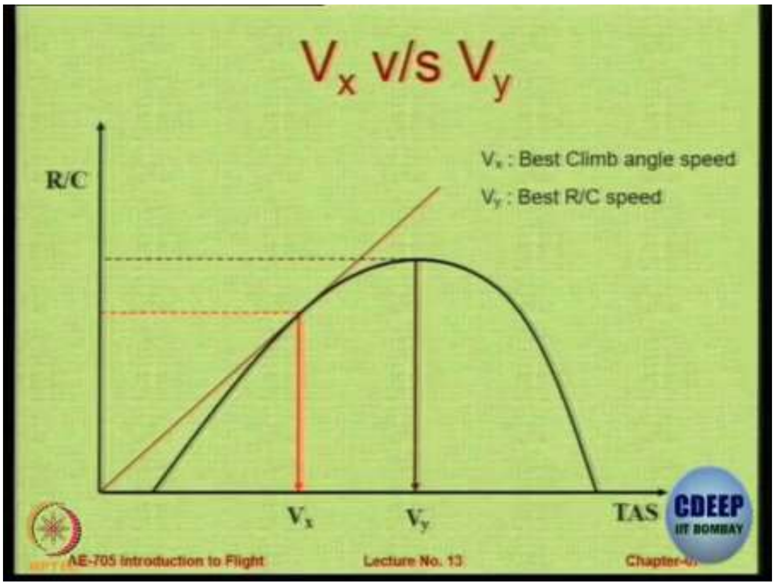

So let us see Vx versus Vy on the chart which shows rate of climb versus true air speed. So the rate of climb actually varies like this with true air speed, it increases, below a particular sped you cannot climb at some speed you have ROC equal to 0 that is just lift equal to weight that is the stalling speed. After that you have excess power you are able to climb but the excess of T minus D is small so therefore the ROC is small so the point where the line is tangent to the R by C line would be the best angle speed, and the point where it would be maxima R by C will be maximum that would be the maximum R by C speed notice that Vx is always lesser than y, how do you remember? Because x comes before y.

So therefore Vx is less than Vy. You have to remember these things right in manner otherwise it will be difficult, when you are given only 15 - 30 seconds in the quiz and then it is more than one can be correct then you have to remember these tricks to remember the answer okay.

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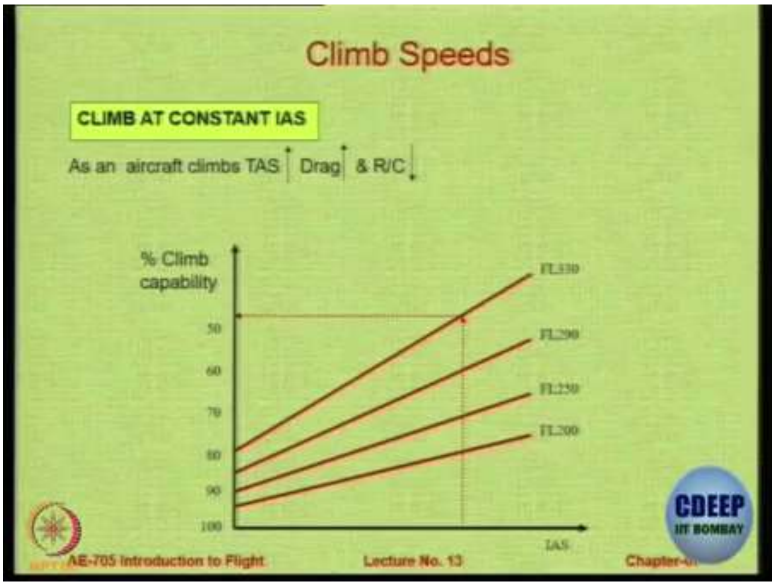

So if you want to look at constant IAS climb, you can notice that the percentage climb capability that means how much of the energy can be used for climb it also changes with the altitude or the height which you want to go. So as an aircraft climbs its true air speed increases therefore drag will increase because drag is function of true air speed not indicated air speed and if drag increases the T minus D will reduce therefore the R by C also will reduce. So that means slowly if you start increasing your speed continuously you will get lower and lower R over C at sometimes it is 0 R over C.

So that is why it is very important for us to know the difference between the power available and power required. So the minimum power for the piston engine will be at a tangent at a horizontal tangent to this line that will be at speed Vxp p stands for power, propeller engine aircraft, Vx is the minimum speed and the maximum difference between power available and power required will be at higher speed Vy and that is called Vyp.

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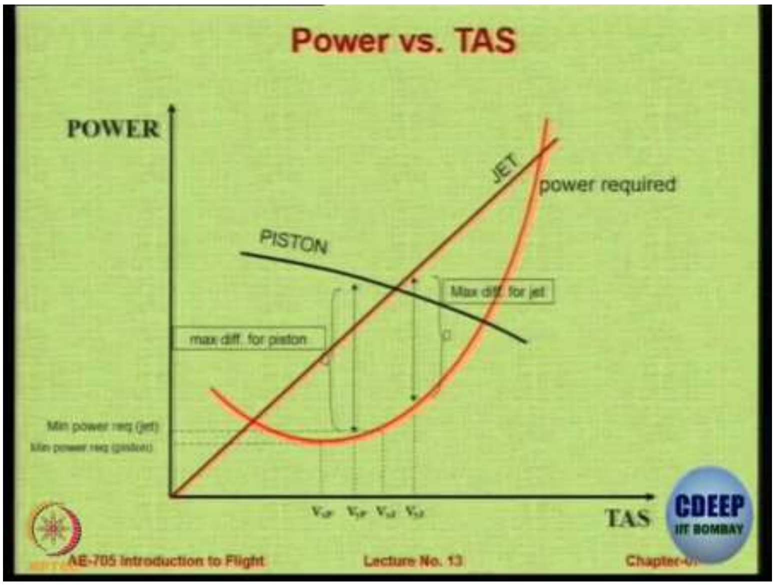

Again y is the symbol for max ROC speed and p for turbo prop or piston prop. On the same graph if I want to now show power available for jet engine air craft it is T into V, T almost constant for turbo jet, for turbojet engine aircraft so T into V will be straight line proportional to V. So here you find that you have Vxj and Vyj at a slightly different value so looking at the graph what do we see, we see that Vx is always less that Vy which we have already seen before and also we have seen that typically Vxp and Vyp, Vxj and Vyj also have the same relationship.

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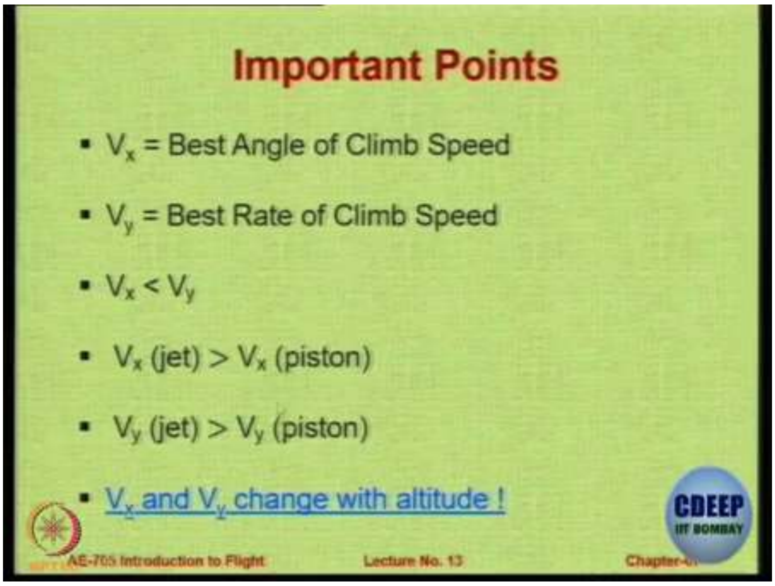

So here are the important points for you to remember always Vx is more than Vy, for jet it is higher than piston, both for x and y. because these intersections takes place at a slightly larger velocity. Now, what happens to these values with altitude? They do not remain the same, so they also change with the altitude.

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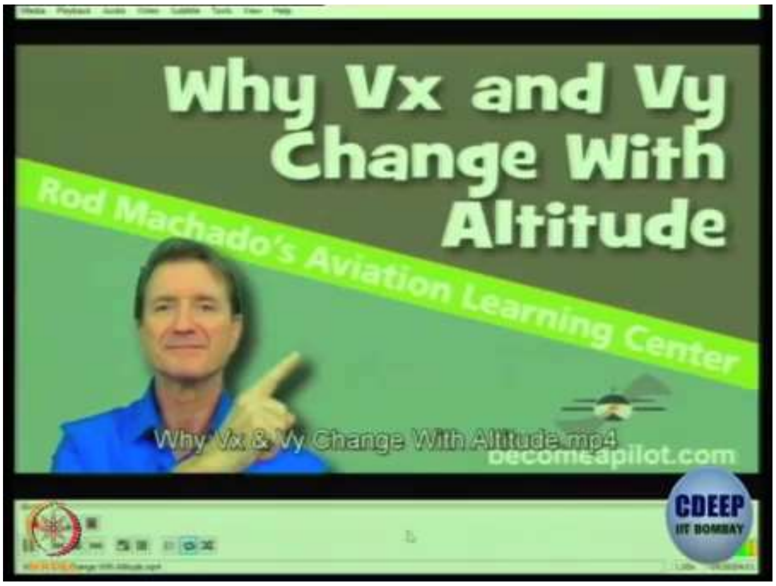
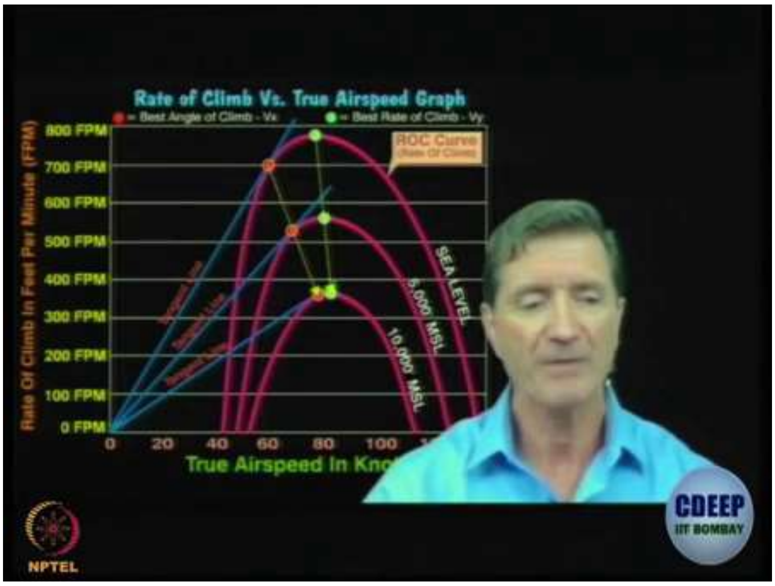
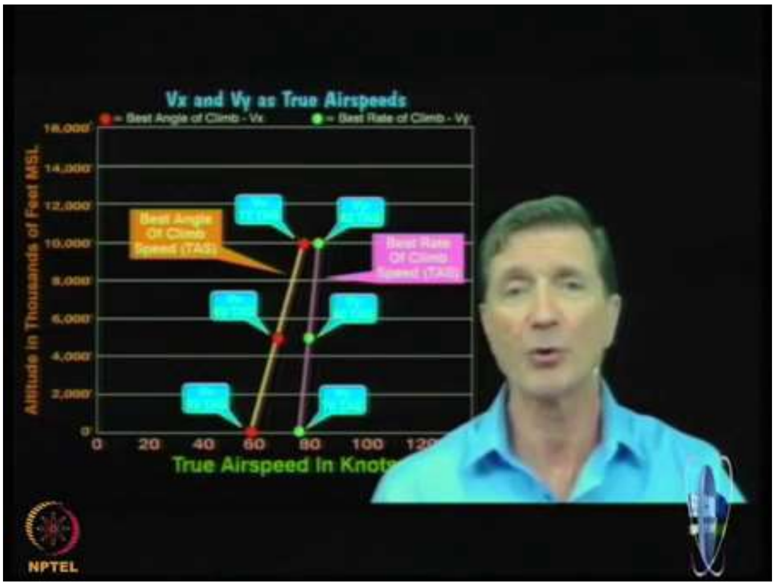
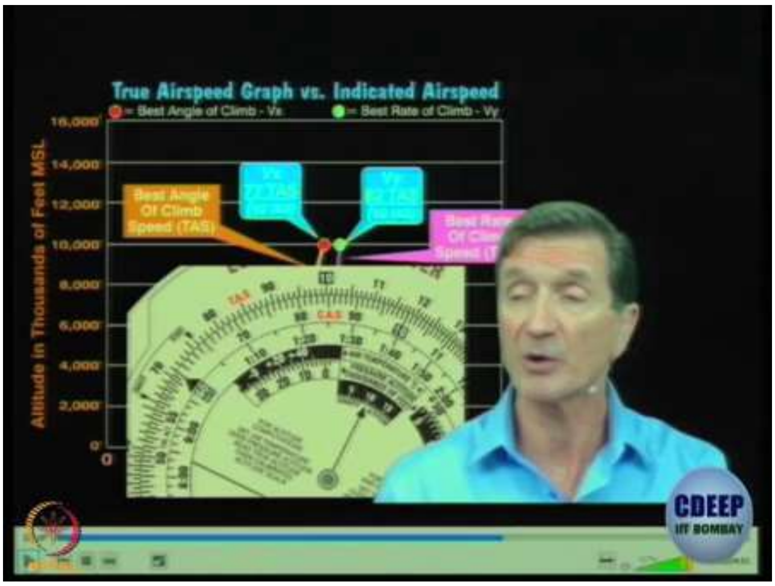
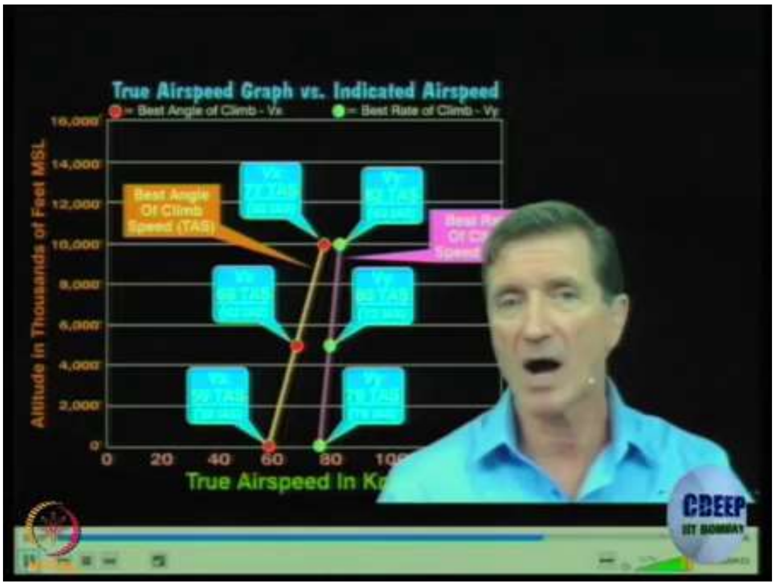
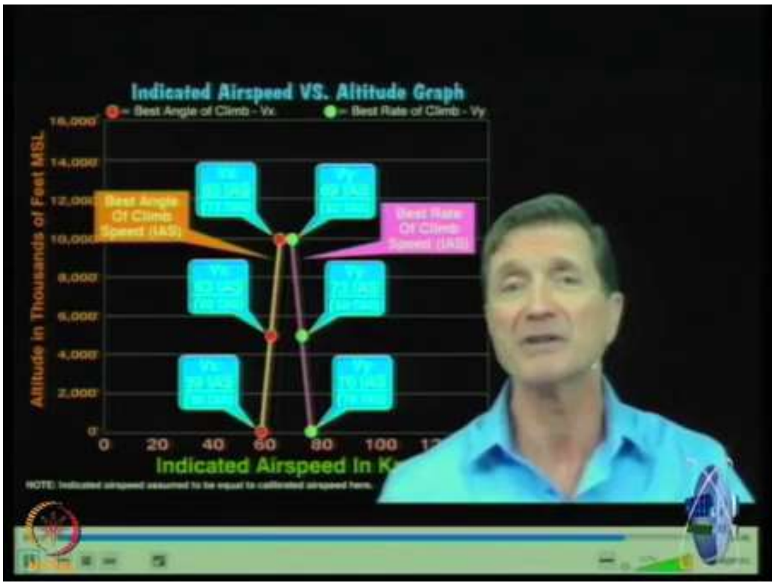


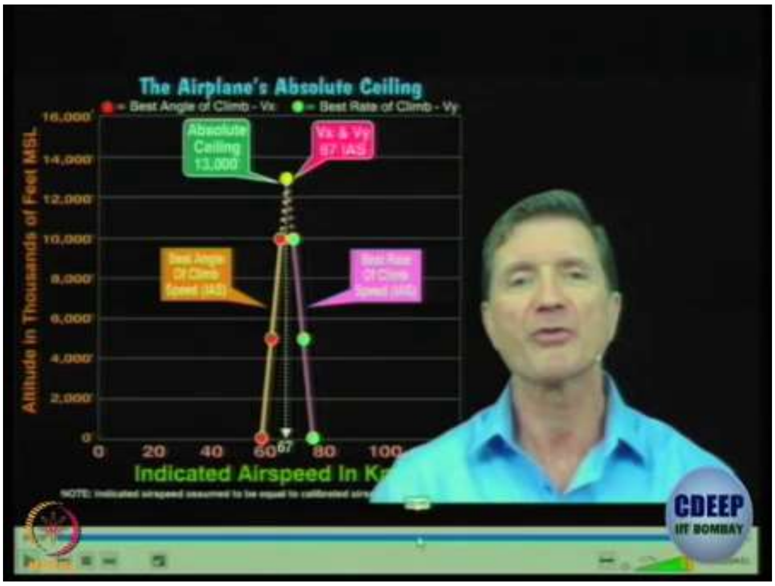

Rate of Climb Vs. True Airspeed Graph
= Best Angle of Climb - Vx
= Best Rate of Climb - Vy
ROC Curve
(Rate Of Climb)
800 FPM
700 FPM
600 FPM
500 FPM
400 FPM
300 FPM
200 FPM
100 FPM
0 FPM
Rate Of Climb In Feet Per Minute (FPM)
SEA LEVEL
5,000 MSL
10,000 MSL
0 20 40 60 80 100
CDEEP
IIT BOMBAY
NPTEL

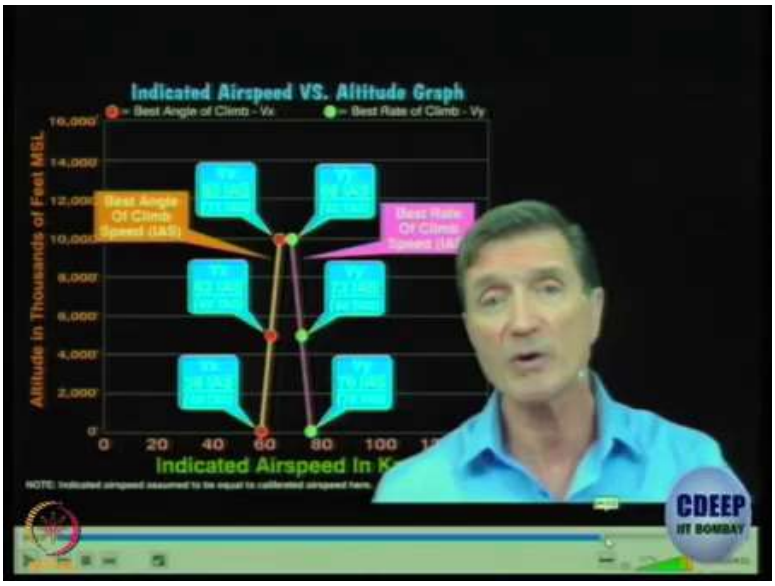

Vx and Vy as True Airspeeds
= Best Angle of Climb - Vx
= Best Rate of Climb - Vy
Best Angle Of Climb Speed (TAS)
Best Rate Of Climb Speed (TAS)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Altitude in Thousands of Feet MSL
0 20 40 60 80 100
NPTEL


True Airspeed Graph vs. Indicated Airspeed
= Best Angle of Climb - Vx
= Best Rate of Climb - Vy
Best Angle Of Climb Speed (TAS)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Altitude in Thousands of Feet MSL
TAS
CAS
CDEEP
IIT BOMBAY


True Airspeed Graph vs. Indicated Airspeed
= Best Angle of Climb - Vx
= Best Rate of Climb - Vy
Altitude in Thousands of Feet MSL
16,000'
14,000'
12,000'
10,000'
8,000'
6,000'
4,000'
2,000'
0'
Best Angle Of Climb Speed (TAS)
0 20 40 60 80


Indicated Airspeed VS. Altitude Graph
= Best Angle of Climb - Vx
= Best Rate of Climb - Vy
Altitude in Thousands of Feet MSL
16,000'
14,000'
8,000'
6,000'
4,000'
2,000'
0'
Best Rate Of Climb Speed (IAS)
0 20 40 60 80 100


The Airplane's Absolute Ceiling
= Best Angle of Climb - Vx
= Best Rate of Climb - Vy
Absolute Ceiling 13,000'
Vx & Vy 67 IAS
Altitude in Thousands of Feet MSL
16,000'
14,000'
12,000'
10,000'
8,000'
6,000'
4,000'
2,000'
0'
0 20 40 60 67 80 100



Video: Rod Machado’s and thank you for attending my aviation learning center. I have a question for you, have you ever wondered why Vx and Vy, the best angle of climb speed and best rate of climb speed respectively change with altitude well perhaps I can offer you a different angles from which to look at this particular question. I want you to take a look at these three rate of climb curves. There is one for sea level one for 5000 feet AMSL and one for 10000 feet AMSL, Now each curve represents the rate of climb for a typical small general aviation airplane from different altitudes. And the very tip top of each curve represents the maximum rate of climb for that particular altitude.

Now unless there is been oxygen shortage in your neighborhood, it will be pretty to you that is altitude increases the maximum rate of climb decreases but I want you to take nose that the top of the curve shifts to the right slightly as altitude increases. In other words as the maximum rate of climb decrease with altitude, the air speed at which this occurs increases slightly measured as a true air speed, this is found by dropping down to the horizontals axis of the graph which is calibrated in terms of true air speed by the way the reason I am using true air speed on horizontal axis instead of indicated air speed…it allows us to more accurately represent the airplane’s performance at various altitudes. Since the green dots represents the best rate of climb speed at 3 different altitudes it is pretty clear that Vy does not decrease with increase in altitude. Now let us create 3 lines running from the origin of the graph intangent to each weight of climb curve, the each of the line touches each curve the red dot represents the best angle of climb speed or Vx.

Professor: The best angle of climb is tangent.

Video: Which is simply found by dropping straight down to the grass horizontal axis, geometrically speaking the slope of each tangent line running through each red dot represents the maximum vertical gain for a given distance travel horizontally and we know this to be the classic definition of the best angle of climb speed. Important thing to notice here is that the best angle of climb speed also increases with an increase in altitude but it does so a little bit faster than the best rate of climb speed therefor Vx and Vy as true air speed converge on each other as altitude is increased. Now here is the plot of Vx and Vy as true air speed values in the traditional ref, so ask yourself what air speed would you need to indicate to achieve each true airspeed value for Vx and Vy at sea level 5000 feet and 10000 feet AMSL and a way to find that out is to use a computer and as you can see here at 10000 feet AMSL on standard day we need an indicated airspeed of 65 knots to produce…

Professor: So now he goes to the piloting information because he has plotted the graph in terms of true air speed but pilots do not know the true air speed normally pilots only knows the indicated air speed and you cannot tell the pilot that VAS equals to Vs into root of rho so take a calculator, calculate density at 5000 feet okay 6.5 degree per kilometer mar jayega by that time he will crash, so they do not do all these calculation today they have a small computer with them. Earlier they use to have these slide rule kind of system so they would inbuilt all these values into these kind of hand held devices where they would enter a IAS and get the equivalent airspeed subtract the various errors listed in the card and get the value of true air speed. Modern day cockpits have an indicator in front of them but that is there only on very advance aircraft. On very small aircraft on GA aircraft you may not actually see always the true air speed then you have to do these kind of things to figure out.

Video: Airspeed of 77 knots and indicate the airspeed of 69 knots to produce a true air speed of 82 knots. And when you do this, for all the other airspeed values, you get these indicated airspeeds. Now, let us take our indicate airspeed values for Vx and Vy and plot how they change with altitude. Now, here is the graph you are probably more familiar with. So, why does the best rate of climb line here, obviously Vy line shown to the left. Vy is the best rate of climb speeds increase with altitude as a true airspeed. It just does not increase that quickly. Therefore, the indicated airspeed value needed to produce any given true air speed value decreases at a slower rate for Vy than Vx as altitude increases and that is why the best rate of climb line tilts to the left and converges with the best angle of climb speed line. In fact, the point at which the converge is the point where the airplane has zero rate of climb. Also known as it’s absolute ceiling. So, there you have it, a brief explanation is to why Vx and Vy converge on each other as true air speeds and as indicated air speeds.

Professor: So even if you plot the true air speeds then they will be little bit…both will be inclined towards the right but they will meet at some point, if you plot indicated airspeed then they will actually be like a vertical triangle, the Vy value will be reduced actually okay and the Vx value will still be increased but not at the same rate.

Video: True air speed value decreases at a as indicated air speed.

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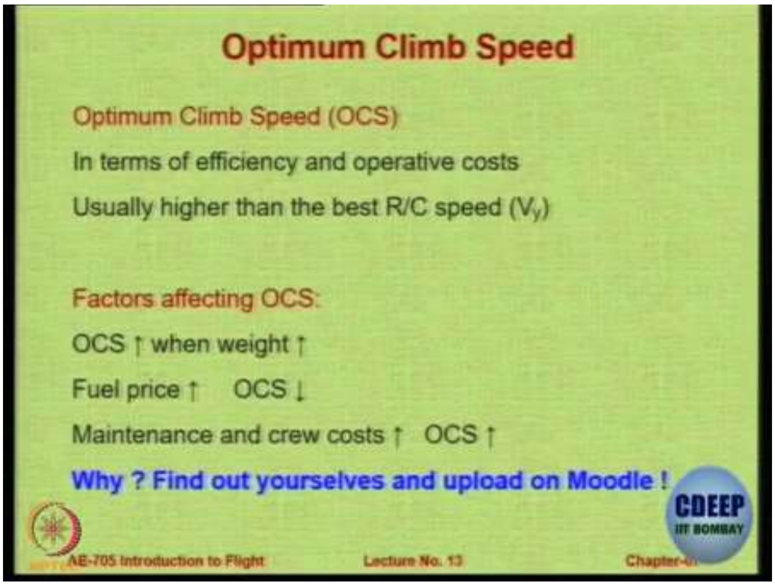

Professor: So this is what you will get if you use indicated. Now there is something about optimum climb speed also, which is the speed at which the aircraft is actually made to climb, this is not driven by either by Vx or Vy this is driven by economics. Yeah.

Professor: No, wait wait wait what did you say there do not have a landing gear or an engine do not confuse between landing gear and engine they are 2 different thing. They do not have an engine agreed but they have a landing gear, yeah they have landing gear you have seen it. In that, in the video that I showed you it showed in fact the landing gear was retractable type with hydraulics.

Professor: They have?

Professor: See, there are three ways of launching one way of launching is with engine that is a motor glider okay but even a motor glider how did roll on ground it has a small landing gear it could be fix. In many cases the landing gear of the glider is half the wheel single wheel half outside half inside so that the drag is minimum. But there is landing gear and then in the nose they have a skid they have a skid, skid it is basically a small piece where you rub on the ground. So what they do is they come, they land on main wheel they have a landing gear they do not have an engine but have a landing gear okay and in some cases the landing gear is retractable type because it depends on whether it is going to give you lot of benefit it will because drag will reduce drastically but then there is complexity issue weight complexity cost so there is a trade-off there are many gliders in which you have no engine but you have landing gear which goes inside.

But in most gliders you have a fixed landing gears but a very beautifully shaped one so that the drag is minimum, the most common one is the single main wheel one small tail wheel but then when you land on the ground you have very long wings they will hit the ground this way or this way because it is very difficult to land perfectly like this and then remain like this it will go this way or this way. So on the tips they have a small support so that it can rest on the ground okay so the engine is not there but landing gears are there okay.

So coming back to the optimum climbing speed so we are looking at efficiency and operating cost when we are flying an aircraft for money for commercial purposes. So these speeds are usually higher than the best rate of climb speeds you are not interested in having only the optimum rate of climb that is just a numerical value what you want is higher efficiency so there are some factors that affect the optimum climb speed the weight goes up the speed goes up so heavier aircraft climb at higher rate if the fuel price goes up normally speeds goes down and maintenance and crew cost are higher if OCS are higher so this is something that I want you to find out and report on moodle why is it so and how is it done? Remember this is not for gliders this is not for sailplanes this is for only commercial aircraft in other words I am saying that commercial aircraft do not operate at either Vx or Vy they operate at OCS optimum climb speed which is slightly higher than Vy. So, your job is to find why and repot it in moodle, okay.

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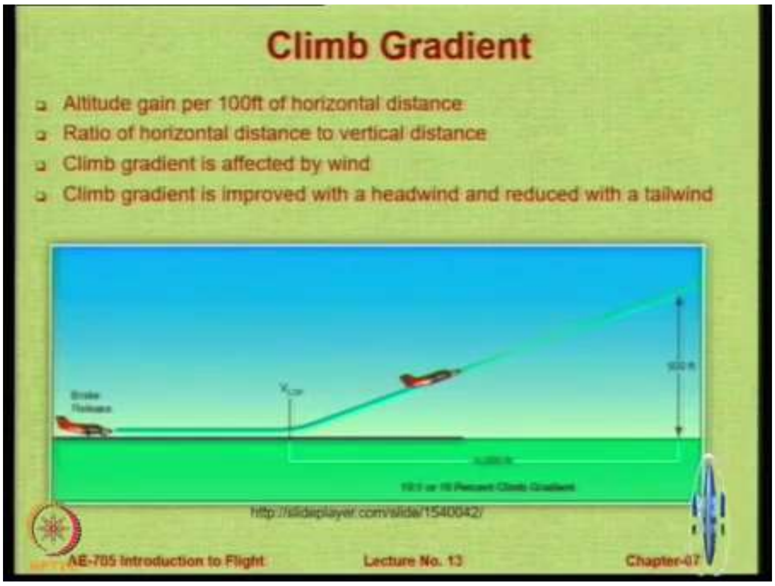

Moving on to climb gradients. Basically climb gradient is an indication of how much altitude is gained per unit horizontal distance and the unit is basically 100 feet in this case so it is like how much do you gain 100 feet horizontal distance okay. So it can be called as ratio of horizontal distance to vertical distance and this is affected by wind and by many many other factors.

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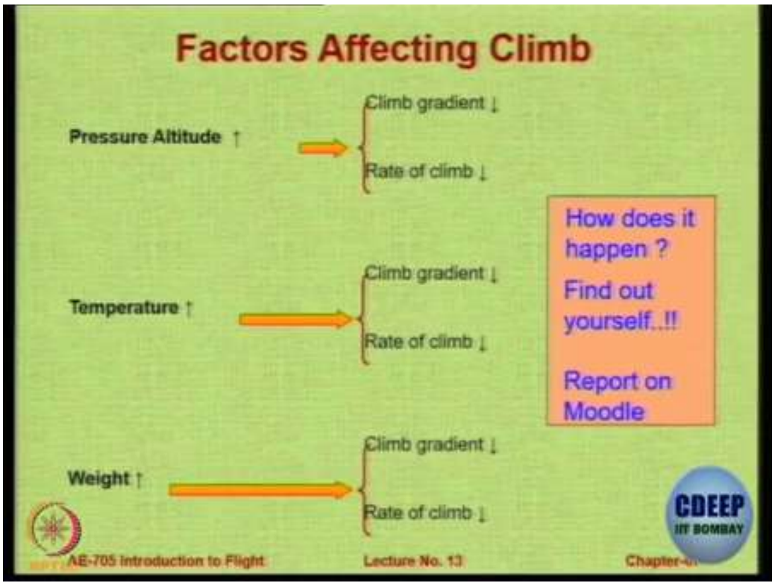

So let us see factors one is pressure altitude, so if you are at higher altitude and if you are taking off your climb gradient will go down and therefore the ROC will go down. Temperature is also very bad and weight obviously so all these three affect the climb performance of an air craft in a very negative fashion okay. This is what that I do not want to cover I would like it to do yourself, so it is a homework for you to load on moodle effect of altitude, effect of temperature, effect of weight on the climb performance why it is so that this climb gradient reduces and the ROC reduces if you go into it?

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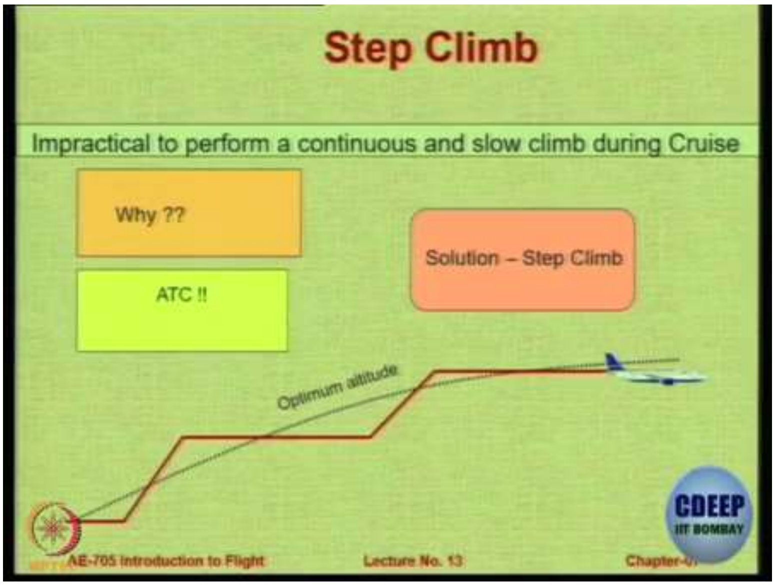

Now this is an interesting concept that, remember that as I told you as you, as you climb up slowly you are consuming fuel and your speed… your density of air is decreasing so what will happen is the rate at which you climb is going to become very slow and it is also not permitted. So why do you think why do you think you are not allowed to continuously climb when you go into a flight? What is the problem? As a passenger aircraft you are taking off from an airport you want to reach cruising altitude and then you want to cruise what is the problem? The pilot will like to do this because as you are as you are climbing you are consuming fuel so you are becoming lighter so therefore you like to go continuously up.

In fact if you want to, let us look at short range flight let us say Mumbai to Pune flight in Mumbai to Pune flight we have these mountains in between but because of short distance we have no mountains and no constraints, what would be the best profile to fly? What would you think be the optimum flight profile for a short distance flight? So the answer is if you want to fly at minimum fuel consumption you take off from Mumbai and you keep on climbing till you reach height from where if you decent you will hit Pune this is called as Saw tooth. But what is the problem in this? Yes what is the problem in Saw tooth flight?

Professor: I will change it no problem do not get worried about climb speed I want optimum from fuel consumption, so the optimum from fuel consumption is I will keep on adjusting the speed to whatever gives me the minimum fuel consumption and then come and decent. So what is the problem? Not only Mumbai to Pune even if I have to go from Mumbai to New York this is the best trajectory for minimum fuel. Keep on going up reach cruising altitude above which you do not want to fly because it will lead to more consumption then you fly level and then far before keep descending slowly so what is the problem?

The problem is you are not alone in the aircraft, in the sky. There are other aircraft flying and who manages them, the air traffic controller and they will go crazy if there are 100 planes each of them are ascending and descending slowly, then how will they keep the track where they are? It is very difficult so it is the ATC who says sorry I should know where you are because I have to separate you so one layer separation is by altitude separation 2000 feet gaps you give the aircraft one behind the other in the same direction. So the ATC would like you to quickly go to some cruising altitude which they will assign you and they will say maintain that so that I know that you are flight level 280 at so and so time.

The next aircraft who is coming I have to put it on the same altitude so many minutes behind you or so many knotical miles behind you okay. So it is the ATC who is going to complain. So the pilots would like to have a continuous increase in the altitude, the ATC would like you to fly at constant altitude so that they can keep track on you. So both of them have a compromise and that is called as a step climb or a stepped flight. So the dotted line is the optimum altitude at which you would like to fly and the red line is the one which ATC gives you. So this is also called as Cruise climb, so you cruise at so altitude and then you altitude has reduced now the optimum altitude for cruise is 2000 feet above this, to tell the ATC give me new flight level for those few minutes 3 4 5 minutes the ATC knows that this guy is climbing. You climb and then again you go level. Then you keep on reducing the fuel you reach another distance where now the fuel is so less that the optimum height is 2000 feet above you. So again you stop that is called as a Cruise Climb so typically from here to New York you may have 3 steps like this in a flight right.

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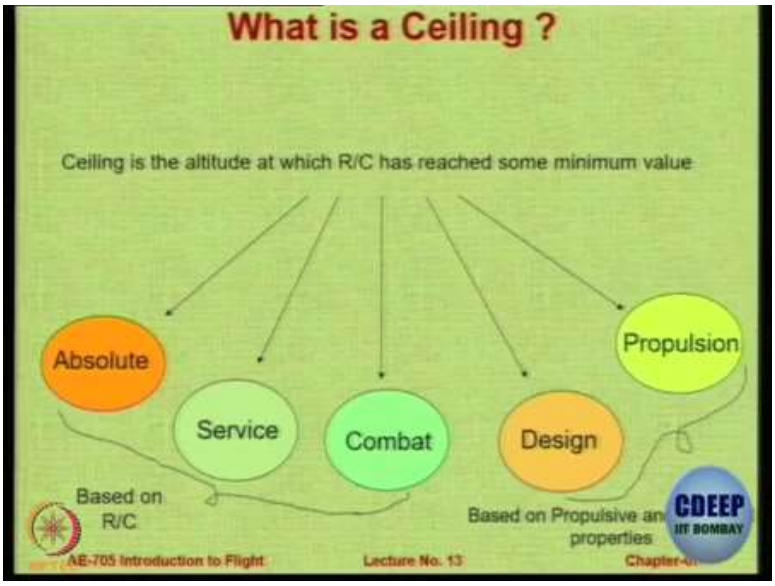

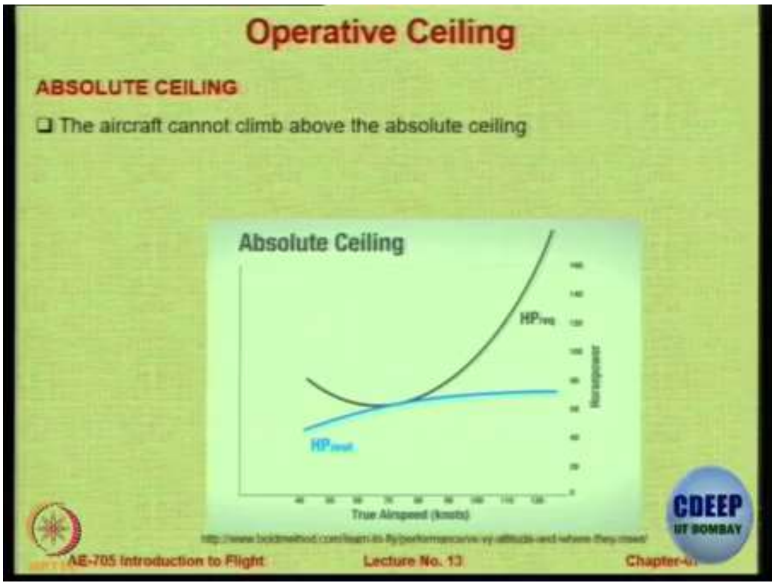

The last thing for today is the operative ceiling, okay. So ceiling is very straight forward, basically what is meant by ceiling? That is not the ceiling, our ceiling is basically is to do with altitude at which the rate of climb has reached some minimum value. Notice it is not 0, it is some minimum value ok, so depending on what is the value there are many ceilings there is an absolute ceiling where the value is 0, then you have service ceiling, you have combat ceiling, you have design ceiling and you have propulsion ceiling.

Now this design ceiling an propulsion ceiling normally we do not talk about it much but the first three are very commonly talked because first three are actually driven by the rate of climb okay. You can numerically decide absolute service and combat ceilings where as these two are based on the propulsion and the structural properties of aircraft. So let us see what they are, absolute ceiling is very simple you just cannot go above it because the power available and power requires become exactly matching they are tangential and you can fly only at one speed about that ceiling okay. So suppose you reach the absolute ceiling now you can fly only at one particular speed if you fly faster you will fall down if you fly slower you will fall down right. Now imagine you are flying at that particular altitude and you encounter a mountain, so what do you do now?

The mountain is higher that the value of absolute ceiling okay you can circumvent by turning if you are very near you cannot do anything because if you go low you will hit it and you cannot go higher, that is why it is dangerous for an aircraft to fly at a altitudes near absolute ceiling because the reserve capacity is very poor, so that is why we define some other ceilings okay. So what are the other ceiling? First one is propulsion ceiling that is the altitude at which the thrust provided by the engine allows you to reach above that the thrust available is not going to help you so it is bit lower than absolute ceiling, absolute ceiling is aerodynamic parameter where my ROC’s are matching but the ROC is zero but before you reach ROC zero you may reach thrust not available condition okay. Then you have service ceiling, in service ceiling we want to have a reserve climb capacity of 500 feet per minute it is not meter per second it is feet per minute, this is considered from safety point of view, So if you have a mountain in front of you at least you can go 100 feet in a minute and avoid it.

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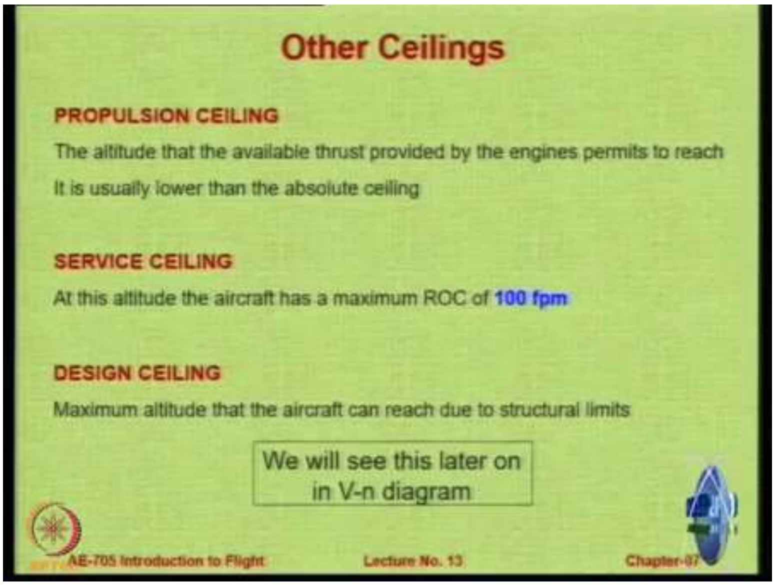

Then we have design ceiling, a ceiling at which you cannot go because of structure limitation because delta P atmospheric pressure keeps falling pressure inside, so the delta P across the structure should not become so much that the structure breaks. So the engine is ok, but the structure has failed that is the design ceiling this we will see later when we study V-n diagram also.

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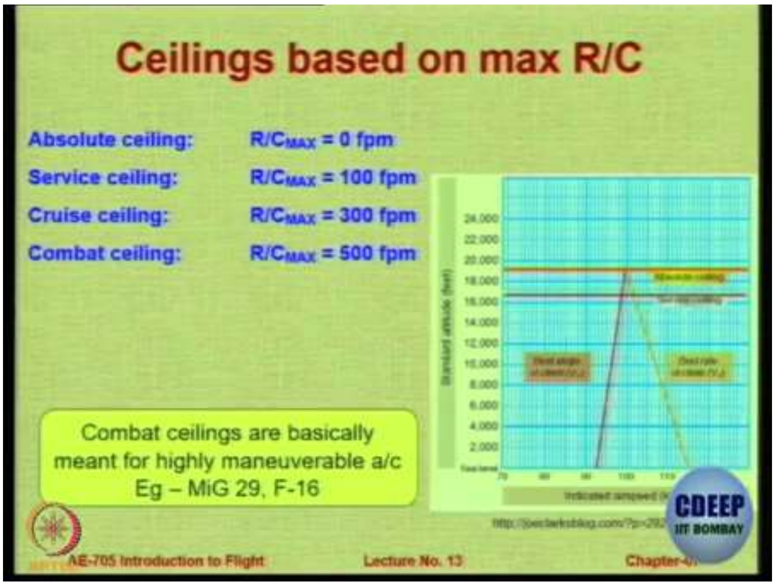

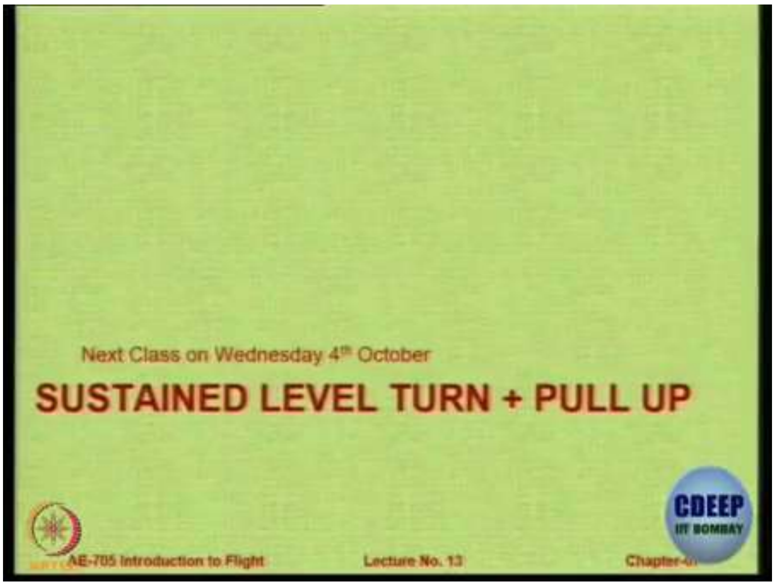

So finally we have these two speeds you can notice the best angle of climb speed and the best rate of climb speed so you have absolute ceiling and service ceiling and then you have this cruise ceiling that means you should not cruise at height higher than the one at which rate of climb is 300 feet per minute from safety point of view. Then you have Combat ceiling for military aircraft so that you do not have you are not a sitting duck target because now you cannot climb okay. So these are numbers which are commonly used okay. Next time when we meet we will take Sustain level turn and pull up.