Introduction to Flight
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Lecture 11.6 - Landing Performance of Flight

Okay, so now we look at landing, so what happens in landing? The reverse of take-off.

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You come from an obstacle height, touch on the main landing gear first and then proceed. Now there are many many problems that may happen in landing.

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You can see one example here, when the nose gear of the aircraft was not working, so there was a very interesting scenario in which one person used his truck, he was, he positioned himself on the truck in front of the landing aircraft so that the aircraft could put the nose landing gear on the truck, okay, so this is a very heroic thing, now this is not what we want to do every time, correct. Obviously, we do not want it to happen like that.

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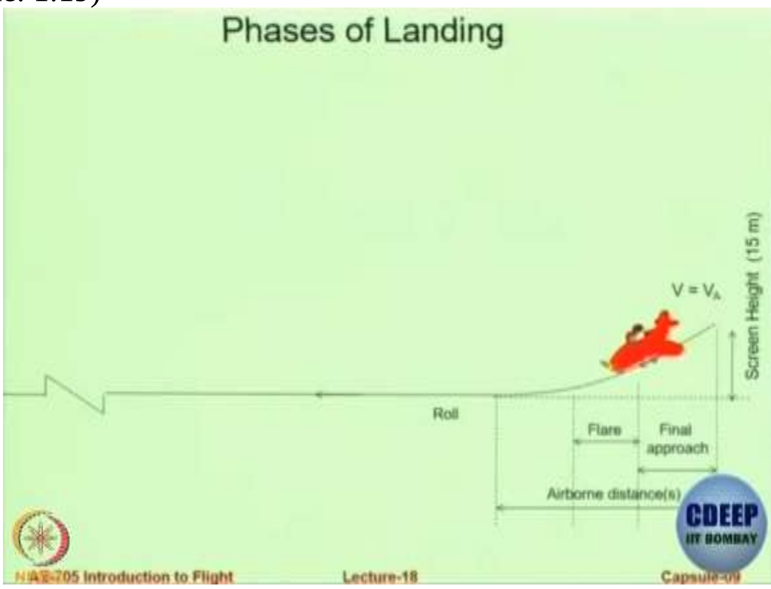

So what do we want to happen is you are coming in at some speed at landing, again you have a screen height or the obstacle height, so this is the final approach, okay and then you have a flare and then you have a touchdown. So the flare is the opposite of transition, is now again a concave circle, so the distance from the obstacle height to touchdown is called as the airborne distance, in takeoff it is called as the climb distance and after touchdown you are just rolling, so that is takeoff ground roll TOGR or TOL takeoff ground roll during landing, till you come to the stop, okay.

So the final approach is a steady descent, the flare is a curve, float is one small point where opposite of rotation, you are touching the ground but nose is still up, so you slowly come down, that is floating and then finally you have the roll and after you actually come down, then you start applying the brakes and you have a ground run.

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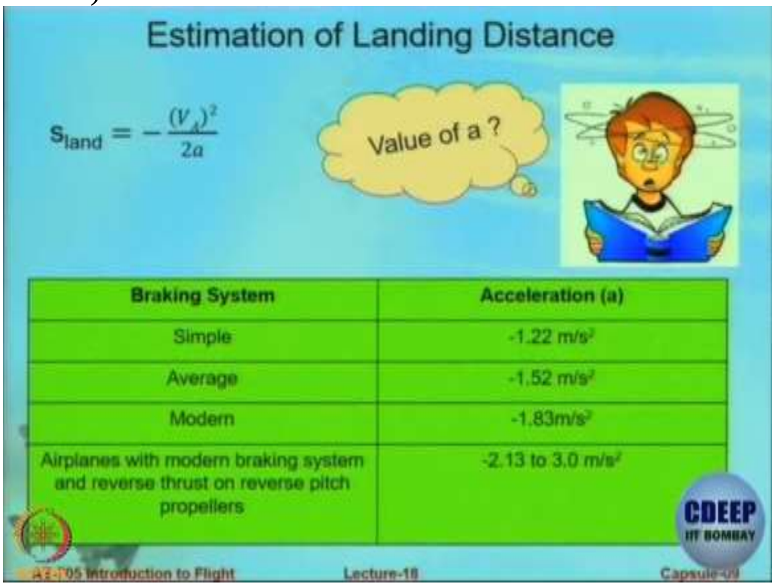

So, let us see how do you estimate, this is actually much simpler, so it is just minus $\frac{V_a^2}{2a}$, where a is the acceleration during coming into land, this is difficult to calculate, so some numerical values are given based on the braking system. I am talking only about the landing, on the ground, so depending on various types of brakes you can have different decelerations and you can use those numbers.

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So, let us look at some interesting things, the landing distance increase will increase as wing loading increases, so again from takeoff and landing both we want to have low wing loading, okay.

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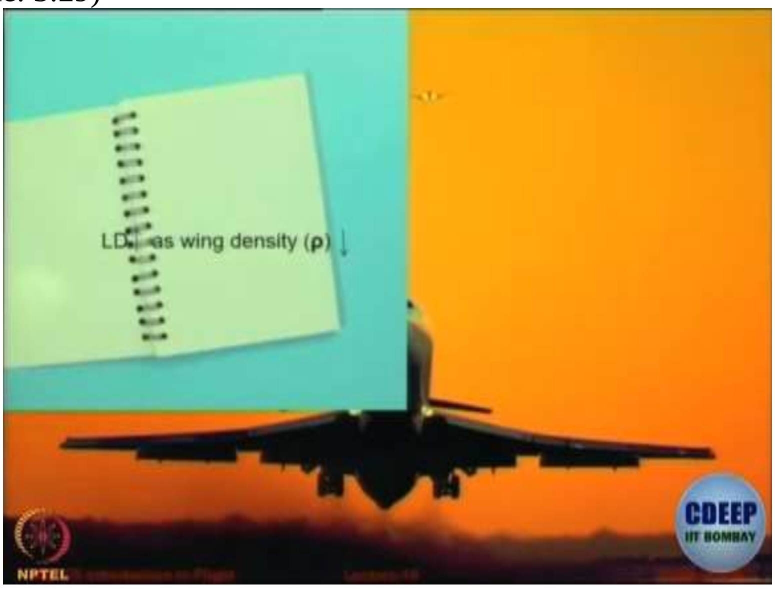

Similarly density, landing distance increases as wing density, not wing density this is wrong. It is actually air density, so when the air density reduces at a higher altitude or a hotter condition landing distance increases.

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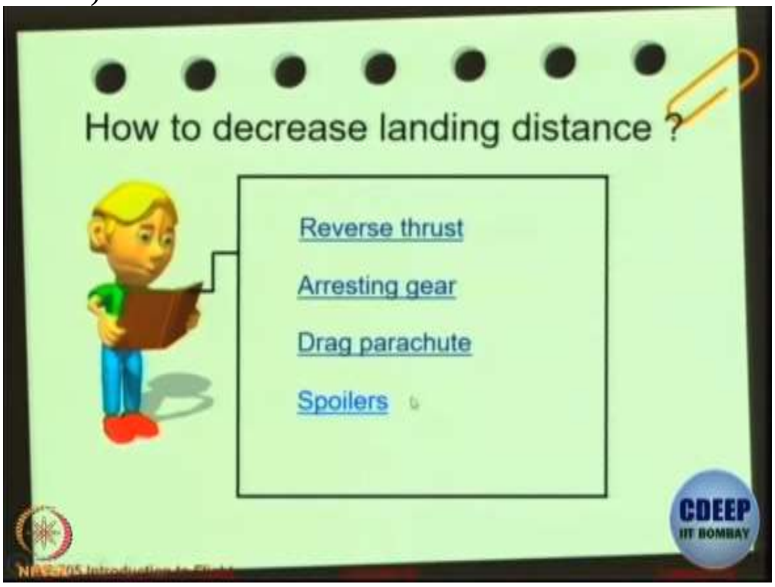

So these are the two important points, so now the question is how to decrease the landing distance? Once again you need to create larger decelerating force, so one way is reverse thrust.

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So, when you touch down, you can see the back of the engine, something has opened up, in fact the air is now coming from there, you can see, the rear is almost closed.

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Another example on a 747, look at the engines, similar thing.

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Another example, this is what I had asked in the question, the first question, These are flaps switch open and the rear is closed, so the air is now being thrown back or thrown forward.

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Notice they come out only after all the wheels are touching the ground, okay so this is reverse thrust, but while calculating the distances we do not assume this is present, we ignore this, why do you think we do that? Because, yeah because it may not be working, you cannot say ‘Sorry’ because the reverse thrust did not work we had a crash, not acceptable okay, so reverse thrust is as over and above the safety, it is the safety margin.

The other way is arresting gear, this is the reverse of catapult so the aircraft entangles itself into some kind of a cable on the runway and you can see there is an energy absorbing piston which tries to absorb the energy.

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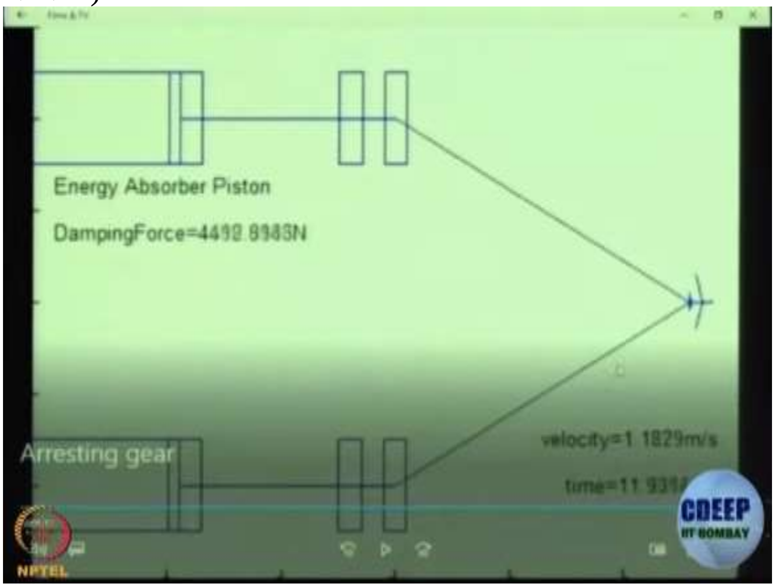

So in a 12 second cycle the energy absorbed, you can see the damping force is so high. Another example is a drag parachute.

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This is also very common in the military aircraft, there are some military aircraft in which drag parachute is compulsory, it is always used, just like in some aircraft the thrust reversal is always used and also in some cases afterburner is always used. So similarly this is a situation where parachute is always used, and then we are all aware about spoilers.

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This is a very interesting video at Mumbai Airport during arrival. See the wings how much it is vibrating, touchdown and the camera is shaken and the spoiler has come up.

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This video was shot by me using my mobile phone when I was landing from Goa to Mumbai only, so you can see how spoilers are working, okay so let us go ahead.

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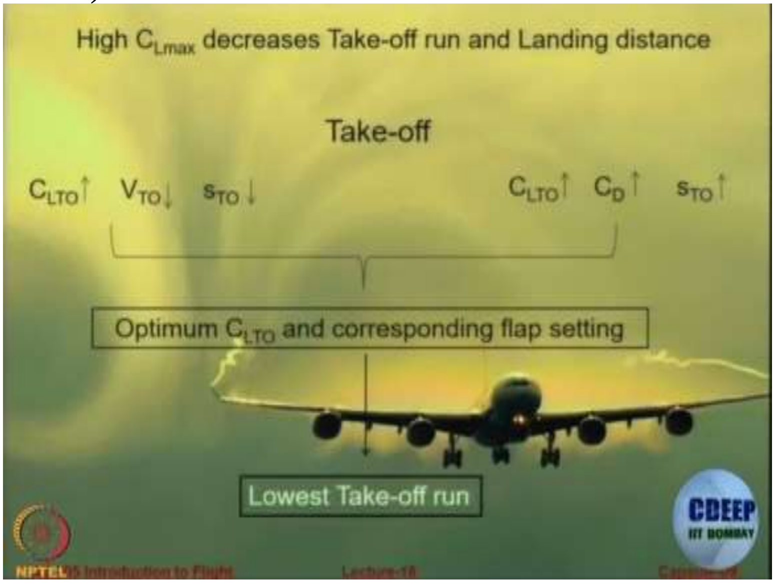

Let us look at the flap settings during takeoff and landing, so flaps are used during takeoff and during landing but there is a difference, in takeoff we are more concerned about increasing the CL at takeoff so that we can have a lower takeoff velocity and therefore the S takeoff can be reduced and if we increase the CL takeoff there is a problem, CD also increases because $C_D = C_{D_0} + KC_L^2$, so if you increase CL takeoff, velocity of takeoff reduces that is a good thing. So takeoff distance reduces but at the same time CD also increases the takeoff distance will increase. So there has to be a balance between the two, so we must have in such a way that the decrease in velocity is more than the increase in the drag during takeoff.

So, essentially what is important is not just CL increase or CD increase, what is important is L by D, lift over drag. So, we choose a setting at which we get more benefit from velocity reduction and less problem from drag increase. So when you use the correct combination you get the lowest takeoff run. This is during takeoff.

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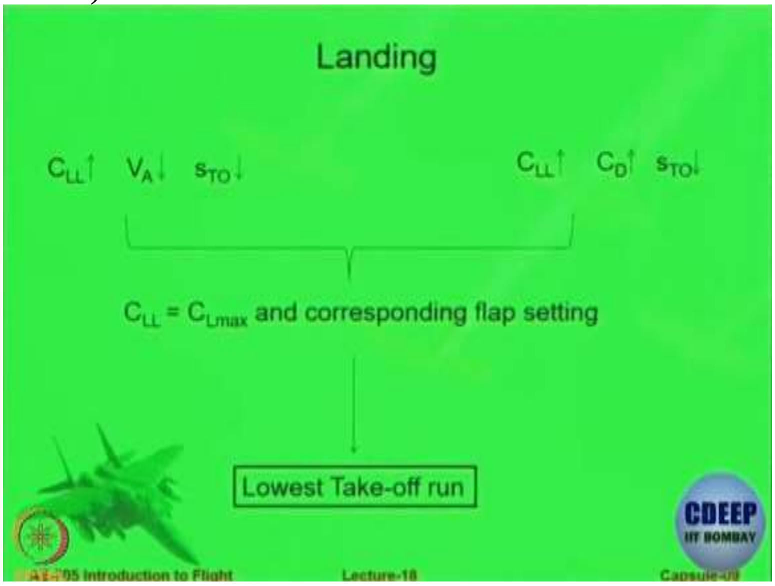

During landing so CL at landing if you increase then the approach speed will reduce, if the approach speed increases or reduces the, this is not STO this is S landing this is a copy-paste problem, it is S landing and if you increase the CL at lift unfortunately again the CD will increase because again CD knot is equal to, CD equal to CD naught plus KCL square, so as S takeoff is going to, so this is a benefit, both of them are beneficial now. So here there is no problem, there is no conflict, so what we will do? We will go for the maximum possible in this case, maximum possible means largest value because the largest value of CL will give you both lower approach speed as well as higher drag.

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So, generally the CL max at takeoff, generally is approximately 80 percent of the CL max at landing and CL max at landing is equal to 100 percent of CL max, so the aircraft always lands or tries to land at CL max possible with the best possible flap setting. So at landing CL equals to CL max, at takeoff CL is equal to 0.8 times CL max, so therefore the flap setting that is used for takeoff and landing generally vary between 20 to 40 degrees for takeoff and 40 to 60 degree or even higher 65 degrees is also common for landing okay, so that is the beauty.

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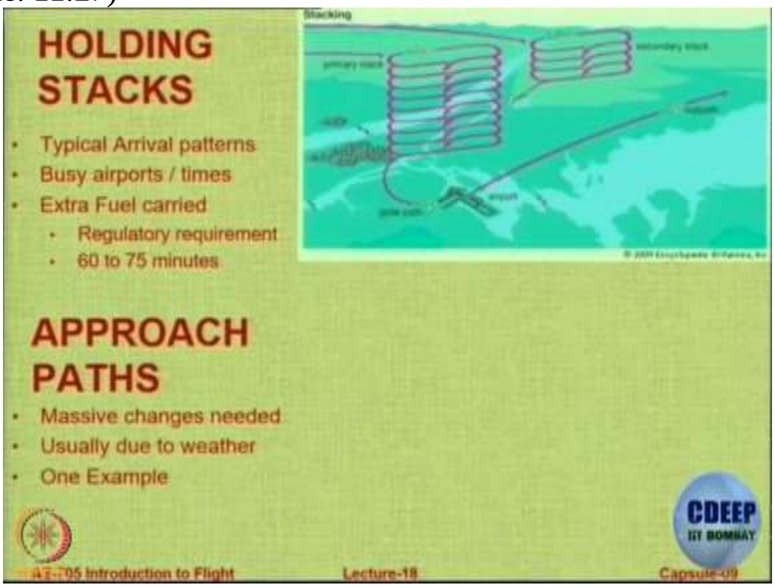

Now, let us say we are coming into land but runway is not available, many reasons are there but mostly because of weather, because of some problem at the runway, so the pilot is made to fly on what is called as the holding stack, these are oval paths above the airport or near the airport at which you have to maintain a particular height and a particular speed. There could be many people in one stack over the other, these are typically used in the arrival at busy airports and at busy times at any airport. So to be able to have enough fuel to meet this requirement there is a regulatory requirement of extra fuel for holding, and approach paths also can have a massive change depending on weather, depending on operating conditions. So one example I will show you.

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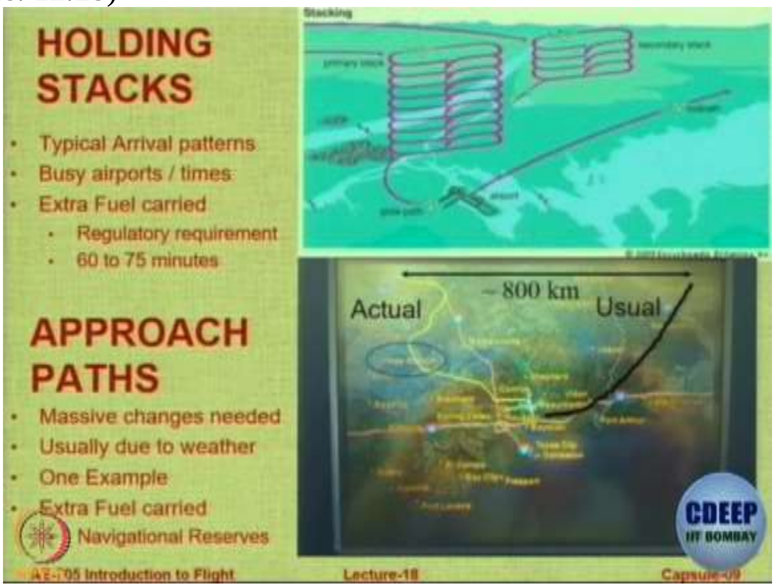

This is a screenshot from a pilot, so this is the usual flight path for a flight arriving at this airport, this is Houston, Houston airport in Texas USA, so flights which arrive from Europe normally come along that path but because of bad weather they may actually be made to travel extra 800 kilometers and come from this side, that yellow line, incidentally caller station is a place where I spent about 3 months so that is why I just marked it there.

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Let me show you how, a very good example of a simulation. On one particular day lots of people were travelling to meet lots of their friends et cetera, it is a Valentine's Day and that caused a massive massive demand for travel and coupled to that February in UK can be very bad weather, so you see what happened on that particular day around 3 years ago and you see that effect on the flight.

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This is UK. You can see landing stacks. This day from 2014 shows how severe storm can add to that challenge. So there are three colors, blue color is the flights, yellow is the delayed flight and red are the diverted flights. You can see holding stacks over Houston. NATS Stands for National Air Traffic service of UK which provides the air service just like we have Airport Authority of India.

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Okay, so now we come to the last part and that is the most dangerous part that is takeoff and landing during crosswinds, crosswinds are basically winds coming from the side, so one example or let us look at this:

[Video Presentation]

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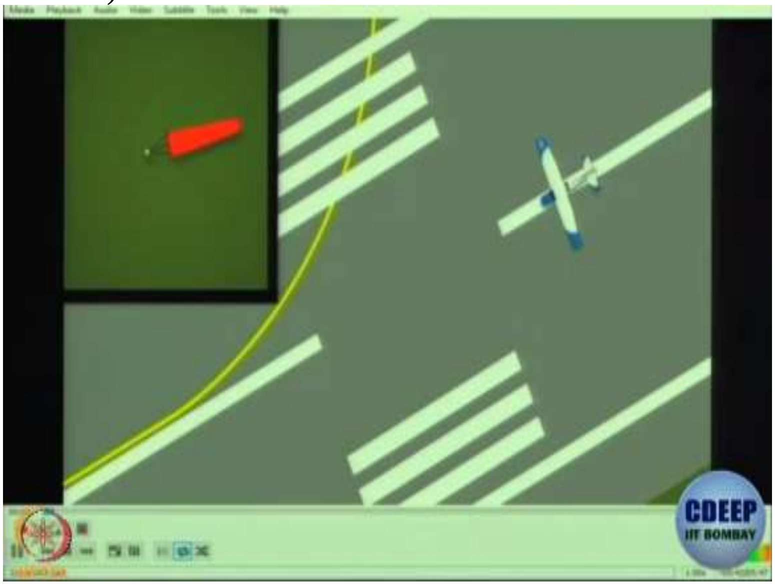

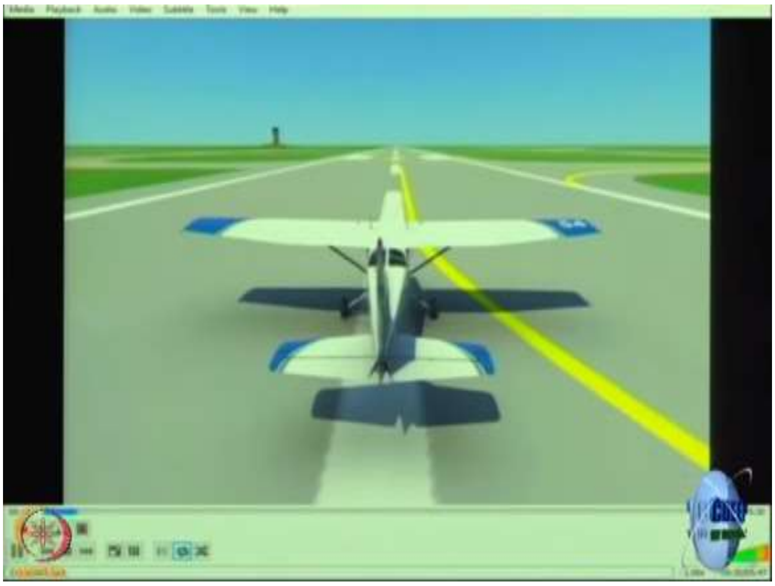

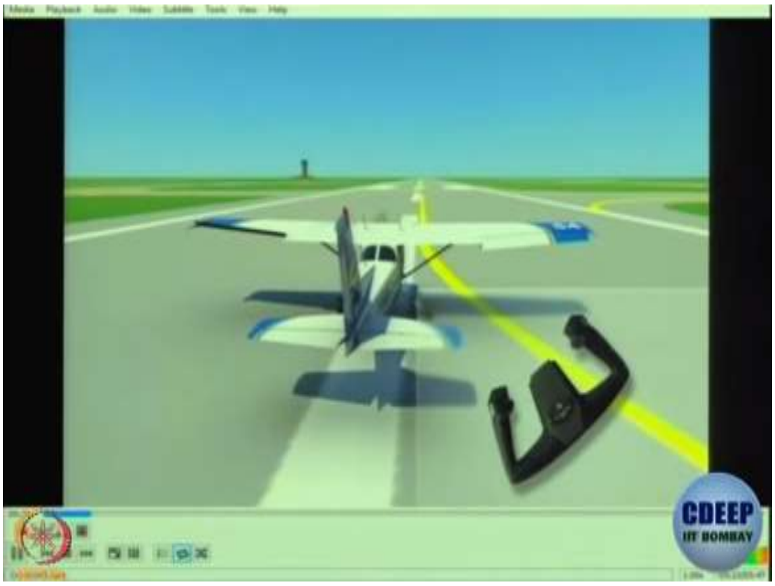

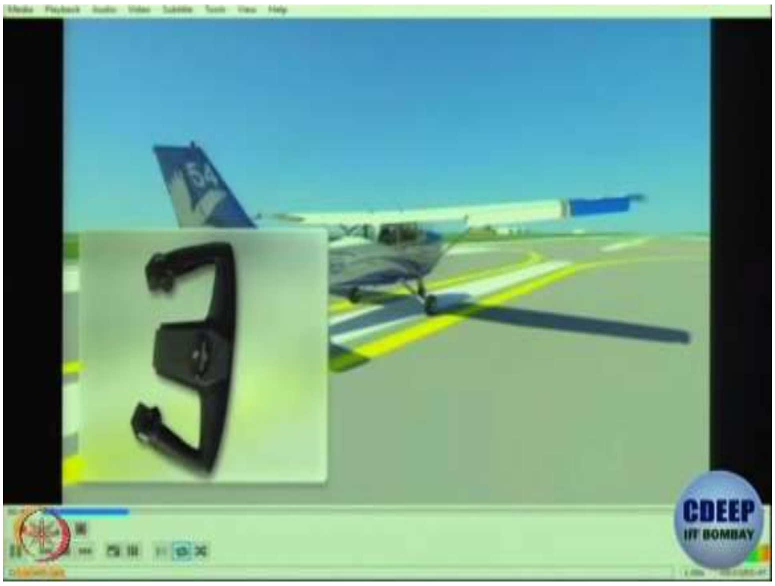

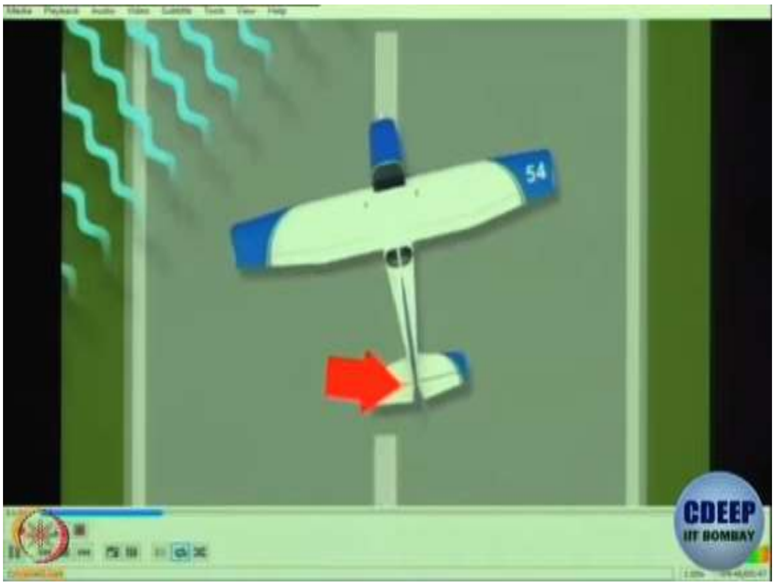

I have a question, so why do you need a right rudder when you are not having any crosswinds? If you noticed he said that in normal takeoff you will require a slight right rudder, and now, if there is a crosswind from the left hand side you have to put more right rudder, if there is a crosswind from the right hand side you have to put less right rudder, okay. Let me show it to you once again, listen carefully, A normal takeoff where there is no crosswind you need right rudder, Why? In normal takeoff when there is no crosswind why do you need some right rudder? In a normal takeoff you need some right rudder, yeah.

Student: Sir, might be because of propeller.

Professor: Yes, because the propeller throws air in one side, so the air hits the aircraft with a bias, correct. So, if you do not put right rudder, depending on the direction of the propeller rotation you will have force on one side, so in the Europe and in the USA you require right rudder, in Russia you require left rudder because Russian aircraft propellers rotate in the opposite direction okay. So, whatever the case may be…

Okay, so you got the basic idea.

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So let us see one example of dangerous crosswind landing, now this video is scary for some people, so I am giving you a warning. It is a real life situation, you can see it happened in Madeira in Spain just last year. So it is a very beautiful Spanish town, coming into land, audio is not needed because there is nothing, you just see it is coming into land, it has crossed the runway and now it is turning and just before landing again there is crosswind. So now see, if you look at the right wing now, look at the runway it is not straight it is actually up, flat and then down, so this particular airport is located next to a mountain and there are some side winds or crosswinds and this mountain system creates a complicated disturbance. So you are not, you are never sure about what will happen, so it is lucky that aircraft survived but you saw the way it went across the runway and then turned, it could have been very dangerous. There are more dangerous examples which I will show you in the next….

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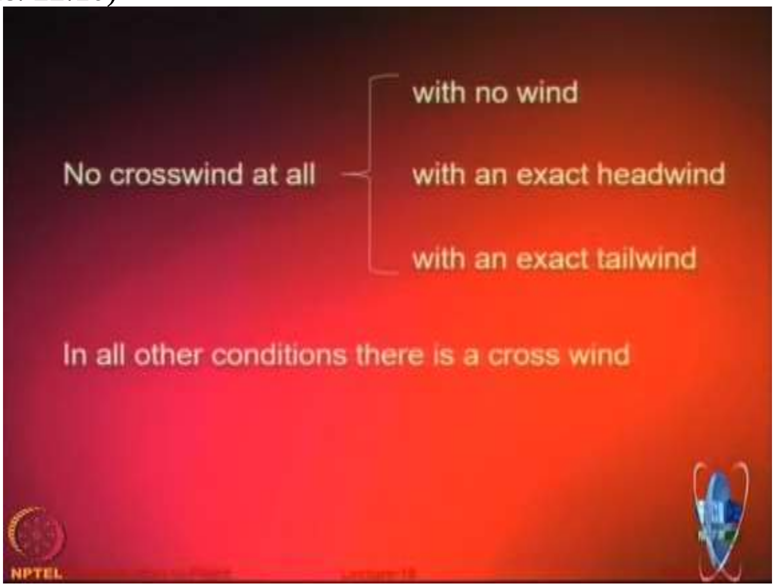

So, you can have 3 situations, you can have ideally no wind or you may have a headwind or you may have a tailwind, okay this is very good example. This can be easily handled, in all other situations you have a crosswind and sometimes the crosswind can be more, so there is a typical requirement which says that an aircraft is allowed to land if the crosswind that it encounters is less than one-third the stalling speed, it is a rough rule, it is thumb rule. So, if your stalling speed is 90 knots you can land in 30 knot crosswind, if the crosswinds is 50 knots and V stall at 90 knots you are not supposed to land, you are supposed to abort the landing, as we will see in some examples.

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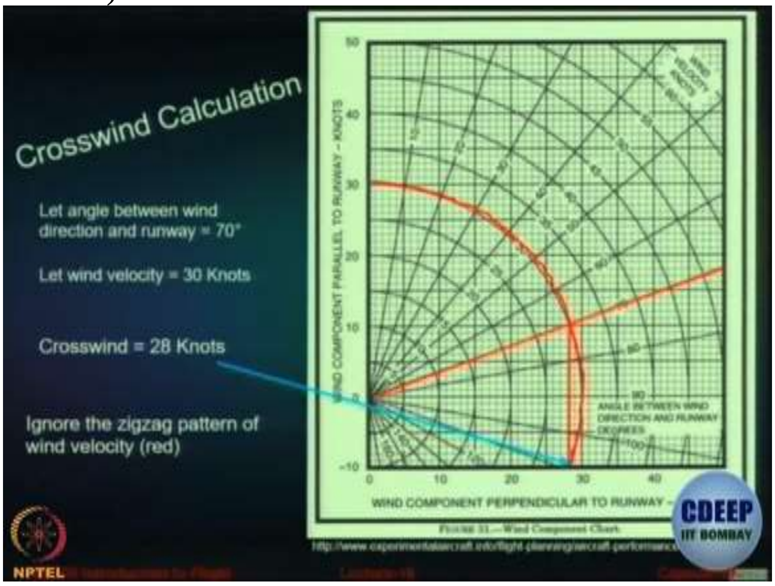

So, how do you calculate the crosswind value? You use a chart like this okay, so you look at the angle between the wind direction and the runway that is given to you by the air traffic control authorities, that when you are coming into land, there is a crosswind coming at 70 degree angle. So this number is known to you okay, let the wind velocity be 30 knots, so you have this 30 knots line, so where it meets 70 you just drop a horizontal, drop a vertical line and that gives you the crosswind. If this value is more than one-third of your stalling speed, chances are you cannot be allowed to land, this is how it is calculated.

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Now let us look at a vertical takeoff and landing, for which there are examples available both from either a tilt rotor like this:

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Can you identify this aircraft? Which aircraft is this? Nobody knows?

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So you cannot name that aircraft, the previous one? What is it called? This is the one but what about the previous one, V-22 Osprey look at how it operates in vertical takeoff mode, let us see it once again, so look at number 1, number 2, and number three will be the nozzle, So three things have to be deflected, first thing that you saw is opening of the canopy for the lift engine, there is a dedicated engine in the front.

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Notice how the two horizontal tails are fully bent down, full deflection, the aircraft is almost stationary coming down at a very low speed.

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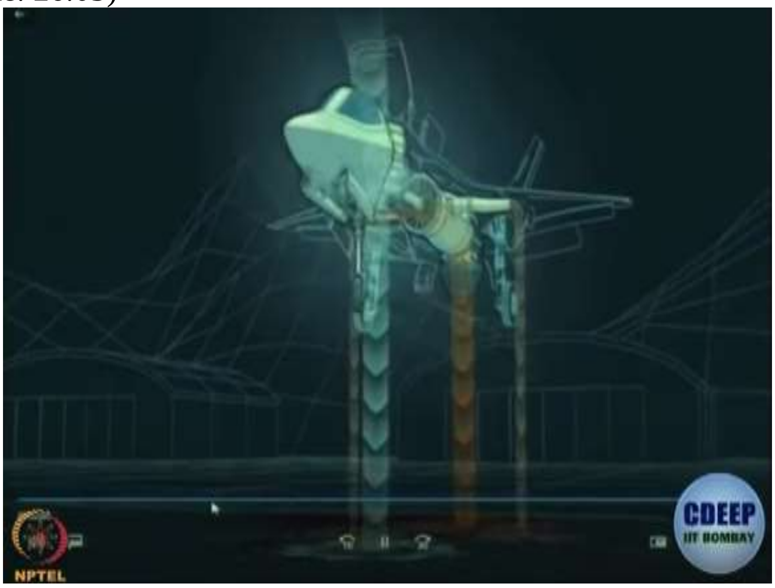

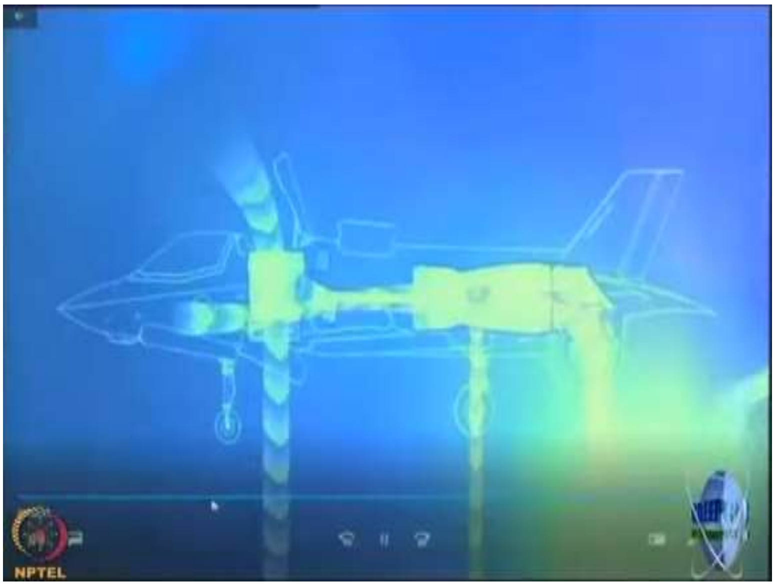

You can now see the mechanism how it is done, so this aircraft has a dedicated lift engine. This lift engine sucks the air from the top and throws it down to give you one force and then there is a nozzle in the middle of the engine and exhaust is also bent down, so it rides on three legs and there are actually two more on the wings for giving lateral support. So there are basically 3 plus 2, 5 jets on which it sits, so why not use in personal aircraft or in transport aircraft?

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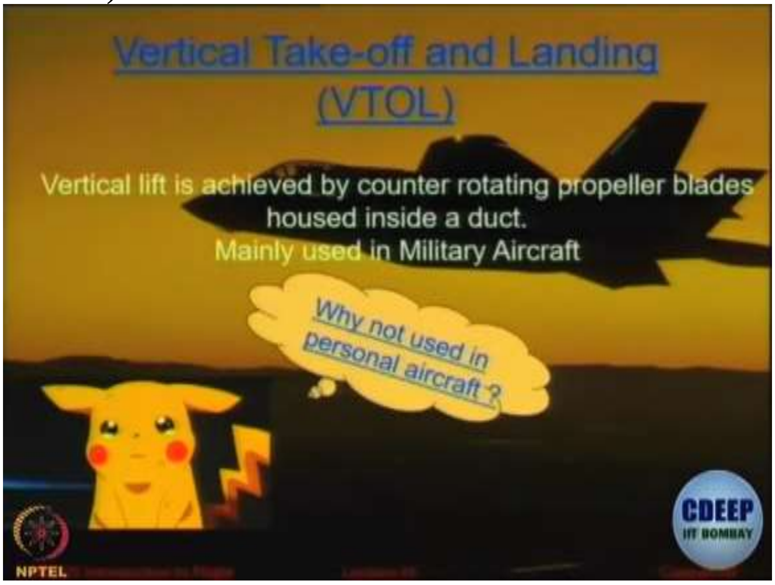

It would be fantastic, right. You can take off from IIT Bombay and go to IIT Kanpur and land, if it is permitted or if it is available, so why is it not there? There are many reasons for it.

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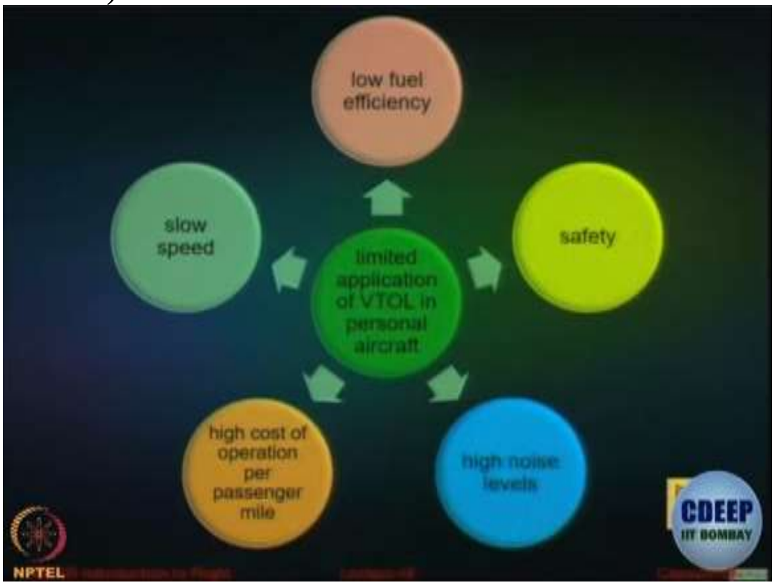

The first reason is extremely high consumption of fuel, then there are safety issues, you saw one trial but there were many many failures before this actually succeeded, then there will be huge noise level which are okay for military aircraft but not for conventional aircraft. If we provide it, the cost per person will go up so much that you would not be able to afford it and secondly this gives you a very low speed, so because of these reasons we do not normally see in personal or transport aircraft.

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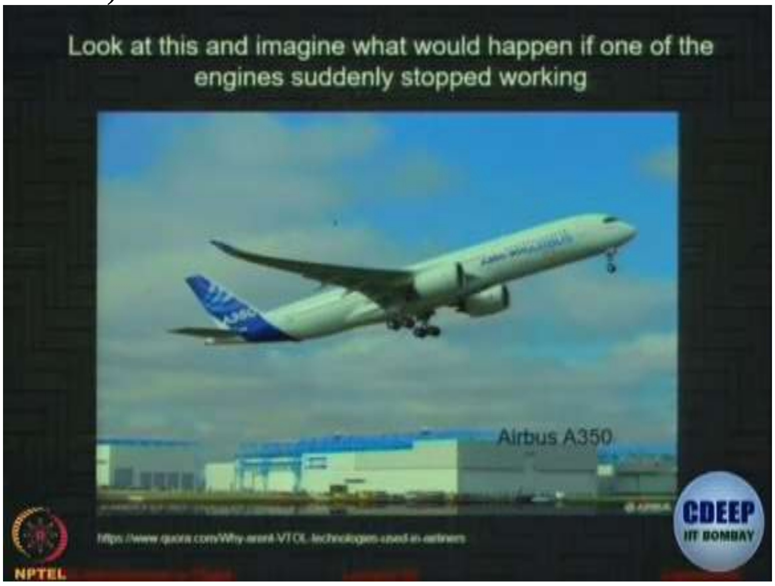

So, this we have seen so many times so what happened if one engine fails, but if you look at what happens when one engine fails in this kind of aircraft the consequences can be disastrous.

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CDEEP
IIT BOMBAY


CDEEP
IIT BOMBAY


PLAY
V22 Osprey crash.mp4

So here is one example of an engine failure during the takeoff. This aircraft has a very unique record, it is the aircraft that took the maximum time for design and development, no other aircraft in the world has taken so much time from conception to testing to finalization, the amount of time needed by this aircraft was a world record highest. So, I want you to tell me on a Moodle page how much is that time, how many years did it take for this aircraft from conceptualization to certification.

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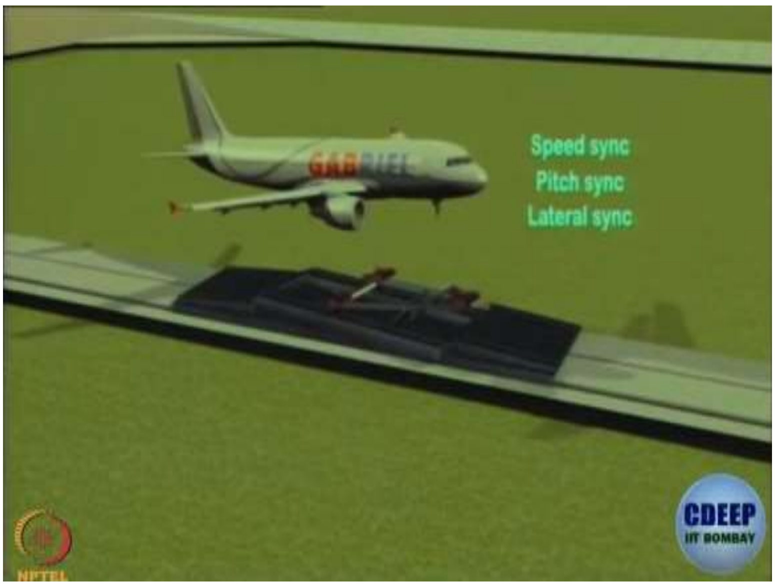
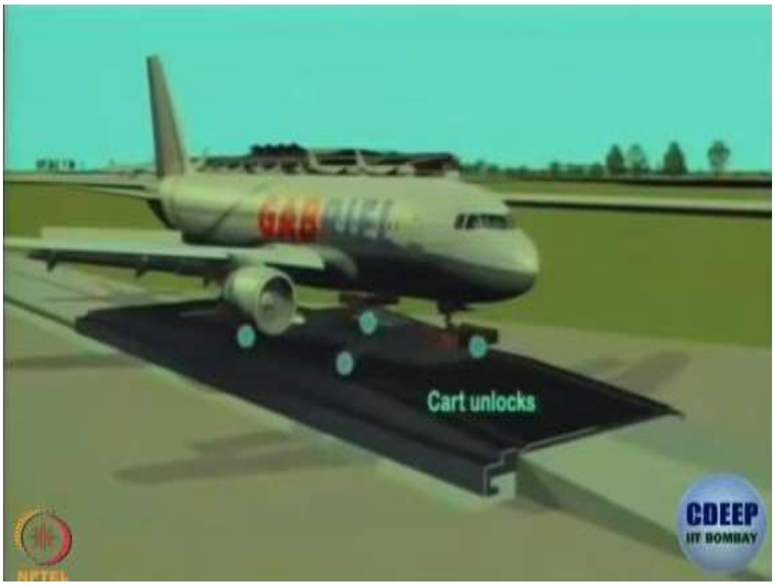
takeoff weight:
94,00%
CDEEP
IIT BOMBAY
NPTEL


Magnetic Track
for ground acceleration and braking
GABRIEL
CDEEP
IIT BOMBAY
NPTEL


Speed sync
Pitch sync
Lateral sync
CDEEP
IIT BOMBAY
NPTEL



Now, let us look at what is in store in future for landing, this is a project, it is a research project. No landing gear. Around 6 percent weight can be saved. No friction. Okay, this is about the future, there are many benefits as well.

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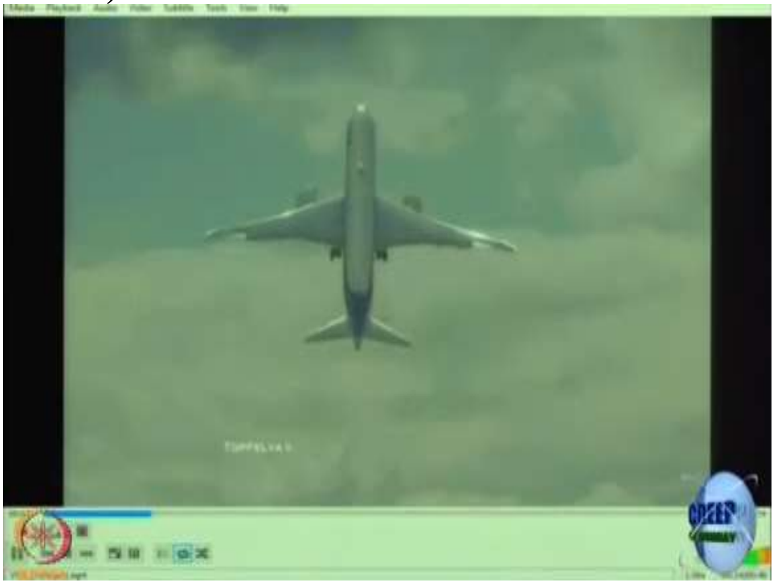

Okay and I want to end with this very beautiful video of a vertical takeoff in a transport aircraft. How it is possible for a transport aircraft to take off vertically?