Introduction to Flight
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Lecture 11.4- Takeoff Performance of Flight: Part I

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To the second lecture of capsule number 9 which is the 18th lecture and the content of this particular presentation was made mainly by student Hemashree, self-confessed, cute but psycho, ok. So she was here for two months in the summer.

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This talk of this lecture is going to be actually covering the most interesting aspect of flight which is the start and the end phases of flight. Things during other phases are little bit under control because mostly we have auto-pilot working in the cruise phases. It is only in the takeoff and landing when the real action starts and that is also the reason why this phase of flight, the takeoff and landing phase is the one that has seen maximum number of incidents and accidents.

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So let us have a look at takeoff and landing, so takeoff as you all know essentially comprises rotation or movement of the aircraft on the ground followed by leaving the ground, can you identify the aircraft? I will show you once again, yes I would like you to identify the aircraft by looking at the features of this aircraft, it is a very distinctive aircraft. Can anybody guess? Yes? Yes, so nose and the wings are not so distinctive because many aircrafts look like this but the chevrons on the nozzle are a giveaway, right. So this is Boeing 787 Dreamliner.

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So the question that I want to ask is what is the need for the aircraft to travel some distance on the ground, why did it not just lift the ground? That is because it has to achieve a particular speed called as a V LO or V LOF in many cases, ok. So what is this VLO or VLOF?

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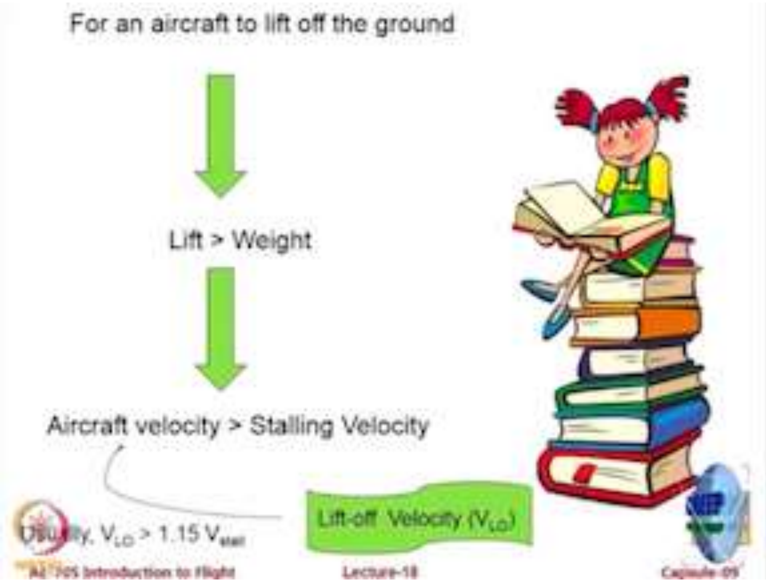

So essentially this is the required to achieve a condition by which you can leave the ground. So what is required for the aircraft to lift off the ground? You require that the lift has to be more than weight, ok. And to get that the velocity of the aircraft should be more than the stalling velocity, ok. But do you think an aircraft can be operated or should lift off just at V stall? Or do you think some margin should be given? It will be unsafe to lift off at V stall.

A parallel example is there are many people who, you know you have an assignment to load at 11:55, people start loading at 11:54, it is dangerous, because during that process if something happens you will exceed the deadline. So one minute late is also late. So similarly if you start doing things at V stall and if something happens, some unforeseen thing happens you can crash. So therefore there is always a margin and that margin is normally 10 to 15 percent.

So you do things slightly earlier than the deadline. Similarly, you lift off at a speed slightly higher than the minimum permitted speed or minimum possible speed, alright.

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So let us see there are some phases during takeoff, it does not take place in one shot.

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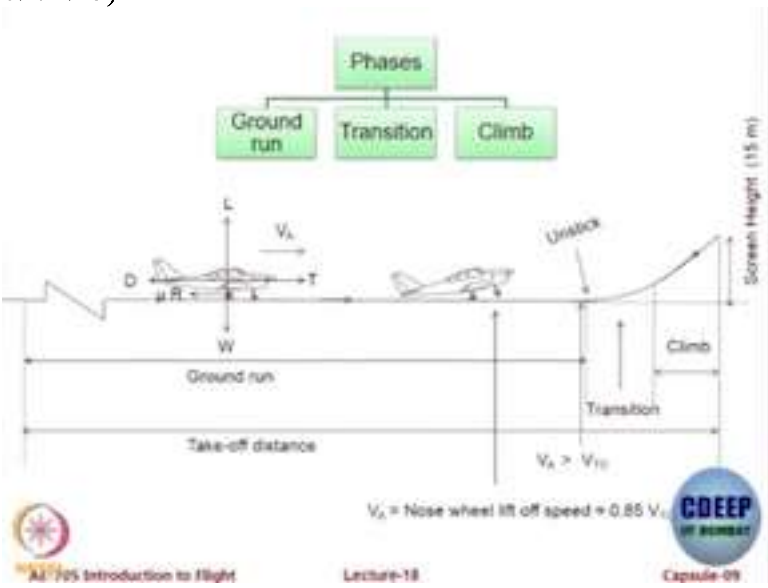

So there are three basic phases, there is a ground run which is from the time you start from the stationary position to the point where you leave the ground. After that there is a transition phase when you clear the obstacle height or screen height as it is called and you have then a climb phase. So some people say that the transition is before obstacle height whatever it may be, there is some phase after liftoff, which is the transition and then you have the climb.

So here is an aircraft on the ground and it is moving from left to right under the force of thrust T, so this force of thrust T definitely has to be more than drag otherwise it will not move, ok. So drag will not be there at 0 speed so as it moves it starts building up, you need to have more thrust but apart from the drag force opposing the thrust we also have the force of friction, the value of that is mu into the reaction, ok. And the reaction is the net vertical force, so you have the lift acting on the aircraft and then you have the weight acting downwards and let us say the aircraft is moving at speed VA, right.

And then you reach a speed at which the pilot initiates what is called as rotation, the aircraft is still on the ground but in a nose wheel type aircraft which is conventional type, the main wheel is still on the ground but the aircraft nose is going up, ok.

So this is done at a speed which is approximately 15 percent below the takeoff speed, ok there is a speed at which it can be initiated, you can not do at any speed because it will not take off, the nose will not go up, the control has to be sufficiently powerful to give you the required pitching up moment, so why do we do this? Any idea, why we do this, why do we rotate the aircraft? It is still on the ground but we want to pull the nose up, what is the benefit? Tell me what happens if you do not do rotation?

Yeah? First of all what happens if you do not do rotation? A pilot gives throttle, keeps on increasing the throttle and does not do rotation, what will happen? So let us say, take a mic, take a mic, will the aircraft take off or not if you do not rotate?

Student: It will never take off.

Professor: So what will happen, it will never take off, it will continuously on the ground, do you agree? No? So what will happen according to you?

Student: It will take more ground run.

Professor: Yeah, so it will eventually rotate or it will eventually lift off, ok, but it will need more ground run that is because two things are going to give you lift up for a fixed density, one is the lift coefficient and the other is the velocity. So if you only bank on velocity you will ultimately get hopefully some speed at which it will lift off, but you will require a very long ground run, however if you initiate rotation you are getting the benefit of Cl also because alpha will be giving you higher Cl. So, that is what you do, you rotate the aircraft but you can not rotate it at any speed.

If you become greedy and rotate it before the specific speed whatever you may do the aircraft inertia will overcome and you will not be able to rotate. So during rotation the aircraft is still on the ground and after that it starts into that transition phase and finally it goes into the climb phase, ok.

So there is a speed called as the, I will show you in the next slide various speeds, but there is a speed called as the unstick speed. So the distance on the ground from where you start to the place where you leave the runway, all the wheels leave the ground that is called as the ground run or sometimes take off ground roll TOGR or ground run, same thing, ok.

So this is the transition but there is also a climb up to a particular height called as the obstacle height, so this height is a screen height or obstacle height, which is typically 15 metres, 50 feet and the takeoff distance is the total distance from the starting point to the place, to the point on the ground where you clear the obstacle height. So it will be more than the takeoff ground roll or takeoff ground run because it involves the distance for transition and the distance for climb.

There is a third parameter called as a takeoff field length, what is that? So takeoff distance then you have, before that you have takeoff ground run or ground roll so you start with ground roll, then takeoff distance, ok, but there is also one more parameter, takeoff field length TOFL, what is that? It is 15 percent higher than this number, I will explain to you why it is defined, ok. So remember when you get the data from aircraft manufacturer you have to be careful what is the data, is it ground roll is it ground distance or is it field length?

So normally people define FAR 25 takeoff field length, so that follow the particular definition, we will come to that later on. So if we have to estimate takeoff performance we basically have to estimate 3 distances. So the total time taken for distance and the total distance covered on the ground, both the things have to be calculated for ground run, for transition and for climb.

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You can not neglect the distance travelled in transition or a climb, it could be equal to takeoff ground roll, the summation of transition distance and climb distance could be equal to or even more than the takeoff ground roll. It depends on the climbing capacity of the aircraft, for instance if you have an aircraft which is very very feebly powered, very week or let us say the engine are not behaving properly, then you may leave the ground very quickly but you may be climbing up at the rate of 1 millimeter per minute.

So the takeoff distance will be very very high because until you clear obstacle height you are not counted as having taken off, ok. So it is not negligible it depends up on the aircraft performance, so we look at this particular figure.

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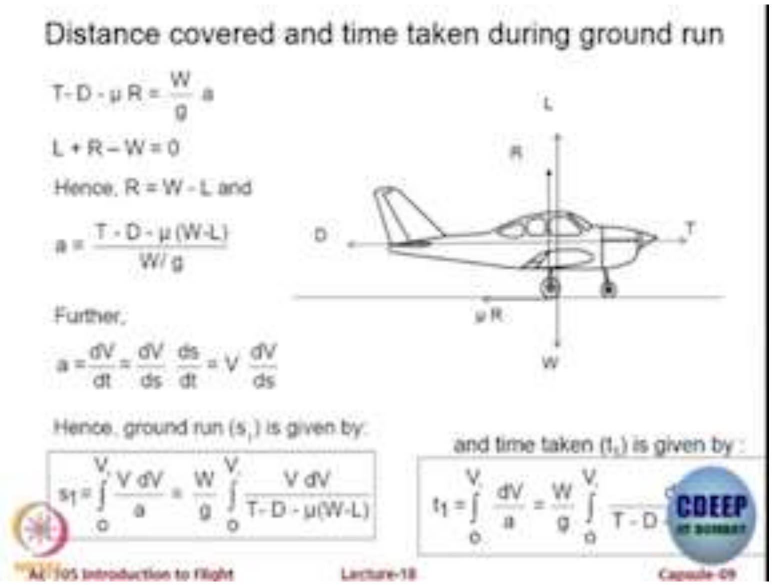

So if you take the balance of forces along direction of motion then

$$T - D - \mu R = \frac{W}{g} a$$

this is simply Newton's $F = ma$, ok. And the value of R is basically lift minus weight. So if you replace R with W minus L, ok you will get

$$a = \frac{T - D - \mu(W - L)}{W/g}$$

So obviously acceleration will help you reach your takeoff distance much further, much faster. So a will be basically the time change of velocity which will be time change of velocity with distance into $\frac{ds}{dt}$ or it will be V$\frac{dV}{dS}$. So therefore if you want to calculate the ground run from start to the point where the aircraft leaves the ground, you just integrate from velocity going from 0 to V1, V$\frac{dV}{a}$, that will be equal to W/g, which is a constant, it does not change during the takeoff. Ignore the loss of fuel during takeoff.

So technically speaking W is reduced slightly during takeoff because there is consuming fuel but that is too small compared to the aircraft weight, so we can ignore that, we can say that it is just V$\frac{dV}{a}$, so $\frac{VdV}{T-D-\mu(W-L)}$. So once you integrate this. Similarly the time will be $\frac{dV}{a}$ so you can integrate it. So these are the two standard expressions for the ground roll. You can also use $V^2 - u^2 = 2aS$, same thing, ok.

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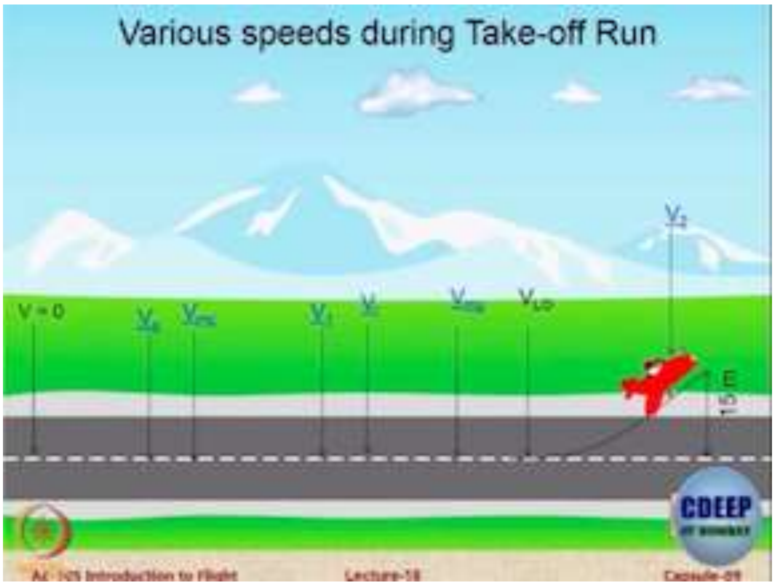

So this is a very important slide and it will showcase many many speeds and each of these speeds has a very important significance. So the first speed is the V equal to 0 when you start, then you have a speed called as V s, V stall, the next is V mc, V minimum control, the next speed is V1 this is called as the decision speed, then you have V r, rotation speed, then you have V mu, V minimum unstick speed then you have V liftoff which you already know and finally you have takeoff safety speed V2, ok.

So all these speeds are having a specific definition, and not only definition they are also very important. The pilot has to remember the numerical value of all these speed except the first one, which is 0, ok.

So just imagine if you are a pilot and you are going to fly an aircraft before every flight, you may have flown thousands of hours but before every flight someone called as a flight dispatcher, this used to be a profession earlier but now many airlines have switched over to automated reports but traditionally there used to be a person called as a flight dispatcher and this person used to meet the pilot and give information and the flight dispatcher documentation used to have values of many of these speeds.

Some of these speeds are fixed to the aircraft but they do not remain the same, they depend upon the altitude of the airport, density of the air, slope of the runway, runways are not flat, no runway is perfectly flat, all runways have some slope, there are certain limits to the slopes.

Today I will show you some videos where you will see fantastic runways which are having horrible slopes, ok but they are runways and that is what, that is the best that can be done, therefore these numbers change with the centre of gravity of the aircraft, with the amount of payload you are carrying, with the amount of fuel you are carrying, with the temperature, with the density, altitudes, winds, all of them affect, so the flight dispatcher informs the pilot today for this flight this is the number and if for some reason the flight is delayed by 2 hours the numbers may change, so then there will be a fresh document given.

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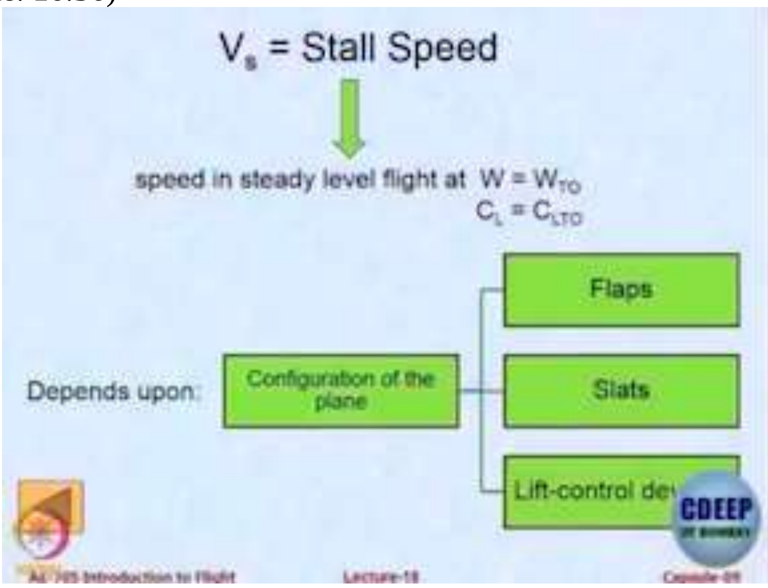

So let us see one by one what these speeds are and what they indicate. The first one is very standard, all of you know what it is, this is the stalling speed, ok. So the speed in steady level flight, it depends on aircraft configuration, it depends on whether the flaps are up or down, how much they are up or down, whether the slats are working or not and other lift control devices, if they are available, all of them affect the value of stalling speed, ok.

So what is meant by Slat? I think we covered this in lecture on nomenclature, but just the revision and anybody can tell me what is meant by a slat, and what it is used for, where is it located on the aircraft, can anybody tell me?

Professor: Ok, so these are like flaps, which are on the trailing edge of the aircraft wing, these are on the leading edge, ok. So why are the provided? Are flaps not enough? Why do we have slats? Can you have only slats? Is it possible to have only slats no flaps?

It is possible but it is not normally used, normally we use slats along with or after we have used the flaps. So you can call them as leading edge devices for lift enhancements, ok. There is a simpler device called as a slot, which is a fixed hole or a fixed gap in the leading edge between the leading edge and the body, ok. So you can have fix slat, you can have various type of slats.

Can you name any other lift control device other than flaps and slats which is used on the aircraft during takeoff and landing? Or we are discussing takeoff right now. Can you talk of, can you think any other device other than flaps and slats, which is a lift control device present on an aircraft during takeoff? So this is a question for your Moodle, ok. Find out and tell me what it is.

Now avoid about Moodle also, you must have seen there are some course recently on Moodle about the longest flight duration etc, some people are just repeating the information, there is already some information about some flight, they are just repeating it, that is not really of any benefit, that will not be counted, that is not interaction, that you reiterate the fact, ok.

What we are looking for is new information, some other video, some other photograph, some other source, some other interesting information, do not just repeat what is there because that does not serve any purpose, ok. So this is a stalling speed.

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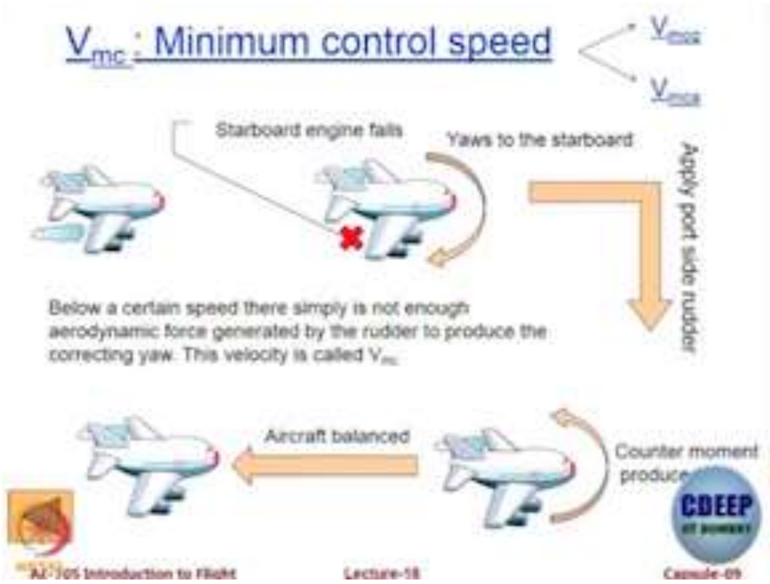

So moving back let us look at V mc. V mc stands for V minimum control or minimum control speed, so to understand this let us watch a short video:

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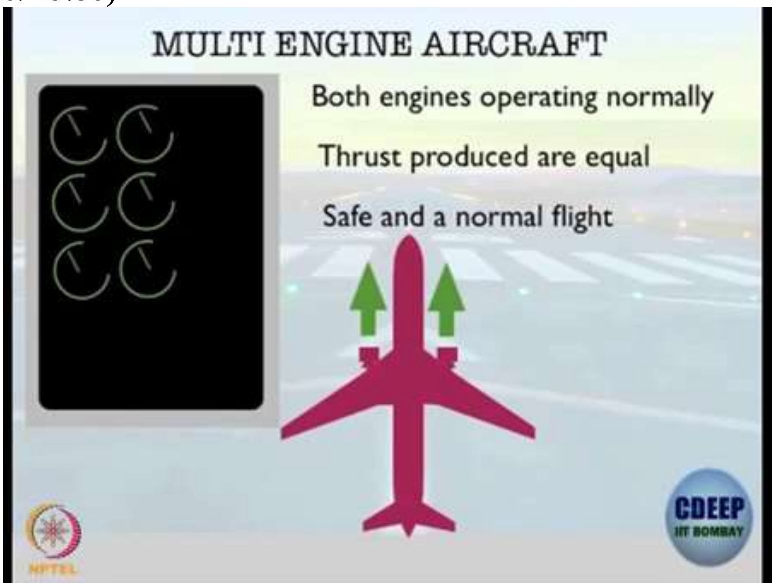
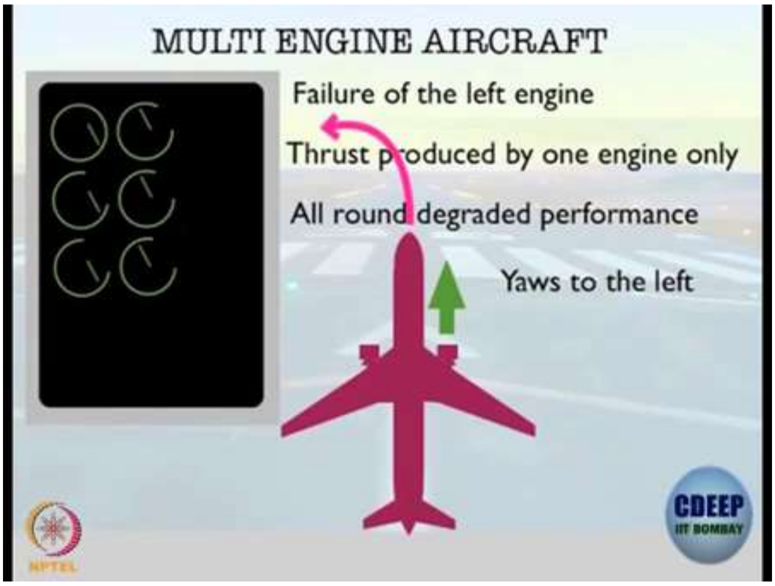
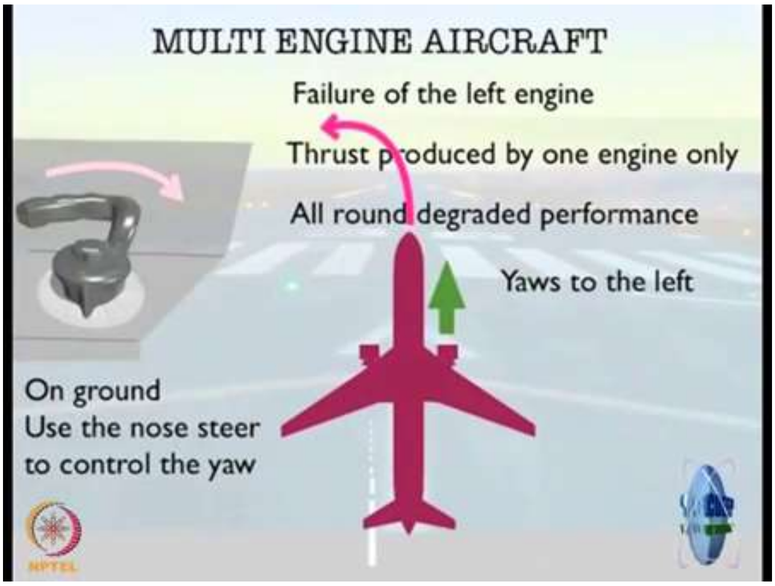
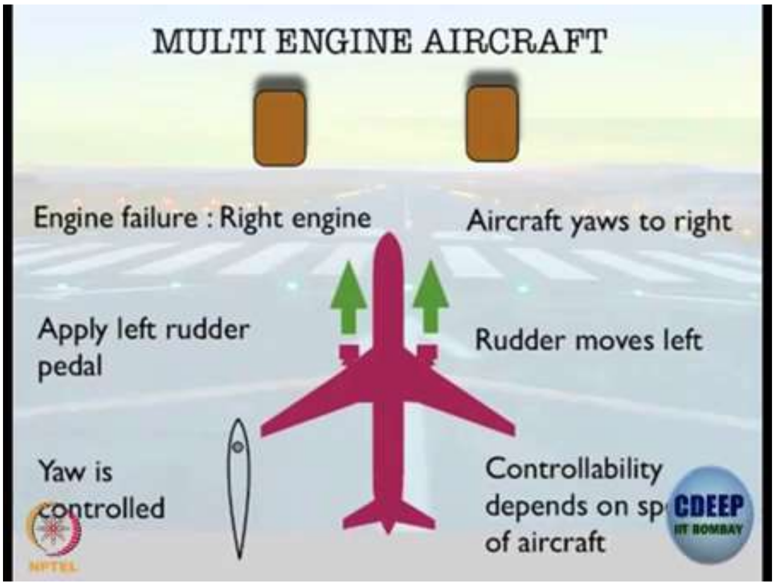
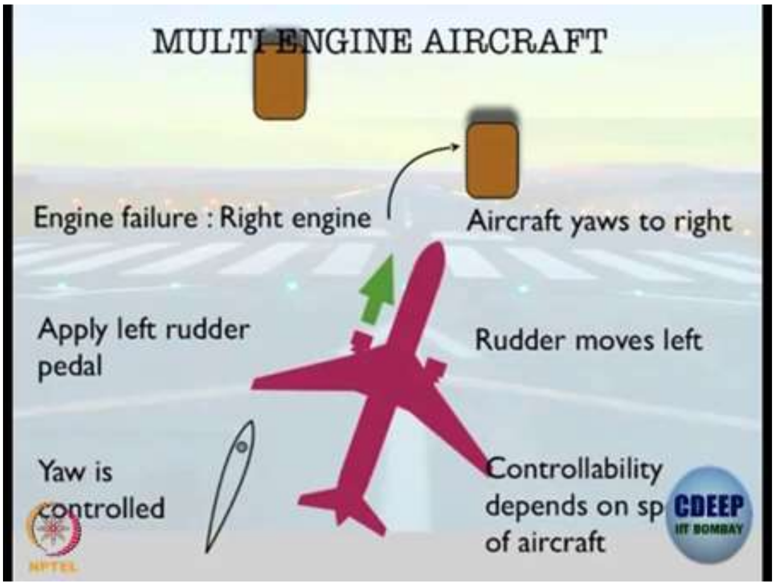



MULTI ENGINE AIRCRAFT
Failure of the left engine
Thrust produced by one engine only
All round degraded performance
Yaws to the left
CDEEP
IIT BOMBAY
NPTEL


MULTI ENGINE AIRCRAFT
Failure of the left engine
Thrust produced by one engine only
All round degraded performance
Yaws to the left
On ground
Use the nose steer
to control the yaw
NPTEL


MULTI ENGINE AIRCRAFT
Engine failure : Right engine
Aircraft yaws to right
Apply left rudder pedal
Rudder moves left
Yaw is controlled
Controllability depends on sp
of aircraft
CDEEP
IIT BOMBAY
NPTEL



So he is just reading out what is written there, so if you cannot hear you just read what is written there, so say a flight, normal flight, both engines producing thrust, everything is ok, in this case one engine conks off. So if you are on the ground when this thing happens you can control by just the gear, but you are still on the ground, ok.

So when you are on the ground and if you are just in the beginning if there is one engine failure, then rudder is not effective because the speed is not very large, so the aerodynamic force is very poor, so you control only using the nose wheel steering but later on when rudders become sufficiently powerful because of the wind speeds then you can do it.

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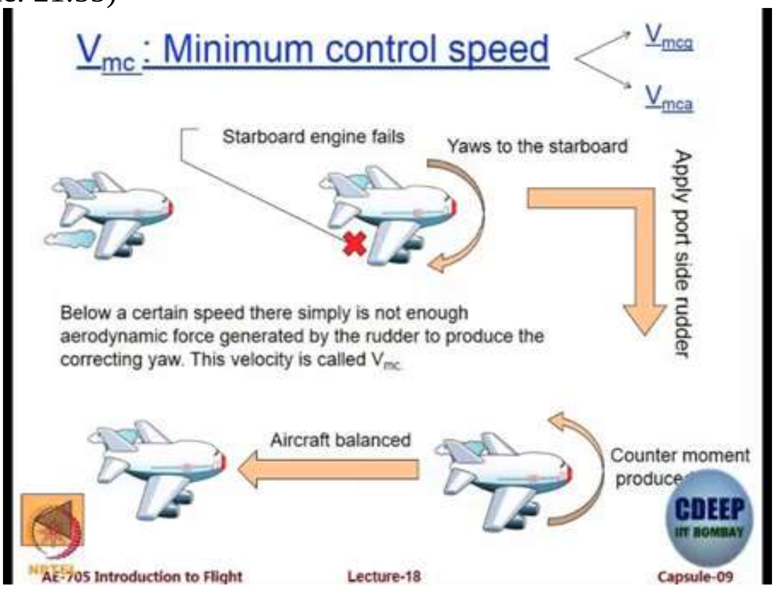

So the same thing is shown through this animation sequence, so you have an aircraft which is flying and now the star board engine fails, so therefore the aircraft is going to yaw toward the star board side, so what you do is you apply the rudder and produce the counter moment rudder is not shown in the animation but you can assume that there is a rudder on the back which is applied, and this aircraft is going to give you balance, now there is some minimum, there is some speed, lowest speed at which the rudder is sufficiently powerful to overcome the imbalance created by one engine non-functional. So this is, the definition is only for one engine not working.

Suppose you have four engines, you do not say two are not working, no, the V mc is defined only for a condition where one engine failure, it could be any engine but obviously the most critical is the outermost engine. So if one engine of a multiple engine aircraft fails, the minimum speed at which the rudder is powerful enough at full deflection to overcome the moment that speed is called as the V minimum control speed.

So what is the significance of this particular speed, why should the pilot know what is the V mc? What do you think, why should the pilot know the value of V mc? And it will not remain same, correct, it will depend upon the altitude, winds, density, temperature, centre of gravity, it will it depend upon CG or not?

It will because the moment arm from the rudder depends upon where the CG is. If the CG is too much behind, see the aircraft CG has to be within some forward and backward limit, suppose it is at the backward limit, rudder is less effective. Suppose it is at the forward limit, rudder is more effective. So the flight dispatcher knows how much weight has been added in which passenger bay or cargo bay. That person also knows how many passengers are there and what is the distribution of seats. So that person actually calculates the likely or expected CG position of the aircraft and tells the pilot, CG is here within this range, hence your V mc will be so much.

So it is a very simple thing, it has to be done using calculation, ok. So but why should the pilot know? Because if the pilot detects engine failure below this speed rudder will not help, so pilot should know rudder will not help I have to use other means or maybe I have to abort the takeoff.

Obviously if an engine failure occurs at a speed below V mc it will be foolish for you to continue because you know that you can't control it, still you are continuing that will be disasterous.