NOC: Introduction to Airplane Performance
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Lecture - 37
Revision

Good morning dear friends, so it had been a long, long session for us. We have covered starting from drag polar, cruise, climb, take off, landing, endurance, range, so many things we have covered. I think, now it is a right time to give you halt and very actively discuss few things, which I used to have lots of confusion and that is why today's Maan Ki Baat will be very, very special in nature.

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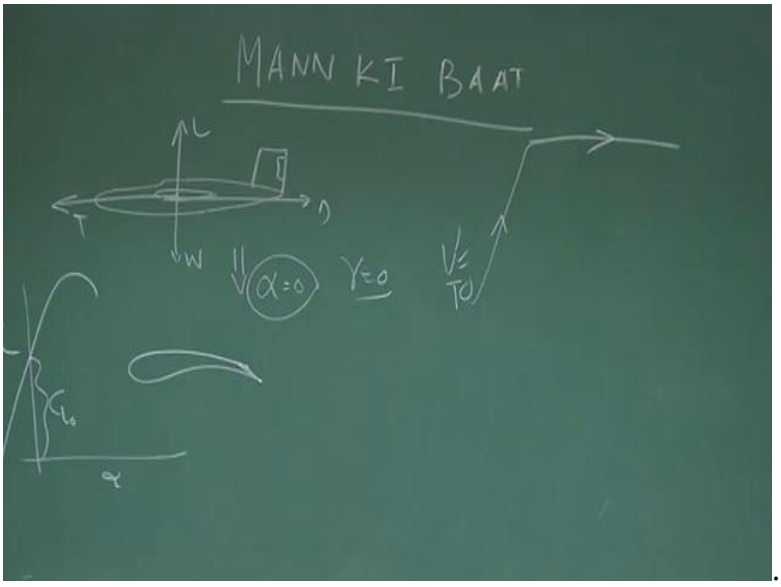

We will be very frank in asking questions, since there is no direct interaction, so I have tried to simulate my good olden childhood days or young days or younger days, when I used to have many questions, whether it was first year of B.Tech here or it was class 11th in my school or around that period. The first thing came to my mind was a diagram, which every time we were drawing thrust equal to drag, lift equal to weight. You are now by now over saturated with this statement that, this is typically a level unaccelerated flight, which is referred to us cruise flight.

But, I recall my days, when my professor is to write like this, many times I is to get a feeling that as if this is flying at alpha equal to 0. It is to give me an impression that as if

it is flying at alpha equal to 0, this diagram is so dissipative. But, I am sure you are not committing that mistake, you are much smarter than me, you are young people, much younger people, I am sure you are not committing that mistake.

This diagram no were represent alpha equal to 0, because anyway we need to have a lift, this only tells you about a gamma equal to 0. One of you make counter it, it is telling, what is the problems are, even with alpha equal to 0, I can fly, because I can use a cambered aerofoil and at alpha equal to 0, I am able to generate lift. So, what is the problem; that is fine, the statement is fine, but this diagram does not tell you anything about alpha.

But, for understanding is, we are flying at a small angle of attack; it only talks about gamma equal to 0. Then, second question, which is much before class 11th and remember class 7th or 8th, if somewhere in some book how an airplane fly, reading through book called tell me why you are something like that. So, there also I have seen, though I did not understand at all those days, you thrust balances the drag and lift balances the weight. Then, I used to think, if the forces are balanced, how it is having velocity.

Let us now forget that, when we were given education, if this question was asked, state Newton's laws of motion, first law of motion and we will immediately stand up and say everybody continues in it is inertia of motion or inertia of rest unless, it is acted upon by external force and that is all. We thought, we have understood Newton's law, it was late, much later realized the meaning of external force, understood the meaning of inertia of motion or inertia of rest.

So, this is typically an example, when airplane starts with V equal to 0, it climb is V equal to V take off, it climbs and it finally, accelerates to a speed, at that speed when it is in motion, all the forces are balanced. So, by Newton's first law, it should continue to stay in a motion and that is why, it is moving in a constant speed. It may look funny to all of you, but unfortunately that was where I used to think, I must share through this session of interaction, whatever doubts I is to have, it may help, if not you, it will help me.

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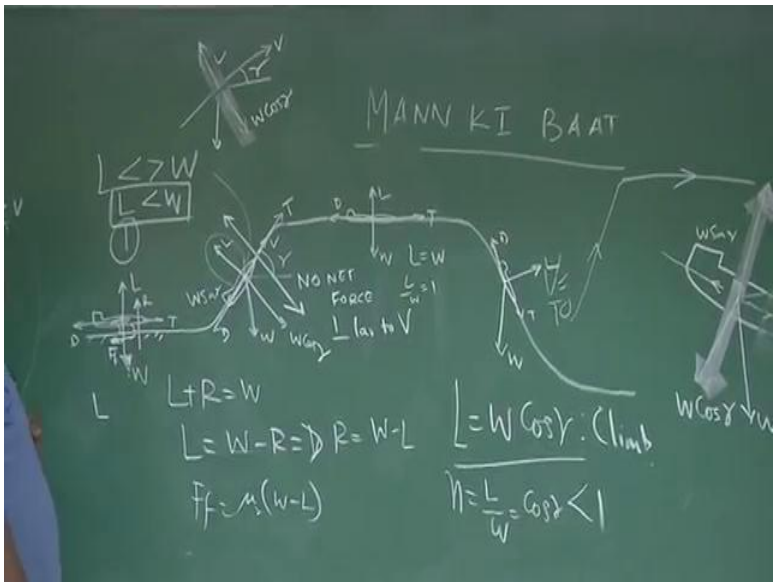

This is the second part, which I was again revisiting my notes and you could see, this is the typical representation, this is the wing, this is the tail here, it is a landing gear. Typically, during this phase, we have lift here; we also have weight here, some reaction R, thrust and drag. We know by now that, it has to accelerate from V equal to 0 to V take off, then it will do a rotation for 3 second, transition climb and clears that screen height.

So, when it goes for a climb, this is V, this is W and this is lift and of course, there is a drag and there is a thrust. If I draw here in the cruise phase, we also have similar diagram, here is a thrust, here is a drag, there is a weight, there is a lift. And when I am trying for landing, then the diagram is something like this. This is W, this is lift, this is drag, lift, drag and off course, if you put thrust, thrust is put to very minimal. That is basically the representation of lift, drag, weight and thrust.

Now, let us try to visualise here, here if I see clearly that, because of lift and weight, there is a reaction experienced by the surface and in turn it gives you a reaction as per Newton's third law. Action and reactions are equal, but the catch point is, they act on different bodies; that is action, if it is on my this hand, right hand, the reaction will be on my left hand.

Similarly, the weight gives action on this surface, which acts on this surface, reaction acts on the aircraft and they are equal as per Newton's third law. And you also know by now, because it is moving like this, because of friction, there will be a frictional force.

This frictional force and a wheel moving itself is an interesting area to read and understand. I will request you, please try to understand, when I ride a bicycle, what happens, what are the direction of frictional force and that will be really interesting and I never did all those things.

That is why I took long, long time to understand, what become basic, things, which we should create a sense of enquiry in mean that never happened, but you people are different, you people are younger generation for you. Every time, you ask a question why, for our generation, we never had the liberty to ask why, do it, we have to do it; that is all, but you are different, you have a different time, different training.

So, my always request to you, please read basic things, try to understand, how you walk, what is the role of friction, how a cycle tyre rolls on the ground, how a bicycle moves, how the direction of friction changes. These are the basic things, which you should be able to appreciate, how a lever work, these are the opportunity, these are the time, when you should try to read. Nowadays, you have a Google engines, so many things you have, but ensure there that character is built in you, why.

So, here if I see in the first phase, while going for a take off, I write L plus R equal to W or lift is W minus R and you are expert that, this implies R equal to W minus L and frictional force is mu into W minus L. So, L plus R is W fine, L equal to W minus R, frictional mu into R; that is W minus L. Now, you could see one thing, if you make lift and weight are equal in this phase, what will happen, the moment you make W and L or lift equal to weight, frictional force will become 0.

Now, imagine if the friction on the ground is 0, can you walk, if the friction is 0, can the wheel rotate; that is why I am telling you, please try to read all those things from bicycle, how a bicycle moves. So, definitely here lift is not equal to weight as simple as that. Moreover, you should also understand, that I want to have a grip on the airstrip, so that my wheels move, otherwise steering will be extremely difficult by the pilot.

So, this we all agree by simple common sense that lift is less than or greater than weight, if I ask and definitely lift is less than weight. What is the charter here, the charter is the airplane should go in a straight line like this. But at the same time, you know, if I want to fly like this, I have some angle of attack, small which we have not shown here; that lift is

coming because of that angle of attack. So, if it is going like this, you also know that, the lift is perpendicular to speed or velocity.

So, what happens, if there is a body which is given a velocity V and it is pulled by a force F or say T, what sort of motion this will experience, we all know this will experience a curved path, which will result in centripetal acceleration. That is, it will no more stay in a rectilinear flight, this is okay or not, I repeat here again the force F or T in this case which is applied perpendicular to V. This we are expert by now, this will cause a motion which will give centripetal acceleration and the velocity vector will go on changing like this, so it will no more stay in a rectilinear path.

But, what is our aim here, our aim is not to fly like his during climb, no, our aim is what, we should go for straight rectilinear flight; that means, this gentleman lift has to be balanced; that means, there should be no net force, no net force perpendicular to V. This is clear, if there is no net force perpendicular to V, then there would not be any curve, it will go in a rectilinear motion.

How do I do that? So, I generate lift such a way, I take the component of W. So, one component is W cos gamma by now gamma you understand flight path angle and there is a component W sine gamma. So, I generate lift that much only which is equal to W cos gamma. So, I generate lift and this is a weight and this is W cos gamma and this is gamma. If I and this is velocity vector, if I and this is lift, if I want that net force perpendicular to V is 0. So, I generate that much of lift which is equal to W cos gamma.

So, I write here L during climb, L equal to W cos gamma, which is climb and that is why; we say the load factor during climb is less than 1, load factor is n, which is L by W, in this case, it becomes cos gamma. So, it is less than 1, for gamma to be greater than 0, very simple. This also tells us that, the induced drag during climb will be less compared to the cruise, because now you require lesser lift, because you want to balance lift equal to W cos gamma not lift equal to W.

Why, we have chosen this component, because that I know that, this is a rectilinear motion it has to go, if I want that it should go in this motion, I should ensure that any force perpendicular to V, there should not be any component as simple as that. Now, come back to the cruise, this is the cruise, cruise is very simple carries L equal to W and

you could see that L by W is 1. When, you say load factor is 1 or we generally we use 1 g load factor.

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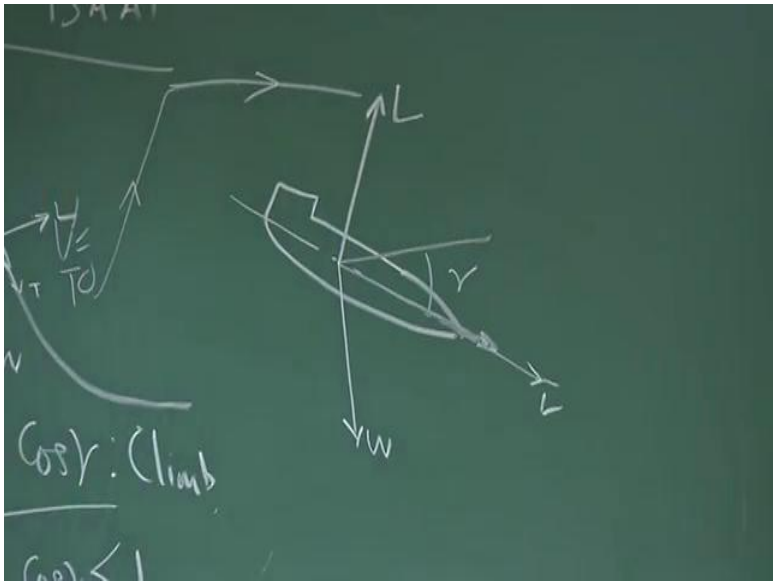

What happens here, let us see in this case, let me draw it separately, this is V, this is your gamma, this is the L, this is W. What is my aim, my aim is again as it was here, this aircraft has to go in a rectilinear motion or the C G of this airplane has to move in a rectilinear motion.

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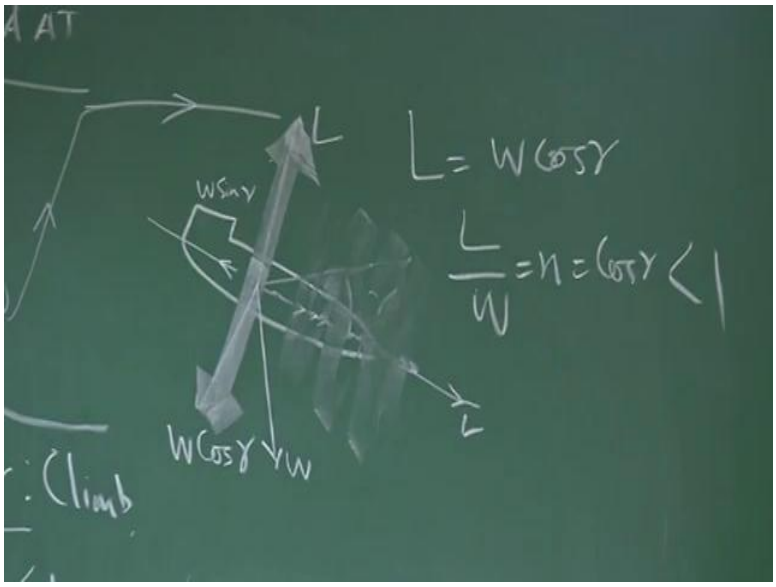

That means, if this is the velocity direction I do not want any force perpendicular, any component of force perpendicular to V. So, what is the best, what is the force, possible force perpendicular to V in this diagram, weight is there. So, W again cos gamma and of course another is W sine gamma R. So, this lift should be sufficient enough, just sufficient enough to balance W cos gamma.

So, you have again lift equal to W cos gamma and you could see L by W equal to n equal to cos gamma is less than 1 for gamma to be non-zero. What is the message; message is, please understand that, when I am trying to fly in a rectilinear straight line flight, if I have unbalanced force perpendicular to V, then it will go for a curved path, this way or that way. And that is how, I set what is the lift required, what is the drag required, all drag means the moment you balance lift equal to W cos gamma, you know, it will give induced drag from there drag also gets modified.

So, this is the basic of flying, you need to keep this back of your mind, what are you doing, all those phases, I am trying to fly at a rectilinear motion. And I should be able to visualize, if I close my eyes, how the airplane is going, what is the angle and how it is able to achieve all this manoeuvres. If I now ask you a question, it was going like this, it has to turn like this.

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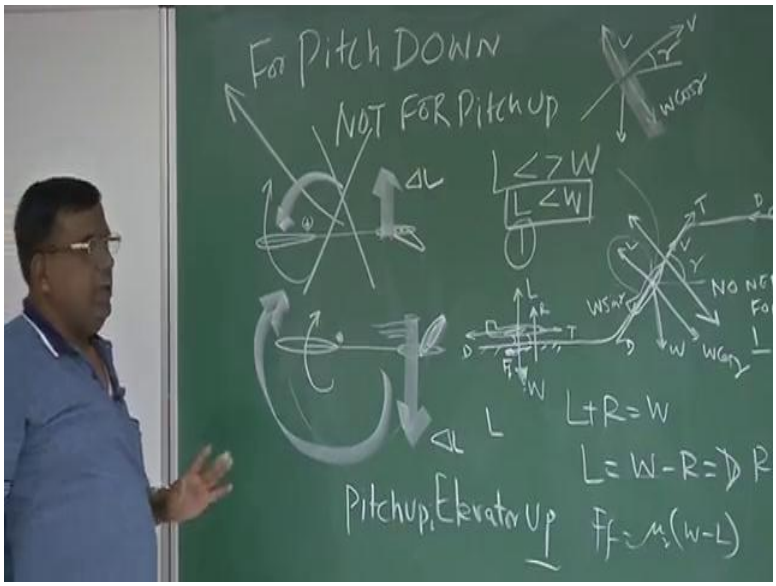

So, what he does, if this is your airplane, this is tail, if he wants to switch of like this, he has to put the elevator down. If he puts the elevator down what happens, then force is

here additional force that will do what; that will give nose down moment. So, generally there is a ((Refer Time: 18:18)) among the youngsters, if I want to pitch up, I put the elevator down, no, if I want to pitch up, what I have to do, I have to this is the wing, this is the tail. If and C G is here, if I want to really pitch up, I have to put this elevator up.

Elevator up means, the moment elevator is up, remember, even without any aerodynamics George Cayley, this will experience a force downward direction and this downward direction delta lift will give a moment nose up. So, for pitch up, we call it pitch means, the angle of the between the axis of the airplane and the horizontal. So, for pitch up, elevator up and as per the convention, so this is not for pitch up, I cut it, not for pitch up. Then, what is this for, this is for pitch down, this part is clear as far elevator moment is concerned.

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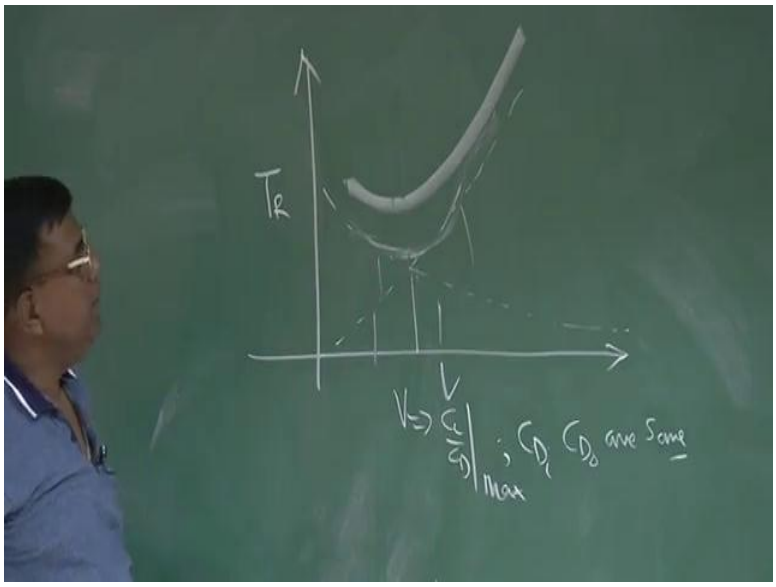

Before, I continue a discussion; I want to mention one drawing of figure, which I have drawn, which is not strictly to the scale. See, if you check I have drawn thrust required power and while discussion, we were talking this about induced thrust and this is the parasite thrust. At this point, where V is for C L by C D max, we know that C D I and C D naught are same.

So, this graph actually if I correctly draw it should like this to be on the scale, because this two graph, you know they get added up, you know at every point, this is summation of this two variation. So, here both are equal. So, this should be doubled up not exactly

here. So, this correction you should by I am sure you have understood this and you have taken it as it is supposed to take.

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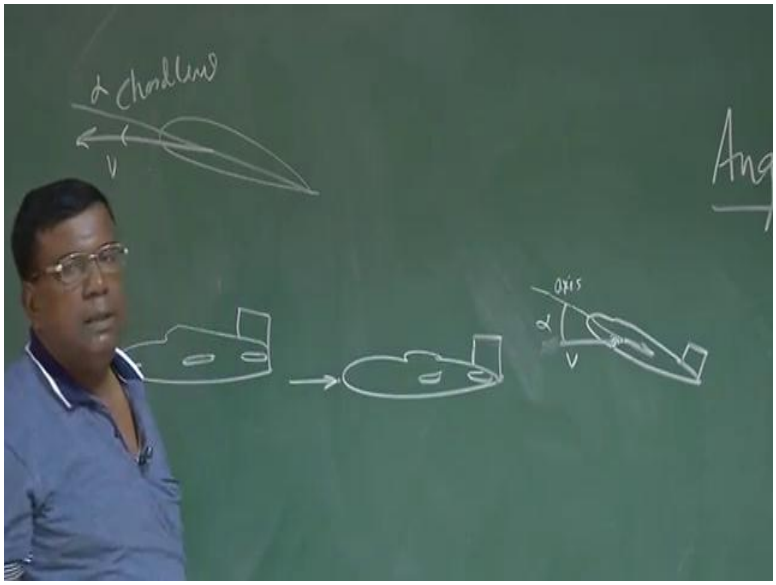

This is another important thing when you talk about; I thought of hearing angle of attack. We know that the angle of attack is the angle between the chord line and the velocity vector. It is a chord line and this is the velocity vector, so this is the angle. So, we write like this, so this is the chord line and this is the velocity vector, this is the alpha. In our representation, we have mostly use relative airspeed; that is actually the airplane is moving in this direction.

But, relative to air, when you are representing, then we are showing it like this, as if the airplane is stationary and the air is rushing on the airplane, this is one representation. And regarding angle of attack, we will see that, let us say the airplane is moving with some angle of attack, let say this is and this is the velocity vector. So, what I will do, if I want to represent in terms of relative air, I will not draw like this, I will draw it like this and this is the axis or chord axis. So, this is my alpha, this is one way to represent.

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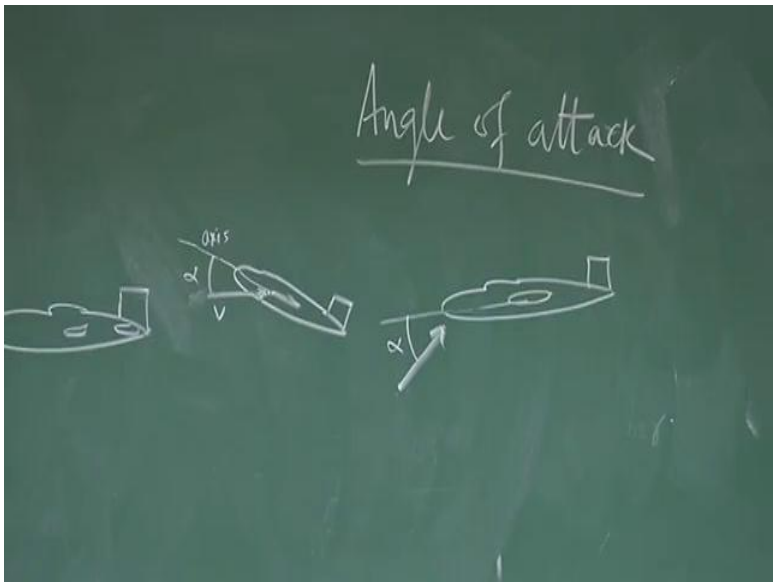

Another way to represent is to keep the aircraft like this and show the velocity vector air relative velocity vector to be like this and define this angle of attack all are equivalent I have to understand.

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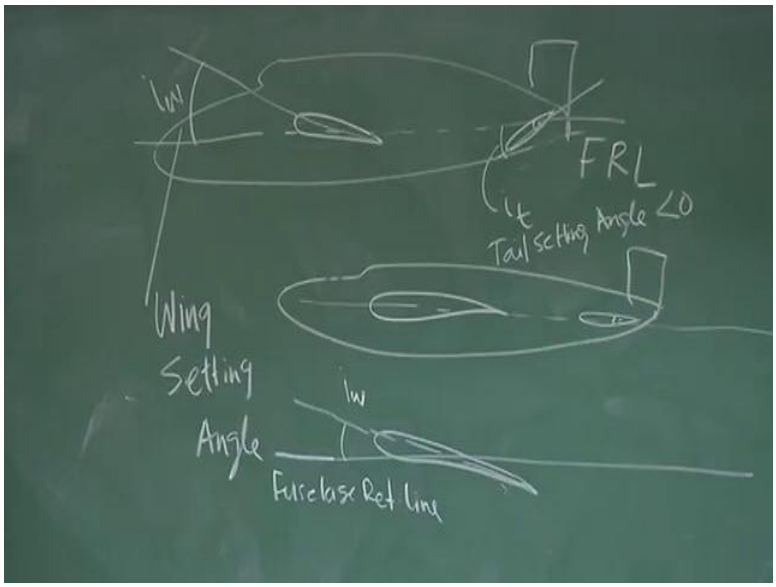

There is another interesting which you will see, if you come near an aircraft, if this is the central line, you will find the wing could be installed on the central line like this or it could also be installed like this. That is a chord line is making some angle with the fuselage reference line, you understand what I am saying. Suppose this is the airplane

and let us say this is the central line or fuselage reference line, in this case, this was mounted like this and in this case, it is actually mounted like this.

And this angle, angle between the chord line and the fuselage reference line nomenclatured as I W as far as symbol is concerned and this is also called wing setting angle. This is also called wing setting angle, once wing is set as per design, it is not that you are going on changing the wing; you are not allowed to play around with wing. Even, during the wing opening for maintenance, it is a very, very herculean task, very precise and very discipline task, because after all wing is the main friend of us, who gives the lift.

But, the question comes, what is a need of this, of course, immediately you will tell; now if airplane goes straight, still it will get a lift. So, good and somebody will advocate, if I have a combination like this, where wing setting angle is not there. Then, to generate angle of attack at the wing, I have to move whole airplane like this, for this case, whole airplane has to have some angle, in that process, the fuselage also will give more drag.

But, in this case, fuselage is straight, passengers are straight, but wing is only producing the lift without really rotating the airplane. So, we will have this justification, but the point is, for most of the cruise fly, the angle of attack required is so less. It is hardly 1 or 2 degrees actually aircraft when it is operating at a optimal altitude and correct cruise speed, this has not taken the you know dominating factor in aircraft design, depending upon situation, you can do, you can give some setting angle you may not give.

So, there are much other issues which has to be handled, I will try to address those things in a very friendly manner, without going into complex aerodynamics and all. So, this also you should not start building thought process in your mind, it is not necessary all the time wing will be like this, wing maybe set at a setting angle. Similarly, we will see soon that, this tail almost all aircraft will find, the tail is not set like this; tail is actually set like this. That is I call it IT tail, setting angle and which is negative less than 0 minus 2 degree minus 3 degrees.

You will understand, why this is a required, but I thought I have since you have not seen the aircraft closely enough. So, little modify your imagination about an aircraft wing how it is mounted etcetera, etcetera. Now, let us also ask a basic question, wind in flight, how the forces are trying to balance the very informal way.

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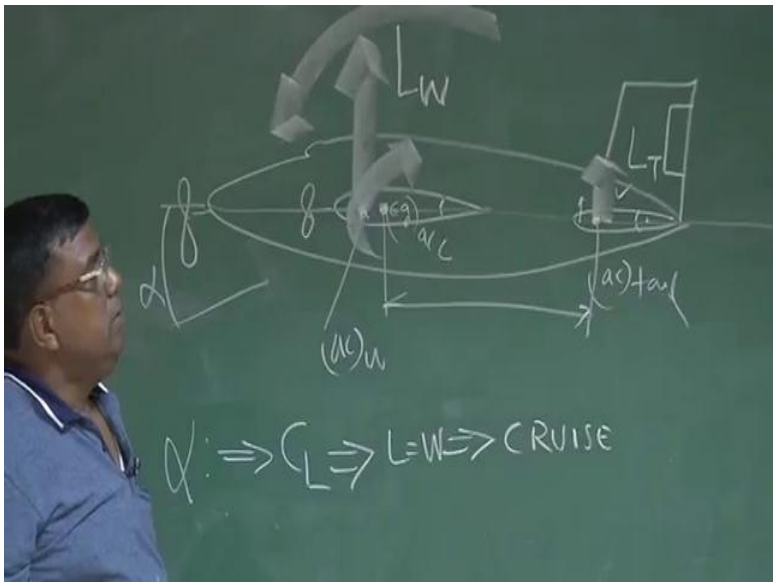

Let us say, this is a fuselage, this is the vertical tail, stabilizer or rudder, this is horizontal stabilizer part of it elevator and let say, this is the wing and somewhere here or here. There could be engine, running here or whenever we are trying to talk about aircraft in flight this very important parameter is centre of gravity. You will understand why that is important in subsequent lecture, but I can tell you that has importance in from the point of view of stability of the airplane, I will stop it here.

Now, let us see, there is let say C G is somewhere here C G of the whole aircraft and let say a c of wings is ahead of C G. Similarly, let say a c is here, a c of tail. So, for time being neglect fuselage effect as far as lift is concerned, we are trying to see the lift effect. Forget about fuselage; think that fuselage is not giving much of a lift. That an angle of attack you could see the wing will generate lift, I call it lift on wing, it will also give drag, I am not drawing that drag, I am telling you that, we are trying to see something through lift.

Similarly, lift on the tail, will be here, this suppose it is flying at some angle of attack alpha. For which lift equal to weight; that is I am cruising, it is that alpha for which I have appropriate C L, which ensure that, lift equal to weight and that is the cruise flight, I am considering that. So, far I was telling assume that all the moments are balanced. So, let us try to see, how it could be done, you know in free space, free air or atmosphere,

everybody tries to rotate about axis of a least moment of inertia, which is passing through centre of gravity.

So, we said if I rotate like this, it is rotate about an axis passing through C G. So, this is the centre of gravity. So, this lift will give what, will gave a nose up moment about C G, no objection. What about this man will do tail, tail will give nose down moment. If you want net moment is 0, I am neglecting fuselage effect, then you have to ensure that for the given distance, which is fixed from C G here to tail aerodynamic centre, I must produce enough tail force to balance this moment.

So, now can you tell me, what type of deflection I should make on the elevator, suppose the moment is not balanced, what type of force I should generate, I should generate additional force.

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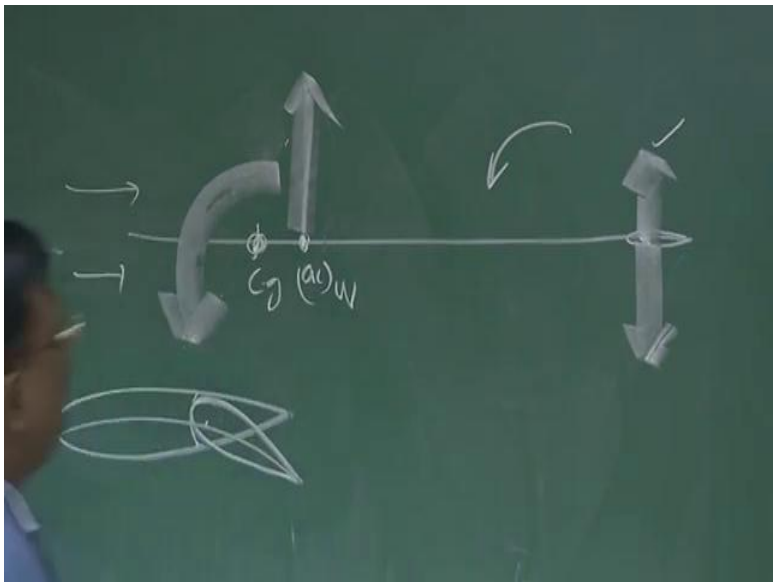

In this direction, which is here to generate this force, which way I should deflect the elevator down or up, remember, if this is aerofoil and if I deflect this downward, the cambered increases. So, lift increases, C L increases, C L. So, lift increases, remember that; that means, here also we will deflect the elevator downward. Such that, this force is good enough to balance this moment, what is this moment, this moment was caused by the lift on the wing and we have assumed a c of the wing is ahead of C G.

But, if there are planes, where a c of the wing, so this is C G let say a c of the wing is behind C G, I am moving in this direction and here, there is a tail. Then, if there is a angle of attack, if there is a lift, then force will be here. Now, a c of the wing is behind, so this lift force will give a nose down moment. To ensure that this moment is neutralized or nullified, I need to deflect elevator up or down. I know one thing to this a nose down moment, so I have to generate a nose up moment.

And nose up moment would be done, if I give a force up or down, which one, see, if I am giving a generating this force, this will give a nose down moment, but that will not nullify it. So, I will repeat, if I generate a nose up force from the tail, it will give a nose down moment and nose down moment means, this is not going to nullify this, because wing is already giving nose down moment, I want a nose up moment. So, I will not go by this configuration, I will say I need to generate a force downward.

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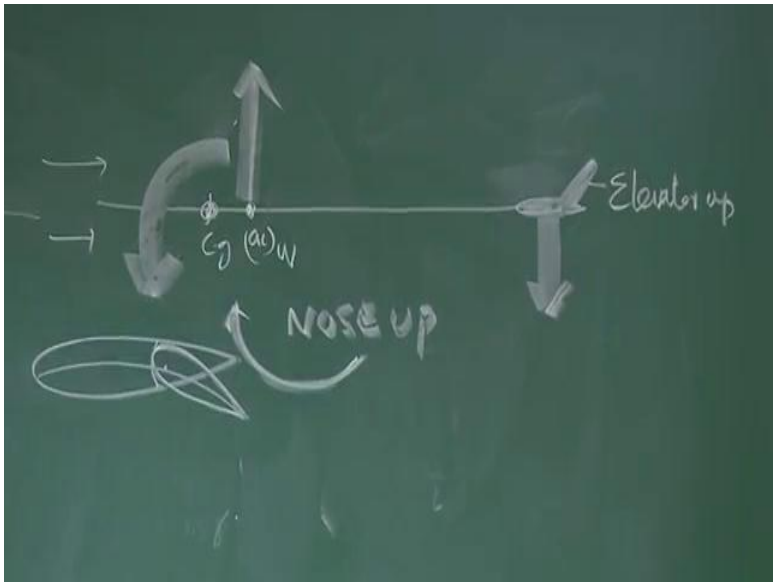

This downward force about C G will give a nose up moment, because C G is here, how do I get that downward force at that tail, should I put the elevator down or up. Obviously, by now your expert, I should put the elevator up. This is the tail elevator up that will generate the downward force and I should be able to balance the moment and in an aeronautical term, we call we are in a position to trim the airplane. So, this I wanted you, so many things we have learnt, but let us see how these forces are utilized to make sure airplane flies.

Thank you very much.