NOC: Introduction to Airplane Performance

Prof. A. K. Ghosh
Department of Aerospace Engineering
Indian Institute of Technology, Kanpur

Lecture - 07
Revision

Good morning students, I hope you have good session in the first week. I was also going through these lectures and I have few questions in my mind. Incidentally, we are all aware our prime minister occasionally or regularly to be more precise announces a program called Mann Ki Baat. And in that, he tries to share his feeling about, what is happening in and around this world and more specifically, what is happening in this country.

I also thought, let me also see all these lectures for last one week and let me share with you my Mann Ki Baat and the success will be decided by the answer, where whether my Mann Ki Baat has become your Mann Ki Baat or not, right.

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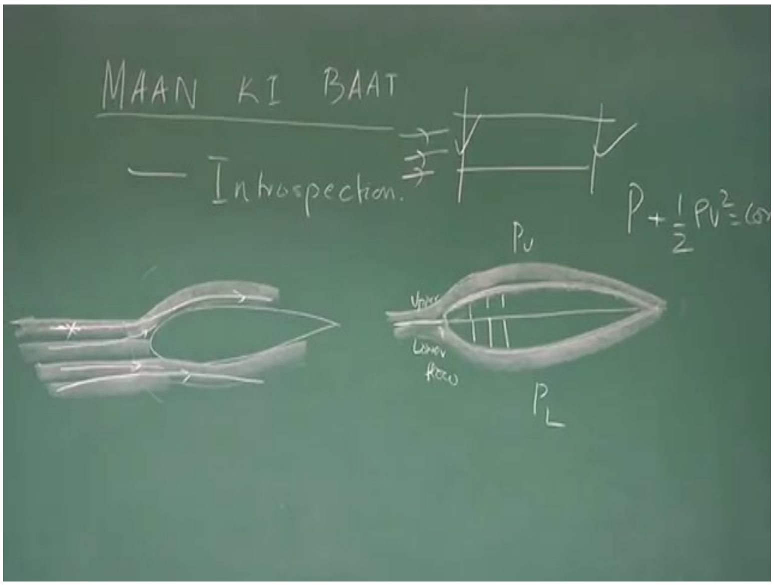

So, I give this title Mann Ki Baat and it’s basically introspection, we will try to revisit, whatever we have studied in the first week and this will be a routine feature. The new week will start with the Mann Ki Baat, where we revisit whatever we have discussed and whatever I feel, that is these are the points where I should be more specific, I should give more stress. These are the area which I should not give you too much of stress at this time.

Because, we are going on pumping information to you and we do not have any eye contact with you. I do not get a feedback, whether I am able to communicate or not. So, it is better that we follow this practice and try to crystallize the basic foundation before we take off, right. If you go in the first session, you will find we have defined something called aerofoil and we have realized that aerofoil is basically a 2D concept that is it has a contour with an infinite span.

The basic message here is that, we are restricting the flow to go in this cross section. There are no cross flows, this way or this way; that means, the flow will be more characterized by the contour of this aerofoil, that is if this is the aerofoil, then the contour of the wing and the flow over the wing will be decided by this contour and there won't be any lateral flow or cross flows, right. In that we define something called streamline, we din't define streamline, we want to define the streamline in a little bit of explicit manner, without going much into the details.

What actually happens? Suppose the fluid flow is coming like this, what happens here? Here some fluid will go like this, some will go like this, right and this flow over this surface, both these surfaces will decide, what is the pressure difference, ok? Now, the question comes, why at all there should be a pressure difference? This question we need to ask, we need to understand little more and we will be addressing that part.

First, if I want to represent this flow, which direction the flow is going. One of the ways is to define streamline. What is the streamline? You imagine those points in this flow and if I draw tangent at this point, that should give me the direction of the flow. So, this becomes your streamline, ok, that is another streamline that is any points you pick draw a tangent that should give you direction of the flow. This helps in visualising, it helps in modelling, ok.

So, you can write like this, so many streamlines will be going like this. Infinite streamline I can draw, right?, because these are fictitious line. This only helps, to understand to represent the direction of flow, nothing more than that, ok. However, this concept will find aerodynamicist have used in developing analytical model of relevance to understand, what is the forces, how the force is acting, what will be the force behaviour with the orientation of the aerofoil, etcetera, etcetera, right?.

Forgetting about streamline and all, if I draw a symmetric aerofoil, symmetric we have defined that this distance from the chord line, they are same. Though, it is really not drawn properly, but I hope you understand, by now what is a symmetric aerofoil. What will happen without going into aerodynamics or anything very specialized? By natural justice we find, the half of the flow will go like this and half of the flow will go like this.

Because, one of the, this half over a particular line flow will have a direction like this, the other part will flow go like this. So, there will be another line where the flow will be just like that, there would not be any flow at that direction. So, it separates lower as well as upper flow, this part separates upper and lower flow, I am not using any aerodynamic term. So, now see one thing, if it is symmetric aerofoil; that means, from here to here and from here to here.

If I measure there length they will be same; that means, the flow over this, if we remain attach, it will travel from here to here. Flow here will travel from here to here and they will travel equal distance ok and this is another law of justice or natural law, is that whatever fluid is coming here, they have to come out. They cannot get stagnated at one point, they cannot get accumulated at one point which we call the continuity of the fluid particle motion, right ?.

That is if you try to draw a pipe, if I allow fluid to flow through the pipe, I know that whatever is going here has to come out, ok. If that is true; that means, if they are travelling equal distance, upper portion as well as lower portion; that means, they will have same average velocity. And if the velocity, average velocity is same; that means, the pressure here and pressure lower has to be same, because you know Bernoulli's p plus half rho v square has to be constant, right.

$$P + \frac{1}{2}\rho V^2 = constant$$

And since, both are having same average velocity, so the pressure remains same. So, the pressure, upper pressure lower will be same and hence there would not be any lift, this is one of the explanations, ok. There are many explanations and the explanations are designed or formulated to suit mathematical modelling. So, you see there are many ways of defining this, other than what I am explaining here. This is using a very fundamental common sense, ok.

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Now, think of, if this same symmetric aerofoil is at an angle of attack alpha (α). Now, the question comes, what is the angle of attack? To understand what is the angle of attack, again revisit. If this is the plate ((Refer Time: 09:23)) and if this is the velocity direction, I am concentrating on the vertical plane and in vertical plane, whatever the angle between this velocity vector and the chord of the wing is called an angle of attack, ok.

Now, what happens if I try to visualize like this? What you could see that, flow will something go like this and some flow will go like this, what is the difference between this picture and this picture ((Refer Time: 09:59)). Now, you could see that the upper part of this fluid, they will be travelling more distance than the lower fluid. Am I correct? This is going like this, so it will be traversing larger distance than this fluid particle.

However, because of continuity, whatever has entered here has to come, at the same time that is fluid particle all will come at a same time here, that also tells us since this is to travel larger distance. The average velocity here has to be greater than the average velocity lower or I call it upper. Is this clear?

$$V_{av_{upper}} > V_{av_{lower}}$$

If it is at angle of attack, now I could see this fluid stream has to traverse larger distance compared to the lower part of the fluid.

However, all the fluid has to come at same time; that means, the upper part has to hurry up, because larger distance. I say the average velocity of the top surface will be higher compared to the lower surface. And if upper part speed is higher and we know that p plus half e v square is constant, $\left(P + \frac{1}{2}\rho V^2 = constant\right)$ that is the Bernoulli's theorem. So, if this man is higher; that means, this man has to go down, if this increases this has to go down, that is why the pressure here reduces.

Pressure upper now goes down compared to pressure lower or I say pressure lower is greater than pressure upper, so there is a lift. $(P_L > P_U \Rightarrow LIFT)$Is this clear, ok? I have purposely avoided technical term, which an aerodynamicist will use, they will define something called stagnation point, I am not using those things, right , ok. Then, we were discussing about cambered aerofoil.

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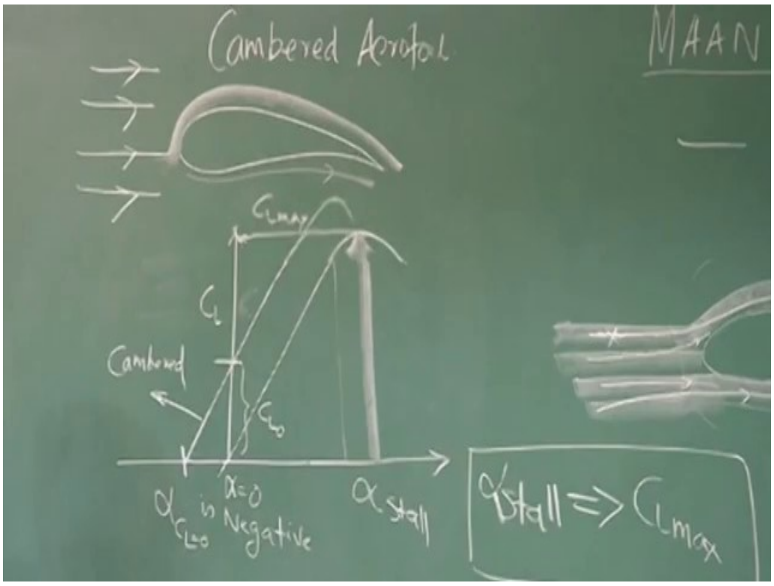

And now that symmetry has been broken. Now, what happens? You could see here, from this geometry if the flow is coming like this, this part has to have higher speed compared to the lower part. Same theory will apply here and we will have pressure difference and we will have lift, ok. We also realize that if I plot CL versus alpha, for a symmetric aerofoil up to certain point it is linear and after we call it here. Strictly speaking we call it CL max that is the maximum CL, this wing or this aerofoil can generate.

And after that they drop in CL, increasing drag and that area we call stall. So, conventionally we call this angle, at which the flow separates we call alpha stall (α_{stall}). So, this two important term, one is alpha stall, but you could see also at alpha stall CL is C L maximum; that means, if you further increase the angle of attack beyond this alpha stall, you will not get additional CL $\left(\alpha_{stall} \Rightarrow C_{L_{Max}}\right)$. In fact, CL will reduce, this is a additional thing we should also understand.

And for a cambered aerofoil, we will find this graph is no more like this. It is like this, where at this I write cambered and see at alpha equal to 0. For a symmetric case, CL was 0, but for cambered there is a positive value which is called denoted as CL0 and if I extrapolate this point you find here, alpha for CL equal to 0 and which is negative. You could see here if I am flying at this alpha, then the CL is 0 and this alpha is negative, right, ok.

This is very important, which is also denoted as alpha 0 in many text book you find like that. For cambered aerofoil, I get larger CL at smaller geometry angle of attack, but at the cost of what the alpha stall reduces. So, although we are getting this C L mode; however, alpha stall will reduce.

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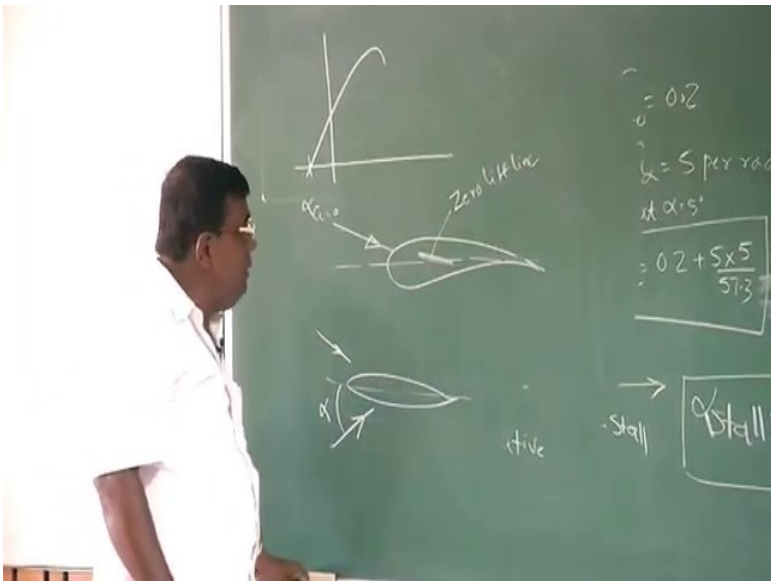

If this is a cambered aerofoil and this is alpha for CL equal to 0, which is negative and if I draw a cambered aerofoil, I know, I know there is a zero lift line that is, it is called zero lift line. That means, if the flow comes like this that is, at a negative angle of attack. How much corresponding to this alpha CL? If the flow comes like this, then there would not be any CL generated by the cambered aerofoil. In flight mechanics, we use this concept more frequently when we are discussing about stability and control.

I repeat this, this you could see that, this is a negative angle of attack, because positive angle of attack is... But, this when a flow is coming like this, this is positive angle of attack. When I draw like this, it is a relative air. The airplane is actually going like this, ok, ok , but negative will be in the reverse direction, that is why this is negative angle of attack, ok. So, this was what we discussed or we create a foundation, I am trying to add little bit of more inside into it, so that our next lectures become very smooth. After this from aerofoil, then we will try to talk about wing and we talk about finite wing

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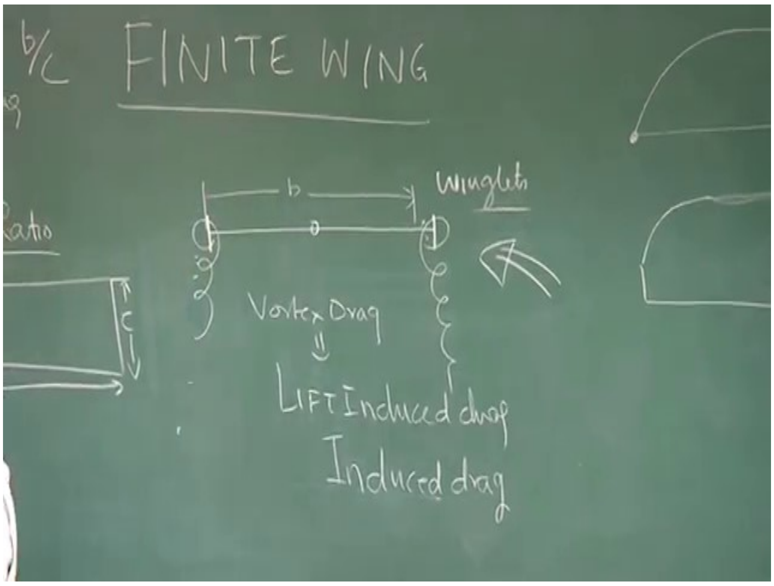

We talk about finite wing and we realize finite wing means, ((Refer Time: 17:37)) this span is not infinite, it is finite. So, at the tip of the wing here, because there is a pressure difference in the bottom and the top, there will be vortices or they will draw kinetic energy, rotational kinetic energy at the cost of the machine energy. So, there is a drag and we call a vortex drag. So, if I draw it like this, something like this.

So, this is vortex drag, it is also called lift induced drag or sometime simply induced drag. And we realize that, if this span which is this b becomes infinity, then this vortex drag will not be there, because there would not be any physical pressure difference. So, the vortex drag or induced drag will be zero and that is like, you are approaching towards an aerofoil, which is two dimensional and there we define something called aspect ratio.

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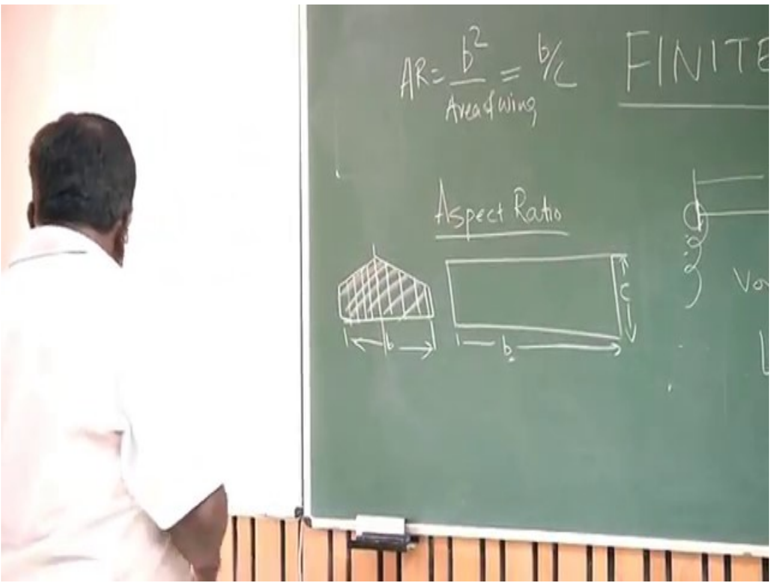

And we define aspect ratio as, if this is the span and if this is a chord, then aspect ratio was defined as b square by area of wing that is the aspect ratio of the wing. If I want to calculate aspect ratio of the tail, then span square tail span square by area of the tail.

$$AR_{wing} = \frac{b_{wing}^2}{S_{wing}}$$

$$AR_{tail} = \frac{b_{tail}^2}{S_{tail}}$$

For a rectangular wing it becomes b by c; however, if the wing is something like this, then actually you have to find out the area of the wing, which will be here and span square divided by area of the wing will become your aspect ratio. Then, it will not be b by c, because c is changing, chord at every point is changing.

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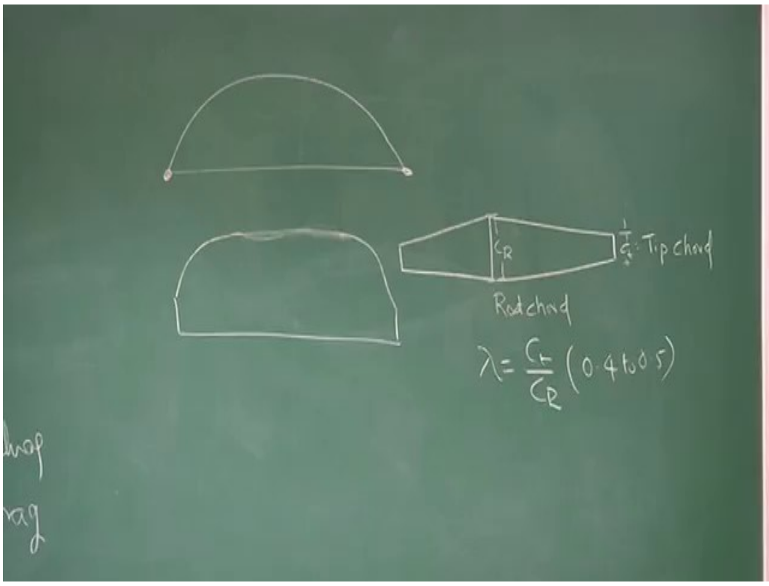

While discussing the induced drag, we very lightly mentioned something about lift distribution. We talked about elliptic lift distribution, where the induced drag will be minimum and the lift distribution was typically something like this, where if you see here, there are no pressure differences. But, in actual practice what will happen, it maybe something like this. The best way of course I should not draw it something like this, but it may change, it will not be elliptical.

The best way to approach towards elliptical distribution is that, you give the wing this sort of a configuration, where I call this as Ct, which is the tip chord and this I define as Cr, which is the root chord and I define taper ratio as Ct by Cr.

$$Taper\ Ratio = \frac{C_t}{C_r}$$

And if I keep this value 0.4 to 0.5, for all practical purpose I am approaching towards elliptic distribution not elliptic, but it is towards elliptic distribution, ok, that you could see that we are making here the area less. So, we are discouraging the lift at the tip.

But, let us come back here ((Refer Time: 21:58)), as a designer I would like to reduce this effect. So, what do I do? One of the most popular way of doing it is, we know that ((Refer Time: 22:14)) because of the pressure difference, physical pressure difference between bottom and the top surface, there is a flow like this. So, what do we do? We discourage them to come from bottom to top, right and this is the basic concept behind winglets.

We will find many airplanes will have winglets. That is you put some surface here, then many variance of design for designing the winglets. But, the concept is by putting this you are physically separating this two portion bottom and the top. So, that they have less vortex, ok, so the winglets is the concept that is used. There are many other concepts that is used, you can put aerofoil at the tip which are not that lift effective, you can destroy that contour.

So, that you are destroying the lift generation at that point and that way the pressure difference at that point will be less. So, you expected to get less vortex drag or induced drag, ok, this is another thing on aspect ratio. How I was sharing with you, how I understood? If you see George Cayley explanation, that you need angle between the surface and the velocity vector ((Refer Time: 23:40)), definitely there is an area.

So, I was asking question if I put this, I put this, both are having same area. So, how do you distinguish this? Now, we know by now that, I would like to put the wing like this, not like this, ok. How I understand this?

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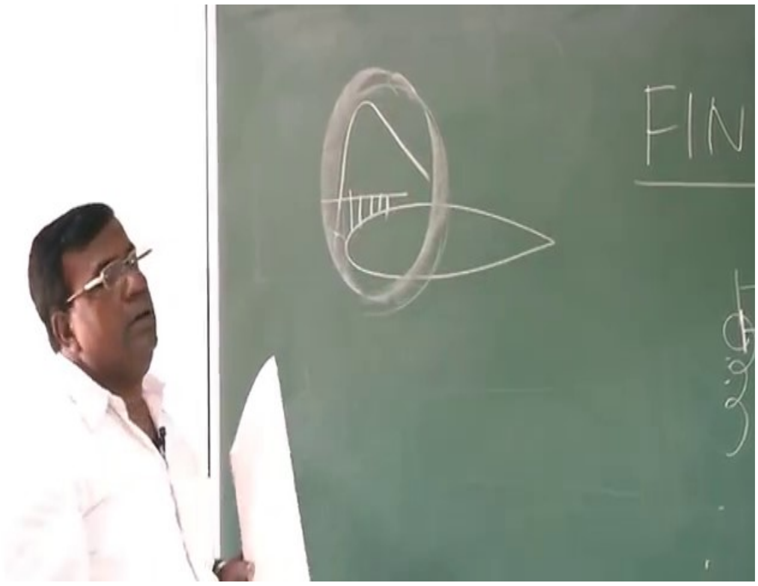

See remember one thing, whole lift distribution which comes because of aerofoil, the whole...the this is the region here, where I have explained you the flow accelerates and there is a drop in the pressure. Mostly, this portion is responsible for generating the lift in a dominant way, ok. So, if I put an wing like this ((Refer Time: 24:28)), I can think it has a large number of aerofoil, ok, but if I put like this, then I have got a smaller number of aerofoil, anyway, because the top portion, front portion is going to contribute more towards lift. So, that is why I see that aspect ratio should be clearly understood and it is importance. Then, we were having a session where our quality control manager Rekha Sharma was physically demonstrating you the components of airplane and their role, ok.

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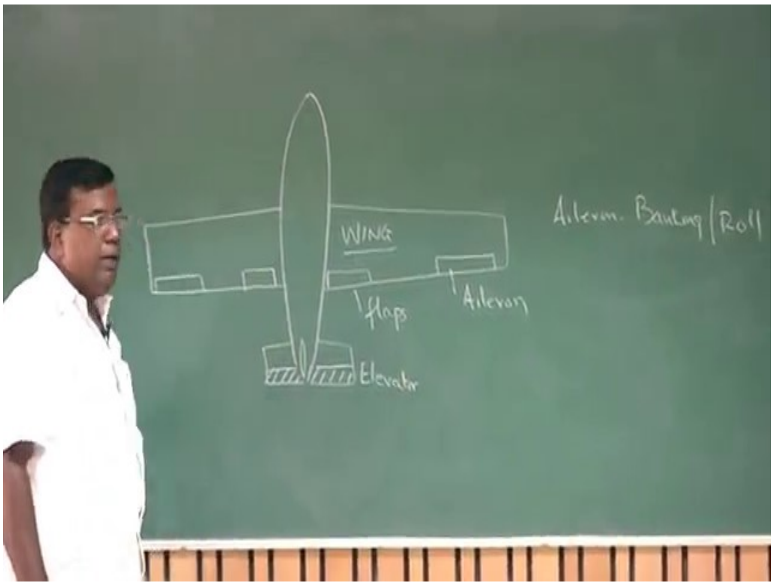

This was wing, ok and we by now know this is aileron, these are flaps. In fact, all these components are flaps only, it is for a specific purpose we are giving name to this portion as aileron and this is flap. The role of aileron is what? Question is this. Suppose, imagine ((Refer Time: 25:38)) this is the wing and I am putting, I am putting this aileron down and this aileron up, what will happen? The moment I put the aileron down, this wing camber will increase.

So, it is lift will increase and this will go down, so it will turn like this. So, this aileron, a pair of aileron is used for banking the airplane, ok. So, aileron is for banking or sometime for roll also, this referred to. Then, we have got this is the elevator. What the elevator will do? Imagine, this is the... Imagine this is the horizontal tail, ok ((Refer Time: 26:38)) and part of it is the elevator, so I am moving in this direction.

If I put the elevator down what will happen? Again you see, the camber is changed and as per George Cayley, now this portion is having an angle, but I will explain with as if the camber has changed, so the lift will increase here, as the lift increases here c g’s is in some front, so it will give a nose down moment, right?. The airplane will now go down that is, if I put the elevator down, the aircraft will go down like this. In contrast, if I put the elevator up, so now, force will be downward, so the nose of the airplane will go up, we say airplane will go nose up.

So, to take the airplane attitude up, I will put the elevator up to take the nose of the airplane down, I will put the elevator down. Is it clear? If I want to take a nose up, I will put the elevator up, force downward, so it goes like this. If I want to take the aircraft down, so I will put the elevator down. So, this will give a force upward and c g is in front, that will take it down, ok. So, that is a primary role of elevator.

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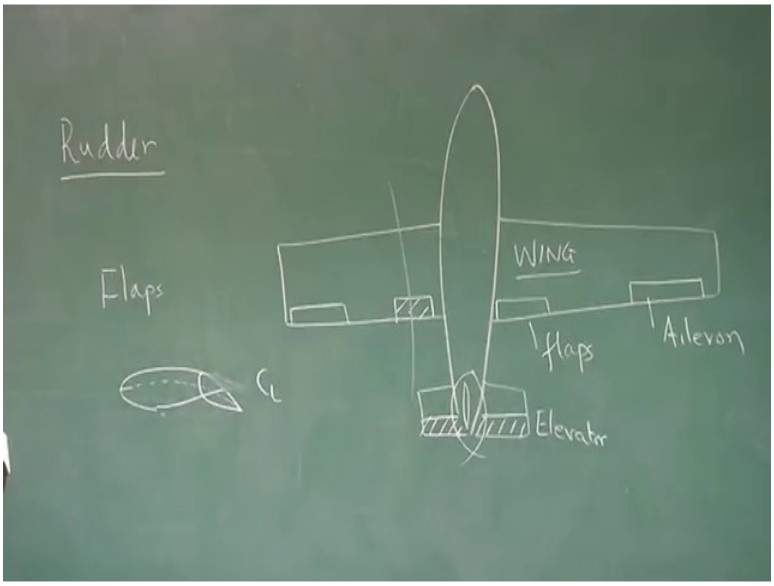

Then, we will have rudder, ok. Again you think like this ((Refer Time: 28:21)), suppose this is the vertical surface, see this is the aerofoil, this is the vertical surface and I am going in this direction. Now, if I put this rudder towards my right I am flying like this, so I have deflected towards right, what will happen? If I deflect towards right, then it will experience a force in this direction, that will give yawing moment which will take the airplane towards right that is, if I put the rudders towards right, the airplane also will go towards right like this.

If I put it other way towards left, the airplane will go towards left, ok, so that is the function of rudder. Then, comes here the flaps, if I take a cross section here, so it also has an aerofoil, right? and this is the flap, let us say I am drawing here. As I putting the flap down, what is happening? What has happened? The whole camber of this section has increased, right? so the CL for a given angle of attack will increase. So, this is the way to increase the CLmax, we will see that when you talk about landing and takeoff, how to increase CLmax, so that I can take over the lower speed. So, this is the role of this flap, ok.

If I understand all these things clearly, I will be able to synthesise all this things through the requirement of an airplane for a specific performance that is, why it is important to know. See the next lecture will be on the atmosphere. Why it is important? Because, whatever lift drag we are getting that is coming out at the cost of interaction of airplane, a body with a medium. So, far we have been talking about the configuration of the body, aerofoil, wings, flaps, fuselage, tail, elevators etcetera. But, since it is because of interaction of the body and the medium, we need to know the property of the medium also.

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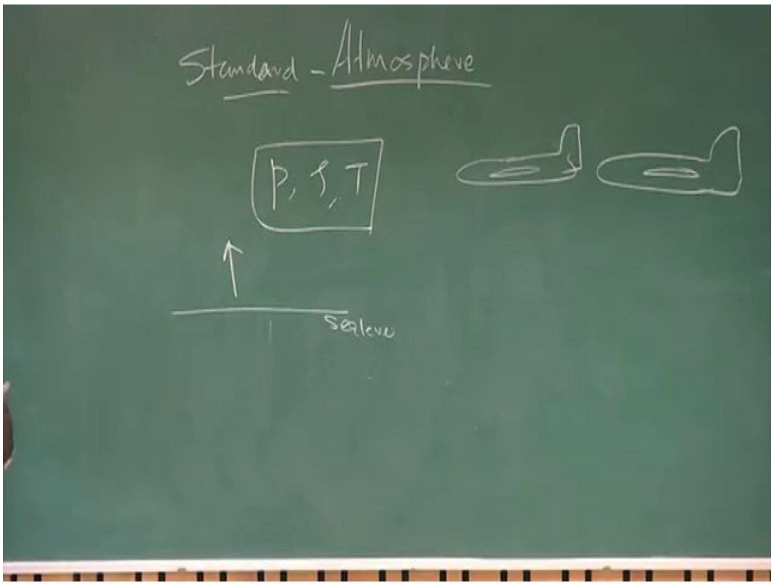

So, the next lecture we will find will be on atmospheric or atmosphere, right? and more precisely, we call it standard atmosphere. Why this is a requirement? See if you have purchased a motorcycle and somebody asks you, what is the average fuel, average you are getting? You say that, company told it is 50 per litre, but I am getting 35 or 40 per litre. Then, you go to the company, the company will simply say, see in the road where or the traffic where you have or where you are driving this motorcycle is not an ideal condition. This will indeed give 50 kilometres per litre, if you are running on a highway and where they are no traffic jam, you can maintain a speed.

So, what actually they are telling? When I am trying to compare to motorcycle performance, I need to know that the platform where I am driving this motorcycle should be well defined, ok. Similarly, for an aircraft if I want to compare performance of two airplane, then I need to compute, evaluate their performance characteristics when they are flying at a common or same atmospheric environment, right? and that is why this concept are standard, standard atmosphere came into picture.

You will see that, we will try to develop methodology which are all established methodology based on experimental results and with an assumption that, air behaves like a perfect gas that is, we will assume that p equal to rho r t valid for this ($p = \rho RT$). And we will try to give a description of pressure, density and temperature as we are going higher and higher.

The approach will be, I will be knowing the condition at sea level, as I go up how the pressure is changing, how the density is changing, how the temperature profile with altitude is measured experimentally and we will be using this to give a description of pressure, density and temperature.

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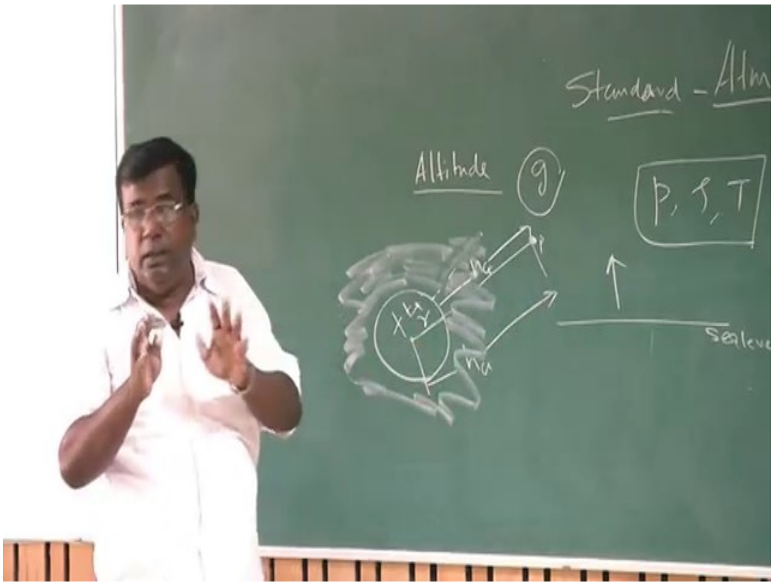

And also please understand when I am trying to find the pressure change as I am going high, higher and higher, I need to also know few things about altitude. Because, if this is earth, this is earth center, if I call the radius of earth, then at any point p if I try to define the distance with respect to the center, let us say it is ha (h_a) which is traditionally called absolute altitude. This has more relevance in space flight, because there is a interplanetary motion, the value of g changes drastically.

But, when I am talking about atmosphere, I will be talking about atmosphere which is present within certain definite altitude measured from the sea level, ok, there are no atmospheres here. So, that time if I use this altitude, I will be doing a wrong modelling. So, that is why there is a another altitude is defined, which is defined as hg (h_g), which is measured from the surface of the earth or more critically, if you want to be correct, you say from the sea level condition, right?

So, this is your hg we will be using this, we will be using this concept and we see that, if I am around 60 kilometres altitude hg (h_g) and the new height will be defining. There is a compulsion to define the new height, which we will be calling as fictious height or geopotential height. Because, as I am going higher and higher please understand, the pressure is because of the weight of the fluid, ok and how we will be computing pressure.

We know the pressure at sea level and as I go higher and higher, I will try to find out what is the change in the pressure that is dp which is negative, change in the pressure. So, change in the pressure has relation with the weight of the fluid and weight means, this g local value of g which changes with height, which changes with height measure from the center of the earth.

So, there is the complication, they have simplification will be made as long as we are within 60 kilometres. And this is what will be required to describe the pressure, density, temperature in an atmosphere which we will be calling standard atmosphere and we will be also defining the standard atmosphere initial conditions, that at sea level when I say standard atmosphere, what are the value of density, temperature and pressure?

And then, so the table I can know the standard value of pressure, density and temperature at any altitude, which will be used to compute the performance of different airplane or if you want to compare the performance, some internal test results. Then, I can use those values also and collaborate, ok. So, next lecture will be on standard atmosphere.