Introduction to Aerodynamics

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Aircraft and Aerodynamic Forces and Moments (Contd.)

So, let us continue our discussion on airfoils; the general shape and various nomenclatures about an airfoil.

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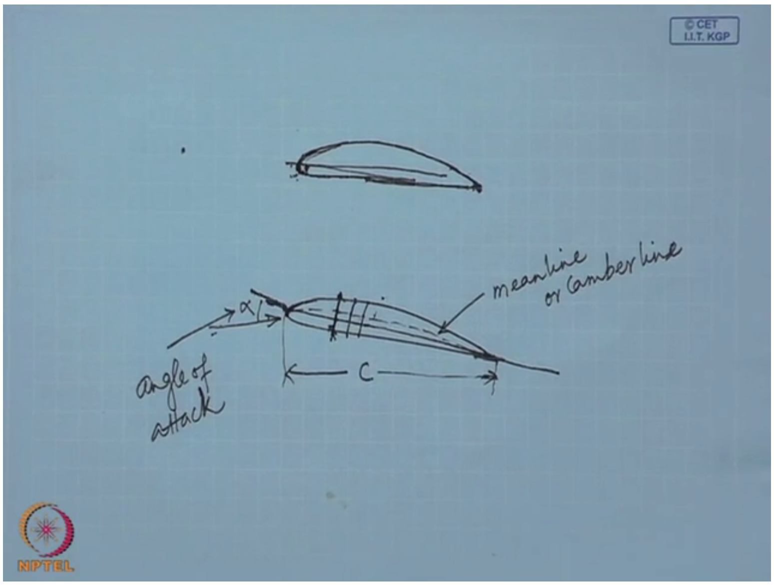

Airfoils are the cross section of the aircraft wings, and the general shape is at the nose or the front part is basically rounded. At least for subsonic application, the front part is rounded and then its thickness keeps on increasing up to certain distance reaches a maximum, and then again decreases to zero or nearly zero at the trailing edge.

So, the rounded nose or the leading edge is rounded and the trailing edge may be either sharp or also may be rounded, but if it is rounded, then also its thickness is very small compared to the front or the nose. Now, we mentioned that if we join the leading edge and trailing edge by a straight line; that line is called the chord of the airfoil.

Now; obviously, question comes that when there is a sharp trailing edge; that is, a trailing edge is point, then we can say that this is a trailing edge, but the leading edge which is always rounded, which is actually the leading edge, which point, which point should we connect to get the chord.

And same question also arise if the trailing edge is also rounded. You know because of manufacturing difficulty, many a time the trailing edge is not exactly a point, but also little rounded. And in such a case, how do you look at these trailing edge and leading edge; the points. This entire region we can call it the leading edge region, but which is that point?

Now, in that situation where there is rounded nose; obviously, the nose is always rounded, the point of maximum curvature or the center of the maximum curvature; that is located and similarly, the trailing edge is also rounded, then the center of maximum curvature at the trailing edge; that is also located, and these two points are joined and then extended to intersect their airfoils. And wherever it intersects, that will be taken as the leading edge point.

So, we need to locate the point of maximum or center of maximum curvature at the front as well as at the end, and then join the line. And that is what is the chord. Let us say then, that sorry we will have one more… The chord is usually denoted by c, and it is a very important reference line because the incidence or the angle at which it makes with the flight direction or the relative wind is called the angle of incidence or angle of attack. And again that is usually denoted by alpha. Let us say this is the relative wind direction, then this angle is called angle of attack or incidence and it is usually denoted by alpha. And the maximum distance of this line from the chord; you will see this line is not at equidistance from the chord. Its distance from the chord changes from point to point.

So, the maximum distance of this line from the chord expressed as a percentage of chord is called its camber; the camber of the airfoil. So, if we say that an airfoil has 3 percent camber; meaning that the maximum distance of the camber line from the chord is 0.3 c. So, the thickness and this camber are always expressed in terms of percentage chord. And the airfoils are usually characterized by this maximum thickness and maximum camber expressed in terms of percentage chord. So, if we mention that the airfoil is 12 percent thick; that means, the maximum thickness of the airfoils is 12 percent or 0.12 c.

Now, this is the wing cross section. Now let us look to little bit of wings how the wing looks like, though of course, it is not the details of it is not related to aerodynamics and we will be hardly interested later on of all these details, but still this is something all of you must know. The wing cross section is airfoil, but how is the wing? The wing is usually hollow, it is not solid.

Besides providing the most important aerodynamic forces and moments, and also providing support to the engines, lending gears, and many other things, wing also serve as the main fuel tank of the aircraft. That the fuel that the aircraft needs for its operation is mostly stored within the wing; that means, that the wing is not a solid structure, it is hollow. Only the shape is given by what is called the skin which is just a thin plate, very thin plate.

It is you can imagine that you have a seat metal turned in the shape of the wing which is quite thin. Of course, if it is just like that, then you can understand that because of the huge air load that the wing supports, it would not be able to sustain if it is just only a seat metal; just only the skin. So, there are certain internal structures which give the wing its strength so that it can maintain its shape because its shape is very important. These aerodynamic courses and the moments that the wing provides is just because of its shape.

So, the shape must be maintained, but just if you have only a thin metal, sheet metal turned like that, then of course, the sufficient strength will not be there. And not only that you know in early days of aviation, the wing skin used to be even of cloths; fabric. And even now, small aircrafts; they have fabric wing. Now that of course, cannot support these air pressure or huge air load that the air craft supports. So, there are internal structures, but the internal structures are arranged in such a way that the major part of the wing is hollow which can be used as fuel tank.

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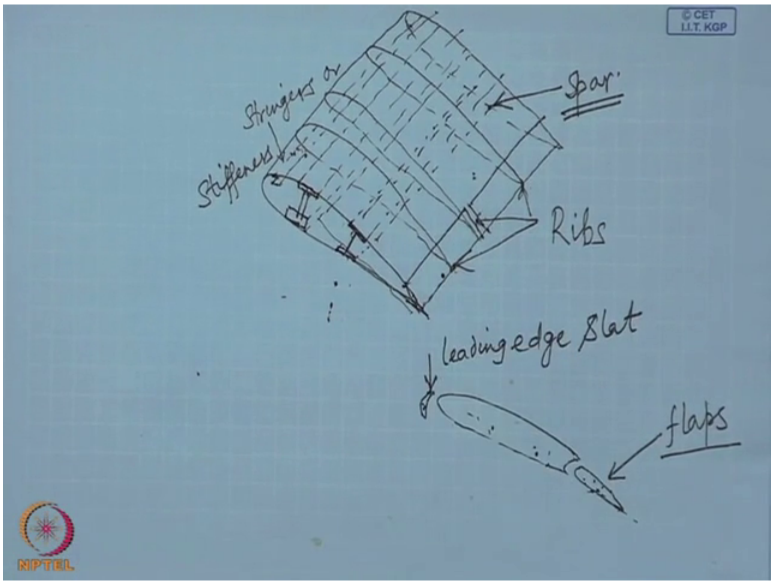

So, let us look to these about these internal wing structures. Not that they are directly related to our course of study, to give it sufficient strength and also to provide connection with the (( )), there are some number of beams. Depending upon the aircraft, it might be one beam or might be two beam or three beam which are usually having eye cross section and extended from wing route to wing tip right and extended throughout. These beam type of structure are called spars and they provide the most of the strength that is necessary to support the loads. These are called spars. Of course, details of these you will be studying in your structures course. So, they are called spar.

Also, there are longitudinal members to stiffen the scheme. So, even if you have that two or three such spars, then also that the intermediate space between these two spars or ahead or behind these spars; the skin there may buckle or miss sub depressed because of the air load. The skin is quite thin.

So, to provide support to the skin, there are stiffners. Again say very small beam, but they are not connected from upper surface to lower surface, they are attached to either upper surface or the lower surface. And they may of z section or c section or hot hat section, and they are also extended from route to tip. They are called stringers or stiffeners. There will be many such stringers or stiffeners to stiffen the skin; stringers or stiffeners. They are called ribs. All of them are of airfoil shapes. empty spaces or hollow spaces in between. So, that is what the wing structure is.

In this context, we will also mention that the wing; it looks to be a one component, but actually this wing cross section most often is made up of or the airfoil is not made up of single component. It is made up of number of components; that means, in a practical case, the airfoil can be something like this. Some cases, this also can be even two or three. Here I have shown that this airfoil is in three parts, but these two parts which are now separated from this main part; they can fit with it so that you will just see only a line. When they are fitted together, you will see just a line without any gap.

However, they can be deflected with respect to or relative to this main component. Then these components are in generally called flaps. In generally, these components are called flaps, and then they are further named from their; following the purpose that they are serving like this; leading edge flap; this small parts are the leading edge is usually called a leading edge slat, leading edge slat. Flap is a general name and there are specific name based on what purpose they are serving.

One (( )) say this flat fitted at the trailing edge of the wing can be used for two purposes; one purpose is just to provide little higher lift during landing and takeoff. The aircraft when it lands or takes off needs little more lift than while it flies or rather lift coefficient; little more lift coefficient. Will say what those lift coefficient are. And these flaps, deflecting these flaps that had amount of lift can be obtained. Same thing; this slat, actually all these flaps, that is, the general purpose; that they usually provide when deflected a little change in lift depending upon in which direction it is deflected, it may increase the lift or it may decrease the lift.

Usually if the airfoil has a positive camber and then the flap is deflected downward, then the lift is increased. If the flap is deflected upward, lift is decreased. So, now, imagine that on two wings, we have two flaps. If both of them are deflected downward, they will increase the lift which is required during landing and takeoff. So, during landing and takeoff, these flaps are used only for that purpose to get enhanced lift and then they are called high lift devices.

Now, think that in one wing, it is deflected downward, in other wing, it is deflected upward. What will happen then? In one wing, the lift will increase, on the other wing, the lift will decrease. And consequently then the aircraft will experience a movement about the longitudinal or what you call the x axis; meaning a rolling movement. And in such a situation, those flaps will be called eulerian. When the flaps are used to provide this rolling movement, they are called eulerian.

Now, in many aircraft, these purposes are separated. See the flap is made in two part; part which is nearer to the (( )) which is called the inner part. So, if this is route part, so, up to certain distance, up to this part, it is one and this part is again its separated.

So, this near part, this near part on both the wing will always be deflected symmetrically; that means, both will be deflected downward together and will serve as high lift devices. You require it during landing and takeoff. While this outer part; though will be not used for that purpose, they can be used only for providing the rolling movement. And since you know rolling movement is movement about the longitudinal axis, if these eulerians are towards the tip, that is beneficial because in that case, the moment arm becomes longer. Even with the small difference in force, you can get larger moment. So, they are more useful if they are at towards the tip.

So, at this stage, that is all about wing we wanted to say because these rolling movement and all those. Only our role here is to find the pressure distribution, then how this rolling movements are coming, and how the rolling movement is going to effect the aircraft motion is of course the subject matter of flap mechanics, not aerodynamics

So, this we will not discuss further, but we should know what those movements are and what their purpose is, how they can be obtained or how they can be modified because as an engineer, that is also one of your job. Not just to know that what the lift is for a given wing, but also to know how to change that lift or how to get more lift by changing the shape anyway.

The tail plane; as we mentioned that there are two tail planes and both are basically small wings. So, their structures and almost everything are nearly same; however, none of them are usually having leading edge slat, usually no horizontal or vertical tail uses leading edge slat, but they do use that tail edge flap, but, not for providing high lift. I mean that is not the main purpose. In their case, the main purpose of those reading is flaps for the horizontal tail, the leading is flap is called elevator. The leading is flap for the horizontal tail is called elevator. And once again if a change in lift occurs there, it again produces a movement, but this time you see the movement is about the

(( )) span wise axis; meaning, it will change the incidence. Either it will take the nose up or down; aircraft nose up or down, and that leading edge flap of the horizontal tail plane is called elevator. And it provides the pitching moment necessary to change the incidence of the aircraft.

If we do not need to change the incidence, we do not need to use the elevators; that means, we do not need to deflect the elevators, they will remain fitted with the horizontal tail as it is. Horizontal tail; also called as a stabilizer, horizontal stabilizer. Similarly, vertical tail also called vertical stabilizer because the horizontal tail and vertical tail; they provide the necessary stability to the aircraft. That is their main purpose, like the main purpose of the wing is to provide this aerodynamic force required to fly. The horizontal tails and vertical tails; the main purpose of them is to provide the necessary stability.

See these are the main function. It does not mean that they do not do anything else. This horizontal tail of course, always produces certain amount of lift, irrespective of whatever small it is, it always produces certain amount of lift, certain amount of drag, but that is not their main purpose for which they are used. Their main purpose is to provide stability and to hold those elevator and radar.

The flap of the vertical tail is called radar. It provides the directional control like it provides a movement about the vertical z axis, vertical axis and swings the nose to the left or right; that means, it has sudden control over the direction of the flight, in which direction the flighty should go, and it is called radar.

The difference another difference is there that in most cases, the airfoils used for horizontal and vertical tail are symmetric, are usually of course, there is no hard and fast rule that they have to be symmetric, but most cases, they are made symmetric and in wing, they are always camber Even though the wing is not there within the (( )), but for this case, we consider the wing is extended through the (( )) and then the top view of it. If we look from the top, whatever we will see; that is what is the plan form and this area is area of that plan form.

So, as you mentioned the if the wing plan form is trapezoidal, then basically it is an area of that trapezoid. As an example, if you have a cylinder, what is its plan form?

Student: (( ))

A rectangle, yes.

So, the plan form area of that cylinder is simply the area of that rectangle. That is what we are… Similarly, all other forces are normalized using the same parameter; half rho u infinity square s. The drag coefficient; the other force is drag coefficient, sorry drag force is denoted by D and this is the drag coefficient.

Similarly, the side force coefficient; let us say c y also can be written as… The moment coefficient let us say the pitching moment coefficient; this is pitching moment coefficient c m, pitching moment is usually denoted by m. m by…

Now this is of course, not moment; half rho infinity square is not a moment. We need another length to make it moment, and the length is usually the aerodynamic chord, mean aerodynamic chord. The yawing moment is usually defined denoted by n…, not c but b. For the yawing moment, that is, the moment about the vertical axis, the appropriate length parameter is the span; length in that reaction, not the chord. So, here it is b.

The rolling moment; here we need to be little careful, rolling moment let us for the time being because we would not need it, we will be using let us r; of course, it is not the usual notation. For pitching moment and yawing moment, m and n is usual notation. For yawing moment, the usual notation is l, but we are not going to use that because we have already used it for lift.

So, let us write it r and again it is… There is a little bit of conflict of notation in fad mechanics and aerodynamics. In fad mechanics, the notations are much more straight forward. The three forces are denoted as x y z. The drag is x, side force is y, the lift is z, and these three moments; rolling moment is l, pitching moment is m, yawing moment is n, but in aerodynamics, lift is always used as l and hence we have a little problem while writing rolling moment. So, lets for the time being we write it r.

Now, when aircraft flies straight and level, it is going straight. So; obviously, there is no side force acting. If there is a side force acting, then of course, it cannot go straight, and also since it is flying straight and level; obviously, no moment is acting on it or all moments are zero.

So, in that situation, all three moments are zero and side force is zero. Only two nonzero are lift force and drag force. So, this lift and drag force are perhaps the most important of the aerodynamic forces, and as we have already mentioned, that this lift and drag forces; and why only lift and drag, all these forces come because of the pressure and stress distribution, viscous stress distribution on the surface of the aircraft and mostly on the wing.

And once we get the pressure and sheer stress distribution on the airfoil surface or the wing surface or to be more accurate, over the entire aircraft surface, we can find all these forces and moments; just a matter of integration. Once we know the pressure and the stress, we can simply integrate it over the aircraft surface and get all these forces and moments. In that process, one may be zero.

And as we mentioned in the beginning that the role of aerodynamics is to try to find out that pressure and stress distribution, to find that pressure and stress distribution and not only finding the pressure and stress distribution, also using that knowledge, to change the pressure distribution or stress distribution to our advantage, which is the design problem. The design problem is as you have (( )) that it gives you the task that this is what we need, how to get it.

So, the question may be like this, that this is what the pressure distribution we should have, how to get that pressure distribution; that becomes a design problem, and what type of pressure distribution we should have? That of course, comes with little bit of experience and little study; different type of analysis that what type of pressure distribution gives us the best result. So, we should try to get that type of pressure distribution. And then we should look to the problem that if we want to have this pressure distribution, how we are going to have the wing, what type of wing it should be?

So, the aerodynamics and try to answer these two questions, that if this is the wing or this is the aircraft, what are the forces it will have, and if we want to have a little different type of pressure distribution or stress distribution, how we will change our aircraft or we will have a newer aircraft with different type of these aerodynamics. And that is what we will try to do over a number of aerodynamics courses and which we will try to introduce here.

Now, the pressure distribution and stress distribution will definitely come from if we analyze the flow; if we analyze the flow that occurs over a body. So, here, now the problem completely changes. Instead of analyzing the motion of the aircraft, we are now trying to analyze the motion; the flow motion, the flow. So, we should have certain as you know that to analyze any problem, the first thing that we need is to set up some physical laws in the mathematical form which gives the answer to this or the mathematical model, mathematical model of the problem.

So, the first thing that we should do is model this flow problem mathematically and then we will try to solve this problem. The modeling of the mathematical problem is basically nothing but expressing the laws of nature or the physical laws in mathematical form. And you are familiar with many such physical laws. I think all of you are familiar with these physical laws; conservation of mass; that is very a important physical law, conservation of momentum is another very important physical law and so on. There are many such physical laws. So, if we can express them mathematically for our problem, we will be able to set the problem in mathematical form.

So, that will be our first task. And since our system is basically fluid, so, we have to set up this system for a fluid system. You have already set up these systems for rigid body, you have set up this systems for some other elastic body or deformable body; mostly solid. Now same thing we will be doing now for fluid.

And one more thing, at this stage, perhaps we should mention, let us say that we know the pressure and stress distribution on the body. We have already said that now to get the forces, it is simply a matter if integration. So, let us look to that integration at this stage before we start our modeling the fluid dynamical or aero dynamical problem.

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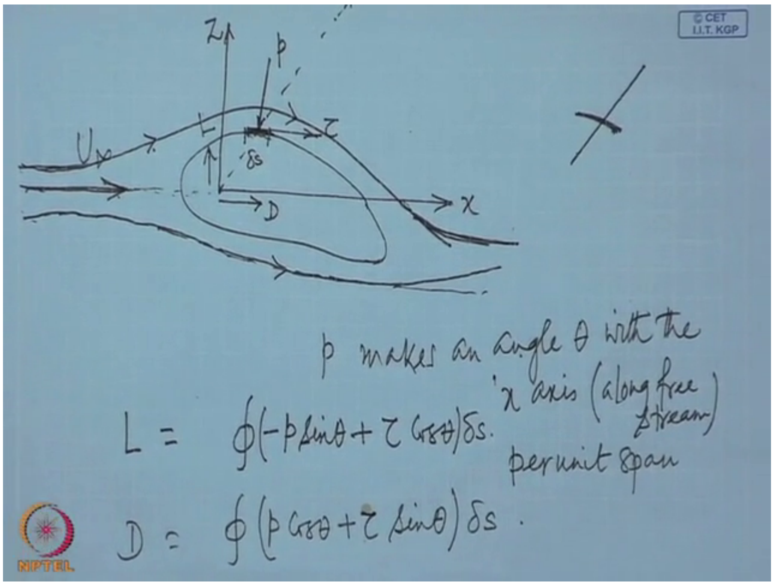

Let us consider for simplicity on only a cross section of any arbitrary body to which the flow is coming with the undisturbed stream speed of u infinity. Let us consider a small element of the surface and let us denote this length by say delta s. This small arc length is denoted by delta s. You know on this small element, we have pressure and stress acting. Pressure; you know always acts normally to any surface. So, the pressure is normal to the surface, and the stress is tangential, we will let us call it tau. Then how much will be the force? We can have one set up x and y axis or x and z axis. The other direction is the y direction. Can we get the force? The force along this direction will be the drag force; force along this is direction will be the lift force because this is same as the x.

We can even sketch the flow by something like this, Let us say pressure makes an angle theta, pressure makes an angle theta with the vertical axis. Pressure makes an angle theta with the vertical axis; sorry pressure makes an angle theta with the horizontal axis. Pressure makes an angle theta with the horizontal axis or the x axis. p makes p makes an angle theta with the x axis. x axis is along flow, along free stream. Free stream is a stream which is not disturbed by the body; that means, if there are this body were absent, what about the stream would have been; that you can see that it is just parallel lines represented by parallel lines with velocity u infinity at everywhere, because of this body, that will be disturbed, and that is called the disturbed flow.

So, our x axis is along this free stream or along the direction of u infinity. And then how much will be the lift force? Integrated over the entire surface into minus p sin theta plus tau cos theta into the area element. Area element; how we will you get? We will consider a unit length along y axis and we will assume that there is no change along that for the time being.

Of course, if there is change in that, then we will consider into delta y or otherwise now let us consider delta s into 1. So, this is per unit span. It is called per unit span; lift force per unit span; that means, we are considering the span wise length of unity only. And similarly, the drag force can be written as sorry this is integrated over the entire curve… Again this is drag force per unit span.

Now, at this stage, we may further mention that at least for the lift, the major contribution comes from pressure. The contribution from this stress or sheer stress tau is much smaller compared to the contribution from the pressure or rather its almost negligibly small compared to the contribution from pressure. So, amongst the two, as far as lift is concerned, pressure is the most important. And at least in this course and also perhaps next one or two courses on aerodynamics, most of the time, we will be discussing only about the process where we can consider only pressure, not the sheer stress; that is, most often we will deal with the situation where there is no sheer stress. The reason is that the contribution of sheer stress to the lift force is negligibly small compared to the contribution from pressure. Of course, that is not true for the drag.

So, in our next lecture now, we will move on to our proper aerodynamics with this brief introduction that what aerodynamics intends to do or what is the subject matter of aerodynamics, why is in required to do, and then we will move on to aerodynamics from next lecture onwards.