Introduction to Aerodynamics

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Aircraft and Aerodynamic Forces and Moments

So, welcome to introduction to aerodynamics, this is an introductory course on aerodynamics. The subject matter of aerodynamics is finding there are determining the forces and moments, that acts on anybody that moves through a fluid. In our case we are mostly interested in air, but the basic principles are same irrespective of what fluid. It is considering the bodies as an aircraft; see when aircraft moves through a body. It experiences certain force as, you know that aircraft exerts, forces on the air and air in turn exerts forces on it, and this force and moments and estimation of their contribution to the motion that is what, the subject matter of aerodynamics.

Since, this force on moments comes, because of the pressure, and viscous stress that is develops on the surface of the aircraft. So, aerodynamics tries to determine these pressure and viscous stresses on the surface, and of course these pressure and viscous stresses are dependent on the overall flow. So, you can say that aerodynamics is the study of the flow about, anybody that is emerged in a fluid and moving through it.

We are mostly interested, in the body of aircraft and if we consider aircraft is say, what are the forces that act us on an aircraft. We know that there is a buoyancy force, but usually the buoyancy force is so small that, it is hardly considerable when compared to the total weight of the aircraft, and we can neglect it for further motion. Now, aircraft considering the simplest possible flight, which is that aircraft flying in a straight level flight. That it is going straight, and keeping it is altitude more or less fixed under this condition.

You know that the forces need a balance, the wait force needs to be balanced by some force similarly, the engine thrust is also balanced by some other forces, and these forces are in this configuration of flight are known as the lift and drag force. That is when the aircraft is in a steady level flight, it is weight is balanced by the lift force, and thrust is balanced by a drag force. Both of these forces are aerodynamics nature that is they come, because of the relative motion of the aircraft and the air or the fluid.

Now, if there is any disturbance in the flight of course the moment develops, and the configuration of the aircraft changes. The force coming from the pressure distribution, and viscous stress distribution, and they are distributed over the entire surface of the aircraft. It is not necessarily aircraft it can be any body, which is emerged in fluid. Now, as you know that a distributed force can be represented by a system of force, and moments same thing can be done here also. And, these force and moments, they can be resolved in any three mutual orthogonal directions.

If, we consider these three mutual orthogonal directional like this, particular remember these direction, the let us call it x axis the x axis is along the relative wind. It is along the relative wind that means it is along the direction of the relative velocity between the body and the fluid is neither horizontal nor vertical or anything, it is along the direction of relative velocity between the body and the fluid. So, as an example if we consider that an aircraft is moving in atmosphere, which is at rest then the relative wind is simply the direction of or opposite of the direction of the aircraft speed. So, in that case the x axis is opposite to the direction of the aircraft velocity.

If, an aircraft is flying through an atmosphere at rest, the x axis is along the opposite of the direction of aircraft velocity or aircraft speed. However, in general we will call it is the direction of the relative wind. The x axis is relating the direction relative to the wind. And let us, call at this stage the z axis, which is upward, but not vertical it is normal two of course the x axis, so it is upward, but it is not vertical. Since, x axis is not vertical horizontal the z axis is not vertical, and the y axis is which is perpendicular to the plane formed by x and z.

Usually, for an if we consider the body to be an aircraft, we call it the direction to the right wing, right side of the wing with respect to the pilot, to the right side can be with respect to an observer. The observer may be as in front observer may be behind, so of course the right will change. So, it is right side with respect to the pilot, usually that is called the starboard side. These names came from shipping, where they have the left is usual called the portside, as ships comes in to a port, it is left side usually faces the port towards the port. So, that left side is called the port side, and the right side is called the starboard side.

And, same nomenclature is used here in aircraft also, the right side of the aircraft is called the starboard side, and the left side is called the port side. So now, the axis system that, we will that is usually followed in all aerodynamics. We will study in other subjects the aircraft motion the dynamics of complete aircraft, and in that context you will define various type of axis system, but the axis system that is used in aircraft sorry aerodynamics is like this. The x axis is around the relative wind, z axis is normal to x axis upward positive, and y axis is normal to the plane of found by x and z and to the starboard wing side is positive.

Now, if we resolve the force, in these three directions in these three direction the component in the x direction is called the drag force. So, you see that the drag force is a component of the force along the relative wind direction. The drag force is along the relative wind direction, and again taking that example; that aircraft moving through atmosphere at rest, then it is opposite to the direction of aircraft speed. The drag force is opposite to the direction of the velocity of the aircraft. The force which is normal to this x axis that is along the z direction is called lift. So, lift force is normal to the relative wind, it is not vertical lift force is not a vertical force.

It is normal to the relative wind, and the force in the y direction is called side force if, it is positive if it is towards the starboard. If, this direction is towards the starboard it is positive. The three moments the three moments about, these three axis are called as pitching movement if it is about the y axis. The pitching let us, come from the moment about x axis the moment about the x axis is called rolling moment. Now, what will this moment do as you can see that, if and rolling moment acts on an aircraft it will try to being one wing of the aircraft down with respect to the other wing, one wing will go up the other wing will come down?

That is what the rolling moment will do, if a rolling moment act us on an aircraft, it is one wing will come downward the other wing will go up. If, the starboard wing goes down, the rolling moment is called positive. Similarly, the moment about, the y axis that is an axis, which is along the length of the wing are all most along the length of the wing. A moment about that axis is called the pitching moment, and what will be the action of this moment, as you can see that if there is moment acting about, this axis either their nose of the aircraft will go up or go down.

If, the sense of the moment is such that, the nose of the aircraft goes up, then it is called a positive pitching moment. Similarly, yawing moment about, the z axis which can be called approximately vertical, it is not the vertical direction, but approximately vertical direction then, now a moment about it. What you will do it will take the nose to the left or right, it will tend to move the nose towards the left or towards the right. If, it tends to move the nose towards the right that is towards the starboard side the yawing moment is taken as positive.

Now so, we have defined the three aerodynamic forces and aerodynamic moments all this force and moments comes, because of the relative fluid flow over the body. So, this also another basic premises in aerodynamics that in aerodynamics, we consider the body is at rest while the fluid is moving, in the real world say if we look an aircraft it is the aircraft which is flying the atmosphere is more or less at rest.

There might be a small wind which is say negligible as for as the speed is concerned is negligible to the speed of the aircraft. While and aircraft flies at a speed of some seven hundred eight hundred again thousand kilometer per hour, the wind is about some forty fifty even less than, that some time to twenty kilometer per hour, so which is negligible.

So, usually it is in the real life the aircraft moves that, air is at rest the atmosphere is rest at rest in aerodynamics. We considered it other way, it is always taken that the body is at rest and the fluid is moving through it that is we considered the relative velocity. And all these forces this lift drag pitching moment, yawing moment all comes because of these relative flow, relative velocity because of the flow fluid of course, that is the subject matter of aerodynamics to analyze that flow fluid and to obtain this forces.

Now, think about an aircraft which is flying straight and level, when it is flying and straight and level of course, no moment is acting no moment is acting and again as long as it flies straight and symmetric. You see that this side forces or this yawing and rolling moment they do not act, this yawing moment and side force rolling moment they come into picture only, when there is and symmetric flight. If, there is no asymmetric flight these forces are moments do not come into picture.

So, during the flight time of an aircraft, most of the time the aircraft is not experiencing any yawing moment or rolling moment neither any side, force of course there are certain situation, when all of these are acting or even these yawing moment, rolling moment and side forces are acting, but most of the time during its flight only lift and drag, and possibly pitching moment acts.

Now, before we move to the real subject of aerodynamics let us, give certain important information as for as aircraft is concerned. You know an aircraft consist of different components, the most important components of an aircraft are it is fuselage, the wings horizontal and vertical tails and engine. These are the most important component of an aircraft, the horizontal and vertical tail they are also like wings and so the most of the conventional aircrafts as we can say perhaps.

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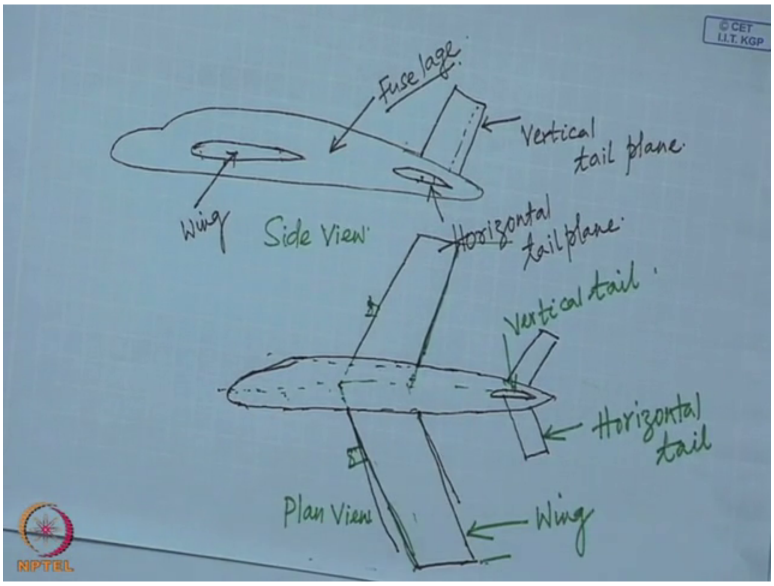

We can sketch that they look something like this. This is what is the side view of an aircraft if, you see it from side this is what is look like a side view, where this main body is called the fuselage, where it houses all the important pay loads.

If, it an commercial airliner this is where all the passengers will be, this is the wing as it appears in a side view of course, in a side view. We will see only a cross section of the wing this is called the horizontal tail plane of the aircraft, here also you see only the cross section and this is called the vertical tail and see there will be an engine usually attach to the wing. So, we can name it this.

The wing the horizontal tail and this is vertical tail. This is what is the plan view here, we have shown the wing as something like trapezoidal. That is not necessarily true that, there wing has to be trapezoidal the plan form can be of various shape. It can be even a triangular what is called the delta wing and see we have shown here. The leading edge this is called the leading edge, and this is called the trailing edge.

So, the leading edge of the wing, we have show here as a straight. It is not necessary to be straight, it can be curved. So, this is our representative view of the aircraft or representative aircraft, we can say a conventional aircraft there are many nonconventional aircraft, where you can clearly identify all these different components in such a manner.

Now, as far as the aerodynamics is concerned, the most important component of the aircraft is the wing. Because this produces perhaps more than ninety five percent of the total lift that the aircraft produces, for a conventional aircraft all most the entire lift come from the wings. So, this wing is the most important aerodynamic component, tail is of course a small wing the horizontal tail, vertical tail is a vertical wing. We can say now, we have seen this cross section of the wing, which as a special shape usually it is quite thin.

The thickness is of order of say the of course, it is a variable; it is not that for all aircraft the wing thickness is same. The thickness is of the order of something like say ten percent twelve percent of the chord may be even less. Now, we will define what is this chord and certain important definition.

Which are required in the latest stages of aerodynamics that will come for what the shape, that the wing takes in it is plan form? In it is plan view is it call it is plan form the shape. That the wing takes in plan view is called it is plan form. See, in this case the plan form is trapezoidal, so when we call the plan form of a wing it is simply mean that, how does it looks.

When we take its plan view that is when, we take it is projection in plan then, the distance between one wingtip to the other wingtip that is the distance from here to here. The distance from here to here is called the wingspan distance from left wingtip to the right wingtip is called the wingspan. In doing so you see that, we are considering even that part of fuselage the wing is connected to the fuselage.

So, in within the fuselage the wing is not there, wing is not extended, but while talking about the span. We talked about, the entire wingtip to wingtip as if the wing is inside the fuselage also; another very important quantity is the plan form area. As, we have seen that the plan form is simply the view, that the wing takes in it is plan view, so the area of that plan view is the wing area.

Now, then there is a question that when, we take the plan view of the wing as we can say that, in the plan the wing is up to this to the fuselage. So, this is the plan, in this case the plan view is say trapezoidal. So, the area of this trapezoidal this two trapezoid, but it is not exactly. So, it has to be extended within the wing, within the fuselage that means while finding the wing plan form area.

The wings will be extended up to this and the area of these two, fuselage these two trapezoids not only up to the fuselage, but to the center of the fuselage extend the plan view or plan form to the center of the aircraft and then find its area that is what is the plan form area. Square root of sorry square of span divided by plan form area is called the aspect ratio of wing the aspect ratio of wings. So, span distance from tip to tip.

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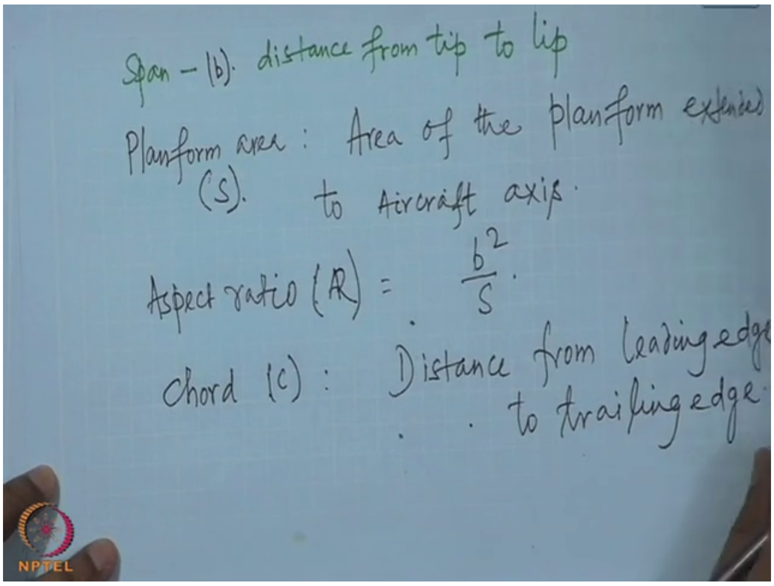

There are common aerodynamic notation for these quantities, the span is usually denoted by b. The span is usually denoted by b, more or less and universal notation. The plan form area is denoted by the word letter s capital S, the aspect ratio most often denoted by a joint a r in some cases we will find only a also, but most often it is used as a joined a R and that is the notation we will also follow. It is simply b square by S; chord denoted by c, it is distance from leading edge to trailing edge. Now, you can see that in general this chord is then, changing is not fixed quantity and there are various mean chords defined one is of course, geometric mean chord the other is called the aerodynamic mean chord.

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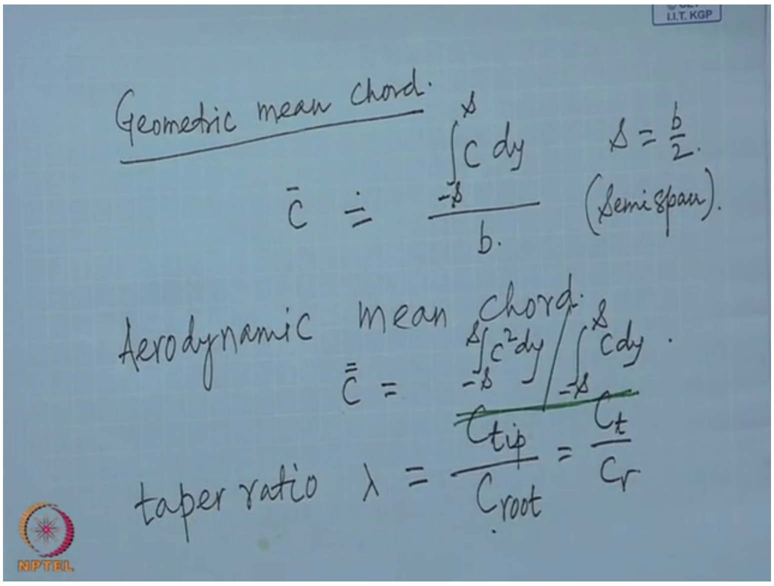

How, we will you define this geometric mean chord, it is obviously quite the small s is to represent semi span half of the span small s is stands for b y two. Now, the wing we have already talked about, wingtip the wing at the junction or at the central axis as, we said that if we extend the wing to the center of the aircraft. Then, the chord length at that or that is chord is called the wing root coming back to that, old figure the wing root here. So, this is root this is tip this is leading edge. This is trailing edge there will be a difference in the chord length at the tip and chord length at the root and their ratio is called the taper ratio tip chord to root chord. The ratio tip chord to root chord is called the taper ratio, we forgot to tell a aerodynamic mean chord the aerodynamic mean chord is defined as if, the wing is shift backward with respect to that, is from the root to tip. If, it goes backward with respect to the say the y axis then, the wing is called a sweptback wing and the angle between the y direction and the leading edge is called the sweptback angle again. Let us, with respect to this figure itself, if we have this is the direction of the y axis then, this angle is called sweepback angel.

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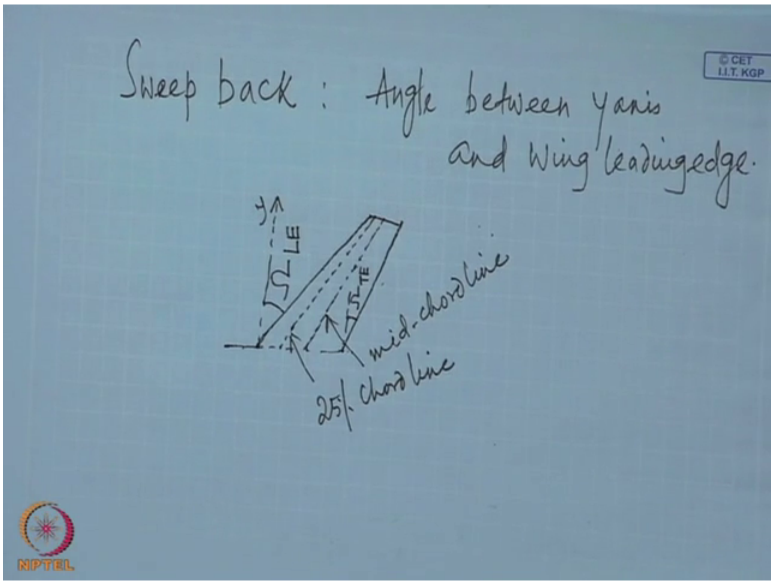

Eventually what we defined is specifically it is called leading edge sweepback. It is called leading edge sweepback wing though, we have called it sweepback, because the sweepback may vary at different. That is the leading edge may have a different sweep angle than, the trailing edge. The trailing edge sweep angle will not be same as the leading edge and also if we take any other line on the wing at certain fixed percentage of chord.

Then, the sweep angle of that line may be different or other in general. They are different let us say that, we think about a mid-chord location, that is at every section on the wing. We locate the mid-chord and then join it by a line then we get a mid-chord line. Again let us, take it one particular wing cross section only let us consider and let us say this is the direction of y axis. So, this is leading edge sweep similarly, this will be trailing edge sweep usually denoted by this.

And similarly, let us say we have mid-chord line that is at every station, we are locating this line is passing through the middle of the chord at every station, or say think about the twenty five percent chord line. So, each line has all the lines have different sweepback and as we mentioned that in many cases the aircraft leading edge itself can be a curved line. And if it so happens then you can see that, the sweep if an on a particular line itself changes.

They are called variable sweep geometry, if the leading edge is curved then, the sweep angle changes along the leading edge itself. So, they are called variable sweptback wing. Now, we will come this section of the wing. The section of the wing is called an airfoil all British

English was aerofoil sometime, we may call aerofoil and nowadays in the American English it has become airfoil.

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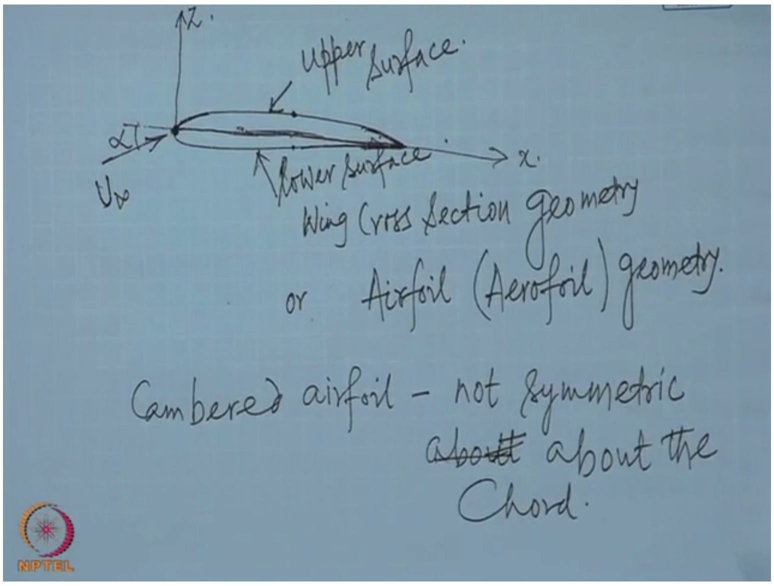

So, both will be used wing cross section geometry. (this is what is an usual shape of airfoil. If, we join it from leading edge to trailing edge the line joining, it is called it is chord the line joining, the leading edge to trailing edge is called the chord. And at any particular chord wise location, if we have the distance between the upper and lower surface is called it is thickness. This is called the upper surface of the airfoil and this will be calling the lower surface in aerodynamics of airfoil.

Usually, this point where the chord intersects, the nose of the airfoil is taken as the origin of the axis system. And it is conventional to take the x axis along the chord in the study of aerodynamics. Usually, the leading edge sorry the coordinate origin is placed at the point, where the chord intersects the nose. That is here and the x axis is taken along a chord and of course, the z axis is normal to it the most important quantity in aerodynamics. As, we have saying that is called an angle of attack angle of attack, it is the angle between the relative wind and the chord line.

If, we call this is the relative wind, we will be denoting it by U infinity why we will come later infinity and this angle between this. And this is all alpha and remember that the force lift force is normal to this U infinity and the drag force is along U infinity for a supersonic, use often the leading edge of the airfoil is also pointed, while for subsonic use the leading edge is smooth and round, but for supersonic use often the leading edge is sharp.

Now, we have defined thickness and chord in aircraft, almost all length almost all length parameters are non dimensionalized with respect to chord often it is mean aerodynamic chord or mean geometric chord either of them. So let us say, that the thickness or all other parameters of an aircraft, will always be expressed in terms of percentage chord airfoils are usually designated by their thickness. So, when it is called that airfoil is ten percent thick meaning, the airfoil has maximum thickness of ten percent of it is chord. That is if the chord of the airfoil is say, one meter then the maximum thickness of that airfoil is ten centimeters.

If, we call the airfoil has ten percent thickness, if the maximum thickness. As, you can see that the thickness changes from leading edge to trailing edge, at the trailing edge the thickness become practically zero and the maximum thickness occurs. Somewhere, ahead of mid-chord depending upon the type of airfoil, it is ahead of mid-chord. If, the chord is if the chord does not intersect or does not divide the airfoil into symmetric hub, that is upper hub and the lower hub are not symmetric with respect to the chord.

Then, the airfoil is called a cambered airfoil then, the airfoil is called a cambered airfoil. If, it is symmetric that is, if it is exactly at the middle of the airfoil then, the airfoil is called symmetric. So, the airfoils can be either symmetric or asymmetric, which is called cambered cambered c a m b e r e d cambered cambered airfoil, it is not symmetric about the chord.

Now, in such a case of course, you can see that you can imagine or you can construct a line. Which is exactly at the center of the airfoil, at each section at each station? You can think about, the thickness and then take the midpoint. And, join all the midpoint and you will get a line, which is just at the middle of the airfoil within the middle of the airfoil. So, that line is called the mean line or camber line, that line if we join the fifty percent of the thickness line at each station and construct a line.

That line is called the mean line or camber line if the mean line is above the chord then, the airfoil is called positively cambered that is when, the mean line is above the chord it is positive camber if the mean line is below, the chord it is negative camber. Usually, all practical aircrafts are positive camber.

Something else, we missed that is a dihedral what is dihedral see the an aircraft has two wings on, it is two sides on the left and right. And think about that for each wing, if we think about the cross section all the cross sections are an airfoil all the cross sections are an airfoil. So, thinking about that wing over the semi span at each station, it has it is own airfoil. Now, the chord of each of these airfoil chords of each of these airfoil may not be in the same plane.

If, they are not in the same plane then the wing is called a twisted wing a geometrically, twisted wing when the chord at each section is not on the same plane. Then, the wing is called a twisted wing and in such a case we can see that the angle of attack at each cross section will also be different the angle of attack at each cross section will also be different. However, if the chord is on the same plane then, the wing is called untwisted. And in such a case if all the airfoils are same airfoils then, the angle of attack at each section will also be same a wing is called or aircraft is called dihedral- having dihedral wing. When, the two wings are not on the same plane.

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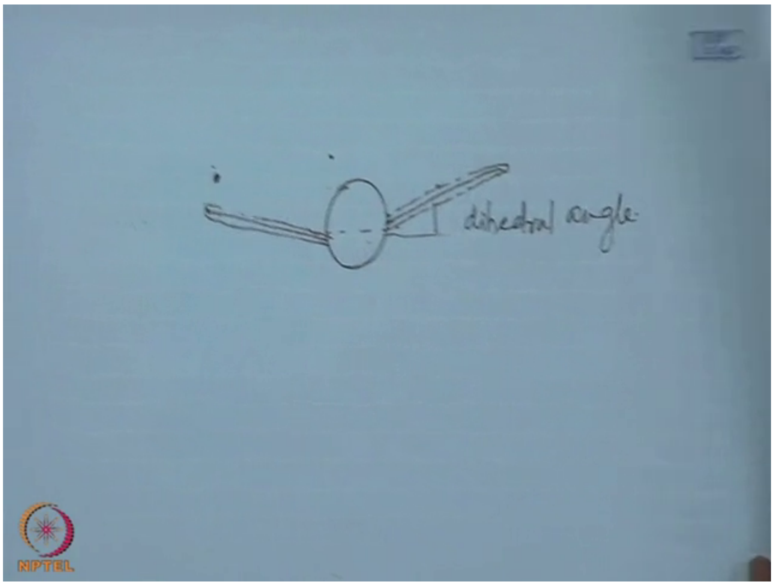

In a front view with a dihedral wing, it will looks like this. So, this is called a dihedral wing and this angle is called the dihedral angle. Similarly, the wing is such that, it is tip is drooped with respect to the root. Then, it is called anhedral the opposite is called anhedral. Where the tip is droops, tip droops or the tip is below the root it is called anhedral.

So, we know how defined dihedral and also wing twist I think, we will stop today. What we have done essentially is we have defined certain important components or important parameters as far as aircraft is concerned. Which will be subsequently used for aircraft aerodynamics? And which of course, as a student in aerodynamics you should know in the beginning before you start your aerodynamics.