Flight Dynamics II (Stability)

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Module No. # 07

Lateral Directional Static Stability and Control

Lecture No. # 19

Roll Stability, Wing Sweep Effect, Rudder

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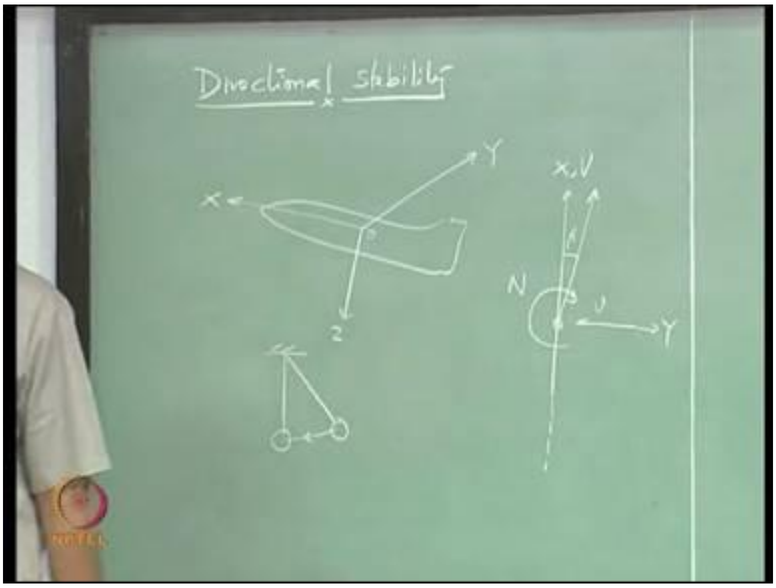

So, we are looking at directional stability of airplane, and we are talking about the motion of airplane in XY plane, right.

So, it is the rotation about the Z axis that we are talking about. And, if you remember, I said, lets say that there is a level flight condition that the airplane is flying, going straight along this line and suddenly, so this, velocity is also along this line, ok only straight line path it is going on with this velocity, lets say this V. Suddenly it sees a gust, which is from this side that will result in a sideslip angle. So now new velocity vector will be something like this. And the angle between these two, is called the sideslip angle, in this plane, XY plane, right. So this beta is small beta introduced by a gust of wind, ok, the wind is not a constant wind, its not staying, its coming and hitting the airplane and going back, right. And, that is how we talk about stability. We want to look at the stability of a system with respect to motion it shows when you disturb it. So if you look at this picture, the aircraft should be able to kill this beta, right. So that is what is meant by the stability, is it not? So, look at the, this pendulum model, and lets say I give a small input to this bob, now it has gone to some other location, right, there should be a restoring force which is trying to bring it back, only trying to bring it back and that will be, given by the restoring force being created automatically. So this beta is as a result of the gust that is coming onto the aircraft from this side, so what aircraft should do, aircraft should kill this beta automatically, right, then only we will say that the aircraft is directionally stable. And that condition for directional stability is ... this derivative should be greater than zero, right, so its obvious. So whenever there is a beta created, you have to generate a moment or, the aircraft should automatically generate a yawing moment, which is trying to kill this beta, is this clear, ok. So, we have already looked at contribution to Cn beta because of different components on the aircraft. So we talked about delta Cn beta because of the wing fuselage interaction, interference, and we also talked about the contribution coming from the vertical tail, vertical tail is actually a stabilizer, so it has to give you delta Cn beta which is positive. Wing alone can also add to Cn beta, how, how will that come? How can wing contribute to this Cn beta? Because of the drag right, the induced drag. There will be a difference in the drag on the two side, two parts, two sides of the wing, and because of that there will be a yawing moment, right.

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And there is some contribution also coming from the engine plant, it can be a direct effect or indirect effect. But lets not bother about these two, because they are difficult to calculate, ok, some expression is given for this term, and this is very difficult to find out. So, if you want to have a better estimate of Cn beta then you should actually include these two effects also, but then you have to find them from the wind tunnel testing or do a CFD calculation, but both of them are difficult.

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So these two are actually major contributors and we will not go beyond this. Lets talk about ...., so these two are major contributors. Ok, this is about stability, what about control. You also need a control for changing the direction of the plane, airplane, what is that control called, rudder, ... right! What is rudder? Rudder is a small flap attached to vertical tail at the trailing edge, right, so something like this. So looking from the top, this is your vertical tail, and then this flap is rudder, right. So what is rudder doing, what is rudder doing? So, same effect, remember this vertical tail is a symmetric airfoil and now you have this small flap which is rudder at the trailing edge of the vertical tail. When you deflect this rudder, this small flap, its going to change the camber of this part, and because of that, there will be a change in angle of attack at the vertical tail.

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So your velocity is coming, lets say, in this direction. You are going straight, in a level flying condition, and this is the relative wind coming onto the tail, right. So now I am looking from the top, we can deflect the rudder in two directions, one is ..... this and the other one is this .... So, which one will give positive moment and which one will give negative moment? We are talking about the yawing moment created by the rudder.

12:00

And let us say CG is somewhere here, this one, because… So, you will, you will get a force, which is, for this deflection you will get a force in this direction, right. So, the moment will be, if I say this is the force Yv; then I can take a moment of that force about the CG, and that moment is what, positive, right, because X is going towards Y, we always have to follow this .... rule right. When X is going towards Y, then it is a positive moment, that is what happening in this case.

And that deflection of the rudder is negative, according to the convention. So, we are trying to always generate a negative moment by applying controls, right. In case of Cm delta e also, it was negative, right. So, C n delta r is also negative, that is the convention that we are going to adopt. So, this is your negative rudder deflection, and this .... is positive.

So, let us try to find out, what is that, moment. ..... we can add a sign, right. Because this Yv, the sideforce, that is being created by this deflection is in the negative direction, positive Y is this.

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This subscript is for, v is for vertical tail, Y is the sideforce, so sideforce on the vertical tail is Yv. So what is Cn? Cn is, Cn is with respect to the wing reference condition, we are writing all coefficients with respect to the wing reference condition, right. The vertical tail efficiency and tail volume ratio of the vertical tail. So Cn is ..... And, this alpha is being created by the rudder, right. So we can write this as ......, so Cn delta r, remember this is what we are going to need, all the coefficients, we do not really care about the dimensional numbers, right, because when we want to do the, make the wind tunnel measurements, we are going to only put the scaled down model of the aircraft in the wind tunnel and we are going to measure these coefficients, right.

18:40

And this quantity, the change in angle of attack that you can get by the rudder deflection will depend upon the control surface area over the total vertical tail area, right, so its like an effectiveness parameter, and this is vertical tail effectiveness parameter, same as what you saw for the elevator. or .... Now the question is, where would you actually you will need rudder, in what all conditions you will need rudder. We will try to list down all the cases where we will need rudder. And accordingly, we have to size the rudder depending on requirements. So the rudder sizing will depend upon the requirements you will have. So the first thing is, what he is saying is, that there is an engine failure, right. Asymmetric power conditions.

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So lets say both (engines) of them are located at distance l from this center line and they are producing thrust ..., right, there are two engines, one on each side of the wing, and they are located at equal distance from the centerline and lets say one engine fails. So if one engine fails, lets say this one fails, what you are going to see, you are going to see a moment in this direction, right, and that will be T into l, so you have to overcome that moment that is created due to this engine fail condition. So there you will need rudder, to fly along this path, is not it? Second situation, ... turn, ok. What is happening, how are you turning? You are trying to bank, how do you, how do you, lets say ..... So rolling is basically because of the, differential lift condition. So even if one aileron is lets say at zero and I deflect the other aileron, it will give me a roll, right. Lets look from the front and see what is happening. So this is your .... wing, two sides. I am now seeing from the front so I can see these two wings, right, and I want to bank my aircraft, right. So what happens, you have to generate lift on one side which is higher than the lift on the other side, right, that is how you will execute a banking maneuver.

So, let us say this is L plus delta L, while here you have only L; this will give me a roll, roll or bank, is it not? What is happening, because of that. So, let us say let us say this, this roll is positive. So, X is moving towards Y, wait a minute, Y is moving towards Z. So, you are getting a positive roll about X, roll is a motion about the X axis of the aircraft. So, you are getting a positive roll, but what else is happening, automatically.

Because of this, because of this increased lift here, the induced drag will be higher, right, as compared to this. So, you are automatically also seeing D plus, ... right, D plus change in small D, because of this extra lift. And that is going to introduce a yaw motion, and which is against the roll. So, let us see if I can give you a better picture. So, I am, I am trying to give the aircraft a positive roll, because I want to bank, right.

So, it is like this ... right. Now, because, because I have increased lift over this wing, then only I can get this, right. I have increased lift over this wing, and let us say this wing has the same lift as the level flying condition. So, you see a drag which is higher. Earlier drag on the two parts of the wing was perfectly balanced with the thrust right, and I was able to fly the aircraft in level, not accelerating, right; steady condition. But now because of this, there will be a moment, because of this drag which will try to rotate the aircraft in this XY plane about the Z axis. Is it not?

So, it is actually rotating in the XY plane about the Z axis to increase the side-slip angle right. Do I want that, when I am banking. So, the yaw motion is exactly opposite to the roll motion. Roll you are trying to do in this positive sense, and you see a moment - yaw moment which is in the negative direction opposing the roll right. Everybody sees that. So, how do I now correct that yaw motion while banking; we do not want to see that - that when you are banking, you do not want your, your banking like this; you want to go this way, and your aircraft will start rotating like this. You do not want to have that kind of motion right, associated with roll or the bank maneuver.

28:58

So, that is also controlled by the application of rudder. You can actually kill that side slip, and then the turn that, you are, or the bank that you get is called the coordinated turn - coordinated bank maneuver. So, this beta we have to kill using rudder.

29:34

Any other situation which comes to your mind, this is definitely very important both of them are really important situations, right. Of course, this may not happen all the time, but this is definitely a requirement, because you will bank your aircraft, in flight. Any other situation comes to your mind. Lets say you are trying to land, and there is a cross wind and this wind is a constant wind. You should be able to differentiate between the two situations. One is, when there is a gust, gust is coming and going and I am talking about stability with respect to that, right. Lets say I am trying to land, now there is a crosswind which is there, ok, its not like coming and going, that crosswind is present. What will it try to do? It will try to take the aircraft away from the centerline to which you have to align your aircraft to, when you are trying to land. So the aircraft may try to go away from the line that its required to follow ok, so this is the centerline of the airstrip, the aircraft is required to land on to this line, the front wheel should touch along this line and you have to move along this line. So, in a crosswind, aircraft may just go away from this line, that is where also you will need rudder.

32:05

You get the point. Is this clear? If there is a side-wind present, then there will be a side-slip, right, and the velocity vector of the aircraft is not going to, you know, its going to go in a different direction, so velocity vector is actually defining the flight path, right, so its having some beta that you need to kill using rudder. Any other situation?

32:54

There is a high angle of attack motion called spin of aircraft, ok, and thats because of the vortex, asymmetric vortex breakdown on the wing, two sides of the wing, so you see large yaw rate.

34.38

Ok this spin motion is actually having large yaw rates, so, to control that, to get out of this motion you need rudder power. Alright, is this clear? (()) Thats a good question and unfortunately I do not have the right answer right now, ok, may be for different aircraft it will be a different requirement. Because a spin motion, you will not usually fly a transport aircraft at high angles of attack, but high angles of attack can automatically also happen when you have a situation called microburst, you know, vertical column of air coming and spreading like this right. If you have such a situation, then you know that, while you are entering, so something like this, so vertical column of air coming down, and lets say your aircraft is going like this, what will happen? Because of this increased velocity here, you will suddenly see a change in angle of attack which can be large, right. So these aircraft actually, the large transport aircraft or combat aircraft ofcourse, they all have to be certified for this motion also. Only when you have the power to come out of spin using controls available, then you will get certification for your aircraft. There is one more motion that we want to talk about. We have talked about stability in pitch, and stability in yaw, right, so what is left now? Stability in roll, right.

37.20

And there are only two angles that we are talking about, right, with respect to which we are talking about stability. So one is angle of attack and the other angle is sideslip angle. So, which will actually, have to be encountered here, or which is the one we have to care about in this case? which, alpha or beta? I am talking about two variables, right. Beta right? Ok, what is going to happen with angle of attack, is it going to give a roll? Not really. So lets now talk about this angle beta.

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So we have a beta angle because of disturbance, right, and I want to kill that beta. So which way the aircraft should roll automatically, right, that is what we are trying to answer, roll stability. If there is a beta, which way the aircraft should roll automatically so that the beta is killed. Right, we are trying to kill the disturbance and here the disturbance is this sideslip angle, small angle. How can you kill this beta, through roll. Just now we talked about this.

A positive roll is going to give you an increase in beta, right, is it not? When you are trying to roll in a positive direction, lets say in a bank, beta is increasing, can you use similar argument to arrive at a condition, you know, where we are trying to kill this beta through roll motion, and that roll motion should be automatic, I am not trying to use aileron or rudder to get this, right. Positive roll is going to give you a positive beta, you want to kill that beta, so you should have a negative roll, right.

So, dL over, this L is rolling moment, it is not lift ok. If you want to differentiate it, we can put a prime here, right. What sign this should have, negative, right. Now L is, QSb into Cl; this Cl is roll moment coefficient.

Ok, so, these three remaining constant, this derivative also means, or ...., right, and its also called ...... You have to remember that lateral directional rational motions are coupled. So, we can never talk about them separately, I cannot talk about yaw motion without talking about roll. And I cannot talk about roll without talking about the yawing motion. So, both of them are coupled motion; except the longitudinal motion, other two motions are coupled all the time. So, this is called Dihedral effect, and …ok, so, if you want to look at it graphically, this is what is for a stable airplane, right, because Cl beta is negative here.

43:40

Now, less of C l beta more of C n beta, or you know, less of C n beta more of C l beta, now it is a conflicting situation, right, which one you want to design your aircraft for? right. So, all that, the coupled effect, will be obvious, when we are trying to talk about the aircraft dynamics, actual aircraft motion - using aircraft equations of motions. So, right now, we are only talking about static stability, we have not yet started talking about dynamic stability right. So, let us try to look at some of the factors, which can influence C l beta, right.

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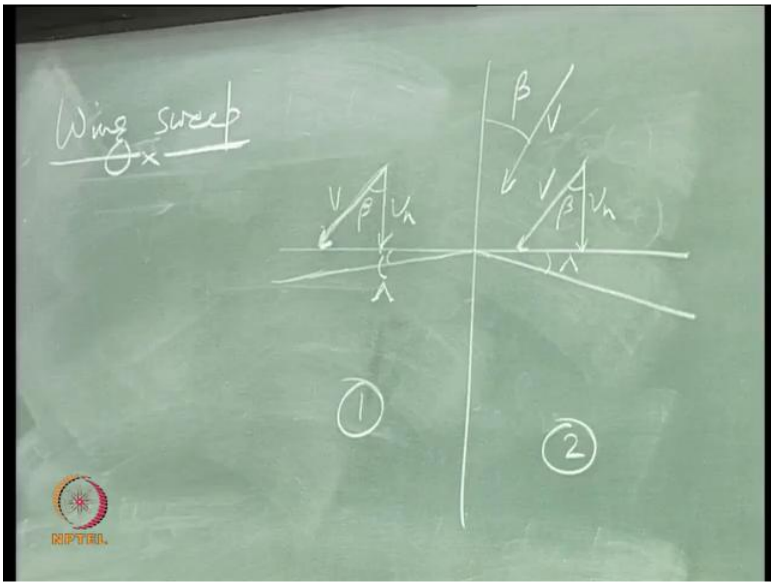

Different locations of wing, in different fashion, will influence the C l beta, and we will look at each one of them, separately. So, you can have wing sweep, sweep - back, sweep forward dihedral, anhedral, high wing, low wing, right. All those situations we will look at now. Let us say your wing is straight, right, and a wind is coming at some side-slip angle beta, right. How would you calculate lift over the wing, what component of velocity we will have to take, normal component, right.

So, let us say I am looking at this location, and same location on this side. So, this is V, and I want to find out the normal velocity that this particular section of the wing is seeing, right. That only I can use to find out the lift over that airfoil section, and call this side 1, and this side 2; this angle is ... right. So, same length of this V vector, I have taken on this side; normal component is going to be same, because this is a straight wing right. So, lift on the, on that airfoil section, equidistant distance from the centre line is going to be same, is it not? So, it is not going to give me any roll, right. Let us see, now you give a sweep. Ok. Right. I think we will stop here, and continue from this point in the next class.