NOC: Introduction to Airplane Performance
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Lecture – 47
Design Basics: Sweep and Dihedral

Good morning friends.

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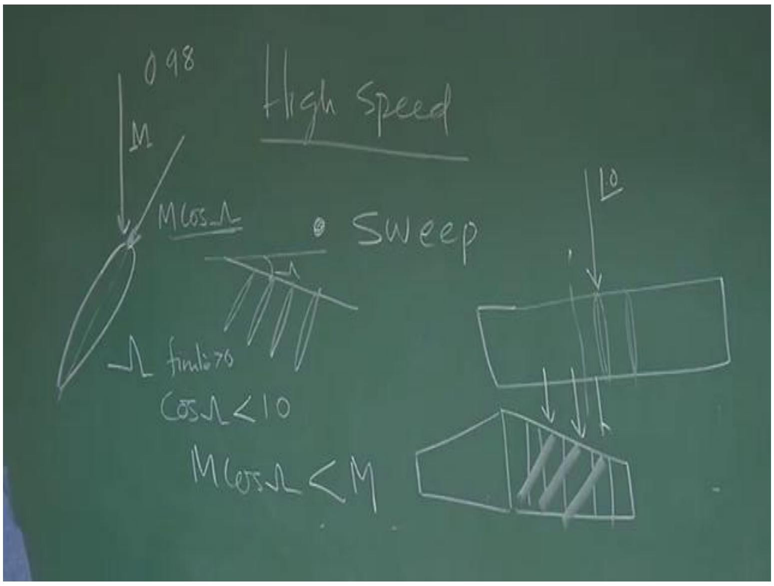

When I come to high speed, you will see one term is very popular which is sweep that is, if you see an airplane before I draw the diagram let us see, if this is the wing and there is the flow here and there are files are here like this staged, these are all only I am showing the cross section. We all understand, the aerodynamic characteristic over the wing is decided by the flow along the chord, the flow normal to the leading edge primarily that is.

So, now, if it is one max theoretically speaking, then this is also one max, so already supersonic it is coming to a supersonic, transonic, supersonic they go close. What is our aim? Our aim is that can I do something that even if a free stream is around one, the normal component is less than one, then the free stream may be around 0.95 near transonic, but normal component to the aerofoil if it is less than 0.95, then I am happy.

So, I have reduced the effective mach number which will decide the aerodynamic characteristics. So, what is done, theory is very simple, you stager the aerofoil in this fashion instead of, now see the flow is coming like this, let say this is M mach number. What you have understood? It is a normal component which is M cross lambda that is, if this is the wing, this is the lambda sweep angle that is aerofoil are stag like this, the contouring is done like this, so that is what I am drawing.

Now, what will happen, since for lambda finite cos of this is less than 1 that is, if lambda is finite and greater than 0, then cos lambda will be always less than 1. If it is less than 1 then that will M cos lambda for a finite value of lambda will be less than M that is, if let say it is 0.98 then depending upon the lambda we are chosen, this normal component can become 0.95. So, reducing the transonic effect seen by this aerofoil, so you are reducing the drag and it increasing the effectiveness in a sense that, whenever you are near a sonic mach number, shock will come that will interact the boundary layer.

Not only loss of lift, but also weather, track, vibrations is also may come to your avoiding that in an every lose way if I start a plane, because since we have not talked about any high speed. So, this is the way a sweep back has become very popular, but if you see somebody shows you a platform like this and the aerofoil’s are staged like this, then definitely it did not sweep back. Because, for sweep back the aerofoil has to be staged like this, the flow is coming like this, the first case is not at all a sweep back it is simply a temper ratio case.

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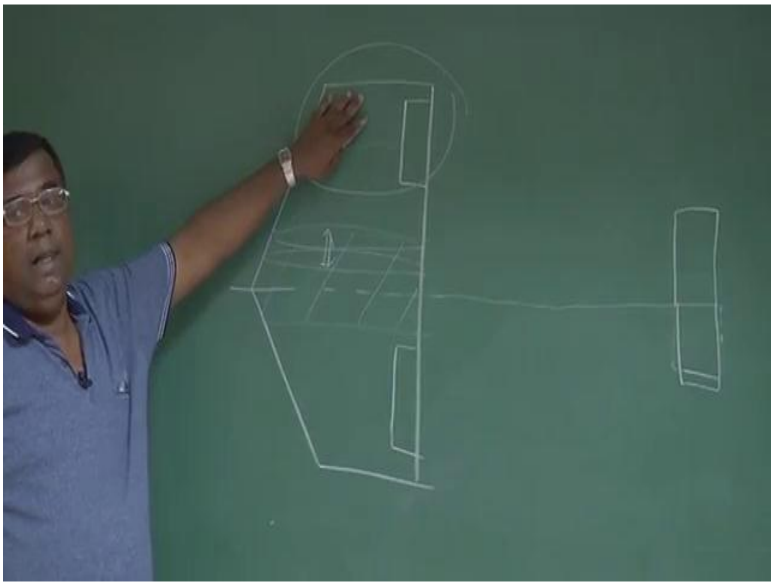

So, one another important theory you must understand, this are the aileron and generally there is tendency for us to fly at higher angle of attack to get the maximum advantage. Another problem there is, as I try to flight at a angle of attack there is the possibility of a stall. So, what is done, one way is that you ensure such that the route stall first, so the pilot gets a warning and then, he brings the airplane out of the stall condition through elevator and aileron, primarily aileron.

So, what is done is, one way is we give a geometric twist on this portion that is, in the tap we put an negative angle, slight negative angle for that, even if here it is around 12, 13 degrees which is closer to a stall, so the area here is seeing is less than 12 or 13 by 2 degrees. So, that this will not stall, but this will stall, so now we can recover. Another way is you select aerofoil such that, the aerofoil of the characteristics here having a smaller stall angle compare to the aerofoil here that is, one of the way it could be handled is by adjusting the t by c of the aerofoil here.

Let say, this aerofoil will be stalling at 12 degrees, these aerofoil will stall at around let say 13 degrees. So, even if there is a stall situation this portion you stall and this will give a warning to the pilot and he can control the airplane through aileron, so this is also possible. So, these are the small, small things which you need to take care in the design and make sure that you have enough autocratic event to the pilot to control it, to recover it from one point to the other, to ensure that he goes from one equilibrium to another equilibrium, if that is important it is equally important also that from a adverse situation it should be able to drive the airplane back to a normal situation and that itself is called a really a good design.

Because, you cannot expect everything will go nice, the climate will be the way we wanted, there will be situation, where the airplane go into a distress, but a good design should have taken those thing in mind and the pilot should have enough bandwidth to take the airplane out of the distress. Suppose we want to, now try to understand few important design aspects of the high speed airplane. How do I distribute high speed airplane and low speed airplane?

You say, if the mach number is less than 0.3 we will treat them as a low speed and beyond 0.4, the beginning of high speed starts. Typically, you know the transport airplane say going 747 airbus, all this series there by flying someway around 0.85 0.8 to 0.85 around that mach number. So, that we get better time advantage in terms of reaching a point, but designing such an airplane, specially the wing we need to be little careful.

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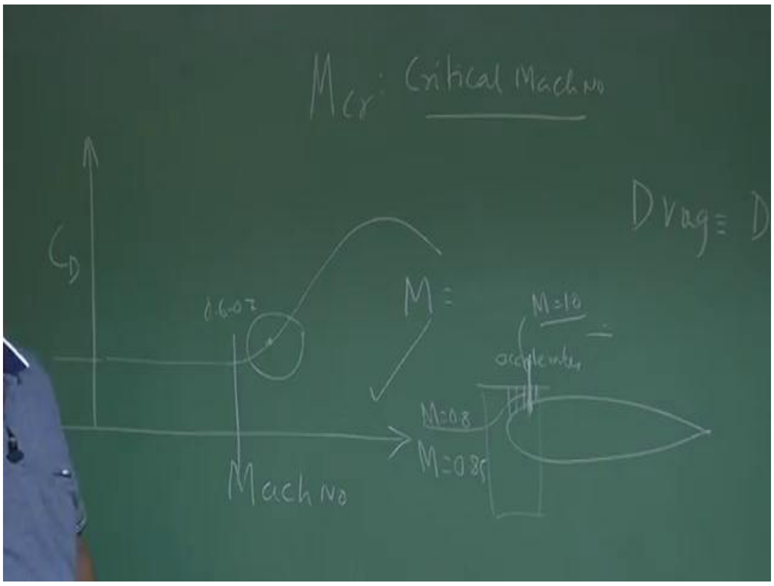

Remember one thing, as for as drag is concerned we know the major component of drag is the friction drag is because of friction or skin friction, some pressured drag, because the flow separation. Also when I go to high speed itching in a transonic and supersonic, the compression will start and there is a formation of shock wave. If there is a formation of shock wave, we know that lot of energy will be lost and that equivalent drag we say D W or W is for wave drag.

Now, we are designing an airplane, let say at mach 0.85 whose mach number is 0.85 or let say 0.8. We need to be very careful about few things, one is typically if you see C D versus mach number plot, typically it goes like this, up to this 0.6 and 0.7 all aero dynamic coefficients are parameters, derivatives all most they remain constant with mach number. Whole story begins beyond 0.6 or 0.7 and there is a region here, but there is a sudden rise in sharp rise in C D.

So, that is typically called mark diverges or drag diverges mach number. To be more precise drag diverges mach number that is, well at some point some mach number there is certain increase in the drag profile. So, good designer will ensure that when he is flying, he is not flying at drag diverges mach number, number 1. So, we need to plot reduces the mach number and find out what is the drag diverges mach number, if it is 0.85 we will not design the airplane for cruise at 0.85 we will try to see something different than 0.85 in 0.75, 0.78.

So, you have to avoid this drag diverges mach number, number 1. Number 2, we have been discussing this is the viewing let say and as the flows comes here, the flow accelerates here. Do you recall this? Because, if I take a control surface like this, the area reduces to velocity will increase to maintain the same continuity of flow. So, there is an increase in the mach number or increase in the speed. So, suppose somewhere here it is 0.8 and you have wrongly design the aerofoil and what happens, at certain point, because the speed is going to increase, at certain point it is reaching mach number equal to 1, then there will be a certain increase in the drag profile.

So, we need to know what is that mach number, what is that free stream mach number corresponding to which. For the first time the aircraft, the local mach number goes to 1 and that is called critical mach number. What is this critical mach number? I repeat which is critical mach number, it is the free stream mach number which is really not 1, less than 1. It is the free stream mach number corresponding to which some point on the aircraft, for the first time it reaches the mach number 1.

So, the corresponding mach number is called the critical mach number, it is so happen that if restream is 0.85 you find here mach has become 1, because flow is accelerating.

So, we need to ensure that is, mark critical or critical mach number should be as high as possible.

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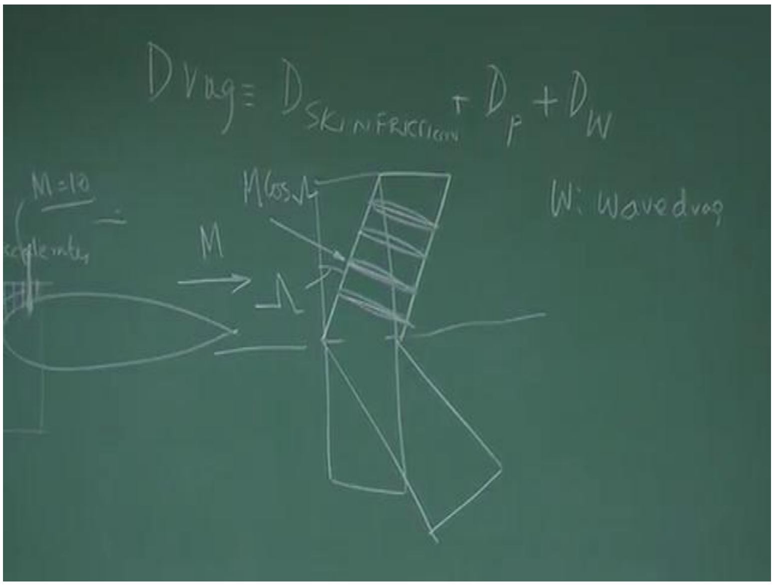

So, how that is done? You know by now, instead of putting rectangular field or rectangular wing we will be giving sweep to this wing, the aerofoil should be like this. So, what happens if this is the free stream mach number, the normal component to this leading edge of the aerofoil will be always M cos lambda, lambda is this angle you call it sweep angle. So, as lambda is greater than 0, the mach number seen by the leading edge of the aerofoil is less than the free stream mach number.

So, you can by giving appropriate sweep angle you can go on increasing the critical mach number, if you want the primary reason why we give sweep back to an airplane. But, as I have told you that nothing comes free, the moment I give you a sweep since the normal component to the aerofoil is less than free stream mach number, because it is M cos lambda. So, the lifting property lifting characteristics or the lift now generated will also reduce, because now it is M cos lambda, so that is the penalty you give.

However, through analysis you could see the total drag reduction is relatively more compact to the loss in the lift, but there is an optimal angle you have to operate or design should take care of all such issues in detail. You must be aware, you can go for a Google search, you could see the Russian mid 21, mid 21 bits it has the very able sweep that is initially the sweep is almost 0 and then, as it increases speed it introduce a sweep back that is, where it tries to optimize the aero dynamic efficiency.

But, doing that you should also understand you have additional load of mechanisms, which could reliably do this at all times number 1, this also among to the increase in the weight and increase in weight always have a adverse effect on the performance. So, designer has to do all these set of a systematic sensitive analysis and find out an optimal or near optimal solution. In the design of wing and it is layout, we will also see few configuration which may draw your attention, it should at least help you ask a question why this wing is like this.

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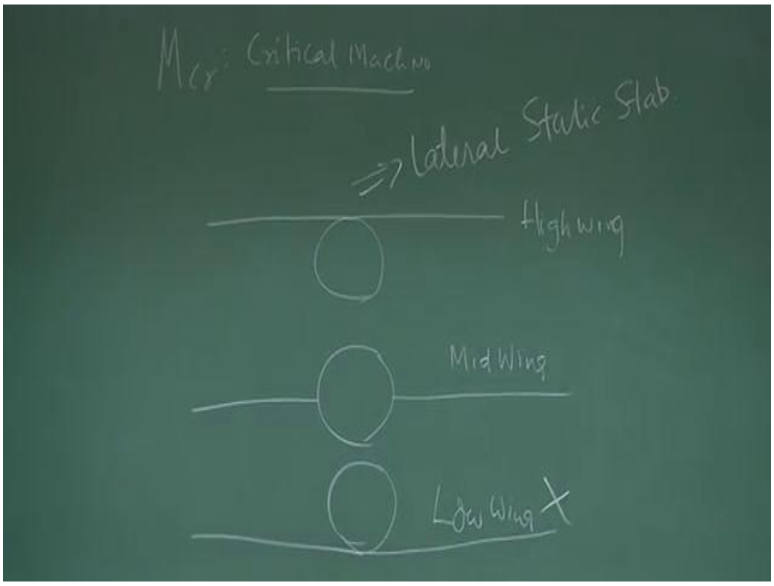

For example, this is the fuselage, I can have a wing which are like this, which is called high wing, I can have an airplane which are like this, these are called mid wing, I can have airplane, where like this which are called low wing. If I compare 1, 2, 3 among them, the high wing is latterly more stable. What is the lateral stability means here? I am going like this straight and because of some disturbance, the airplane has bang like this.

Lateral stability means again I am taking about static stability. So, it means the moment this it disturb like this, it should generate initial tendency to come back to the original bang angle. So, how it is done? For longitudinal case you know it is so the horizontal tail, for directional case it is so the vertical tail. But, for lateral how does it happen please understand. What happens if there is disturbance, the airplane is sideslip like this, as it sideslips there should be some surface which should generate a force and try to take it back.

If I have such surface available in the airplane then I should be able to make it statically stable in lateral mode. So, this understanding see static the high wing case, in high wing case let me explain this is the typically I am time represent high wing case. Now, if there is a bang like this what will happen, because of this lift vector tilted now it would try to sideslip like this, as it sideslip like this air will gust in here and that will give a pressure which will translated into force and moment and will try to turn it back.

So, because of high wing there is a initial tendency to come back to the original bang angle. So, I say it provides lateral static stability, suppose it is a low wing like this assume this is the ((Refer Time: 16:38)) then what will happen as it bangs it sideslips. But, now the air pressure will act on this top surface, the further turn in back, further bang it down; that means, it does not have any lateral static stability that is why when we are having high wing it passes a lateral static stability.

This does not, this is unstable and this is mid wing in between, but suppose there is a comparison that we have to go for a low wing, so what we do, what is the option.

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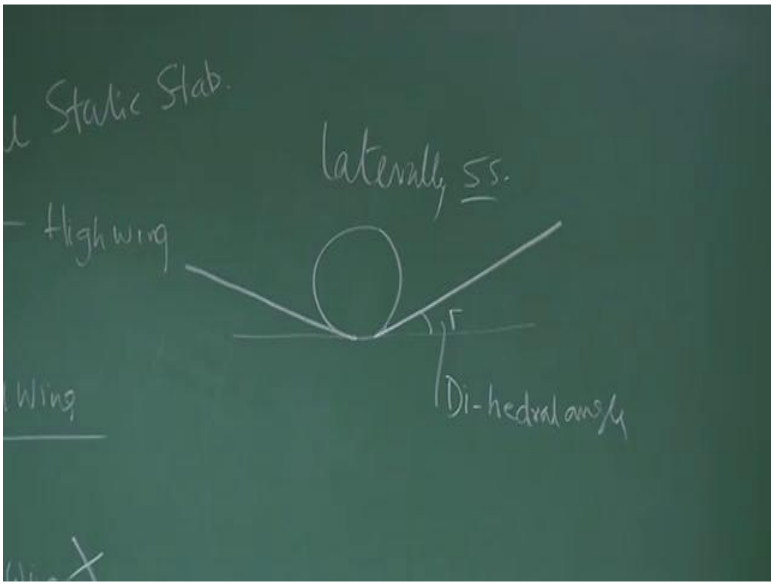

Option is no problem, instead of installing the wing like this I will install the wing like this and this angle this is called Di hedral angle, it could see that this giving a Di hedral like this, this will do exactly same thing as the high wing as it bangs like this it sideslip. Because, the surface is like this it will roll it back that if I that explain you let say this is the Di hedral angle one wing as there is the bang it side slip. So, air will gust in here I give a force it will turn it back. So, giving a Di hedral actually you are making it laterally, statically stable. So, we should not get where if you see, some Di hedral is given.

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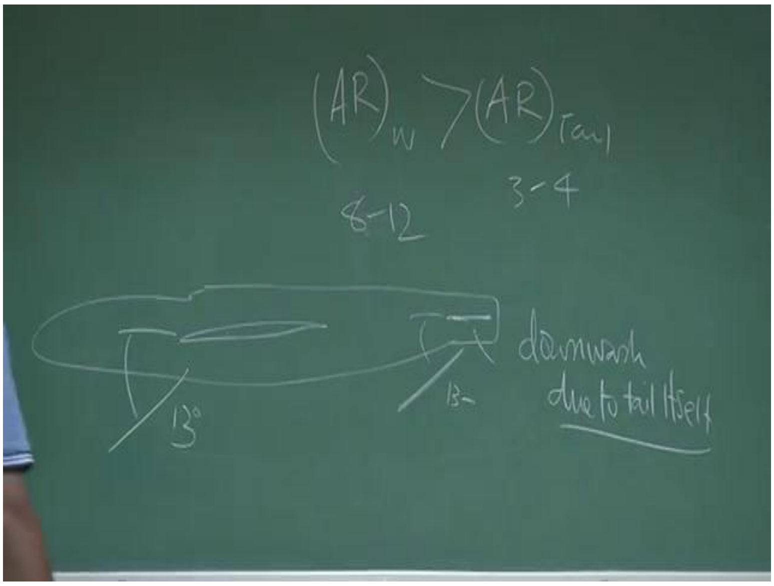

You should also understand one thing that the aspect ratio of wing is always greater than aspect ratio of tail typically if it is 10 to 12 or let say 8 to 12 it is 3 to 4 or 5. What is the reason? Question is what is the reason? We know that if aspect ratio is high then individual component will be less. Because, for infinite it is 0; that means, as aspect ratio is higher and higher goes higher and higher the downwash at the wing goes on reducing, if aspect ratio small then downwash at the wing is large.

So, now, see this is the airplane tail at this is the wing is aspect ratio is more. So, downwash is less, suppose the airplane some over as come near the stole let say 12 degree or 13 degree. So, what will happen, the wing will see 13 minus some downwash angle which is very small, because where put high aspect ratio, but same 13 degree now the tail will see much relates, because tail will have his own downwash which will pretty high, because aspect is less.

That means, even if the wing going to stole the tail will not going to the stole, because of downwash due to tail itself. So, that is why we keep always aspect ratio of the tail lesser than aspect of the wing. So, that even if the wing stoles my tail is here which will not going to stole will try to help me out by giving a moment I like to come down and I will happy very happy coming out of stole. So, this is also one are to observation you must have.

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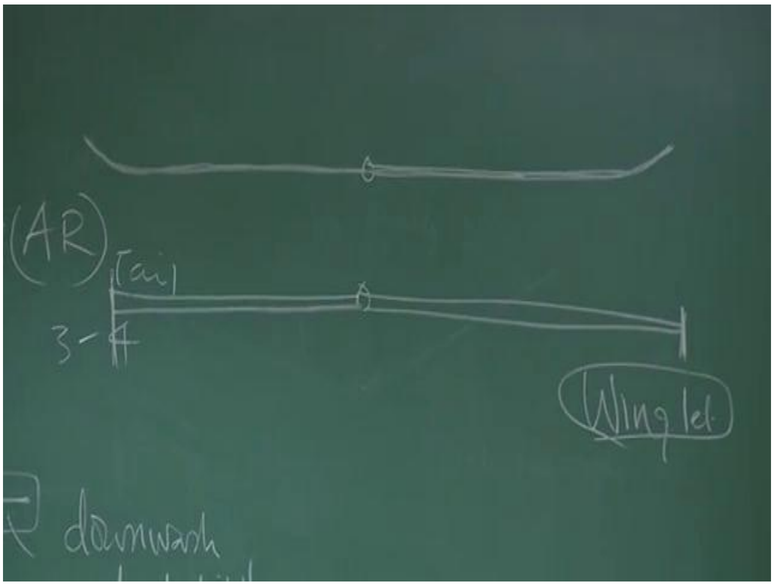

You will also see that if I have what wing like this high aspect ratio wing like this to reduce the endues drag we put some plate here and we call it a wing let. So, that physically starts the interaction the higher pressure and lower pressure. So, what is as whatever is to be form will have now almost it will be demonist. But, suppose we are putting this wing let this the penalty you give, because there is some drag because of the wing let itself.

So, we are taking optimize it this is another way of handling the situation you will find if this is the wing, the wing will be rays like this in continuity to rays like this, this is also doing almost something like this. But, in a very continuous manner only problem of such high aspect ratio viewing and this set of configuration is they became very sensitive to wing that is whenever we launch our glider will go for a ride there are wing, appreciable wing we will not really go for flight that day, it because very, very sensitive to me.

So, going to design an airplane I hope will be taking if they require of course, also on aircraft design, explicitly before that we are planning to have a course on aircraft stability on the control, which is our regular course in third semester. And when we go step by step we will see that little knowledge about this will help you to raise questions in your mind how do I model it, how to I get a data base, so that by designers can utilize it and conveniently create a platform for pilot place very comfortable.

Thank you very much.