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

Lecture - 18
Wing Arrangements

Good morning. We have been discussing about wing, wing plan form, we talked about aerofoil, talked about twist, talked about tabber ratio to ensure near elliptic leave distribution; primarily for low speed airplane so that induced drag is low. We talked about sweep, when we talk about sweep; we are talking about high speed or a supersonic airplane, we also talked about critical Mach number, drag divergence Mach number; all were related to air fall and wing in terms of their land form or their cross section.

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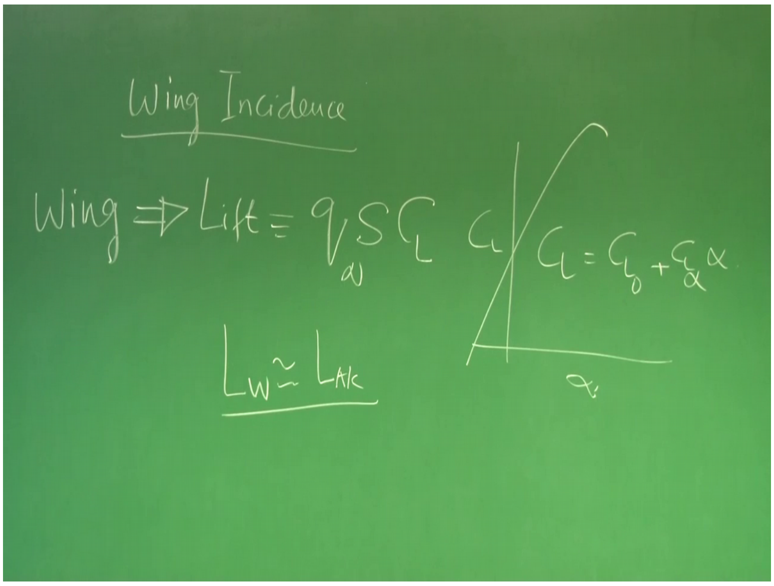

Now, next step is what we will be discussing and sharing what is there in that domain of aircraft. When you talk about wing, we also should talk about wing incidence. What do I mean by that? Fundamentally, wing is primarily to give lift and lift; we know this is dynamic pressure S into C L and C L is depending upon type of aerofoil you are using, so C L is; C L naught plus C L alpha into alpha.

At the initial stage or during conceptual stage; we can assume that lift on the wing is approximately of the same order a lift on the whole aircraft, although we understand lift on the whole aircraft is summation of lift on the wing, on the horizontal tail, the fuselage, and canard.

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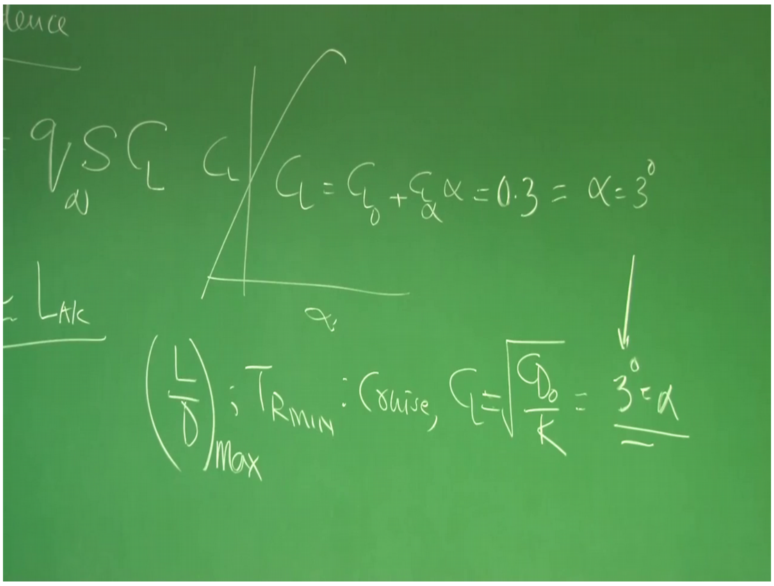

But initially, we just think like that the majority part is wing, so the question is if I am flying such that I am to fly at L by D Max so that thrust required is minimum, it is typically during cruise and that C L is roughly C D naught by K, where you assumes C D is C D naught plus K; C L square. So, I have the option either I designed the airplane; let us say this angle is 3 degrees; what is the meaning of that 3 degrees that C L is; that C L which corresponds to 3 degree of alpha; that is if I come here, if I put here this C L is 0.3 and which corresponds to this alpha equal to 3 degree; that is what 3 degree I am write here.

I have to give 3 degree to the wing, so what is the best way? Suppose this is the fuselage and this is the wing and the wing chord is; assume that the wing is untwisted, the wing chord is parallel to the fuselage center line. So, if I want to give 3 degree; I have to rotate the whole airplane like this. So, we will also have 3 degrees and fuselage also will have 3 degrees. So, lift will primarily come from the wing, but fuselage being at 3 degree will also give some drag; larger drag.

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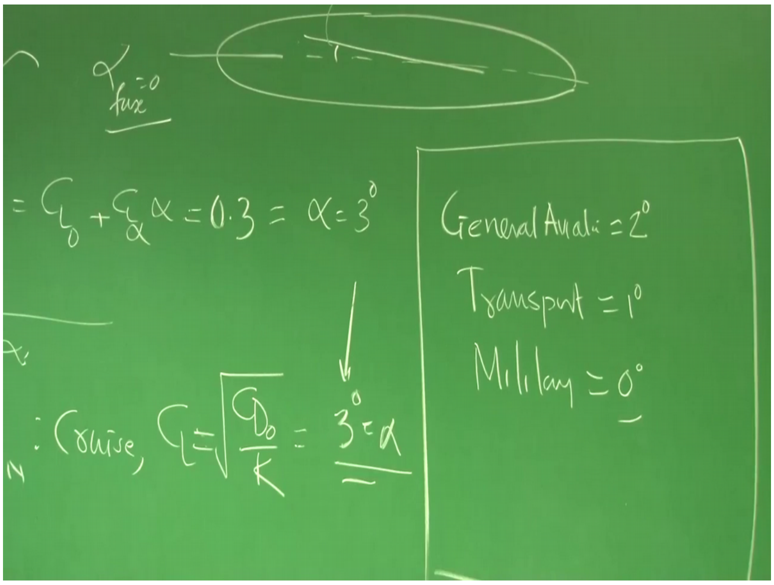

So the question comes, why do you want to fill the fuselage? Why not set the wing; this is the fuselage as in the first line, set the wing so that wing setting angle is 3 degrees. So, in that case ideally what will happen; the fuselage will have almost 0 degree; alpha fuselage will be 0 degree, so drag from the fuselage will be much lower. So, that was the concept behind wing incidence, but now you know there are cambered aerofoil if you are able to generate at smaller angle of attack and anyway this considerations are for cruise and as the airplane will become higher and higher in terms of speed, the angle of attack requirement is very very low.

So, it is not necessary all the aircraft will be utilizing this concept; many aircraft will find this absolutely no wing incidence angle. But historically it is to be noticed that around for a general aviation; around 2 degrees wing setting angle for transport maybe around order of 1 degree and military maybe 0 degree. But whether it is 0, 1 or 2 degrees; it does not make much of a difference as far as carefully designed fuselage is concerned; in terms of drag minimization.

But these are general guideline, you will appreciate that you do not want to design an airplane where if in the cruise it has huge altitude to ensure large angle of a tag, then how the crew members will move inside that aircraft; fuselage. So, this is typically the guideline, we will know more about the utility of this wing setting angle when we talk about; controlling the airplane during the stability design of the airplane, but I thought we must mention this.

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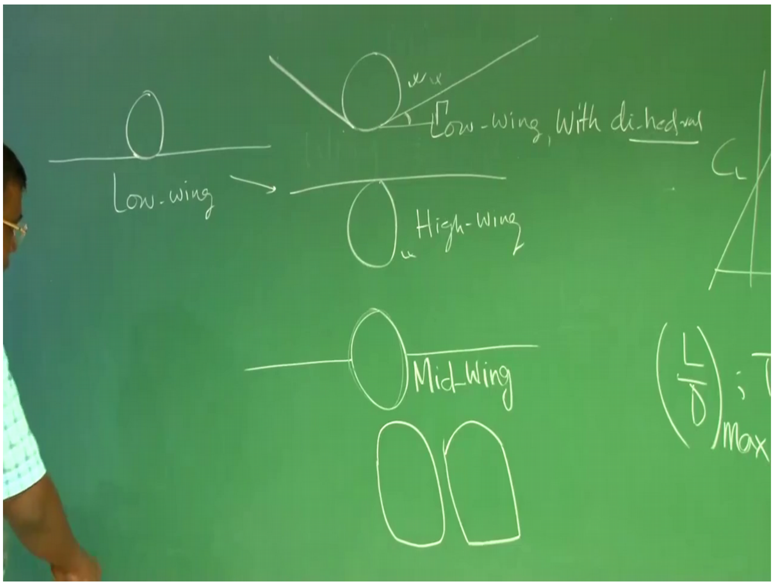

Similarly, you will find aircraft having wings like this located at the bottom; there could be like this and there could be like this. You are aware this is a mid-wing configuration, this is high wing configuration and this is low wing configuration. We also know why such configurations are chosen aerodynamically from stability point of view, that a high wing will be laterally more stable as far as wing contribution is concerned; that is if this is the high wing, lateral stability means if it bangs you should try to come back, it should have a initial tendency to come back.

So, what happens if airplane bangs it starts side slipping and because the high wing, the air will gusting and it will try to turn it back, which you know in terms of C L beta less than 0. For low wing, it is reverse; if it bangs, the contribution from the wing will make it further role or further bang because it is laterally unstable, statically unstable as far as low wing is concerned. But you will find when I am saying low wing, typically I am meaning this; this is what laterally unstable, but here some angle has been given; this is low wing with di-hedral, this is low wing with di-hedral.

This is typical low wing contrast to a high wing configuration here; this is having the characteristic of laterally be unstable as far as wing contrast is concerned. But we will never find a low wing like this; if there is a low wing requirement for some reason or the other, it will have a shape like this and this angle we will call di-hedral angle, so these low wings are given some di-hedral angle.

So, what is the di-hedral angle does? Di-hedral angle will be doing exactly same, what high wing is doing in terms of effects. If it does a di-hedral like this, so suppose this is the wing as it bangs so and starts side slipping, air gusting here, it further bangs but if there is a di-hedral like this for low wing as it turns, the air bringers here and it tries to take it back.

So, with di-hedral again you add lateral stability; mid-wing of course you see from the symmetric midsection of the fuselage; theoretically speaking, but you will find never this shape is completely circular, typical shape could be something like this, it could be something like this depending upon fuselage requirement, other requirements. When I talk about di-hedral, it is important at this stage because we are preparing our self for conceptual design, it is important at this stage to have feel for some numbers; which are historical based.

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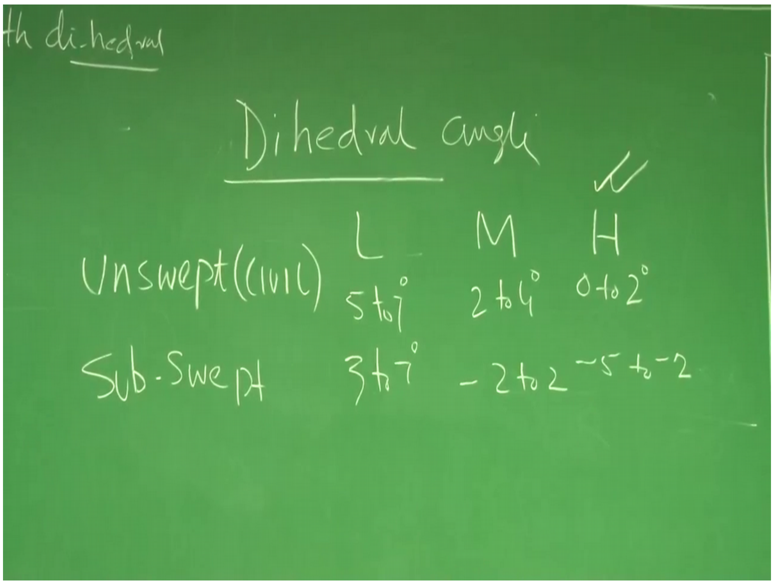

So, if I write di-hedral angle for unswept civil airplane, for low wing, for mid-wing and for high wing typically 5 to 7 degrees, for mid-wing 2 to 4 degrees, for high wing 0 to 2 degrees. In fact, for high wing you may not require any di-hedral; in contrast if we have a high wing, you have to ensure that it should not become over stable as far lateral stability is concerned. But, then these are the combinations because we understand as a designer lateral stability we can get from vertical tail also.

So, if this is already producing lot of lateral stability; the size of the vertical tail you can reduce. But when you reduce it should not be at the cost of rudder power, so all these optimization goes on. Now, similarly for subsonic set it is 3 to 7 degrees minus 2 to 2 degrees and minus 5 to minus 2 degrees, you could high wing and swept subsonic because of high wing; aircraft has large lateral stability it has a vertical tail; we may have to actually reduce the lateral stability because of high wing; there you give an hydra; it will down like this.

So, all this combination goes on then you will be also observing few other things which are related to more on the arrangement and requirement of operation rather than stability.

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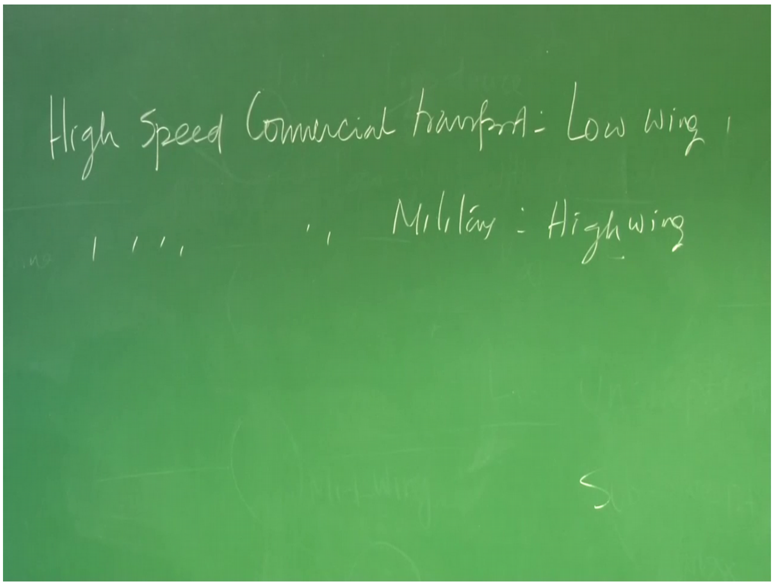

One general observation, you can note down high speed commercial transport are generally low wing. Similar aircraft for military you will find their high wing, this is general trend and these design layouts are not really to talk in terms of stability or lateral stability only it is more driven by your operational requirement because operational requirement for civil transport, commercial transport and military transports are certainly different.

So, as a designer you need to know what type of aircraft you are doing; it is just not knowing aerofoil, wing (Refer Time: 14:42) ratio and all from operational side also you have to be careful and we should take those consideration into the final configuration, that is why I am glancing you through all these information.

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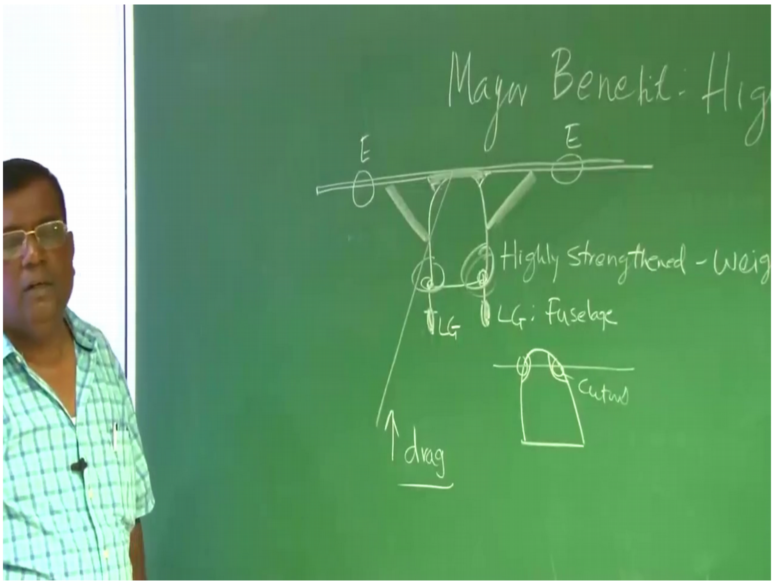

Let us see major benefits of high wing, we are not discussing about any stability issues. Now for example, if I draw a high wing; this is typically your high wing configuration, what are these? These are landing gears. So, where are the landing gear housed for such configuration, high wing configuration it has to be in variably on the fuselage.

So, landing gear is house in the fuselage and landing gear takes all the impact load, so this part of the fuselage; this part has to be highly strengthened. The moment we talk about highly strengthened; natural conclusion would be the weight may increase additionally. One of the major advantage of high wing is we see that fuselage placing near the ground.

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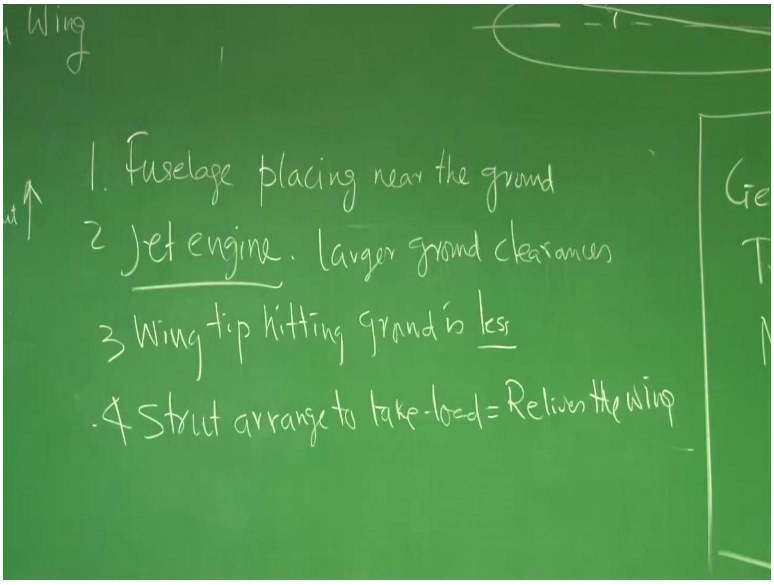

We will understand when you talk about low wing and since engines are here. So, your jet engine or engine in general, especially jet engine we are mentioning where it lot of ground clearance as larger ground clearances.

Another thing because it is a high wing, so we have landing and the because of some defect; some landing defect there is possibility the wing tip hitting the ground like this. So, because the high wing that wing tip hitting the ground during some disturb landing is less because this is the high wing. Another thing you could see that if it is the high wing, I can reinforce the wing for low subsonic or subsonic airplane by giving strut; I can put strut if you take the load on the wing.

So, structurally it makes a wing stronger; the load on the wing is shared by the strut. So, the strut arrangement to take load and thus relieving the wing from stress crossing a limit, one may argue; the moment I put strut the drag will increase, we are talking about low speed aircraft here, we are talking about strut; yes there is a increasing in the slightly increase in the drag.

But, what is dungeon in de strut; they are given aerofoil covered, streamline covered to minimize that, but if you see that drag increased compared to the drag already experienced by the airplane that in comparison is very less, but what you gain is; you can share the load on the wing and thus reduces the stiffening required for the wing; otherwise lateral cause weight of the wing increasing and necessarily all these optimization goes on. But then everything is not happy with high wing, if you see you have to make sure that the wing fixed on the fuselage.

One good thing should come to your mind, why not it goes inside the fuselage. The moment it goes inside the fuselage, if I install it like this which we will be doing for other, if I put the wing like this and if there is a cutout here; then again you have to do the enforcement here, enforcement here. So all these thing will again go on adding the weight and local stress concentration will happen. But if it is like this then what we need some fairing, so wing to some fairing and since this has a thickness; we find there will be a blunt Joel; blunt area which is hitting the air, so this may cause increment in drag.

If it was inside then this portion will not get exposed to the air so we will not get drag because of this exposed portion; this is one disadvantage.

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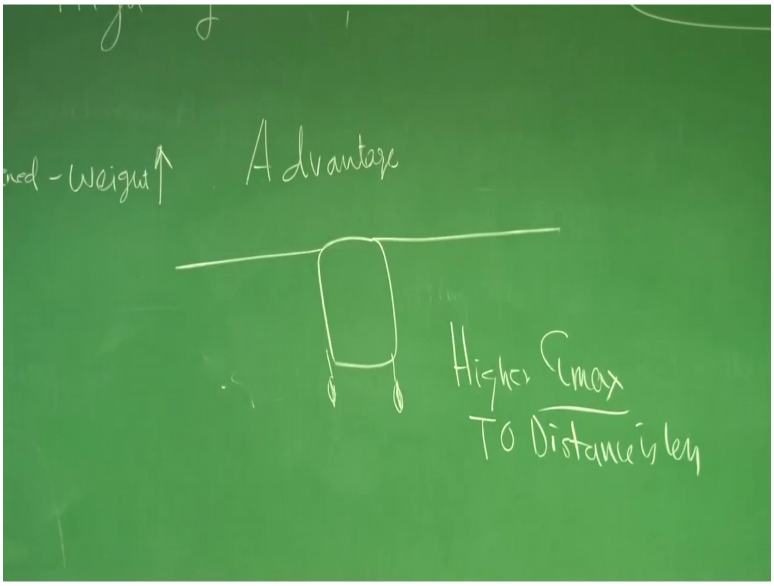

Then again, we will come back to another advantage which is very very important when you talk about the regional transport that is; which are for short distance and the runways are not as good as normal runway. So, if I unpaved runway there you need higher C L max so that your takeoff distance is less then how do increase C L max locally, by using flaps; put flaps down. Since, it is a high wing you have enough space to put the flaps down, maximum deflection of flaps would be whatever you want; there is no restriction of ground clearance, if it is a low wing will find there is a limitations; this is one advantage.

Another you could see that since it is a high wing; ground effect will be little lesser than a low wing if it is here; a low wing would be close the ground. So, if ground effect is not that large so the aircraft will not float because of ground effect when there is sudden increasing the C L, so the tendency of airplane to float which cause a lot of landing problem for their pilot.

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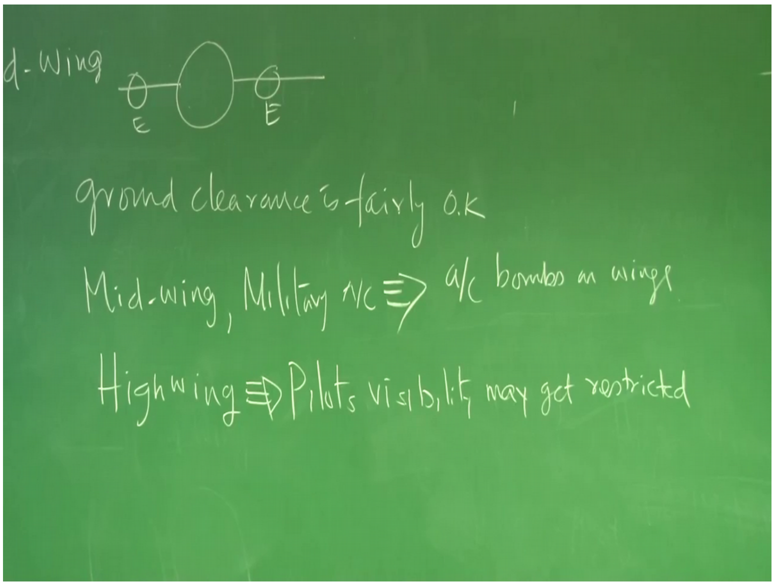

So, high wing will have a lesser ground effect issues; just to complete the discussion, if we think of mid-wing; the mid-wing here also the ground clearance is fairly; not as large as high wing, but fair off.

You know why grand crew is also required because you understand if their engines are here; if they are too close to the ground in the debri form the air sheet they go inside the wing, inside the engine and they may damage the engine, they may damage the propeller for a propeller driven engine, so ground clearance is ok. Typically mid-wing configuration for military aircraft will find mid-wing configuration for military aircraft is jel statement aircraft; primarily to ensure that they can carry aircraft bombs on wings. Also you can understand if high wing; if it is the high wing aircrafts then pilot’s visibility may get restricted. This part is important for a fighter airplane for his survival; he needs to see what is happening outside rear of the airplane.

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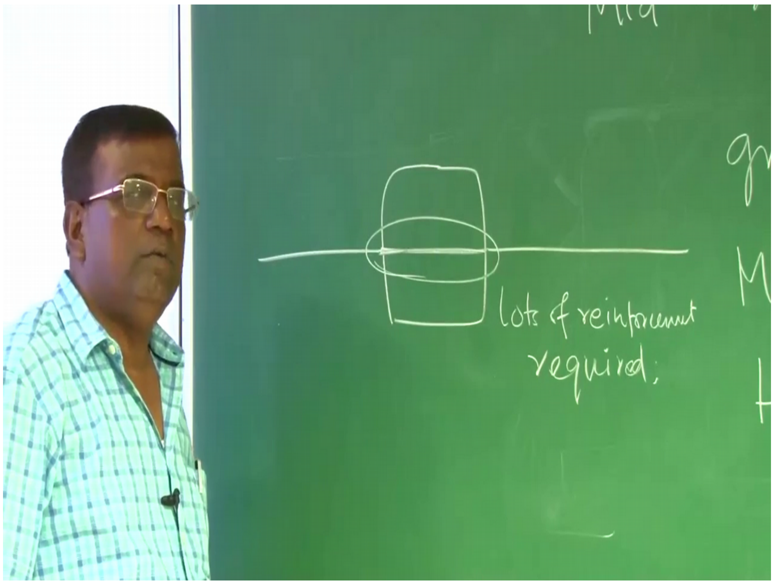

Sometime if it flying like this because the high wing, it may obstruct the visibility of the pilot. Then for mid-wing, you should be also aware mid-wing means this wing has to pass carry over through the fuselage. So, here lots of reinforcement required; I will try to show you with what type of aircraft we have got, how this wing has been mounted. Unfortunately, our all the airplanes are airworthy except one for demonstration; airworthy airplane we will not be allowed to open the wing, but still we will try to show you how these arrangements are made.

I request all of you please see books, do Google search and see how the wings are attached to fuselage for the high wing, for the low wing, for the mid-wing. This is extremely important because you have to ensure that wing is safe enough and if you are not properly designed the weight unnecessarily will increase.

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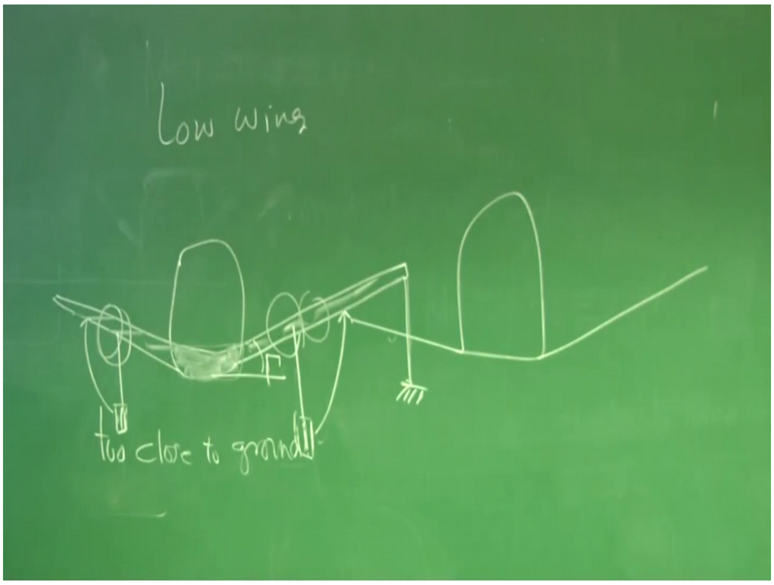

This is mid-wing and when it come to low wing and this is the fuselage; low wing with the di-hedral is here and it has to pass through; low wing is necessarily having an area or the volume of a fuselage been captured. So, we will find that fuselage will have some percentage of area left for wing to pass through; carry over. At the same time you understand, if we are not putting engine here, here there will be too close to ground. So, we have to ensure the fuselage is raised upward so that there is enough clearance.

So, in variably you will find the landing gears; long landing gears which are installed in the wing; there are of larger length, larger height and then this calls for reinforcement here, reinforcement here and then also please understand one advantage that you can stack this landing gear inside the wing. So, landing gear goes inside the wing, so again mechanisms comes larger thing has to move like this.

So, this is what your low wing configuration will demand; mostly the structural people are concerned whenever you tell them high wing, low wing or a mid-wing because their design philosophy will decide whether the weight is going toward increasing side or a decreasing side or the optimal side. It may not be very surprising that this di-hedral angle, what we put for a low wing may have large component which attributes towards a clearance of the skip from the ground; that may decide.

If I do not want the aircraft land and hits the ground, so this di-hedral angle maybe predominantly decided by how much clearance you want to keep from the ground. So, all these combination goes on that is why beginning of the design, I think this sort of a knowledge exchange is important before you start conceiving what will be your conceptual aircraft.

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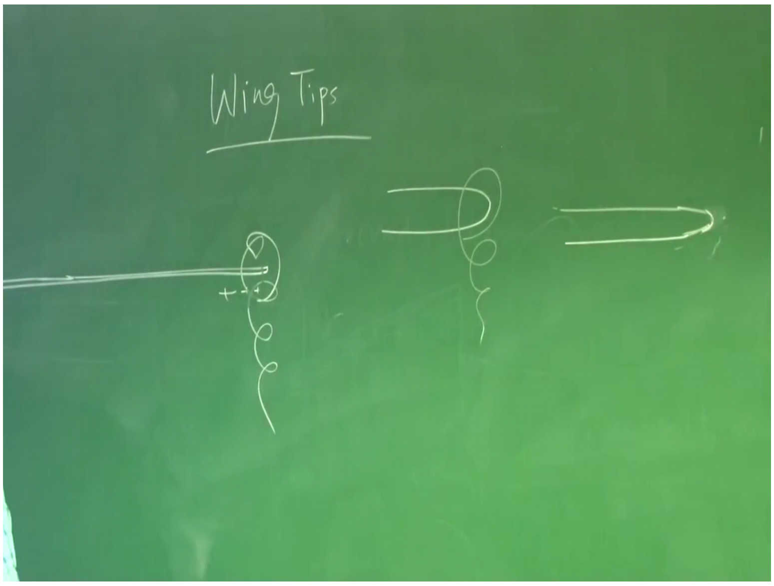

Another important part of wing; wing tips and you know what is; so, importance about wing tips we know that our aim is to ensure high L by D and one way to increase L by D is to reduce induce drag and induce drag phenomena is something here, but the vertices from here because of pressure this differences. So, if you want to reduce this induced drag somehow I should discourage the tendency of the flow from high pressure to lower pressure region.

There are many ways of doing it, if you have a simple faired tip; this will allow the flow to easily go and encircle and create will give vertices. One is better way of how they evaluation happen that you make little sharper; not this sharper but little sharper. The moment, if there is a little sharper; this discourage is smoothly going into vertices; this is another way of handling is historical propeller handle; you simply cut it here.

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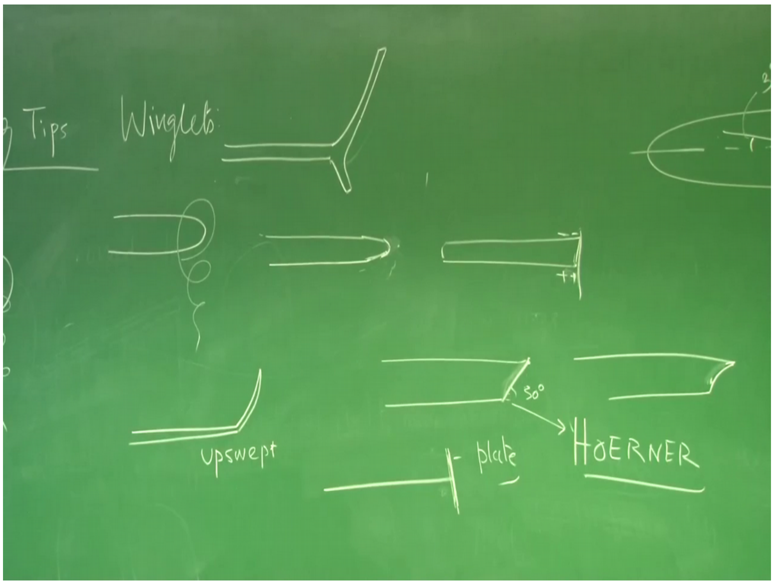

So, there is no abrupt; this abrupt cut, so that will also discourage flow to encircle and go from higher to lower pressure. Based on this philosophy, we will find link tips are also designed like this and this angle could be roughly 30 degree; here also you are discouraging moment of here from bottom to up, we could see that this is very popular in gliders they say just cut it like that. This and sometimes by some curvature is also given, we will find the gliders we come to flight left; I will show you our gliders having this sort of a cut to reduce induced drag.

We will also find this sort of a construction because upswept sinus 912 motor glider which we have has this sort of a upswept. More if you do this; please understand this will affect the lateral characteristics also. Common sense says why not you simply why so many thing, you put a flat plate here and then physical obstructions are lower to upper surface, but just doing this it also increases the drag because of this plate. So, we need to know what is finally, we are getting this was also used.

Whatever I was talking here this is Hoerner wingtips very famous, very popular and nowadays what you say Winglets; they have gone higher something shaped like this. We will be talking about those things in detail; design this looks like this, what is done whatever energy is coming from the bottom to top that they are trying to give a shape on this winglet so that gives the thrust to the forward direction. So, use that energy is that momentum and divert is such a way; I get a forward thrust. So, it is not only put restriction, but conveniently convert that into a thrust we say the drag gets reduced the opposite of drag; this is typically the principle of winglets.

We must do an assignment on winglets, if I remember in one of the forum I may ask you to do an assignment on winglets, this is something you need to understand. So, this is general layout of wingtips; so you have seen aerofoil to wing aspect ratio or tabber ratio or sweep back, we talked about high wing, low wing. Generally what is seen around whatever tips; wing tips; but these are to excite your mind, you are supposed to think beyond this. A designer will take some idea from here and he may make a different alter than layout.

In the next lecture, I will be talking about tail arrangement and once you are through with tail arrangement then I can go for thrust loading, wing loading; again coming back to the performance. So, far if when it closed your eyes you should be able to see aircraft wing, some tabber ratio, lift distributions winglets; all these things should come to your mind. Take take a pencil and start sketching; what type of wing you want, what sort of winglets you want to do. Make it a habit draw different, different sketches now as you start designing an airplane, you may pick one of your sketch; you may pick one of your sketches.

Thank you very much.