Aircraft Structures - 1
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Module No - 02
Lecture No - 07
Aerodynamic Loads and Load Factors

Welcome back to aircraft structures one course this is Professor Anup Ghosh from aerospace engineering IIT Kharagpur. This is the seventh lecture in the series in this lecture what we will cover is aerodynamics loads and load factor.

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So what are the concepts we will be covering is flight vehicle aerodynamic loads that is not in details. It is a very small brief or maybe we must say in a very brief way how the load comes. And then the calculation of load factor at different flight conditions how do we calculate it one example and then we will see the bending moment and shear force calculation for with some example of an aircraft. But before we go into those it is with better to have a recapitulation in the recapitulation, we can say that.

We have already learned in our previous lecture that what is flight envelope is and how does that flight envelope govern the design of an aircraft. How air worthiness criteria and regulations come and we need to follow those and how we need to take care of all those requirements. And previous to that we have learned in various way how different loads are encountered by an aircraft.

And we have also learned the history of aviation, history of aircraft. We have also had look in into the history of solid mechanics which actually lays the path of structural analysis with respect to aircraft structures. So let us start today's class with a note of aerodynamic loads and then a few examples or considerations to calculate load factors and bending moment shear forces.

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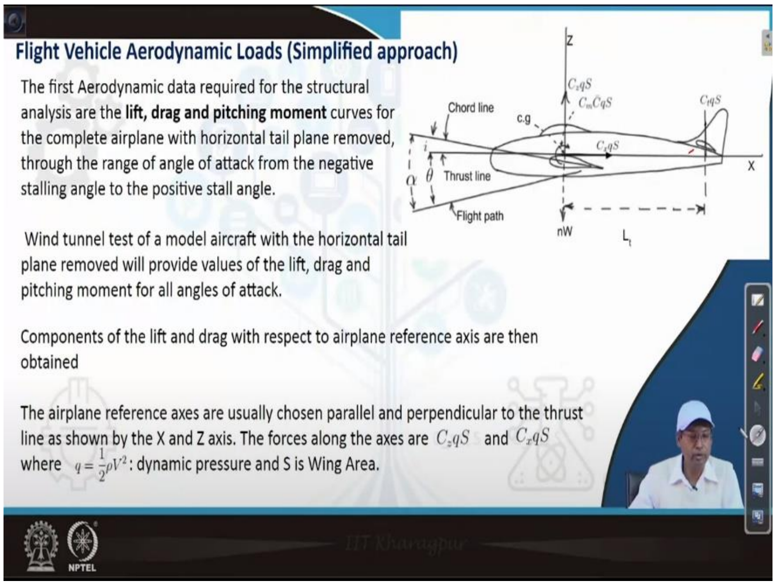

So if we see flight vehicle aerodynamic loads if we think of finding out how the load comes in it is the simplified approach we will be following, as we have seen that we have denoted that C coefficient here as Cz. So we are not worried about in which exact direction the is acting but we are talking about the component of it which is acting in the Z direction. We are also talking about the component as Cx.

So let us see what are the things we do after reading out this small description we will see generally the thrust line is considered as the axis? The first aerodynamic data required for the structural analysis are the lift drag and pitching moment. So unless we have these data we cannot design any aircraft. So then on that the load factor or the flight envelope gives us the maximum load. That is we need to multiply by in. Unless we have the lift we cannot find out the maximum lift or design lift or ultimate lift.

We need to find out drag, we need to pitching moment. We need to prepare this curve with respect to the alpha or angle of attack for the complete airplane with horizontal tail plane removed. This is important this is the general criteria generally the structural design starts through the range of angle of attack from negative stalling angle to the positive stall angle.

Negative stalling angle and positive stalling angle already you have talked about stall angle stalling is the phenomena when aircraft losses its lift probably you are already introduced to it negative and positive is that while it is in positive angle of attack or while it is in negative angle of attack. Wind tunnel test of a model aircraft with the horizontal tail plan removed will provide values of the lift, drag and pitching moment for all angles of attack.

Components of the lift and drag with respect to airplane reference axes are then obtained. The airplane reference axes are usually chosen parallel and perpendicular to the thrust line as shown by the X and Z axis. That is what I mention in a brief the thrust line this line is the thrust line which is generally consider as X and perpendicular to that is the Z axis. The, forces along the axes CzqS and CxqS where q is the dynamic pressure equals to half Rho V square and S is the wing area.

So 2 force coming from the lift is this is the total force CzqS in vertical direction and in the horizontal direction is this much.

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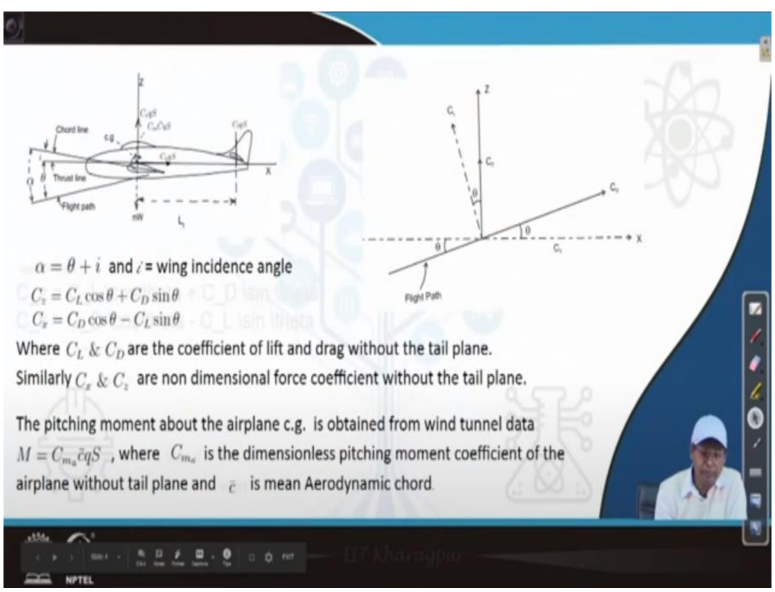

Now what do we do we have that Cz curve and Cx curve from experiment and now it is probably before the experiment numerical studies are done and similar condition we find out those data. We simulate and find out those data here our angle of attack alpha is theta + I is the incidence angle and theta is the thrust angle with the flight path. And definitely a simple with respective to this diagram if you see this we get the Cz as CL Cos theta + CD sin theta and Cx as Cx Cos theta -CL sin theta

Where CL and CD are the coefficient of lift and drag without the tail plane. Similarly Cx and Cz are the excuse me Cx and Cz are the non-dimensional force coefficient without the tail plane. The pitching moment about the airplane Cg is obtained from wind tunnel data which is M generally given as that Cm alpha c bar qS. Cm alpha is the dimensionless pitching moment coefficient of the airplane without tail plane and C bar is the main aerodynamic chord.

So this data we need to need for our structural design we generally many times refer to this for this reason these parameters are shown here to some extended explained and we will see how this data will use for our structural purpose.

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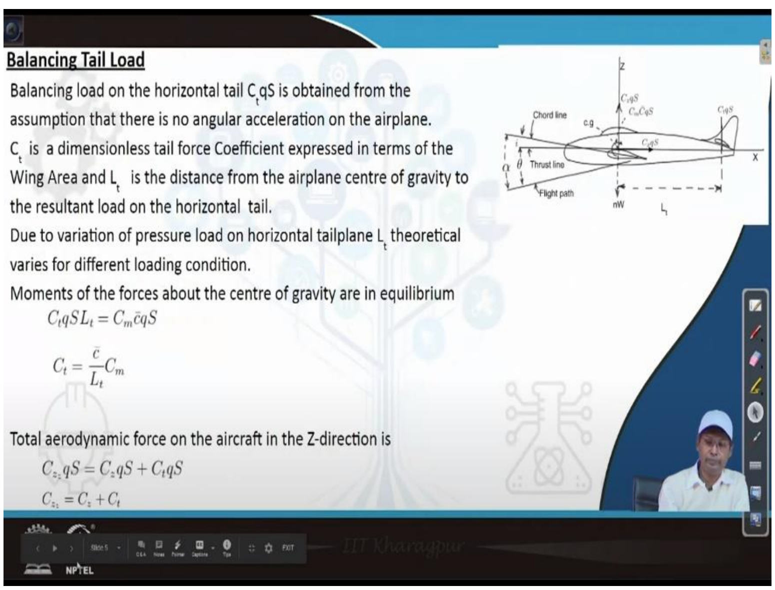

Ok those who have found out but there is something more for different flight condition there is a contribution of the tale of how the balancing tail load comes. So balancing tail load comes this way as we learn balancing tail load on the horizontal tail CtqS is obtained from the assumption that there is no angular acceleration on the airplane. So there is nothing like no angular acceleration and no pitching movement is there or pitching acceleration is there.

Ct is a dimensionless tail force coefficient expressed in terms of wing area and Lt. Please note expressed in terms of wing area and Lt. What is Lt? Lt is distance from the Cg to the point reference point in the tail plane. So due to various pressure load and horizontal Lt is the distance from the airplane center of gravity to the resultant load on the horizontal tail plane. Due to the variation of pressure load on horizontal tail plane Lt theoretically varies for different loading condition.

Lt's varies but anyway we may consider this as fix and we may start our calculation. So moment of the forces; about the center of gravity are in equilibrium. So that is what with respect to this point the moment is considered. So with CM alpha c bar qS that is this one is equals to CtqSLt and that is what is done and then from there Ct is equal to c bar Cm is divided by Lt. And the aerodynamic force on the aircraft in the Z direction comes as the sum of these both these 2 forces which is a equals to scissors Z we considered as Cz + Ct.

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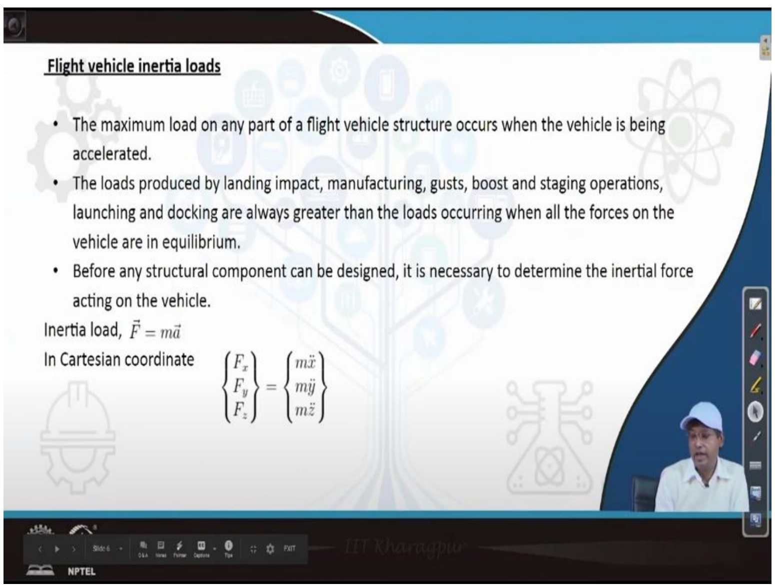

Flight vehicle inertia loads this I was bringing in repeatedly in our previous discussion. Let us see in a methodical way what it is? How it is comes and will let us solve a few example; with that. The maximum load on any part of a flight vehicle structure occurs when the vehicle is being accelerated. The acceleration may be forward may be upward. So let us see how this acceleration may come with example will learn.

The loads produced by landing impact, manufacturing gusts, boost and staging operations, launching and docking are always greater than the loads occurring when all the forces on the vehicle are in equilibrium. So whenever there is a sudden change there is the maximum load encountered by an aircraft that is what is said that is learning impact, manufacturing, gusts and boost gusts, boost and staging, launching and docking all these things.

Before any structural component can be designed it is necessary to determine the inertial forces acting on the vehicle. So we need to find out that is what it says the inertial forces and in general in 3 dimensional point of view we have defined the inertial forces in this form. But for simplicity we will solve problem in a separate manner not in 3 dimensional form. 3 dimensional form is really bit complicated will learn later.

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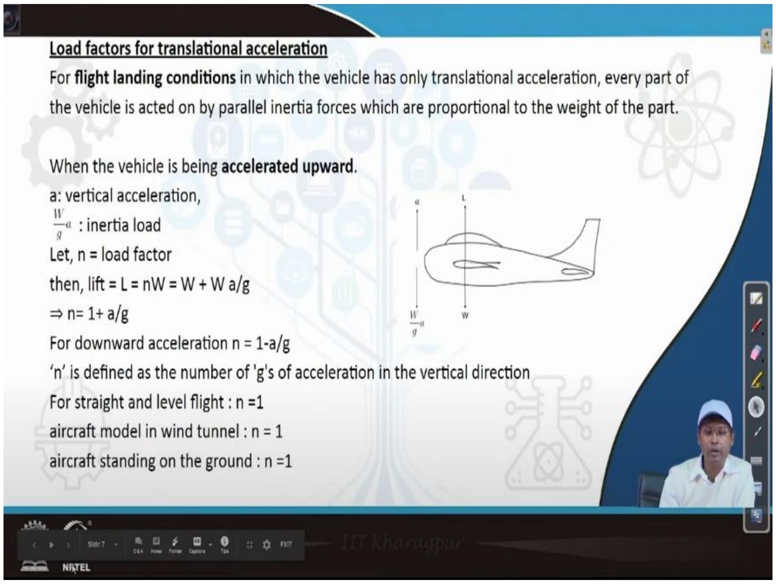

So load factor for translational acceleration for flight landing conditions in which the vehicles for flight landing conditions in which the vehicle has only translational acceleration every part of the vehicle is acted on by parallel inertial forces which are proportional to the weight of the part. So this is a very good example we always see while we experience the breaking of a car. That is what we all have experience.

What happens we fetch we go forward or for a sudden acceleration what happens we push more pressure on the back of the chair. So that is because of our body inertia we are pushing it back and there is a hinge at in our wrist so that is what it is either pushes back while it accelerates or we come forward while it decelerates. But that is a visible movement our muscle system accommodates that is very slowly it is not that slowly happens in all other structures.

In case of aircraft this is very predominant because change of velocity is huge in range. It is not like a car where the in general it varies from 10, 20, 30 kilometer maybe within 2 or 3 seconds. So it becomes more in case of flight vehicles or aircrafts. So that is what is discussed here. When vehicle is being accelerated upward this that is the condition we will be considering now. One point let us consider very carefully that it is accelerating upward. This is what up these direction it is acting.

Now which way the inertia force is acting this is the mass W / g multiplied a this comes from the D' Alembert's principle in the opposite direction. So if it goes up the in a positive acceleration in the goes up it acts in the opposite direction of it. So that is what the inertia load acts on the system. Let n the load factor and from the load factor definition whatever we know that L = nW and that is what is equated with W + W a/g. So lift has to balance both these forces that is what lift is = W + W a/g.

And that is equated with nW and we get the n. And in a very simple algebraic way we get that n = 1 + a/g. For downward acceleration what happens the inertia acts upward. And since the inertial is acting upward this is negative and it is becoming 1- a/g. n is defined as the number of g's of acceleration in the vertical direction. For straight and level flight n = 1. There is no acceleration we say level flight aircraft model in wind tunnel is also 1.

It is equivalent to the level flight aircraft standing on the ground is also equals to 1. So these are the 3 typical condition where what we generally encounter.

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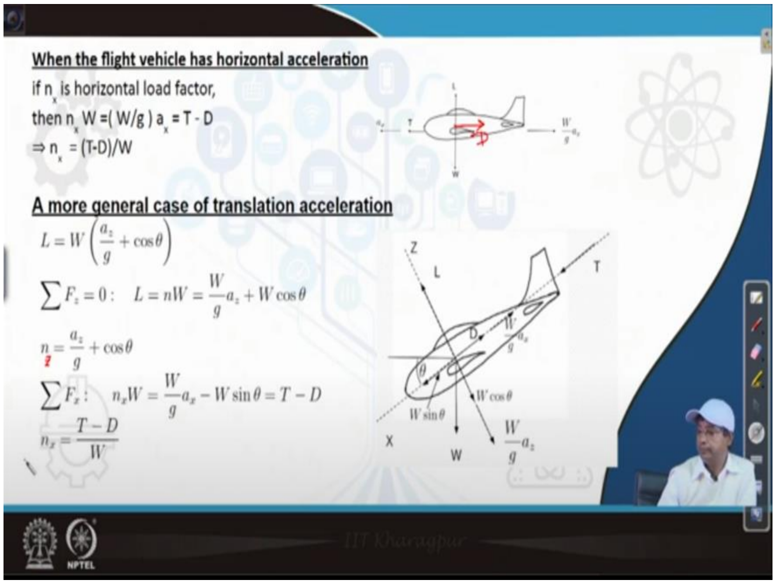

Ok when the flight vehicle has horizontal acceleration this is the case we see we have since it is going this way accelerating is this way ax component. So the aw ax / g is the inertia force acting following the D' Alembert's principle. And that is what is equated in this equation it is very easy. n W = n W / g multiplies by ax which is equals to thrust minus drag. Drag is not shown here actually drag is acting in these direction. So what we do we get from the balance of this is that W ax / g = T - D and nx = T - D / W.

So a more general case if we look at while it is in a different condition and this is the Z axis this is the thrust line, this is x axis this is Z axis W is acting this way. And if we look at the component this is the component in the Z direction is the acceleration acting assuming that it is moving upward so the dummy force, inertial force following the Alembert's principle is acting this way and one more component is acting in this direction. So in the Z direction if you consider the lift is definitely is balancing the component of it.

So this is balances as W Cos theta plus this amount W az / g and if you consider summation of forces in the Z direction which leads to that nW is equals to this amount and n is equals to this nZ = az / g + Cos theta. In the x direction if you look at we have a similar equation T and D is here indicated T is acting this way Dz is acting this way and we finally get nx equals to the same equation what we have here.

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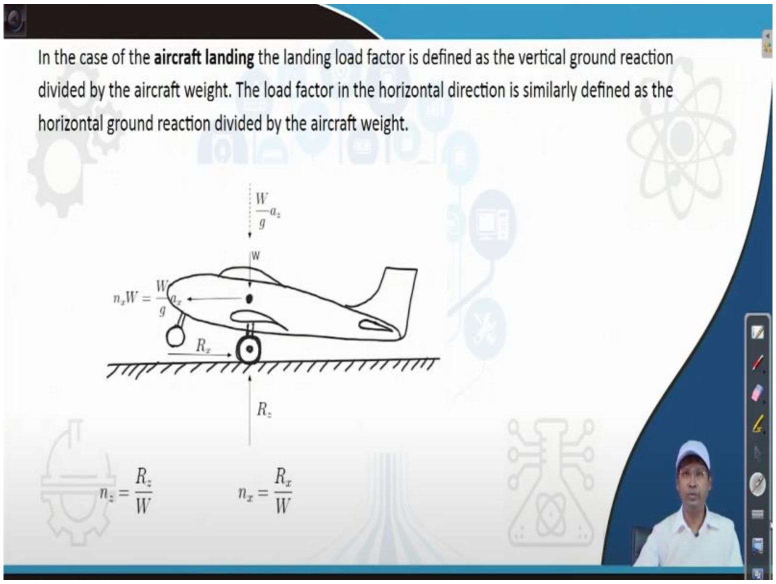

In the case of aircraft landing the landing load factor is defined as the vertical ground reaction divided by the aircraft weight. This is what the ground reaction whatever we get. Please note that inertia force is acting downward. The load factor in the horizontal direction is similarly defined as the horizontal ground reaction divided by the aircraft weight. So whatever the Rx value is that is divided by the weight shown nz is this one and nx is corresponding to this one.

So if you example of different conditions and how do we find out the load factor we have covered and let us try to solve a few examples 1 or 2 examples.

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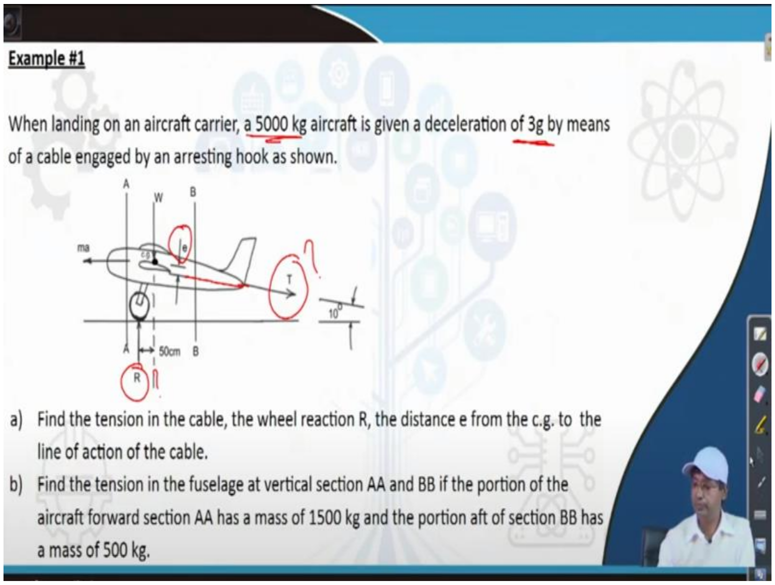

Example 1 when loading on an aircraft carrier sorry when landing on an aircraft carrier a 5000 kg aircraft is given a deceleration of 3g by means of a cable engaged by an arresting hook as shown. Here cable is not shown but the tension by the cable is shown here. This is the tension by the cable and it is given a 3g deceleration weight of the aircraft is 5000 kg. So let us see what are the things we are supposed to find out?

Find the tension in the cable so T what is T? That is first question. The wheel reaction R this is the second question the distance e this distance e from c g to the line of action of the cable. So we assume that this is the line of action of the cable and from cg it is e distance apart. So we need to find out what is that. Another question we have find the tension in the fuselage at vertical section AA and BB in the portion of the aircraft forward section AA.

If the portion of the aircraft forward section AA has a mass of 1500 kg and the portion aft of section BB has a mass of 500 kg. This needs some additional figure that figure we will see later we will come back and do. This portion AA this portion if we separate it out and this portion if we separate it out this portion A has 1500 kg mass. This portion is having 1500 kg mass and this portion is having 500 kg mass ok. Let us try to solve the first portion. Need to clean.

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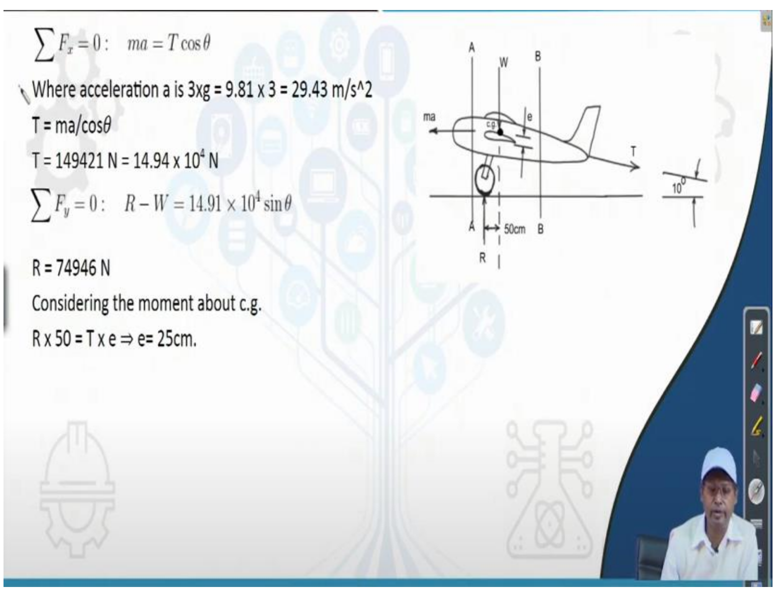

The problem is very simple 10 degrees is given and acceleration is also given. So that is what for the x direction is equation is drawn this type of problem you have solved many times. So there is not much important given on it importance given on it where acceleration is 3G this is important

3 into 9.81 this is the total acceleration and T = ma / Cos theta T is equals to this I do not think there is explanation required. Please note that we are not considering any friction.

Fy is equal to for the reaction we wish consider some of the forces in the vertical direction there are also comes the T portion that Sin theta portion of it and if we solve this simple equation we get R = 74946 newton. Considering the moment about cg this point this is the point what we have we get the value of e as 25 cm. I think you can solve it so the next portion.

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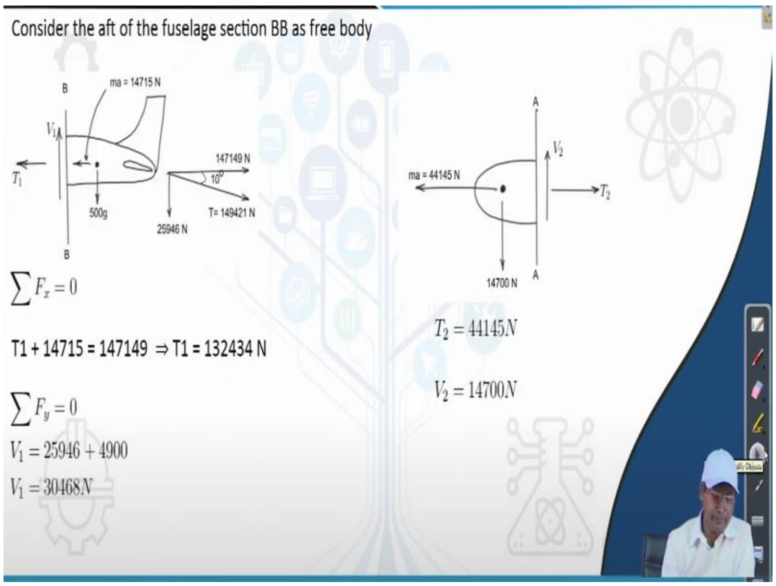

Consider the aft portion or the rear portion of the fuselage section BB which is having mass of 500 kg with respective to multiply by g this is the total force acting here. And this is the acceleration acting at this point. So if we again consider summation of in the x direction what we have this is the force that is what is aft asked. The force in this direction and thus that T1 becomes 132434, newton.

We take this component are this is the component for 147149 this this already you have found out so that is why this diagram have put it here. In the vertical direction if we consider we can find out the shear force acting in this particular cross section. Similar manner if we consider the section left to the AA section the this is coming from the 1500 kg load that is multiplied not shown here with g this is also multiplied not shown here with g and solving similar equations we get that T2 and V2.

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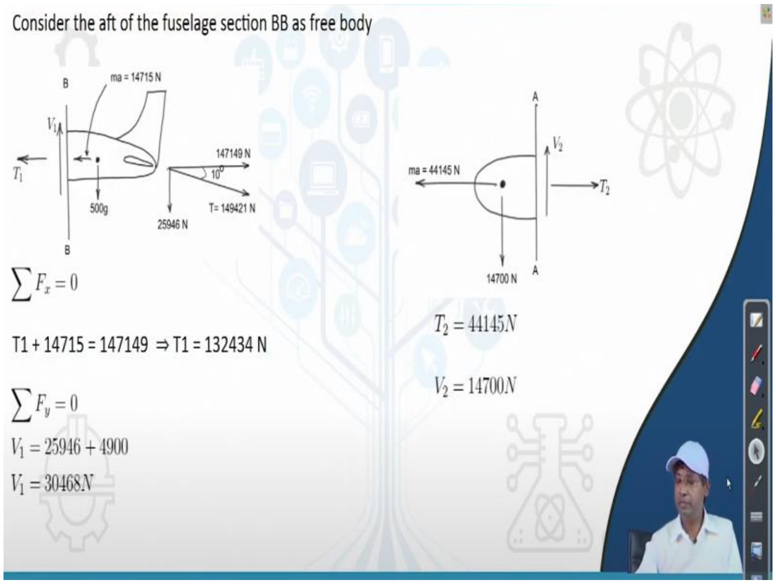

But thing one thing by solving this example it is better to note that while it is arrested on a carrier for landing an aircraft is arrested by hook it experiences a huge load that is in the range of say T2 of say 44 kilo newton or here it is maybe 132 kilo newton. So this is not a very small amount of force and accordingly there are shear forces acting on it on the fuselage. So unless these things are designed properly aircrafts are designed properly it may lead to catastrophic failure.

If you search internet nowadays internet is a big resource and that resource is really you may use it properly there are example videos of failure in this way it is arrested and front portion there is a vertical crack in the fuselage and the front portions goes to accident it is very bad type of failure. Ok let us go for the next example 2.

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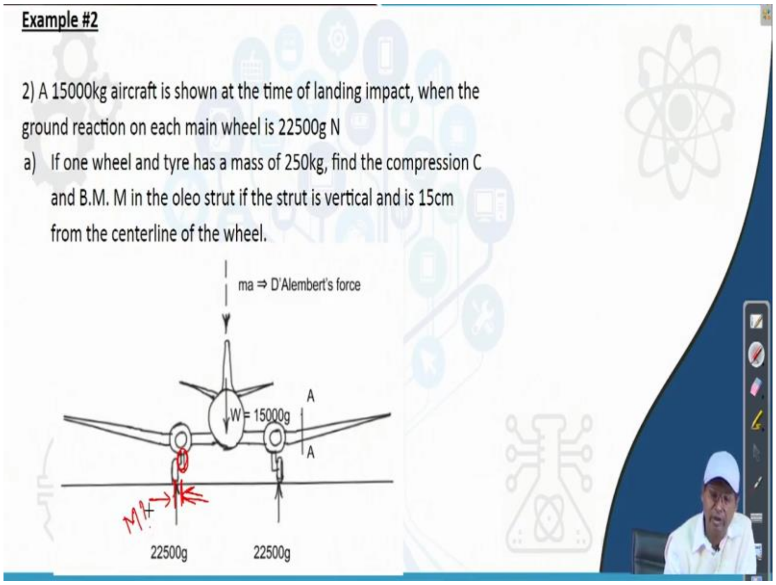

Ok as I mentioned the acceleration following the Alembert's the previous example also before we do anything these example talks about landing impact and important part of in this example is the D Alembert's following the D Alembert's principle what is acting on ma. So it is the deceleration and on depending on the direction. It is though the displacement in this direction's since it is deceleration the inertial load will be acting downwards.

So this point if you keep it in mind. Let us go to the problem now. A 15000 kg aircraft is shown at the time of landing impact, when the ground reaction on each main wheel is 22.5000g newton or 22500g newton. If one wheel and tyre has a mass of 250 kg find the compression C and bending moment M in the oleo strut if the strut is vertical and is 15 cm from the centerline of the wheel.

To understand this language what is oleo strut? Oleo strut is the compression system axial compression shock absorbing system instead of compress system it is better to say shock absorbing system. We absorb in your motorbike probably all of you are introduced to motorbike if you look at the motor bike from of the suspension that is the kind of oleo strut suspension. That type of suspension, are also used to in aircraft that is known as oleo strut.

It is in vertical and 15 cm from the center line of the wheel. So these portion if we look at I think this is the oleo strut portion. This portion compresses to absorb the shock as well as since there is a distance between this and the reaction that reactions will introduce some bending movement and that bending movement M we need to find out.

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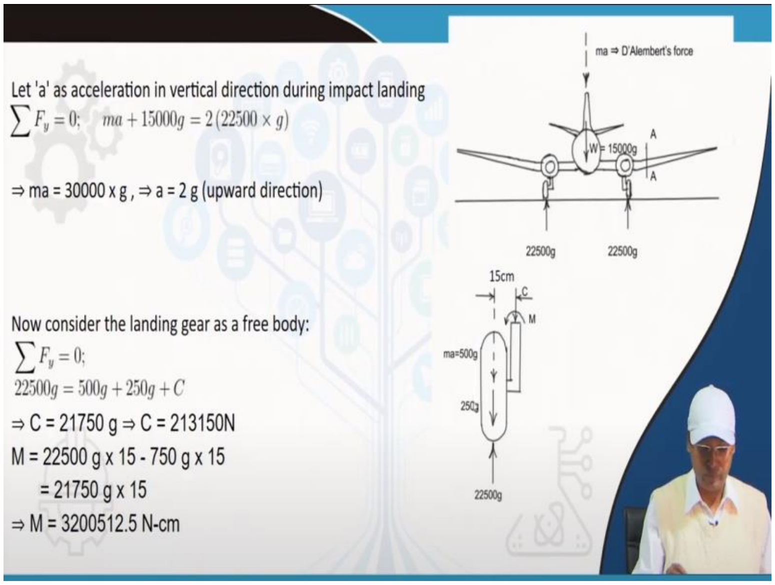

We have discussed in our last slide what the problem is and we have also discussed about why ma here it is acting downward and with respect to that first we need to find out the acceleration a which is not stated here. To do that we consider the equilibrium in the vertical direction considering the y is the vertical direction if we write the equilibrium equation it is something like this and from there we get that a is equal to twice g.

Once we get the value of a is equal to twice g we can find out the forces in the landing gear oleo strut. Oleo strut is the vertical forces here if you draw the free body diagram of the landing gear will this is the oleo strut as we have discussed it is the axial shock absorbing member. So, the axial force we have given as C and the moment encountered here as M. So here for this from your mechanics knowledge we can easily go for 2 equilibrium condition that is at the vertical equilibrium condition.

And considering the vertical equilibrium condition we get that the value of C = 213150 newton. Here this is a 500 g ma because 2G is getting multiplied with the 250 and that there is the reason. For the moment what do we do we consider moment about this point if we consider the moment about this point what happens that this is acting in the same direction that is in 22500 g multiplied by 15 is positive and the other negative portion that is 750, 500 + 250 is considered here and that gives us the moment this way. So let us move to the next part of the problem.

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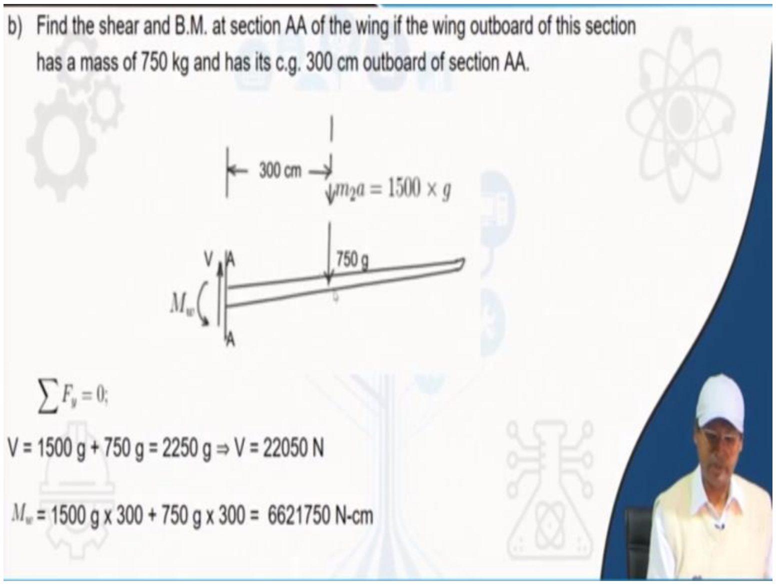

Next part of the problems is that find the shear and bending moment at section AA of the wing if the wing outboard of this section has a mass of 750 kg. So this portion is having a mass of 750 kg so this 750 kg is acting at 300 kg and has its cg 300 cm outboard of section AA. So from here it is acting 750 g is the total force.

So this is a simple same mechanics knowledge we are supposed to use the vertical equilibrium equation is drawn 71500 g is acting downward, and then 750 g this is the inertia force this is the inertia force and this is a weight acting downward, and that altogether makes the shear force in this section for moment we are considering moment about this point and we write the moment equation and we get this value. So we will move forward for the next slide and we will see what we have.

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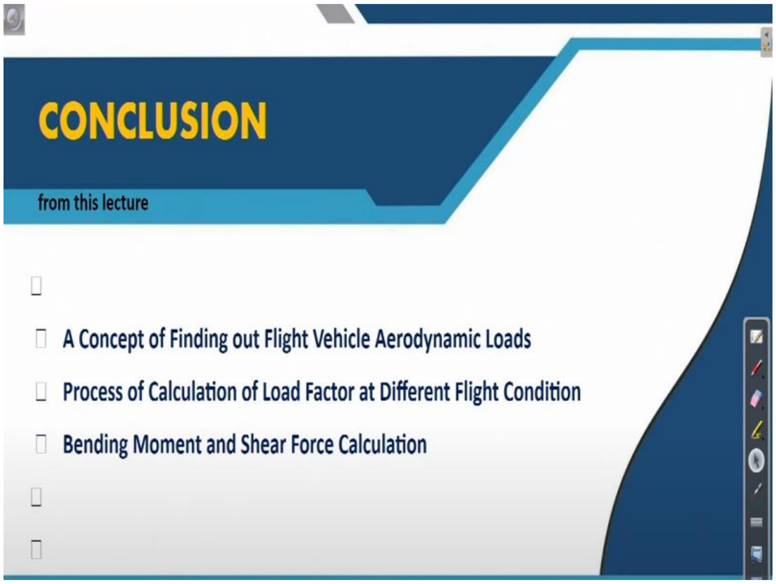

So standard reference we have used what we have learnt from this lecture is that a concept of finding out flight vehicle aerodynamic loads process of calculation of load factor at different flight condition. Bending moment and shear force calculation while it is landing or it may be in different flight condition with example of landing we have learned how to find out how to consider the effect of inertia while we are finding out bending moment and shear force.

And with this let us end todays lecture. Thank you for attending this lecture. We will meet again in our next lecture.