Flight Dynamics II (Stability)

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Module No. # 01

Introduction to the Course

Lecture No. # 01

Earth Atmosphere, Aircraft Components, Aircraft Nomenclature

(No Audio from 00:11 to 00:24) Flight Dynamics II is the name of the course. In this course, we are studying motion of flying objects in air. The motion that we will study is about the equilibrium condition.

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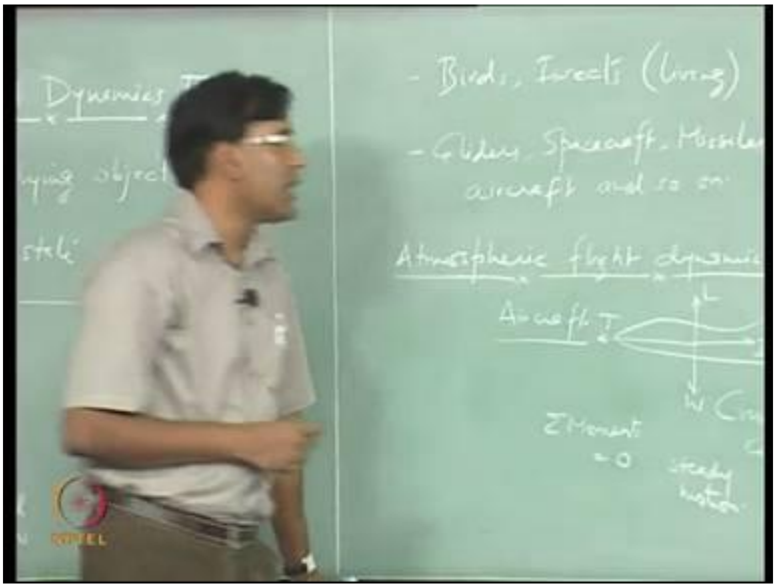

Let us say we assume that, the object that we are looking at, is flying steady equilibrium motion. So there is an equilibrium state, let us say this object is flying. And what we want to look at is what happens to this motion, when aircraft or any flying object, is disturbed from this equilibrium state.

So, what we actually interested in looking at is, the perturbed motion of the flying object from its steady equilibrium flying condition. This perturbed motion is introduced because of the unsteadiness in wind. Several wind conditions, for example, gust or may be a different wind condition, which is suddenly encountered.

There are two things; one is to look at the small motion around the equilibrium state, so this motion is mainly caused by small disturbances, and the other one is related to large motion. So, this is small motion around the equilibrium state and large motion, which requires the control effort. Some of the examples of flying objects are: birds, insects. These are living examples. And there are examples which are man-made machines. In this category, you will have several types of objects: gliders, spacecraft, missiles, and aircraft and so on.

In this course, we look mainly at the class of objects, which are using its interaction with air to produce forces and moments to sustain its motion through air. So, we basically are looking at atmospheric flight, and majority of this course will be about aircraft (airplanes). So, we are basically looking at aircraft atmospheric flight dynamics.

An aircraft, we know that, it uses its aerodynamic shape to create forces and moments which sustain the motion of aircraft in air and what we want to look at is, how the sustained motion, which is, for example, you can talk about a level flying condition where aircraft engine produces thrust, which gives it a forward motion to overcome drag, and because of the aerodynamic shape of the aircraft, you have lift produced which balances the weight. This is the one such flying condition which is cruise flying condition, where lift is balancing the weight of the aircraft and thrust is providing the forward speed, overcoming the drag.

Of course, there are many parameters which are going to affect this balance of forces and also of moments. There is no unbalanced moment acting here which will try to give aircraft also angular motions. So, here we are assuming that, the moments are all balanced and forces are also balanced, so that aircraft is in steady condition.

This motion that we are talking about, small perturbed motion or in general, even the steady flight condition, is going to depend upon various factors. For example, whether the aircraft is flying at sea level conditions or at some altitude which is quite large, will depend upon, what surrounding atmosphere is.

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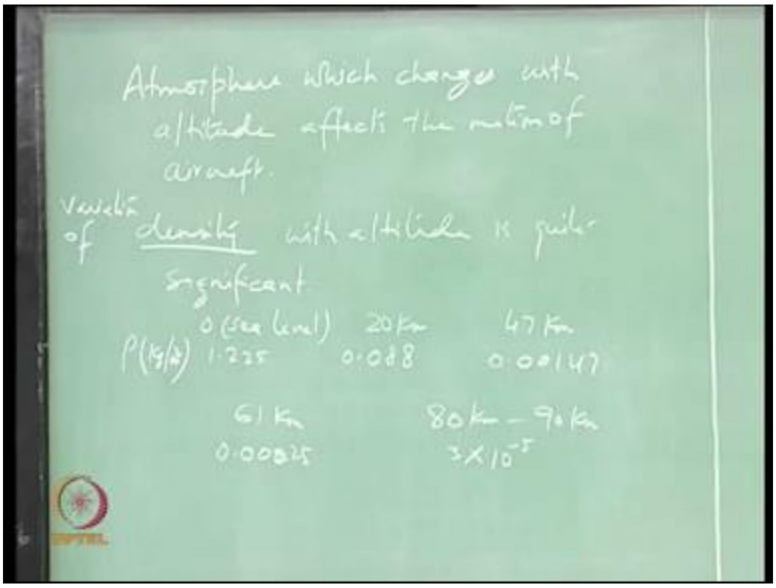

Atmosphere which changes with altitude affects the motion of aircraft. Motion is small motion around equilibrium state or the large motion from an equilibrium state. A typical parameter which is, the density, the variation of density with altitude is quite significant .... (No audio from 09:33 to 09:52) And if you look at the order of magnitude of density at different altitude levels: at sea level, I am going to very soon tell you where this density is appearing in these forces. So, let us look at how this density is changing with altitude.

We know that the value of density of air at sea level condition is 1.225 kg/m^3, and let us look at how it changes over different altitudes. At 20 kilometers, it is roughly 0.088 kg per meter cube, and at 47 kilometers, it is 0.00147, 61 kilometers it is 0.00025 and, at 80 kilometers to 90 kilometers altitude, it is of the order of 10 raised to minus 5 (kg/m^3).

With such large variation in density with respect to the altitude, what changes is the aerodynamic forces and also the moments. So, this is one parameter which is going to affect the motion of the aircraft, through aerodynamic forces and moments that are developed on the aircraft when it is going through air. The other things that can affect the motion of aircraft are its own parameters. For example, each of the components of aircraft (No audio from 12:41 to 12:52).

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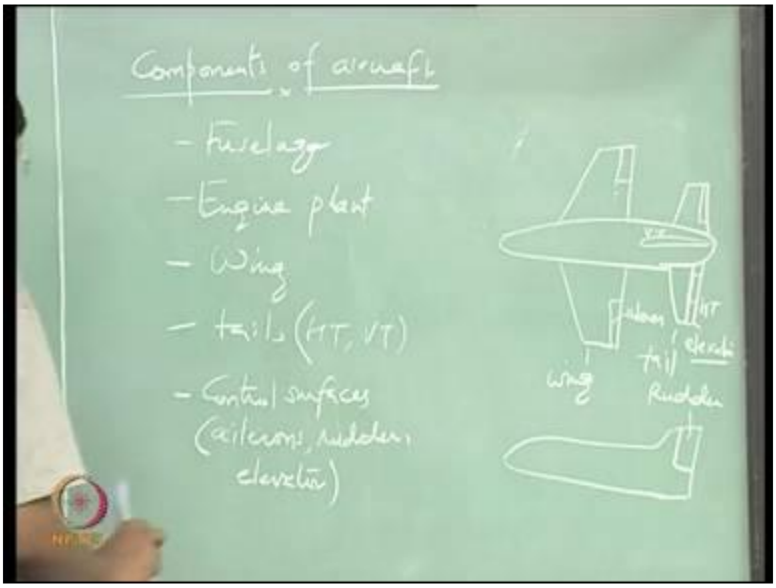

For example, the fuselage, which we designed based on our mission requirements. A four seater aircraft will have some fuselage geometry, or large transport will have a longer geometry. Depending upon how the shape of the fuselage looks like, it is going to contribute to the aerodynamics of aircraft. Engine plants, which is an integral part of aircraft, how it interacts with air, that is also going to play a major role in deciding the motion of the aircraft. And there are several other surfaces, which are control surfaces, mounted on (lifting surfaces of aircraft), airfoil like shapes.

You have wing, tails; which are horizontal tails and vertical tails. (No audio from 14:04 to 14:29) So this is horizontal tail and this is vertical tail. And control surfaces, these are aerodynamic control surfaces which manipulate air passing over an aircraft to change lift and moments. Control surfaces (Refer Slide Time: 14:40) are: for example, ailerons mounted on the outboard side of the wing. Its a hinged surface, which can be moved about the hinge line, rotated about the hinge line, so that, it affects the flow field and thus results in change in aerodynamic forces and moments.

Aileron is the control surface mounted on the wing, elevator is, all of these are small flaps mounted on the major surfaces. Elevator is the small flap attached to the trailing edge of the horizontal tail and, rudder is mounted on the vertical tail. So, these are major components of aircraft and they contribute actually to the motion of aircraft in steady condition or perturbed conditions.

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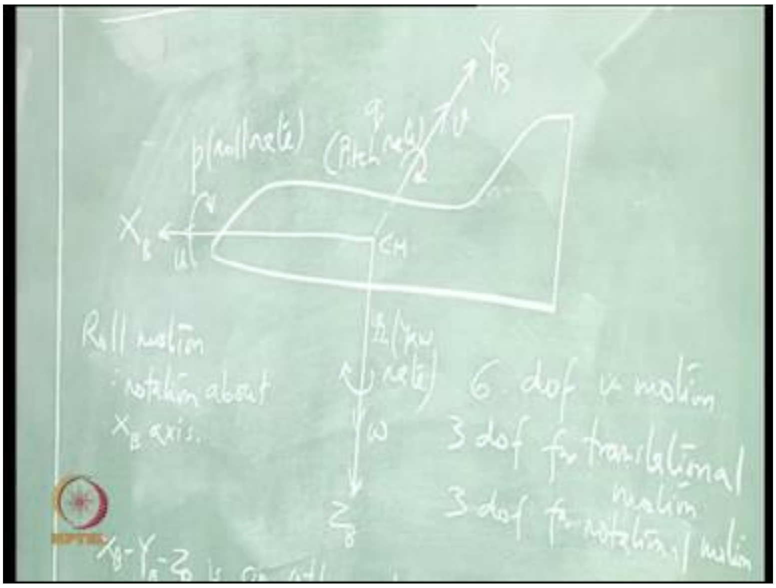

What we are going to do is, we are going to first try to understand aircraft parameters. And in order to do so, let us first define an axis system (fixed) to the aircraft with origin at the center of gravity which is also the center of mass of the aircraft. X_B-Y_B-Z_B is an orthogonal axis system fixed to aircraft with origin at its center of mass, which is also the center of gravity.

We will assume the aircraft to be a rigid aircraft, it will have 6 degrees of freedom in motion, 3 degrees of freedom for translational motion and 3 for rotational motion. These translational motions can be along the 3 axes of the aircraft (Refer Slide Time: 20:10). Aircraft has velocities along its axes which are u, v and w. It can also have rotations about the axes. Rotation about the X-axis is called the roll motion. A positive roll motion would be like this (Y axis moving towards Z axis). And the rate associated with this motion is called the roll rate (No audio from 20:43 to 21:03).

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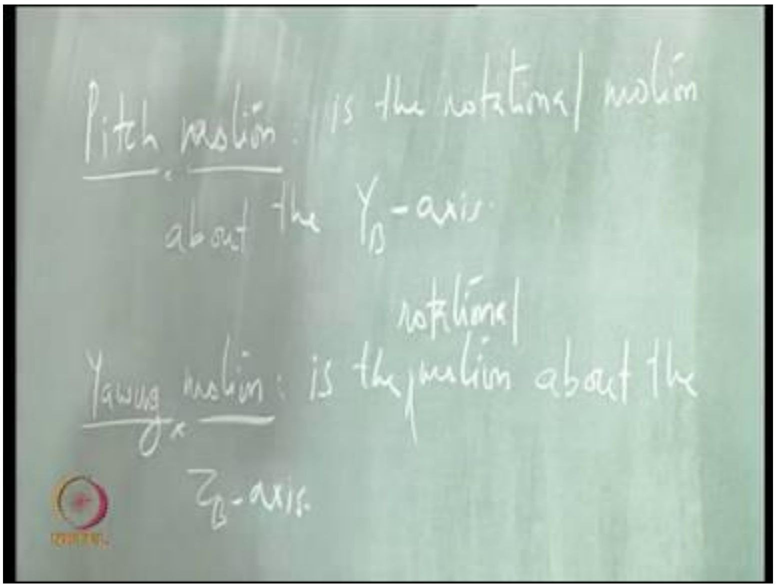

Similarly, we have two other rotational motions. A pitch motion is the motion which is about the Y-axis of this aircraft. A positive pitching motion is when Z_B is moving towards X_B and the variable associated with that is called pitch rate. So, aircraft is rotating about the Y_B axis in this XZ plane and that is what is pitching motion.

Yawing motion is the motion, rotational motion, about the Z_B axis. So, this X axis is moving towards Y in XY plane about this Z axis. A positive yawing motion is when X_B is moving towards the Y_B axis and that rotation is about Z axis. So, this is yaw and the variable associated with this motion is r, which is called yaw rate (Refer Slide Time: 23:39).

Aircraft has three (linear) velocities u, v and w along its axes, which describe the translation motion of aircraft and 3 rotational motion about the 3 axes X_B, Y_B and Z_B, given by these variables p, q and r which are roll rate, pitch rate and yaw rate. Now, this motion is being caused because of the forces and moments acting on the aircraft. So let us look at expressions for those forces and moments.

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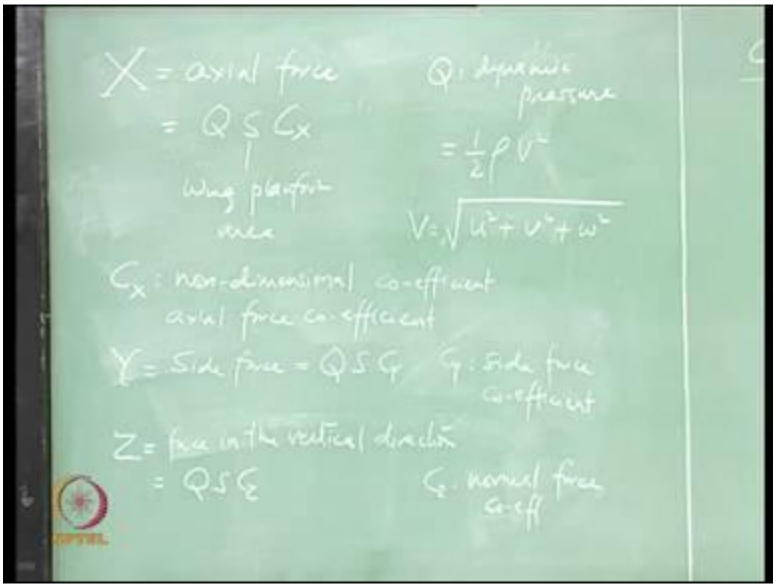

X is the axial force, it is sum of all the forces acting on the aircraft along its X axis and that is called axial force, which is equal to Q into S into Cx. Where Q is the dynamic pressure, expression for which is half rho V squared, where V is the absolute velocity, also the relative wind speed, S is the wing planform area and Cx is a non-dimensional coefficient.

In this case, Cx is axial force coefficient. The force along the Y axis is called side-force which is equal to Q into S into Cy, where Cy is side-force coefficient. Z is the force in the vertical direction along Z_B axis (No audio from 27:15 to 27:42). Cz is vertical force coefficient or we should say normal force coefficient (No audio from 27:51 to 28:05). So, these are the three forces acting along X, Y and Z axis of the aircraft and there are three moments.

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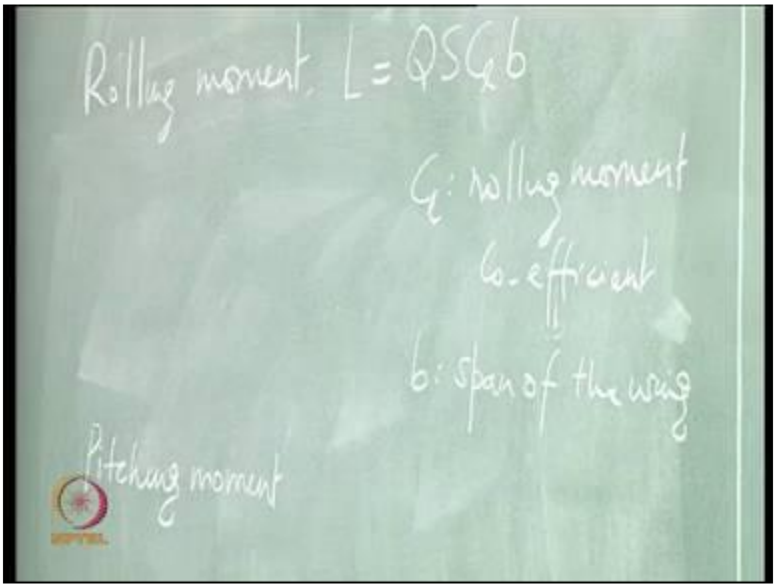

These moments are: rolling moment, the expression for which is, L is the rolling moment, the sum of all the (aerodynamic) moments acting about the X axis of the aircraft is rolling moment. So, everything else you know, Cl is the rolling moment coefficient and b is the span of the wing.

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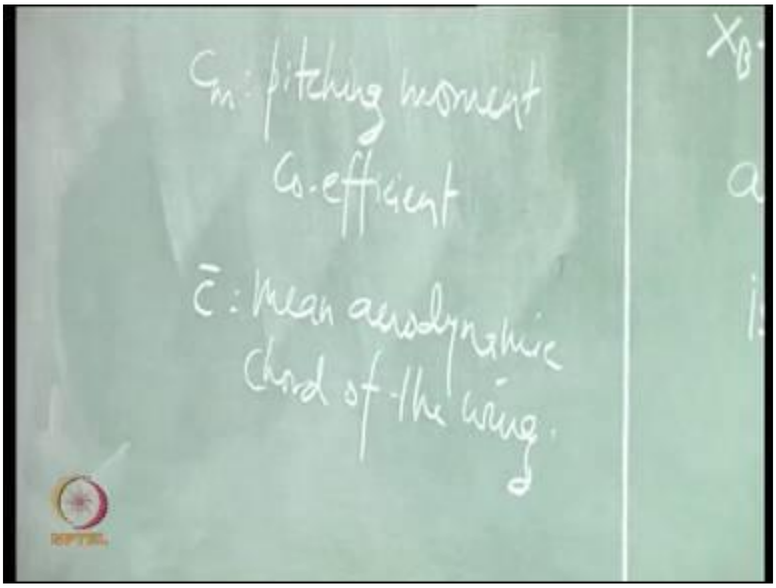

Expression for the pitching moment.

Pitching motion is motion about the Y axis you know. Sum of all the (aerodynamic) moments which are resulting in the pitching motion of the aircraft is given by this M, which is equal to Q into S into Cm into c bar. Cm here is pitching moment coefficient and c bar is the mean aerodynamic chord of the wing (No audio from 30:55 to 31:06).

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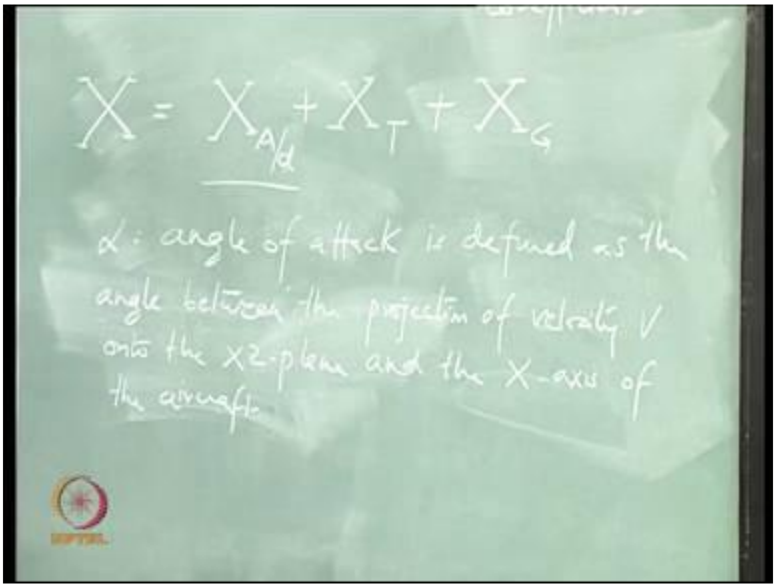

Expression for yawing moment is given by N equal to Q into S into Cn into b, where Cn is yawing moment coefficient (No audio from 31:21 to 31:31). So, axial forces are actually the resultant forces, which are going to depend upon forces due to, gravitation, aerodynamic forces acting on the aircraft. This force for example, the axial force is the sum of its aerodynamic components, thrust component and the gravitational component.

The aerodynamic components (of) the forces and moments are going to depend upon how the wind is oriented with respect to the aircraft. Orientation of wind, relative wind coming onto the aircraft, is described by two angles: which are alpha; which is the angle of attack and beta, which is the angle of sideslip. Let us look at what these angles are in terms of the velocity components of aircraft along its axes.

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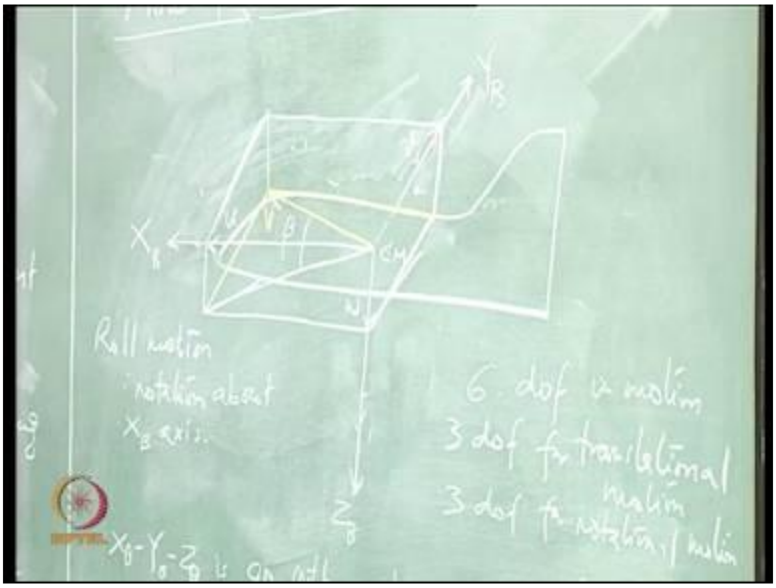

(No audio from 33:30 to 34:28) The relative wind coming onto the aircraft, or the aircraft is going into the wind with this velocity V, with its component u, v and w. The aircraft velocity vector makes an angle beta, with its projection on the XZ plane (of the aircraft) (Refer Slide Time: 35:00). XZ plane is also known as the longitudinal plane of the aircraft and the aircraft is assumed to be symmetric about this plane. Or we can say that the axis system is so defined that, this X Z plane is the plane of symmetry of the aircraft. So, beta is the angle which the plane, this shaded plane, makes with the XZ plane (No audio from 35:56 to 36:45).

In terms of beta and the angle of attack, which is defined as this (Refer to the sketch on board Time 33:28) (Refer Slide Time: 37:00). In this XZ plane, the component of velocity vector is in this direction and the angle, that projection of V onto X Z plane makes with X_B axis is the angle of attack (No audio from 36:46 to 38:45). Alpha is the angle of attack, which is defined as the angle between the projection of velocity V onto the XZ plane and the X axis of the aircraft.

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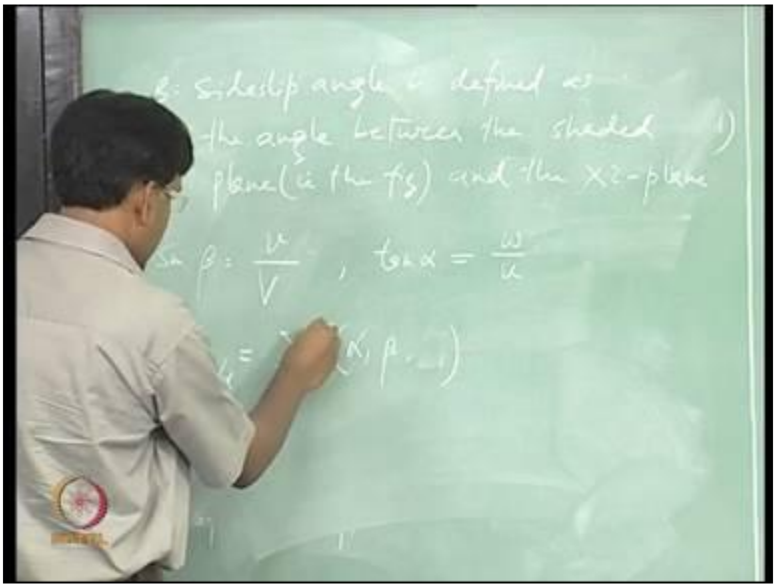

Sideslip angle is defined as the angle between (No audio from 39:02 to 39:15), shaded plane in this picture and the X Z plane (No audio from 39:33 to 39:52). So, in terms of the velocities, these angles are given as beta, sin beta equal to v over capital V, and tan alpha is w over u.

Clearly this part of the axial force, the aerodynamic part, this is coming from the lift and drag components, this clearly depends upon what these angles are. How wind is or aircraft is oriented with respect to the wind, this component is going to depend upon that, and it also depends upon the Mach number. If you also want to include the altitude in this function, then, the force is, aerodynamic force is actually depending upon the Reynolds number, which includes the velocity and the density, both.

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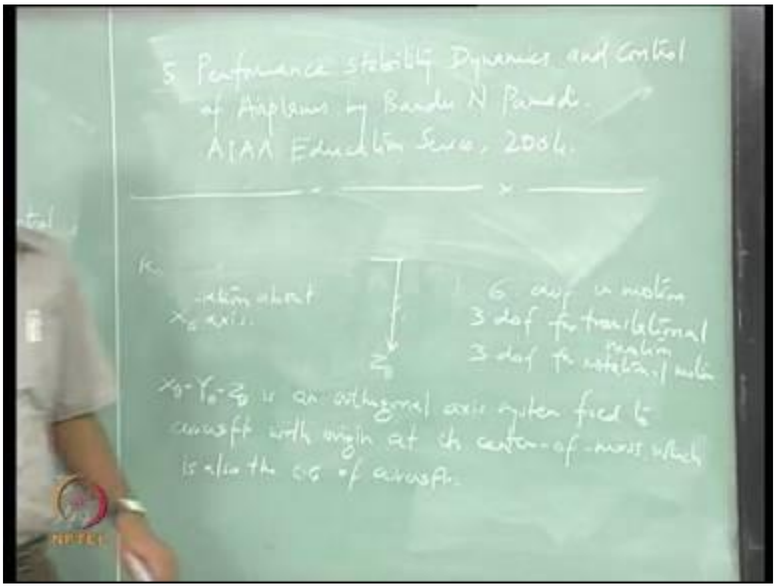

There are many popular books on this subject available now. But in this course, the books that I am going to refer to are the following (No audio from 42:12 to 42:41).

- Flight Stability and Automatic Control by Robert C Nelson published by McGraw-Hill (No audio from 42:59 to 43:31),

- Dynamics of Atmospheric Flight by Bernard Etkin, published by Dover publications (No audio from 43:46 to 44:24),

- Mechanics of Flight by Warren F. Phillips published by John Wiley publications (No audio from 44:40 to 45:20),

- Airplane Performance Stability and Control by C D Perkins and R E Hage, the first edition of this book appeared in 1949 and this is still one of the classics (No audio from 45:57 to 46:17), and

- Performance Stability Dynamics and Control of Airplanes by Bandu N Pamadi, published by AIAA education series of books.

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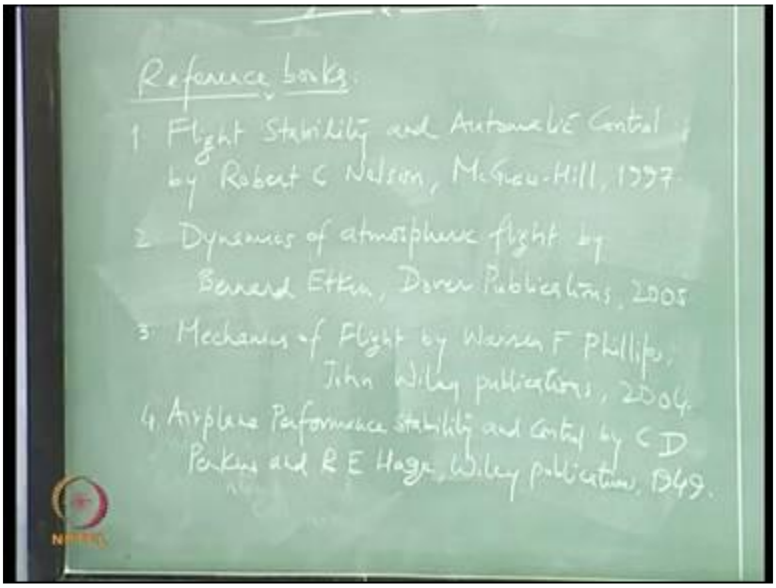

So, throughout this course, we will be taking contents from one of these books for different topics and many of the examples (problems) actually will come from this book by Robert C Nelson. I think we will stop.