Aircraft Dynamic Stability & Design of Stability Augmentation System
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Module 2
Lecture No 10
Forces and Moments on Aircraft

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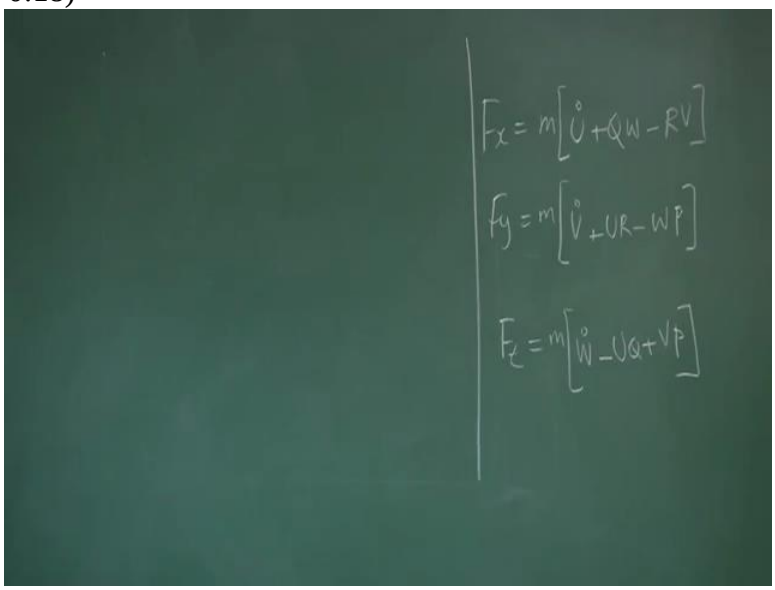

So for our ease of communication, I write FX is equal to M U dot + QW - RV. FY equal to MV dot + UR - WT and FZ equal to MW dot - UQ + VP. We have not asked this question, what are these Fx, XFY, FZ composed of? We will come to that question. We have most focused on the right-hand side, what are the kinematics for this? Now, we also have to handle the other equation which is the moment equation. Let us do that.

So let us come in this session and let us try to find out the expression for moment, moment equation. In the last lecture we have seen, FX, FY, FZ can be expressed as this and we are very clear, we have not talked about what are these FX, FY, FZ, they still will impress forced on the airplane composed of? We will discuss that also. Let us first handle the moment equation.

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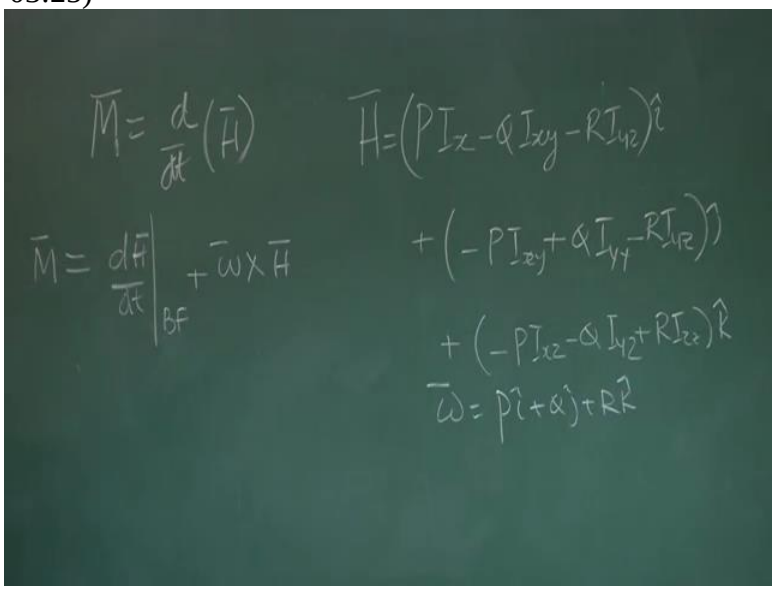

As you know, if everything was with respect to inertial frame, then this is nothing but we have to operate like this. But since now we are working in rotating frame, so use this concept. I can write M as DH by DT evaluated at body frame or rotating frame + omega cross H. It is so mechanical now and you know the expression of H. I write here, which is HX. HX will be PIX - QIXY - RIYZ. This is vector. I write I. + - PIXY + QIYY - RIYZ. This is J. Similarly - PIXZ - QIYZ + RIZZ. This is K. So this is the H vector we have derived already. I have to simply put this expression here. With understanding, omega is nothing but PI + QJ + RK.

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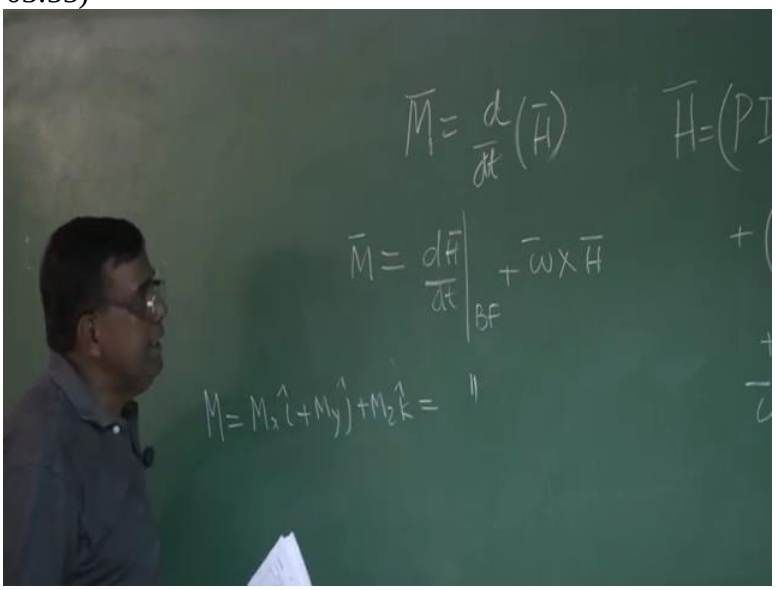

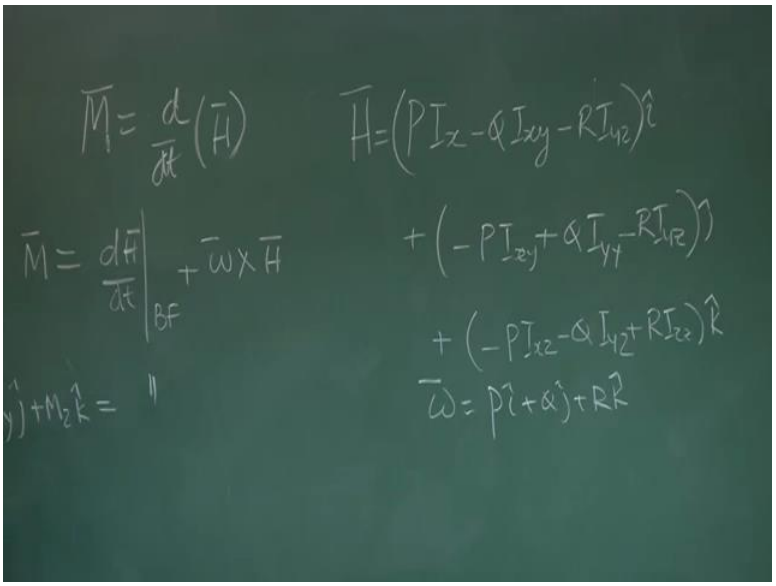

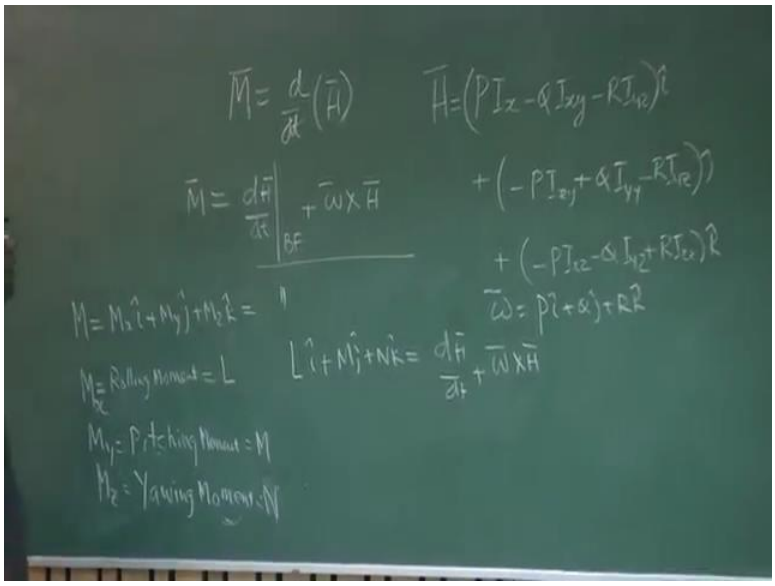

Do this operation and write M as MXI + MYJ + MZK. That is equal to this expression. That is this right-hand side you will get when you substitute for H, this I, this J and this K. Omega is this. This is vector operation and DH by DT is like your scalar. Differentiation you will do and that is equal to the vector M. For MX, we call it rolling moment. That is, moment about X axis. This is aircraft's X axis, Y axis, body fixed axis, Z axis. So MX is rotation of the body about X axis, like this.

And the convention is, if I fly the machine and right-wing going down, that is MX is positive, rolling moment is positive. So this is also denoted by L. MY, pitching moment denoted by M. And you understand, pitching moment means motion about y-axis. That means, airplane is moving like this, this is pitching moment. And by convention, if I am flying with the machine, nose up is positive, nose down is negative. Notation used in aerospace is M and MZ which is the yawing moment denoted by M.

That is the moment about Z axis why this is a Z axis? This is X, this is Y, this is Z. So this is the yawing moment. And convention wise, if the right wing is going back, that is this is the airplane, flying with the machine, right wing going back, this yawing moment is a positive yawing moment. If left wing is going back, that is negative enjoying moment. So these are LMN. So whatever expression I get from here, I will write LI + MJ this MK equal to DH by DT + omega cross H. I will substitute this equation and I will get final expression as what we are looking for.

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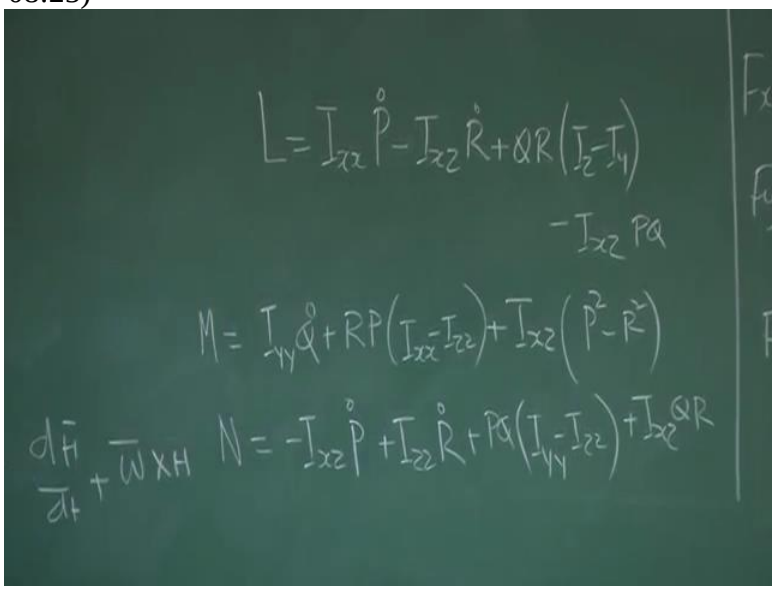

I will get L equal to IXXP dot - IXZR dot + QR IZ - IY - IXZPQ. Let me check, IXXP dot - IXZR dot + QR IZ - IY - IXZPQ. Then M I will get as IYYQ dot this RPIXX - IZZ + IXZ P square - R square. Similarly, N I will get as - IXZ P dot + IZZ + R dot + PQ into IYY - IZZ + IXZQR. I again repeat, you please substitute this in this expression and see indeed you get this sort of an expression or not.

You may be wondering, why this IYZ and IXZ vanished. So we have assumed here, XZ as plane of symmetry which is not a bad assumption. And hence, by definition, IYZ integrally equal to IXY equal to 0. So those terms do not appear in this expression. Okay? What we have got by doing all these things? We have got expressions for FX, FY, FZ in terms of this motion variable, U dot, Q, R, W, etc. we got the moment equation in terms of P dot, R dot, etc. All are here.

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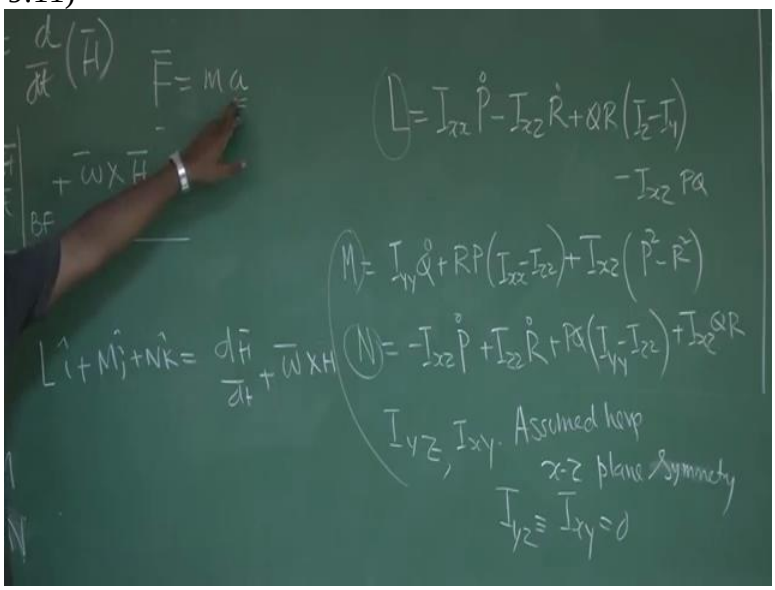

But we have not addressed this question, what are these FX, FY, FZ or M, N and L. Because you know whatever big big expressions we write, if F equals to MA what is our aim? Why are we doing all these things? If I know what is F, if I know the inertia property, I can find A. If I can know A, I can integrate it to get velocity. If I know velocity, I can integrate it to get position. The complete motion, I will be able to describe, translational motion.

Similarly, moment equal to I alpha. Alpha is the angular acceleration. So I can easily find the behaviour in terms of motion. That is the purpose. That is why you see, the pitching moment. Suppose, imagine that there is no R and P, what is this R and P? Please understand before you mechanically use all these things, what is P? P is the angular velocity about X axis's, rolling. P is doing like this about X axis.

What is R? R is the yaw rate about Z axis. What is Q? Q is the pitching rate, angular velocity about Y axis. Now imagine, if I have a system which is not doing yawing, not doing rolling, only pitching.

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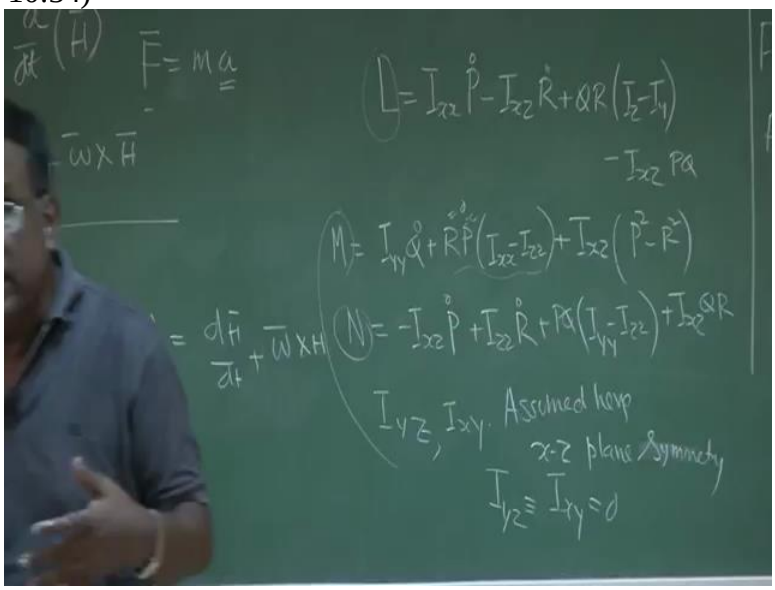

That means, not doing yawing means R is 0. Not doing rolling means P is 0. So this term vanishes. Anyways, P and R are 0. So this term vanishes. So what is M? What this M is doing? M here is the pitching moment. Whatever pitching moment about Y axis is happening, that is only changing the Q dot, pitch rate. But if they are not 0, that is the most difficult situation because airplane will have so many things that this pitching moment will contribute towards R, P, etc in a manner which is sometimes unless you catch it properly, it may create a very diverted solutions.

The airplane may go into dynamic instability. Similarly, see here, how much contribution of R and P Cross, that is product of yaw rate and roll rate. They are going to create a contribution in dynamics decided not only by their magnitude but also what is the difference in the moment of inertia IZZ and IXX. So all these attentions are necessary because many a times, you will find, this value of IXX, IZZ for a combination of R, P and Q which is also IXZ, this will try to make the system more complex. We say it will make the system coupled. That is, the pitching will be UI. UI will be pitching. Like that.

So we say, these are the consequences of inertia coupling. Similarly, in aerodynamics also, it is possible. If there is angle of attack, they go on increasing the angle of attack. There will be close separation of this vertices. That will give you a yawing moment. So that is called as aerodynamic coupling. These 2 types of coupling are very predominant when we are talking about high-performance airplane.

That is why term by term, we understand. We have written this equation mechanically in the most boring way in my language. But can I get the juice out of it? Can I get the forewarning out of it, out of this equation? If you can catch those things, you have won 90% of the battle.

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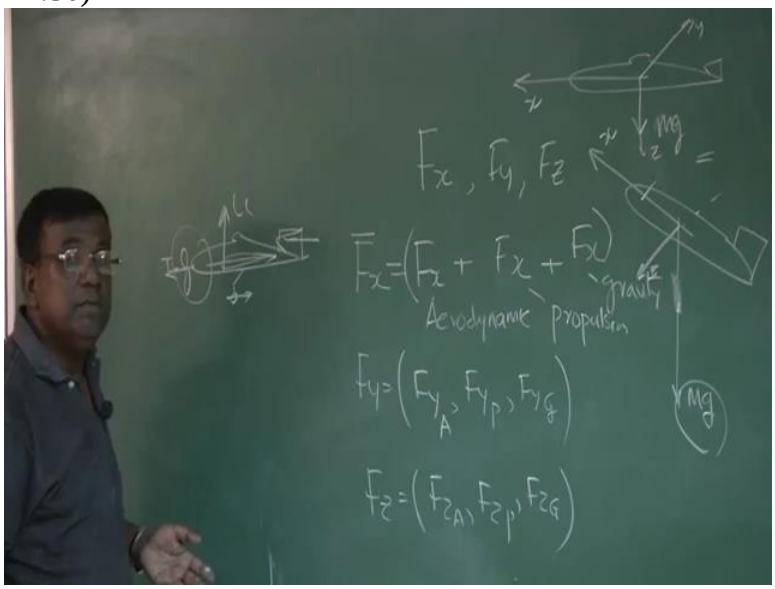

So let us now again divert our attention to FX, FY and FZ. The question I am asking is, what are these forces composed of? We know that these are the external impressed forces on the airplane and they may act at different points. For example, this is the airplane. If there is a thrust here coming to the engine, the point of application is here, majority of the drag from the point here, drag at the vertical tail will be here.

There is a landing here. It will experience a drag. There will be lift. So many things will happen. The moment we are talking about FX, FY, FZ, we know now from this diagram that FX will have FX because of aerodynamics or aerodynamic force. Then Fx component will come because of repulsion. Very importantly, Fx will be because of gravity. Fx will have 3 components primarily.

Similarly FY will also have primarily 3 components. FY aerodynamic, FY repulsive, FY gravitational. Similarly FZ. FZ aerodynamic, FZ repulsive and FZ gravitational. You may get a little mixed up where from Fx gravity will come? My plane is like this. You may think, my airplane is flying like this. This is my X, this is my Y, this is my Z. MG is acting like this, downwards but where from Fx will come? The question may come.

Please understand, in generic case, the airplane could be in this direction, orientation sometimes. Now the X axis will be this because they are body fixed. So now, this is the gravitational force, MG. Now you could see, there will be a component of this force along X direction. That is how we have to find out the component of MG, gravity force along X, Y, Z direction at different orientations of the airplane.

But we have not discussed, how do I define the orientation of the plane? So you need to know in space, how do I define what is the orientation? We have not discussed about that. Unless you know the orientation, how do I find out what are the components of the gravity force. That means, we are getting a pre-alarm. Let us clarify, how do I get the orientation of the airplane in space? We will do that in next lecture.

Let us come back to the aerodynamic force, Fx. You can see here, there will be drag, there will be left. So depending upon the orientation which we have not discussed, how to find the orientation of the airplane in space. But depending on the orientation, lift, drag, all these components will have its contribution towards X, Y, Z direction.

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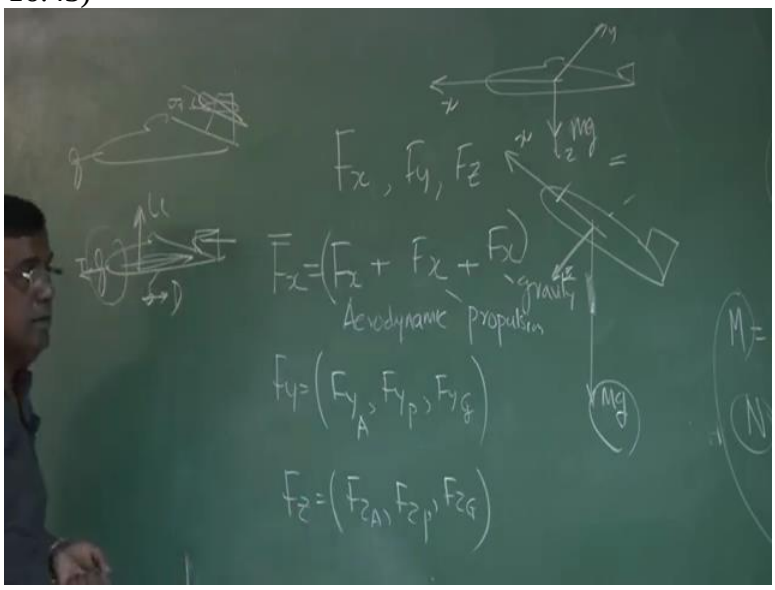

Similarly, propulsive, whether you put the engine here, whether you put the engine here and whether you put the engine at some setting angle, it is very difficult to put them at 0. That is why

putting the engine, some setting angle is there. That will give some component along X, Y, Z direction. That is why, we need to find out FX, FY, FZ along X, Y, Z direction. Primarily contribution will be there because of aerodynamic propulsive and gravity.

If there is a force at the point of application, it will manifest through moment. So it will have moment along X direction, moment along Y direction, moment along Z direction which will be primarily aerodynamic in nature, propulsive in nature and what about gravity? Gravity will not come because we will be finding moment about centre of gravity, centre of mass and since the gravity force passes through that point, the gravity will not contribute anything towards moment.

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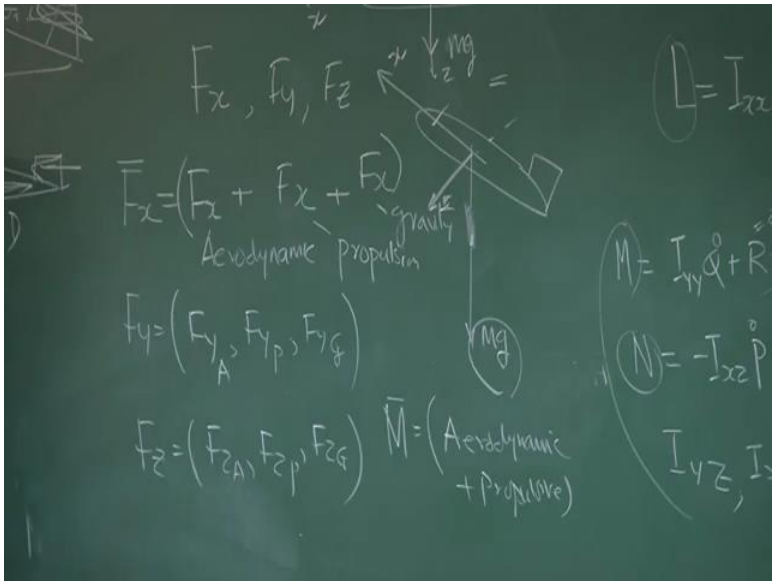

Okay? So for moment, contribution will be primarily aerodynamic and propulsive. But if I want to find out those components, we have (inaudible 18:14) to discussion, we need to know the orientation of the airplane and we have not discussed about the orientation of the airplane. But we now realise, it is extremely important to quickly understand how do I defend the orientation of the airplane? So as I am telling, our next step will be towards understanding that.

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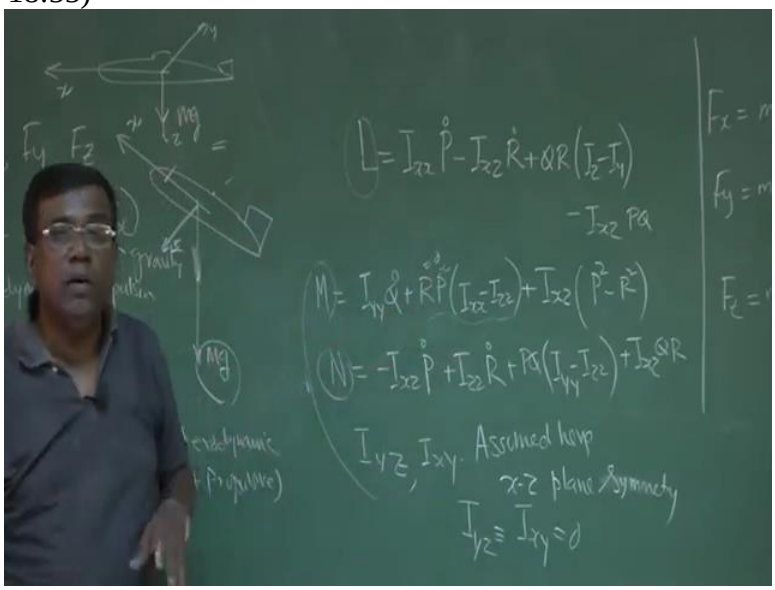

Before I go to that, I come back to this equation again. You will realise that M, N and L, these are the moments which are aerodynamic and propulsive in nature and you can see that IX is IXZ, product of 2 angular rates. It has something like gyroscopic contribution. We realise it as we unfold each term and try to understand what is the meaning of that? Okay? Thank you.