Flight Dynamic II (Stability)
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Module No. # 04
Longitudinal Stability and Neutral Point
Lecture No. # 09
Fuselage Contribution

So today, we are going to look at Fuselage Contribution to Cm alpha $C_{m\alpha}$. So, there are two effects, one is purely because of the fuselage and there is another effect which is wing fuselage interaction. Flow over the fuselage is going to get effected by the wing. Similarly, fuselage is also going to contribute to wing contribution to stability.

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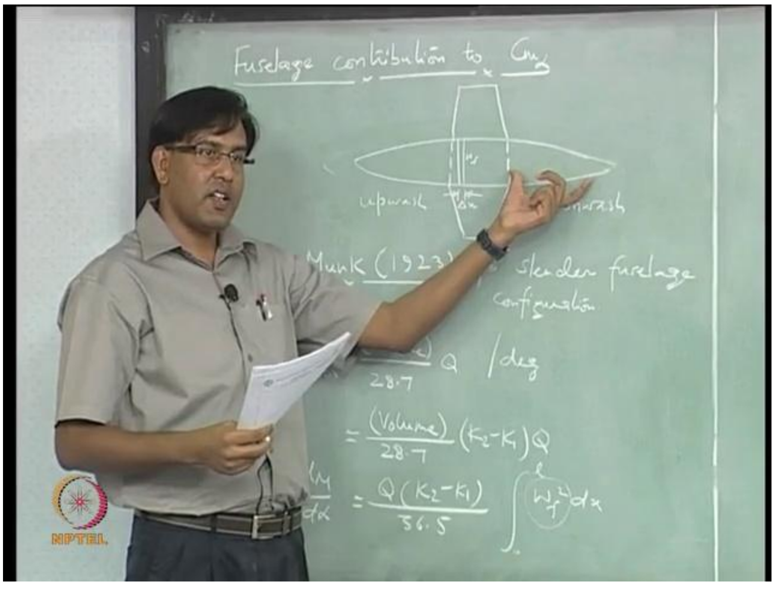

So, as you know this, most of this course is going to depend upon the data, data coming from the wind tunnel or based on some empirical relations. This one is particularly difficult, we just have some estimates provided by people at different stages.

So, there is one person called Max Munk who was the first person to study the effect of fuselage on pitch stability and he gave a formula in 1923 for slender fuselage configurations, based on his experimental observations, he gave an empirical relations.

$\frac{dM}{d\alpha} = \frac{Volume}{28.7} Q$. And this is per degree. So M is the pitching moment here and Q is the dynamic pressure. Later on, he also added another factor to this. $\frac{dM}{d\alpha} = \frac{Volume}{28.7} (K_2 - K_1) Q$. Now this factor was to account for the slenderness ratio (Refer Slide Time: 03:55). So what is also called fineness ratio. And if you .... want to look at how this parameter varies with the slenderness ratio,.... (Refer Slide Time: 04:40). this is not lift over drag, this is length over diameter, varies is something like this.

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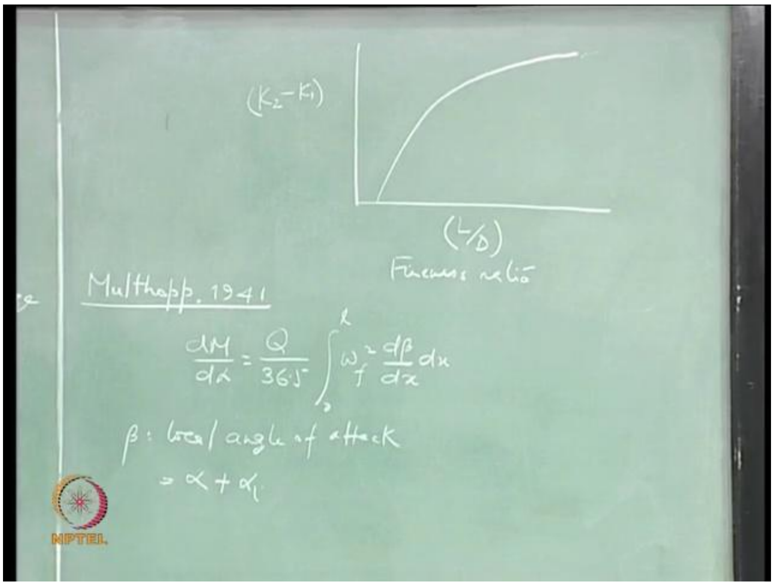

Max Munk: $\frac{dM}{d\alpha} = \frac{(K_2 - K_1)}{36.5} Q \int_0^l w_f^2 dx$

Non circular section, this is for a body which body of revolution. So, you can I think we can extend this formula further to … Now, this is like a volume. So width of the fuselage at any particular section you know into d x that this gives you so, it is like a (( )) squarish section into a length, elemental length along the length of the fuselage, and you have to integrate this. So, that this becomes the volume, they are different.

So, you have to remember that all of these relations are based on experimental observations. This is the corrected version of this one (Refer Slide Time: 06:25).

So, I would say, if you want to talk about bodies which are not symmetric, you know this is how you have to find out the volume. So, w_f can be a width at any section and you multiply it by this Delta x Δx, w_f is the width of any section.

This looks like a cross sectional area into the length element dx, it is like taking it as squarish (()). Can you take it as how it is, because again I am repeating it, it is an empirical formula. So, this person gave it. If you want to know further, you have to … that may have been taken into account in this.

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But, what he did not account for was, the local flow disturbance. So, flow will be disturbed ahead of the wing and behind the wing because of .. Behind the wing there will be a downwash created and in front of the wing upwash. So, this portion of the fuselage, the flow that it is going to see, that is going to be different from what this portion is going to see (Refer Slide Time: 09:00).

And it is this person, ... who gave an empirical relation accounting for this effect coming from the wing. So, wing is the one which is going to disturb the flow around the fuselage and that effect was taken into account by Multhopp and the relation that he gave is something like this .... So, remember we are only trying to get an estimate because we are still at the design stage.

Multhopp : $\dfrac{dM}{d\alpha} = \dfrac{Q}{36.5}\int_0^l w_f^2 \dfrac{d\beta}{dx} dx$

Only after we have gotten an estimate, that we can built one small prototype and put it in the wind tunnel and then after that, you know compute (measure) all the derivatives, Cm alpha $C_{m\alpha}$ will also be measured in the wind tunnel after you have done the initial design. Then you are going to see whether it is matching with what you have started with or not, is not it? So, this is still at the initial design stage.

Yeah, I will tell you. beta β is the local angle of attack, which is alpha of the fuselage reference line and we are writing it as alpha plus alpha i $\alpha + \alpha_i$, which is like effect coning from the wing. So, clearly in front of the wing is one, this derivative is 1 plus d epsilon over d alpha $1+\frac{d\varepsilon}{d\alpha}$ and behind a rough estimate 1 minus d epsilon over d alpha $1-\frac{d\varepsilon}{d\alpha}$.

So, for fuselage portion ahead of the wing $\frac{d\beta}{d\alpha}=1+\frac{d\varepsilon}{d\alpha}$. If you remember, we showed that maximum upwash is going to be around this area and then slowly it is going to taper off (Refer Slide Time:12:44). So, we looked at this picture, where we saw this component of velocity like this, this was upwash in front of the wing, behind the wing downwash is going to be maximum near the wing trailing edge and then it is going to slowly diminish.

So, we have to be particularly careful about sections of the fuselage which are close to the wing and thereby the empirical relation again, there is a curve which tells you, how this is going to change when you move along the length of the fuselage away from the wing. So, if you are close to the wing, this effect is going to be more and if you are away it is going to be less.

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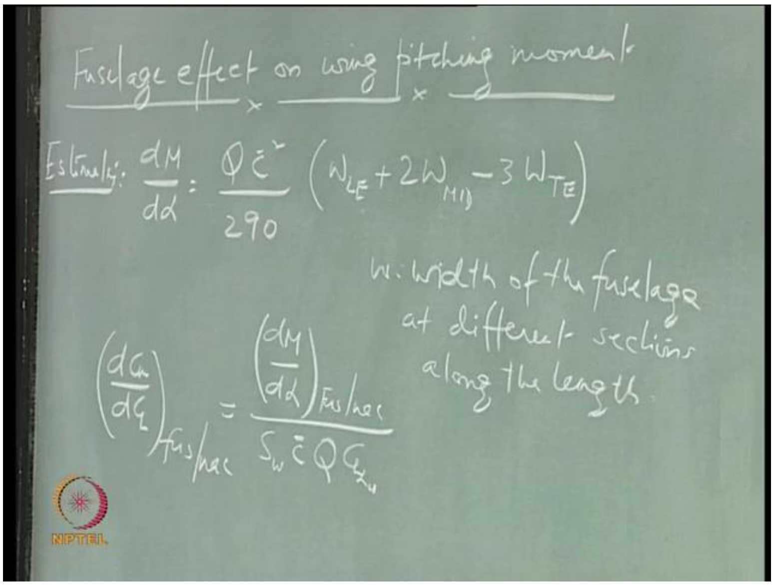

So, you can actually divide the fuselage in different sections and use $\frac{dM}{d\alpha}=\frac{Q}{36.5}\sum_{s=1}^{n} w_f^2 \frac{d\beta}{dx}\Delta x$ where s is the box counting. You have this section and depends on how many such boxes you have taken along the length of the fuselage. Now, this $\left(\frac{d\beta}{dx}\right)$ is going to be different for each section you have to remember that. And for that the relation, the empirical relation is given.

So, you can choose from a plot, at what section you are, how much away from the wing trailing edge or how much in front of the leading edge. Depending on that, you can find this, you can find this from an empirical curve which is given to you and calculate what this derivative is.

This was the effect of the wing on the fuselage (contribution to) pitch stability. Now, fuselage is also changing the local flow around the wing. So, it is also going to change the pitching moment which is created because of the wing, is not it? The interaction is both ways, the wing is affecting the fuselage, fuselage is affecting the wing and that effect can be estimated, it can be a bad estimate.

But, you need such estimates because such estimates are going to be useful in determining the stability or the equilibrium of your initial paper aircraft. You are starting with some design and you want to find out all the parameters which are going to affect the equilibrium conditions and the stability.

So, this is .... this effect is given by this formula $\frac{dM}{d\alpha} = \frac{Q\bar{c}^2}{290}\left(w_{LE} + 2w_{MID} - 3w_{TE}\right)$. All of these are estimations, you have to remember that. The correct value can be found only when you have put your prototype in the wind tunnel and measured the data accurately. Otherwise, you have to trust these estimates. (Refer Slide Time 18:30) So, width of the fuselage at the wing leading edge location (w_{LE}), width of the fuselage at wing mid chord location (w_{MID}) and this is the width of the fuselage at the wing trailing edge location (w_{TE}).

Now from this you can also find out what is d Cm over d CL $\frac{dC_m}{dC_L}$ that is what we are doing in all the cases. Now, since this is for a body of revolution, you know it applies to both fuselage and the engine nacelle, $\left(\frac{dC_m}{dC_L}\right)_{fus/nac} = \frac{\left(\frac{dM}{d\alpha}\right)_{fus/nac}}{S_w \bar{c} Q C_{L\alpha w}}$. If you want a ready formula with less accuracy then you can use this $\left(\frac{dC_m}{dC_L}\right)_{fus/nac} = \frac{K_f w_f^2 L_f}{S_w \bar{c} C_{L\alpha w}}$. L_f here is the fuselage length, overall length, and w_f is the maximum width of the fuselage (Refer Slide Time: 20:40).

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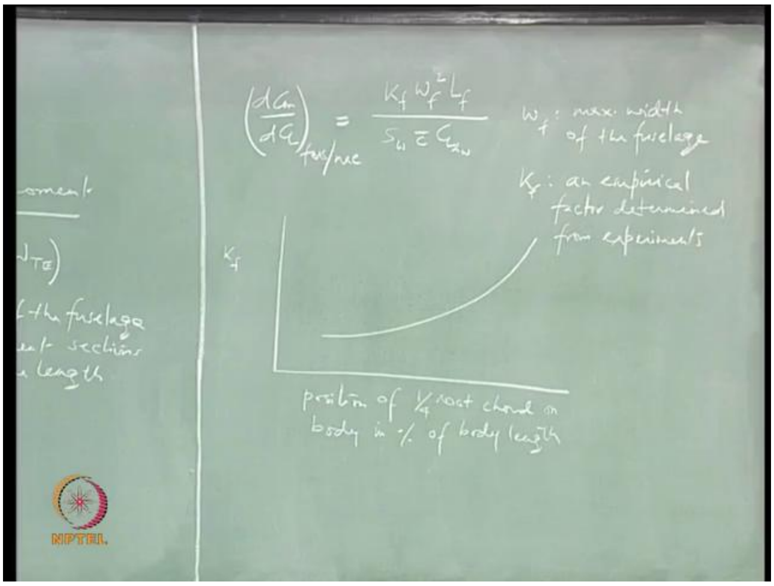

Now, K f is an empirical factor , so there is a curve which gives a relation between K f and position of quarter of root. So, at this chord, take this quarter of that on body in percentage of body length (Refer Slide Time: 23:10). I am writing body here because this form, this is applicable to both fuselage and engine nacelle. Now engine nacelle can also be located close to the wing and we can determine where it is located with respect to the engine nacelle.

It varies something like this, so I am not going to give you a correct picture, you can find this picture in many textbooks on this subject. So, this was 1941. There is one more person who worked on this problem and he gave another estimate, the person's name is Hoak and he gave this formula in 1960s.

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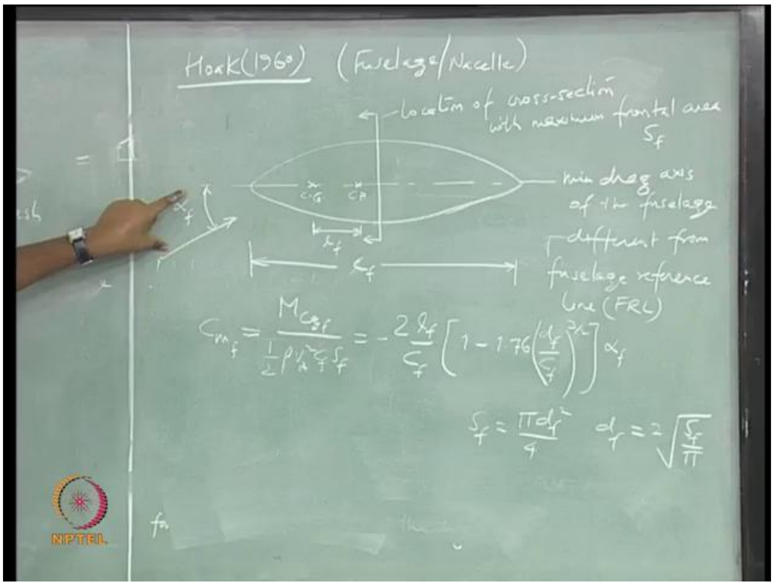

And this you can find in the book by Phillip, W H Phillip. This book is the only book which is giving a different formula, all other books you will find these two relations. So, let us look at this, and this applies to both fuselage and engine nacelle. He calls this length (distance between frond and back ends) as the chord length of the fuselage, (Refer Slide Time: 25:50).

The distance between the CG and the center of pressure of the fuselage is l f.

So, there will be an area which will be if you are standing here and looking at this fuselage, the area, that maximum area that you see is this S f and that is at some location which I have marked here. And this axis is the minimum drag axis of the fuselage, it is different from the fuselage reference line.

Because that is, any line which is different from the fuselage reference line is going to add to the angle of attack that the fuselage is going to see. So, this axis is different from the fuselage reference line. ... If this line is same as the fuselage reference line, then there is no extra angle of attack to be accounted for.

Now, he gives this pitching moment coefficient in terms of these parameters ... and this is about the CG which is understood. .... (Refer Slide Time 29:23) So, look at this, you are taking the reference which is for the fuselage and not for the wing. Finally, when you are going to add this contribution to the airplane pitch stability then, you have to divide everything by the reference area of the wing, is not it?

We have been taking the reference area as the reference area of the wing. This is ... if you assume this Sf to be a circle, then the associated diameter is what this df is 2 into square root of S_f over pi $d_f = 2\sqrt{S_f/\pi}$ .... How do you get that? Sf is this ..., so equivalent diameter is d f for this area Sf. So, this alpha f α_f is also the angle of attack with respect to this minimum drag axis of the fuselage. If I want to now find out what this alpha is with respect to the fuselage reference line that is going to be different.

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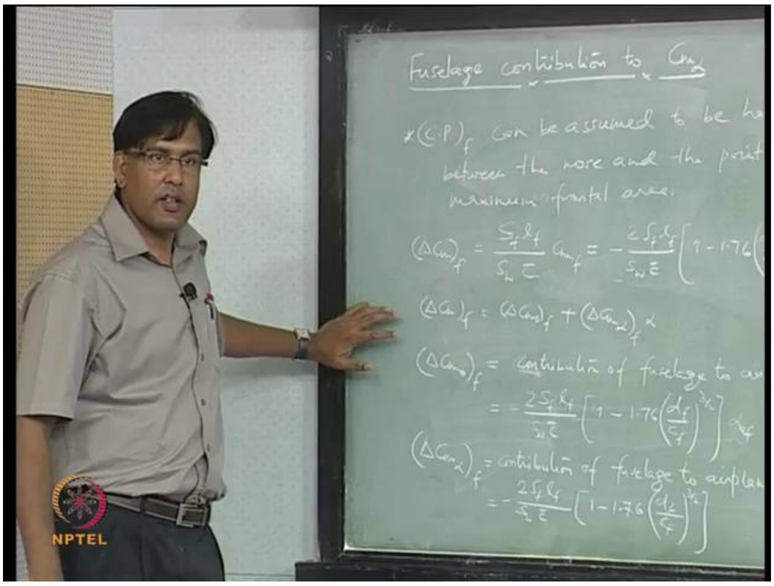

Now, center of pressure of the fuselage in this formula can be assumed ... to be ... This location of this cp, you can take it as half way between the nose and the point of somewhere around this point. So, now this is the contribution to the airplane pitching moment coefficient. So, you have to now divide it by the reference area of the wing.

$$C_{mf} = \frac{M_{CGf}}{\frac{1}{2}\rho V_\infty^2 c_f S_f} = -2\frac{l_f}{c_f}\left[1 - 1.76\left(\frac{d_f}{c_f}\right)^{3/2}\right]\alpha_f$$

So, we have to take the wing as the reference and then we can write ... and here is delta Cm ΔC_m, we are talking about contributions from different components. ... (Refer Slide Time 34:51)

$$\left(\Delta C_m\right)_{fuselage} = \frac{S_f l_f}{S_w \bar{c}} C_{mf} = -2\frac{S_f l_f}{S_w \bar{c}}\left[1-1.76\left(\frac{d_f}{c_f}\right)^{3/2}\right]\alpha_f$$

$$\left(\Delta C_m\right)_{fuselage} = \left(\Delta C_{m0}\right)_{fuselage} + \left(\Delta C_{m\alpha}\right)_{fuselage}\alpha$$

This is the contribution to the total airplane pitch stability form the fuselage,(()) c bar $\bar{c}$ is the mean aerodynamic chord of the wing. So, this same relation actually gives you formula for this and this also (Refer Slide Time: 36:38).

So, you can write what is Delta Cm naught ΔC_{m0}, Cm naught contribution to the whole airplane coming from the fuselage, $\left(\Delta C_{m0}\right)_{fuselage} = -2\frac{S_f l_f}{S_w \bar{c}}\left[1-1.76\left(\frac{d_f}{c_f}\right)^{3/2}\right]\alpha_{0f}$. This alpha naught f α_{0f} is the angle between the fuselage reference line and the minimum drag axis of the fuselage. So, if they are overlapping, then you can say that, that is 0. $\left(\Delta C_{m\alpha}\right)_{fuselage} = -2\frac{S_f l_f}{S_w \bar{c}}\left[1-1.76\left(\frac{d_f}{c_f}\right)^{3/2}\right]$. What do you think this contribution is stabilizing or destabilizing? It will depend upon d_f.

Usually, this contribution is destabilizing. l_f is negative. So, let me just write the statement here. l_f is usually negative. This effect is usually, contribution is usually destabilizing and what kind of effect that is going to have on the neutral point location or the static margin? It will reduce the static margin.

So, this has to be taken into account. It is not a small destabilizing effect. This effect should be taken into account and has to be estimated while you are designing your airplane. The next component, we have one more component left what is that? The engine plant.

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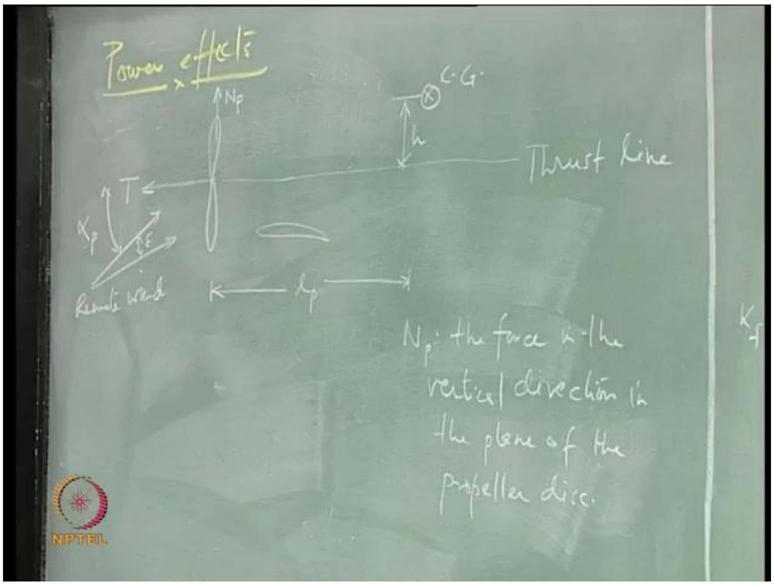

So, that this comes broadly under this topic, which is called power effects. And engine plants can be of different types depending upon what altitude you are going to fly, what speeds you want. So, depending on all that, you have different kind of engine plants and they will have their own dynamics. For example, if you are talking about turboprop engine, then the rotation of the propeller blades is going to affect the flow field behind it and that is going to have an indirect effect on this Cm alpha $C_{m\alpha}$.

Lets first look at the turboprop engine and see what kind of effect it can have on pitch stability. So, this I will call thrust line, ... location of CG is here, which is at a height from this thrust line. So, h is the height of the CG above the thrust line. And distance of the propeller disk when the propellers are rotating, they are in motion, you look from the front and it will look to you like a disk.

So, when this propeller is rotating, then you have a force in that direction, which is in the plane of the propeller disk, N p, and, this is your remote wind direction and if it is located in the front of the wing, it is also going to see upwash. N p is the normal force on the propellers and it will be in the plane of the propeller disk.

No, the blade of the propeller is having an aerodynamic shape. So, there is going to be a force which is acting along the blade length. There will be some unbalanced forces. You can think like that for different configurations. So, that is like trying to diminish the effect of this, but let us look at what happens if we have this kind of configuration.

We have one aircraft which is Cessna in Kanpur, where you will see that when they are trying to you know before they take the airplane for actual flight, they will be testing everything, they will try to see if all the actuators are working fine, engine is working fine.

So, they will start the engine and make the propellers run. You will see that, when the airplane is kind of not flying, it is just standing and wheels are locked. You put some blocks to the wheels and then you start running the propellers, you will see that the aircraft will have a tendency to do this and that is that is coming because of this.

So, there will be a moment created when you run the engine, where is that force coming from when the airplane is not flying? That is coming from the propeller. You will see this when you go to Kanpur next year, you will see this. I said these propellers are located in front of the wings. So, there is going to be an upwash.

So, this is your remote wind and because of the upwash which is this angle epsilon ε, this vector is tilted and this is the angle of attack that the propeller is going to see. Of course, this is very complicated because blade geometry itself is complicated. If you want to talk about what each section of the blade, what angle of attack it is going to see, that is going to be something different, it is very complicated thing. ...

So, everybody gets what propeller disk is, understand? When you are looking at these blades rotating at high speed you do not see these blades individually, but you see a disk that is what is propeller disk. So, we can stop here and we will continue from here in the next class.