Aircraft Propulsion

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Lecture-38
Blade Design and Cascade Theory

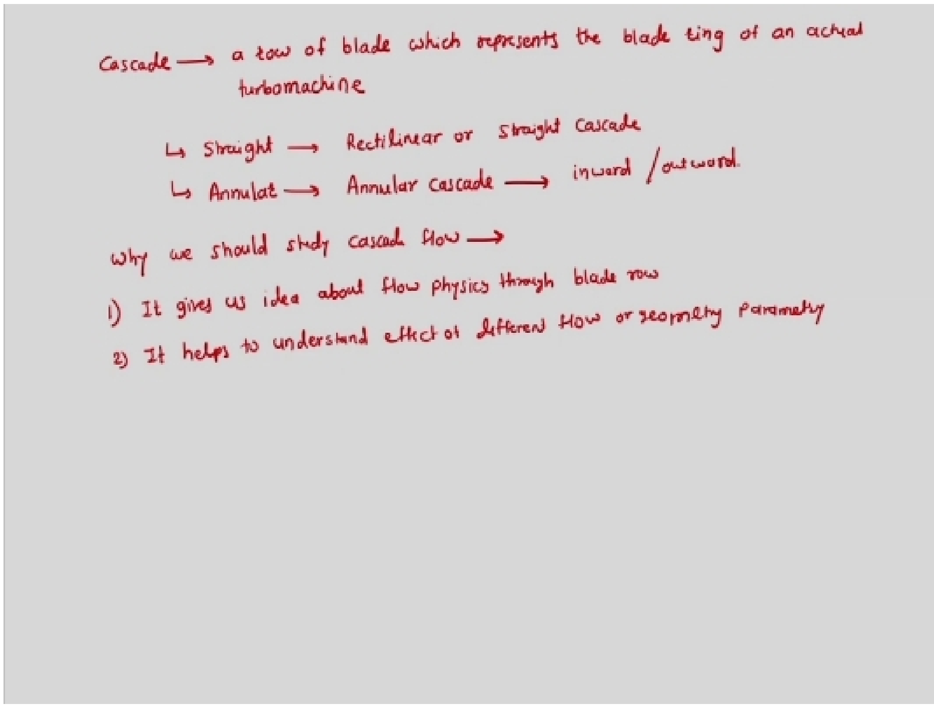
Welcome to the class. Now, we will talk about the blade design in cascade theory. Here our major motive is towards the flow through a cascade. Then we will try to understand what are the different experimental facilities which are used for this kind of analysis, what are the types of measurements which would be done and then what are the types of blade profiles, how measurements are done in the blade profiles and what are the types of the parameters generally which are studied or the effect.

These are the things and then there will be certain analysis related to forces. So, we move ahead and then we will first understand what do you mean by cascade?

Cascade is defined as a roll of blades which represents the blade ring of an actual turbo machine then if this blade ring is straight or this blades are arranged in straight manner then this is called as rectilinear or straight cascade. If blades are arranged in annular manner then it is called as annular cascade. In case of annular cascade it can inward flow or outward flow depending upon the direction of the flow.
Then, why we should study cascade? Why we should study cascade flow there are some set of facilities where the blades arranged will be kept and then the flow through such blades would be analyzed, but then why it is desirable required and essential to study the cascade. So, first thing, why it is essential since it gives us idea about flow physics through blade rows. Secondly, it helps to understand effect of different parameters of flow or geometry.

Actually, we know that the flow variables are like velocity, density, viscosity or there can be temperature as well. So, these flow variables can change as per the flow and hence, its effect on the turbo machine needs to be analyzed and so for that this flow through cascade would help further they can be different types of spacing between the blades, there can be different dimensions of the blades.

There can be different profiles of the blades and then those would also affect the performance of a turbo machine and hence, flow through cascade helps us to get these details where we can study the effect of different flow parameters and also the geometry.



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Then, we had drawn the velocity triangle like this. In case of the compressor where this was C_1, this was C_a, this was C_1 so this would be C_{w1} and this complete would be u. Similarly, at the outlet, we drew the velocity triangles like this where this was C_2 this was C_{a2} to this was V_2 and then we knew angles are α_1, β_1, α_2, β_2 this was C_{w2} and this was u_2. Here, we made certain assumptions and which actually are based on the fact that flow is one dimensional.

So, here we assume flow is uniform in the passage between the two blades, this is a blade, this is a blade and this is a passage. So in this passage we assumed that flow is uniform. Secondly, we considered only stream wise variation in flow properties is considered. Then third, it was only one velocity triangle at inlet and outlet is used to analyse thus having said this it gives quick estimate.

These assumptions are very much helpful for finding out the basic fundamental parameters of performance parameters of a terrible machine quickly. So, these assumptions were helpful for us, but now with this improvement from one chapter to other we are trying to find out what would be further improvement in the analysis, if we try to find out the limitations of one dimensional assumption.

So, there are certain limitations where we know that there is boundary layer this is the blade profile and on the blade profile there is boundary layer. So, flow will have zero velocity on the blade a blade stationery it is like a stator blade and a blade is rotating then it will gain the velocity of the blade. So, there is bound layer and this bound layer will have variation in velocity in the normal direction.

So, further there can be bound layer separation. So, boundary layer vortices separation would exist for flow over a blade. Hence there is velocity variation in stream wise and also cross stream direction further as we have said, this is the spacing between the blades and then this spacing would also change the flow pattern. So, if we are saying this as a spacing between the blades which is also called as pitch, this distance is called as L which is a chord length.

So, this is chord length of a blade, this is pitch. So, if we change this, then also there will be change in flow property. So, flow depends upon, on the geometry and arrangement of the blades. Therefore, it is essential to consider the multi dimensionality. So, considering these 3 limitations, we are moving from one dimensional assumption to two dimensional assumption, where we are considering the variation across the blade passages.

However, real blade would be three dimensional, where there will be variation along the height of the blade also but for the sake of simplicity, we are considering variation only in the passage and along with the variation in the stream wise direction. Here hence, 2D assumption is made and this 2D assumption is very much suitable for high hub to tip ratio blades. A blade height is more than what will happen the variation in the blade direction or blade height along the blade height will be minimal and hence there will be major variation in the passage itself.

So, the 2D assumption is more valid for such kind of situation, but this gives us improved estimate than the first or one dimensional assumption. Now, the facility which will be used for testing such thing is called as cascade Tunnel.

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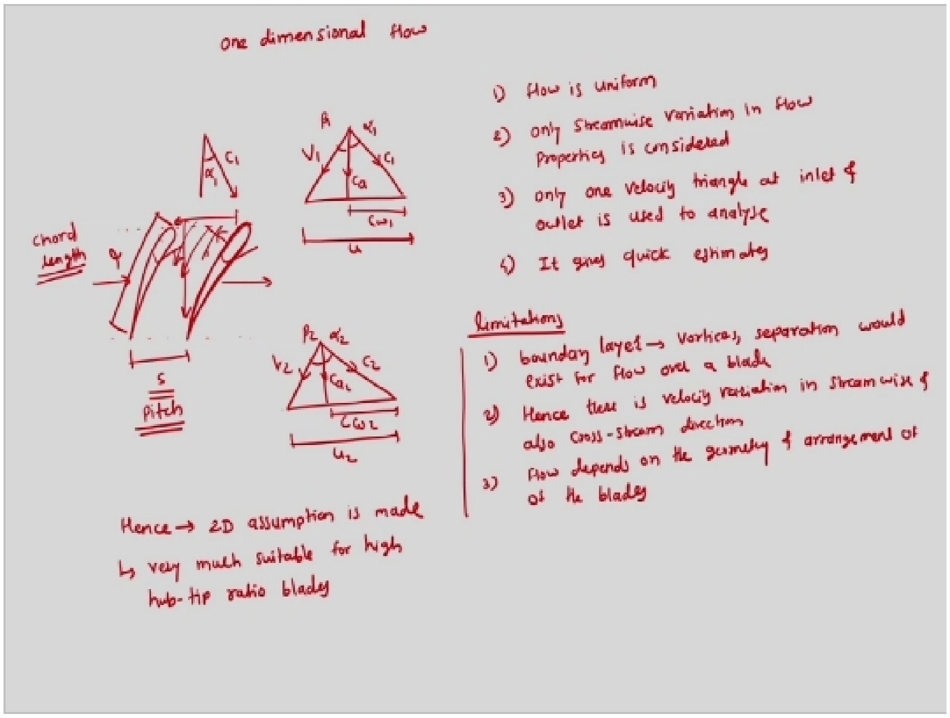

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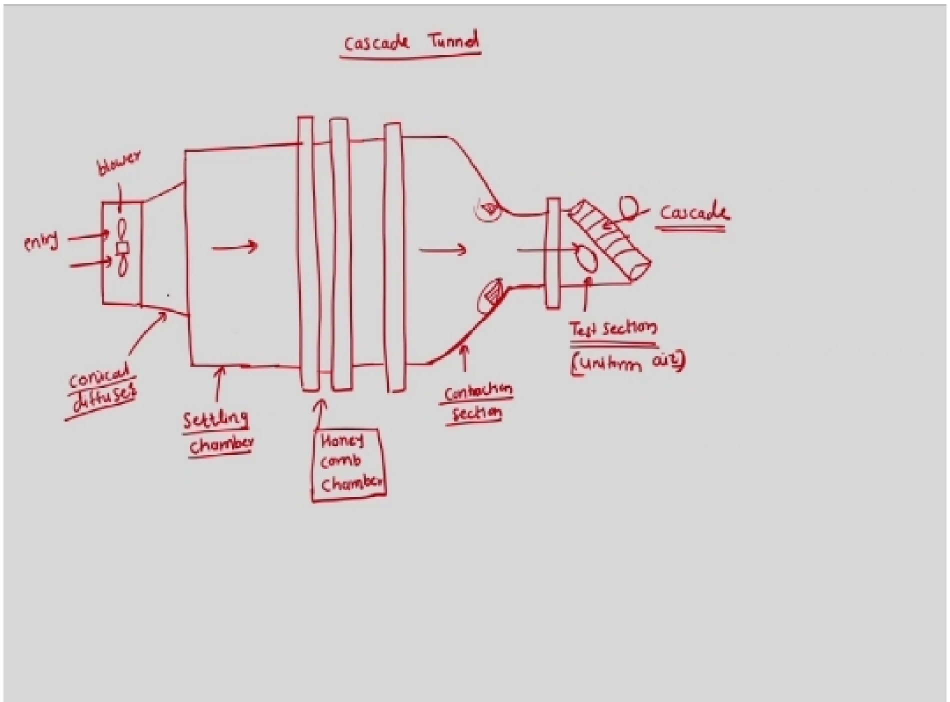
There can be different types of cascade tunnels.

Among those what we are trying to draw here is the one which is blower type of cascade tunnel where, firstly, the drive of the air will be created using the blower and then the part of the tunnel would continue and in the tunnel, as we know, there are different parts, the same different parts can be seen here as well and, but the difference would be in that test section of the Wind tunnel. In a wind tunnel.

We would have test sections where models will be mounted, but in this case, we would not have a model mounted in the test section we would have our cascade mounted at the end so this is cascade or row of a blade and then this is called as blower and then this blower is allowing air to enter and flow into the tunnel. In this tunnel, this is conical section and it is practically our diffuser.

Since we are talking about low speed sub sonic wind tunnel or cascade tunnel and then we have settling chamber after the settling chamber, we have honeycomb section or chamber then we have contraction this is test section. So, these are the parts of a cascade tunnel so, here as said this cascade tunnel would start with a blower, blower would start air letting into the tunnel, then from the conical diffuser.

The air would reduce its velocity and it would further become less in the settling chamber then air would pass over the honeycomb kind of low straighteners and wire meshes such that the turbulence level would be decreased or desired turbulence level can be attained and further, these flow straighteners would let the air passed from the contraction section, which would accelerate the air and make it further, more uniform in one direction, which will finally pass into the test section and then over the cascade.



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(refer time: 17:04). So, here test section receives ultimately uniform air which is going to flow over the cascade some essential points of the cascade tunnel include that we need large number of long blades. So as to have two dimensional assumption but practically it has been seen that 7 blades with h by l, h is the height, l is the cord of the blade equal to 3 which is also called as aspect ratio are sufficient. This is the minimal requirement, which is required and then we have these tunnel blades or the tunnel can be wooden and blades can be wooden then can be from the aluminium or can be resin or glass wool.

Blades are generally made hollow. Blades are made hollow to accommodate different instruments further what we have seen that this contraction, after the contraction there is test section and then we want a uniform flow in the test section which would flow over the cascade, but this contraction would have a bounded layer where flow would have variation in the direction normal to it and this bounded layer is going to enter into the test section.

So, as to avoid this flow of boundary layer or retarded or low energy flow into the boundary layer in general porous walls are kept are used to eliminate, the boundary layer entering in then, what we try to measure is velocity, velocity, basically magnitude then velocity direction and these measurements are done for the velocity, we can do the measurement we can also do the measurement for the total pressure or pressure before and after the cascade.

We will do the measurement of velocity before the cascade and after the cascade. Similarly for pressure measurement we can read before and after the cascade. So, traverse are placed. So, as to measure these parameters further in the cascade the blades would be having instrumentation and such instrumented blades would measure pressure over the blades. So, these are the general arrangements which are done in case of a cascade tunnel.

So, if we try to see then we can see that special arrangement in the test section is like this where we have this part has test section and we know that this is called as cascade and here we would see this is an upstream traverse probe. So, this probe would have sensors mounted before the cascade. So for this, this is the velocity which is C_{x1} this is the flow velocity which is C_1 and this is axial velocity for the cascade C_{x1} and then after the cascade also flowed come out as C_{x2} and then there would be some velocity C_{y2} and then this is absolute velocity C_2.

Then here like upstream, traversing probe and then likewise there will be downstream Traversing probe as well which would measure all the necessary parameters after the cascade this would be there in an enclosure it is called as downstream, traversing probe and here we will see that this would be called as instrumented blade. So these are the arrangements. So far a blade if I see then this is the arrangement in case of a turbine cascade.

This would be the arrangement and hence, here this side of the blade profile is called as pressure surface and this side is called as suction surface. Suction surface would have lower pressure than the pressure surface force would act, from the pressure surface to the suction surface.

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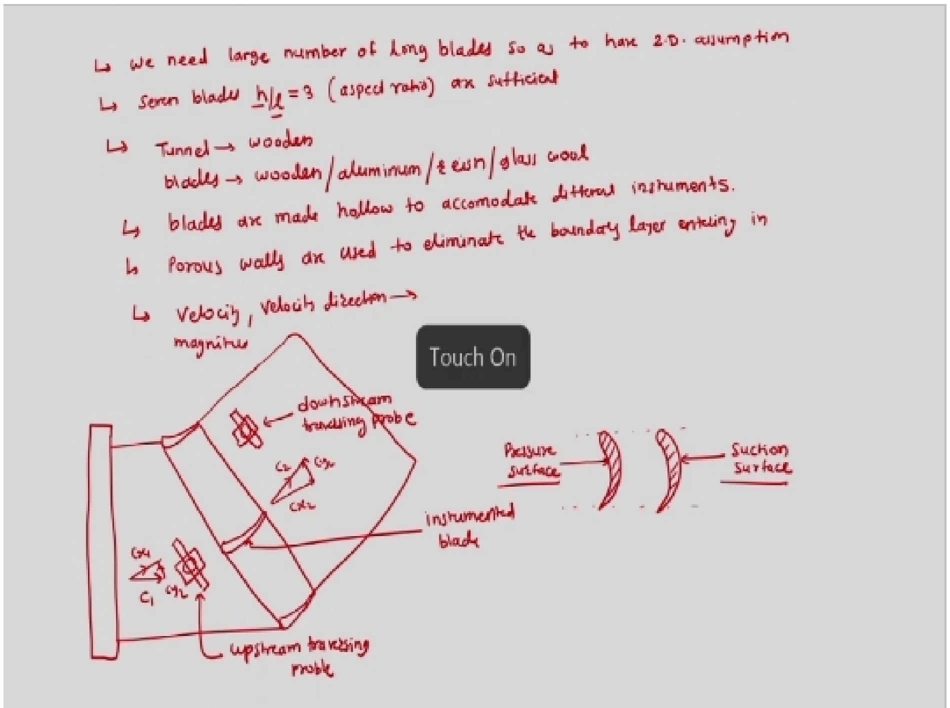
These will be connected to the nanometres which would measure pressure at those locations this is static pressure probe and if we plot pressure versus x by l where this length is called as l and then this is x direction. So we would have certain variation and this is x by l = 1 so if we mount pressure probes on the blade profile then we can get a variation like this for a typical blade is shown, then, we know that we told that we can do the measurement of velocity



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direction and for measurement of velocity direction, they are sensors which are called as yaw meters.

So, typically yaw meters would look like this which is practically a manometer, but it is used for the measurement of direction of velocity. Here, we would have two prongs if we see its top view in the section then we can see that there are 2 holes and those 2 holes are basically connected to 2 tubes and those 2 tubes are connected to manometer and then for the sake of simplicity we can see that it is u tube manometer and here these 2 holes are at certain angle and this angle is theta here, this yaw meter is called as cylindrical yaw meter.

This cylindrical yaw meter would be rotated such that there will be a balance of the pressure measured by 2 static probes and then, those 2 static probes once they measure the same pressure, and this bisection of this angle would be felt as the angle of the velocity vector like this there is 1 more yaw meter and that yaw meter is called as claw type of yaw meter, where again there will be 2 and then the 2 limbs are connected.

Here as well to the 2 manometers or to the limbs of the manometers and then same way this would also be rotated so that this there can be measurement of pressure at different directions and then here, if we see, then we can see that there are internally the tubes and which are connected to the manometers and those tubes when rotated would measure differential pressures in each limb, but when this particular orientation is reached.

They will measure the same pressure says that their difference is negligible and from their orientation, we can find out the directional of velocity then we will go ahead and talk about the cascade performance.

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So we can apply tangential momentum which is My in the direction y, $\int_0^S$ C_y d$\dot{m}$, so which is equal to $\int_0^S$ C_y ρ C_x dy. It is equal to $\int_0^S$ ρ C_x C_y dy, if we apply axial momentum then we can get Mx is equal to $\int_0^S$ C_x d$\dot{m}$ then we have $\int_0^S$ C_x ρ C_x dy so it is equal to $\int_0^S$ ρ C_x^2 dy so, this integration we are doing in the blade passage we are not saying that there is only 1 velocity which is existing and it is uniform.

So, that we are not saying we can draw the velocity triangle at different locations. Since the velocity is varying in different locations in the passage and this is integrated for the passage to get the complete variation accommodated. So we know that mean value of air angle is equal to α_2 at exit = $\tan^{-1} \frac{M_y}{M_x}$ so we have $\tan \overline{\alpha}_2 = \frac{\int_0^S \rho C_x C_y dy}{\int_0^S \rho C_x^2 dy}$.

This is expression for air exit angle, then we can find out integrated value of ΔP_0 which is total pressure loss and it is $\int_0^S(P_{01}$ - $P_{02})$ since we are talking about loss in total pressure between entry and exit of the blade, so entry will have higher total pressure exit would have lower, so it is P_{01} - P_{02}. d$\dot{m}$ divided by $\int_0^S$ d$\dot{m}$ so we have $\frac{(P_{01}-P_{02})\rho C_x dy}{\int_0^S \rho C_x dy}$.

So, these two expressions for one dimensional flow where $\tan \alpha_2 = \frac{C_y}{C_x}$ and $\Delta P_0 = P_{01} - P_{02}$ so here we can take P_{01} to be constant and then that P_{01} can be coming out from the expression where we would have expression now for integrated ΔP_0 is P_{01} - P_{02} ρ C_x dy divided $\int_0^S \rho C_x dy$. So, this is how we can find out the major required quantities which are like blade exit velocity and the total pressure loss how to use the different variables effectively.

So, what are the corresponding terminologies in a cascade, how to implement them for turbine and compressor to find out the forces acting on the cascade. We will see those things in the upcoming classes. Thank you