Aerodynamic Design of Axial Flow Compressors & Fans
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Lecture 44
Design of Low Speed Contra Rotating Fan (Contd)

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Hello, and welcome to module 8, lecture 44 design of low speed contra rotating fan.

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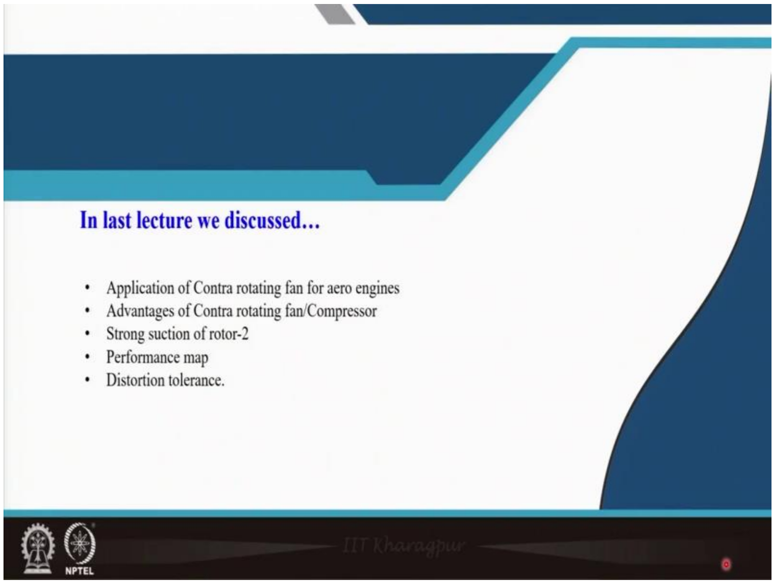

In last lecture, we started discussing about application of contra rotating concept for aero engines. So, if we understand, this contra rotating concept, that's what has been used both for compressor as well as for the turbines. These concepts, that's what is having several advantages. What we realize is there are two rotors which are rotating in opposite direction.

Suppose say my one rotor that's what is rotating in clockwise direction, my next rotor or coming rotor will be rotating in counterclockwise direction. And by doing so, basically the concept what we say, combination of stator and rotor, that's what we are removing. Removing in the sense, we will not be having stator in between two rotors.

By doing so, we are reducing the number of components required for the engine. When we are reducing number of components, we can realize, that's what will be reducing the length of my engine. At the same time reduction of number of components, that's what will be reducing the weight of my engine.

Now, when we say stage, say…for conventional stage it is say stator and rotor combination; for contra rotating, two rotors, they are in combination, that's what is called stage. And that's what will be giving you higher power generating capacity or higher thrust generating capacity. So, we can say per stage power output will be very large.

One more advantage is we will be having two rotors rotating in opposite direction, that's what will lead to reduce the rotational speed of my wheel, and maybe that will be helpful to us in sense of rotating our wheels at a transonic speed, that is also one of the benefit. We will see again by using the velocity triangle concept.

So, in overall if you look at, there are many advantages which lead to attract attention for the researchers towards the contra rotating concept for both compressor as well as the turbines. This contra rotating concept that has not limitation for application to aero engine only, there are many applications, people, they found as per their expectation.

Some of them say for ventilation fan, some of them, they are using for the cooling purpose. There are some special purpose requirements where this contra rotating concept that has given the more attention. Now, here in this case, since our second rotor that's what is rotating in opposite direction, so we can say, we learn when my rotor that's what is rotating, that's what is generating the suction near my leading edge.

Here, in this case what happens because my rotor-2, that's what is rotating at the higher speed that's what will be sucking the air coming out from my rotor-1, and that's what will lead to improve the performance of both, rotor-1 as well as rotor-2, and that's what is a benefit for us, okay. Now, we realize, we have seen our own experimental results that's what is showing the performance of contra rotating fan.

And what it says, like we are having wider operating range compared to our conventional stage. Wider operating range, that means my two-extremes say, maximum mass flow condition and minimum mass flow condition. We also have observed say contra rotating concept, that's what is giving say two kind of stall, that's what is called partial stall and full stall configuration.

So full stall configuration, that's what is equivalent to what stage configuration that has, but when we have done our design, when we have done our experimentation, that time we realize like rotor-1, that's what is acting, you know, it is not going under stall, even though it is operating at low mass flow rate, and that's what is the benefit, and that's what is giving the wider operating range to contra rotating fan.

So, my stall that will remain unstalled or say my rotor-1 that will remain unstall condition, and my rotor-2 that's what will be behaving like a conventional stage or conventional rotor configuration. So that's what is the benefit, that's what we have explored. Now, recent trend towards the development of say concept that's what is called boundary layer ingesting engine, okay.

For that, we know, from entry side or from my nose of my aircraft, flow that will be going all the way towards say engine because my engines will be buried inside my fuselage, may be on the rear side to take the benefit of noise as well as the placement and installation. And that's what has attracted the attention because we are moving towards wide body aircrafts.

Now under that condition, my flow which will be entering inside my engine, that will be having inflow distortion because of inflow boundary layer development. Now this, that's what will lead to deteriorate the performance of my engine. So, people, they are looking for special applications or special kind of designs where they can avoid or they can minimize the effect of this distortion.

And our own experimental work that's what has reported, says like at the entry if you will be having the distortion, at the exit of this stage, contra rotating stage, we are nullifying the effect of this distortion. So that's what is one of the major application we can thought of.

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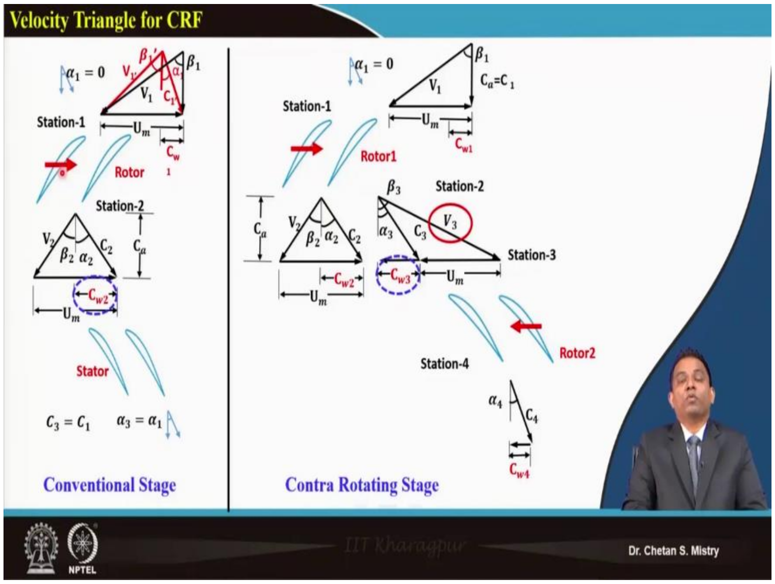

Now, if we look at, this is what we were discussing in sense of our velocity triangle. And what we have found, here if you look at, this is what is say your configuration. Now this is what is for a conventional configuration what we are having. So, you know, flow that's what will be coming out from my rotor, that will be having some swirl component. And that's what will be entering inside my stator.

Now what it does, like, you know, stator that's what will be verifying or may be minimizing the effect of this swirl, and maybe at the exit of my stator, I will be having say no straight flow or as per the expectation for the next stage. Here in this case, my flow, that's what will be coming out in the same way because my rotor-1, that's what is acting similar to what rotor we are having for conventional stage.

But what happens? Say, I am having my second rotor, that's what will be rotating in opposite direction. So, this is what is my rotational direction for rotor-2. What whirl component that's what is coming out from my rotor-1, that's what is getting added up here. And this addition, that's what is giving us benefit. So, we are basically utilizing our whirl component.

How we are utilizing? If you look at here, say our relative velocity component at the entry of my rotor-2, that's what will be going to increase, okay. And that's what will lead to give you outlet as per our expectation. So, the benefit what we can say, the strong suction, that's what is happening because of rotation of rotor-2, that's what will be changing say my flow field within say gap between the rotors, okay.

Now, if we look at, suppose say, here in this case for conventional stage, we have seen; suppose say we are having say tip clearance between casing and rotor blade, and we have found the three dimensionality of the flow near the tip region. What happens? That's what will be striking on my say stator. The stator, it is a stationary body, so my flow always will be striking on my stator at off design condition.

Or, suppose say my rotor speed or my mass flow rate, that's what I am changing, that's what will lead to change the flow striking on my stator. And that's what is limiting my operating range. What is happening here for contra rotating concept? Suppose say we are changing our rotational speed, if we are changing our mass flow rate, we are also having tip clearance flow. But because of rotation of our second wheel, okay, that's what will be reducing the effect what we are facing in sense of difficulty for say our stage configuration.

And that's what is the benefit. Now, there are different studies which are been reported and that's what is of major interest say, what need to be the gap between this stator, or say stator and rotor, that's what is the conventional stage; what need to be the gap between these two contra rotating rotors, that is also very important, okay. We will see all these in detail.

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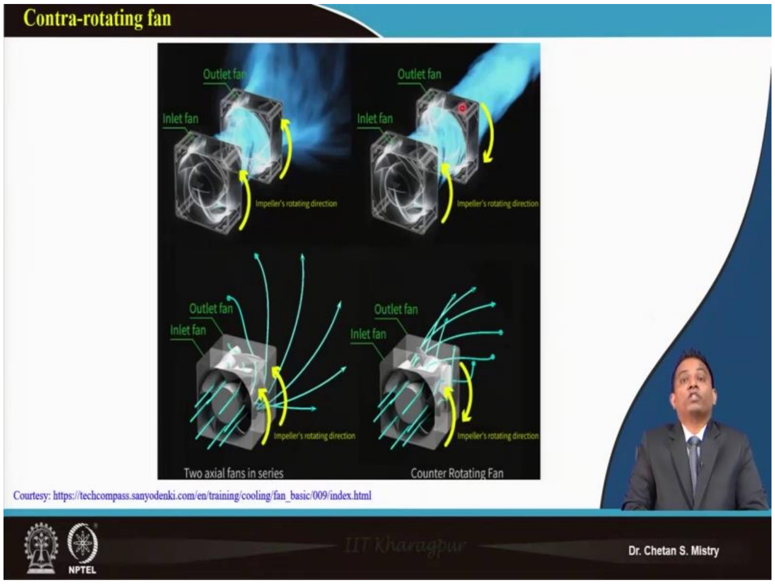

Now, this is what is one of the applications, what people, they have explored. So, there are special application for say high speed computing facilities. Now, they are looking for say cooling. Now, what is the purpose here? If you look at, we are having two fans which have been connected in series. Like, you know, both are rotating in the same direction. So, at the exit, if we look at, say…this is what is your case, you will be having say your flow, that's what is coming out in…in a different way.

Suppose if this is what is your case, you will be having your outlet that's what is say in a dispersed manner, okay. Now when we are having this contra rotating concept, if you will look at, we will be having intense flow that's what is coming out at the exit. Now, there are special applications, where we are looking for cooling of such kind. And that's where the attraction is there.

So, if you look at, say…these fans, you can say cooling fans, they are of few…few centimeter diameter, maybe say at the most maybe 4, and 4 centimeter or 5 centimeter. And that's what is serving the purpose. So just imagine, how people, they are thinking of adopting the technology for special requirement for special purposes, okay.

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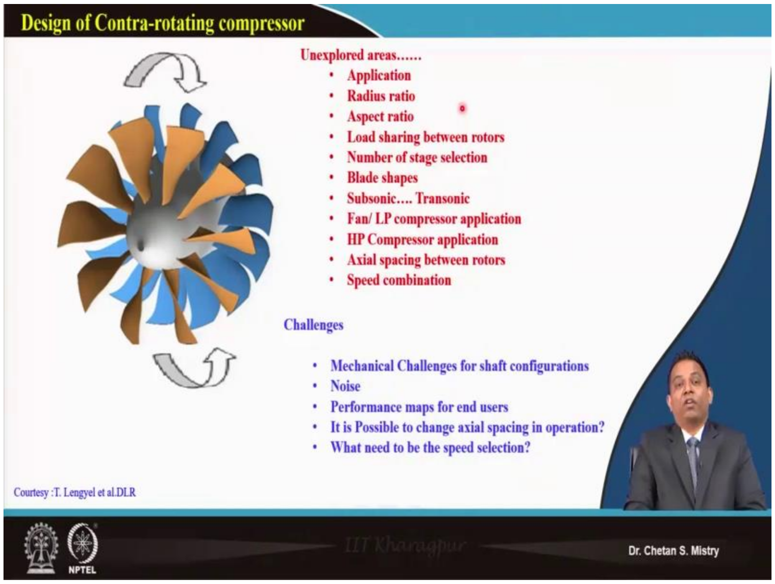

Now, say…here if you look at, this is what we are talking in sense of two rotors which are rotating in opposite direction, okay. Say…here, the special things that's what I want to explore, it is say unexplored areas. Say…still, we are finding the applications for this kind of configurations. What are the application, where all we can apply this kind of configuration other than aero engines, maybe other than cooling fans.

Do we have other applications? Yes, that's what need to be explored. When we are talking about the dimensions, we are still say what need to be the radius ratio? Will it be low radius ratio, will it be high radius ratio, what will happen if I am having higher radius ratio, what will happen when we are using low radius ratio.

That kind of study, that's what is still to explore. Aspect ratio of the blade, that's what is one of the major attraction. We can understand, people, they are moving towards low aspect ratio fans. But for contra rotating, do we have such thought that's what is applicable, that's what is unanswered till now.

Load sharing between these two rotors, we will be discussing today when we start with the design. So what need to be the load distribution between two rotors, okay. If you recall, say when we are talking about say multi-stage configuration, for that we discussed say per stage pressure rise what we are expecting.

Here in this case, per rotor, we need to find what need to be the loading, aerodynamic loading, I am talking of. We can say, what need to be the pressure rising capacity of one rotor, what need to be the pressure rising capacity of my second rotor, and what need to be the pressure rise of per stage…full stage, that’s what is need to be explored.

Say, Number of stage selection, as we discussed. Say, if you look at, say…F-135, where you will realize the number of stages compared to your low bypass ratio engine, they are less for compressor. And that’s what is one of the major attractions. Say, Blade shapes, what kind of blades we will be using, whether it will be having three dimensionality in the shape.

If you look at, we were discussing about the VITAL project where we have seen those blades are of different kind or different shape. There, they are having something that…that’s what is attracting say…attention towards the noise, pressure rising capacity. So that’s what all need to be explored.

Say, whether we will be using this for subsonic application, is it equally applicable for transonic application, people, they are working on development of transonic rotors at this moment. So there, my flow physics or flow structure what we are discussing, how that’s what is changing, it is of major attraction.

Say…do we use this for say fan and LP compressor application or only for fan application? Do we think of applying that for say HP compressor configuration also; like maybe, if you look at, for F-135, all my rotors, they are rotating in counter clockwise direction. Say, for LP also, for HP also. Do we really need this kind of configuration, or maybe we can think of different way?

Suppose say, one can think of having say high bypass ratio engine or say low bypass ratio engine, may be retrofitting kind of thought also can be thought of. Say, you can arrange some mechanism with say gearing or say gearbox or maybe epicyclic gear train, by which you will be adding one of the rotor which will be rotating in opposite direction, and will it make the sense?

Yes, that also can be one of the potential thoughts, okay. What need to be the axial spacing between two rotors, yes, that is also equally important. So, you can realize, we are saying by removing my stator, basically, we are reducing the length of our engine but what should be the gap between two rotors.

When we say my second rotor, that's what is rotating at the high speed, that's what is giving strong suction effect. Suppose say if you are putting very nearby, it may be possible that wake that will be coming out from my rotor-1, that will be striking on rotor-2 very intensely. And that's what will lead to increase noise. So, noise is a major issue.

Then you will think of say increasing the axial spacing between two rotors. If you are increasing the spacing between these two rotors, maybe what benefit we are getting for contra rotating, may not be explored. So that kind of study also need to be there and there is no superficial rule at this moment.

Lot of experimental results, they have been published in open literature where people, they are talking about all those thoughts, okay. So minimum gap or optimum gap, that's what is a question, okay. For our study, we have found 90% chord, of my rotor-1, that need to be the spacing between these two rotors, which is giving best performance, okay.

Now next, that's what is coming in sense of say speed combination. You can realize, suppose if we consider both the rotors, they are rotating at the same speed. One can say why can I not rotate my rotor-2 at the high speed, why not for rotor-1, why both to be rotated at the same…same speed.

Can we think of rotating both the rotors at low speed, same speed? So, those all things, that's what is need to be explored, okay. Now, what all we are discussing at this moment, that's what is putting some of the constraints or we can say this is what is say in sense of challenge. What it says? We are having the mechanical challenge in sense of shaft configuration.

You can understand, we say, two rotors, they need to rotate in opposite direction. Now, can you think of mechanism where you will be having two spools, and those two spools, they are rotating in opposite direction. That's what is very challenging to arrange. Suppose if we consider one of the configurations what we have seen for say European engine, where LP compressor, that's what is on one spool, and if you look at say HP compressor, it is on one spool.

LP compressor, we have realized, that's what is having say different kind of configuration and IP compressor, that's what is on the third configuration, and we have realized because we are having contra rotating concept, so LP and IP, that's what will be acting like a contra rotating kind of configuration.

But it is easy to say, when we are making the engine, that's what is very challenging. So, you need to explore in detail how we can configure this kind of possibilities. Suppose we are talking about say industrial fans. For that, we can have two different motors which we can put as a hub and that's what will be solving our purpose.

But at the same time, there are many applications, people, they are exploring these days for electrical propulsion system in which the motors are available which are rotating in counter clockwise direction. So PLDC motors, they are rotating in opposite direction and that's what is serving the purpose. So, you can understand, as per the need, now research and innovation need to come, okay.

Noise is a major issue, as I told, what need to be a gap between these two rotors that's what is very challenging, and that's what is major attraction for the research these days, because we are looking for the constraints given by ACARE as Vision 2020. Now, performance map for end users, as we discussed, there are number of possibilities here.

Say, if we are looking for our conventional performance map, where we are having our speed lines, that's what is speed of one or speed of my whole engine. Now, here in this case, we are having contra rotating concept so we need to explore what need to be the combination of speeds. So that's what is very challenging to develop at this moment, one thing.

Secondly, your pilots need to train for such kind of configurations. They need to have idea how these things are working. Then only they can operate the engine as per the expectation. Then it says, is it possible to change the axial spacing in operation? See, when we are putting these two rotors nearby, that's what is creating issue of noise, but at the same time it is increasing the pressure rising capacity, okay.

Suppose say, if I am not looking for say high pressure or say I am now interested in reduction of noise, can I change the axial spacing between the rotor during operation? It is a challenge, you can think of, okay. Like people, say they were using say pitch kind of rotor or rotor pitching for industrial fans, during…even during the operation.

Now that kind of thought process, it is being explored, it is under process for engine development where your fan rotor will be having pitching moment. So, this kind of thought also, in future, people, they need to explore. What need to be the speed selection? Yes, because we can say we are doing our design for compressor.

Now, that need to be rotated by the turbine. So, the design for this kind of contra rotating fan or compressor is challenging. At the same time, on counterpart, turbine also is equally challenging. So, we need to explore all these possibilities. And that's what is putting lot of intense research, that's what is going on for this domain, okay.

And by near future, we will be having engines which will be having this kind of configuration. And that's what is for sure because it has so many benefits, and it is meeting with the requirements what we are expecting as a vision for the future engines.

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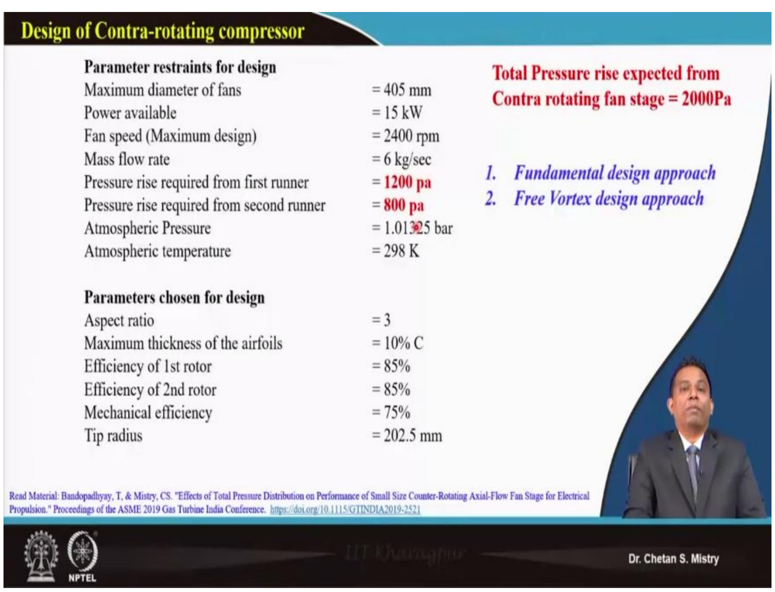

Now let us talk in sense of say design of this contra rotating fan. So, if you recall, in last lecture I was discussing about my own design for contra rotating fan which I did during my doctoral study at IIT, Bombay. Now, for that configuration, I was having some constraints and some restraints and based on that, we have decided with the few configurations.

We were expecting pressure rise of 2000 Pa from the stage, and these are what I have decided or what I have used for my design purpose. So, for my design, as we have discussed, my rotor-1, that's what was expected to give pressure rise of 1100 Pa, and rotor-2 is expected to give pressure rise of 900 Pa.

And what we realize by giving higher loading of rotor-1, that's what is giving benefit in sense of overall operating range, and my performance, okay. Now the question is, say 2000 can be divided in 800-1200 combination, maybe it can be divided into 1000-1000 combination, 1100-900 configuration. It can be divided into 1200-800 combinations. Yes, there are many possibilities.

So later on, we have developed our contra rotating fan for one of the UAV application, that's what is called project AIRAWAT. And for that, we have designed electrical propulsion system that's what was based on contra rotating concept. And for that design, we have explored what all can be done in sense of distribution of aerodynamic loading.

And that's what it says, like when we will be having combination of higher loading towards rotor-1, that's what is giving the benefit. But later on, that's what is reducing the overall operating range. Now, in order to realize that part, for present design or say for present lecture discussion, I have modified my pressure distribution from say 1100 to 1200 and from 900 to 800.

So, we will be discussing the design of contra rotating fan for rotor-1 having pressure rise of 1200 Pa and rotor-2, that's what is having pressure rise of 800 Pa. And for that, we will be adopting say two design approaches, one, it is a fundamental approach, and second, we will be exploring with free vortex concept.

There are other possibilities also. With the interest of time, we will not be discussing all the methods because it will not make much sense. If you are interested, you can do practice and you can check with what all we are discussing in sense of results, and in sense of what all we are getting as output, okay.

So, for present design, we are considering 1200 and 800 Pa, respectively for rotor-1 and rotor-2, and we will be discussing the design based on free vortex and your fundamental approach, okay.

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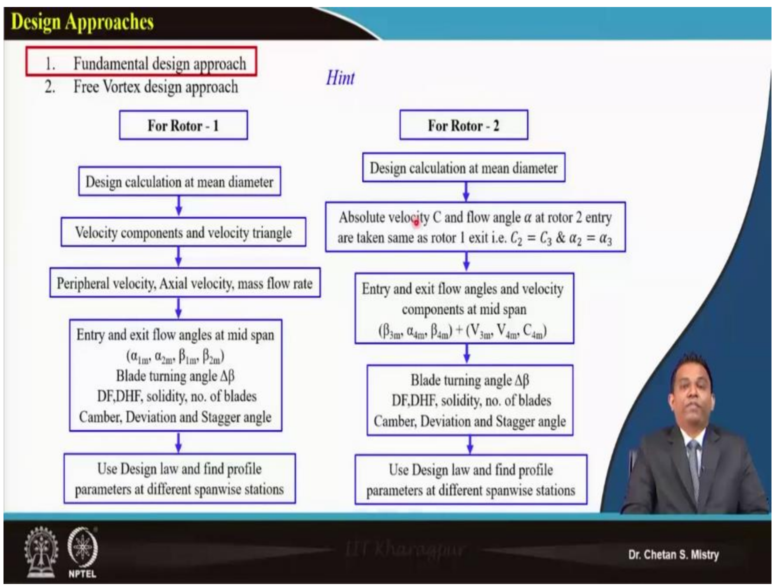

Now, in order to have this kind of configuration, very first, we will be discussing about the fundamental concept. So, let us have hint what all we can do for our design purpose, okay. Here, in this case, we can say for rotor-1, when we start our design, say…we will be having say mean diameter, okay say…we need to calculate our mean diameter.

Then for mean…based on this mean diameter, we will be doing our calculation for different velocity and velocity triangles, we will be developing at the mid station. Then, we will be checking with the peripheral speed, axial speed, mass flow rate. Once we are doing our calculation at the mid station, then this is what will be helping us for calculating the parameters called flow angles.

Then we will be calculating our say parameters called say…diffusion factor, degree of reaction, de-Haller's factor for our verification purpose. We will be calculating our camber angles, stagger angle, deviation angle, okay; and based on that, later on what concept we are opting, say for present method, we will be opting with the fundamental method.

So, we will be obtaining how we will be calculating the parameters at other stations. So, you can understand what we will be doing. Say, for my rotor-1, I am having one blade that's what is made up of say maybe 11 sections. You can go with the 20 sections also, okay. And for that, we will be calculating all parameters at different locations.

Now in line to rotor-2, for conventional stage, what we have discussed, we are having say rotor and stator combination. And for that what we are calculating the flow or velocity with which my flow is coming out from the rotor, that's what is say absolute velocity C_2, that's what we are assuming, that is going to my stator.

So, in line to that, for design of contra rotating fan, listen carefully, what we will be doing, we are assuming the same way the absolute velocity with which my flow that's what is coming out from rotor-1, that will be going to rotor-2. So, you can say my exit velocity from rotor-1 is suppose, say C_2, and my C_3, that's what is my entry velocity…entry absolute velocity, they both are same. This is what is our assumption for the design.

And based on that, we will be doing our calculation at the mid station. Once we will be calculating at mid station, all parameters, we will be doing the calculation for different performance parameters like diffusion factor, de-Haller's factor, relative velocity ratio, all those parameters, along with the angles, we will be calculating at the mid station.

And based on this, what concept we are opting for the design, we will be designing the whole rotor. Now, this is what is low speed application, so you can understand my hub diameter and tip diameter for both the rotors are same. And that's what is making our life little easy.

So, we will be discussing this design in detail in next lecture. Be with me. This is what is very important, what all concept we are opting for, that's what is need to be understood clearly. Thank you. Thank you very much for your kind attention!