Aerodynamic Design of Axial Flow Compressors and Fans
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Lecture 01
Introduction

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Hello and welcome to the first lecture on Aerodynamic Design of Axial Flow Compressors & Fans!

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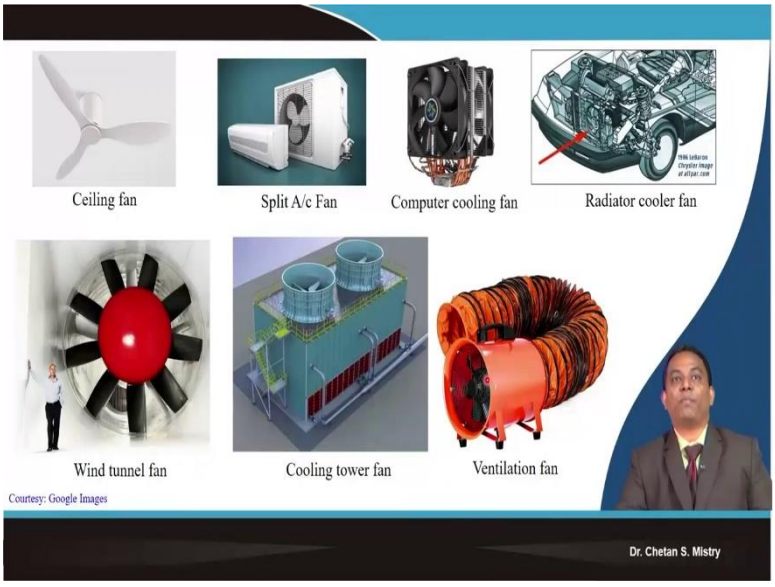

If we look at, this is what is representing different components; ranging from, say... ceiling fan, split AC fan, cooling - computer cooling fan, radiator cooling fan. If we look at one by one, if

we consider, say ... for ceiling fan, the purpose is to supply large quantity of air with low pressure. If you look at say ... split AC fan, this split AC fan, that's what is used for cooling of the condenser. These days, people, they started talking about the high-speed computing; which requires large amount of cooling for those processors.

If we consider, we are having say... radiator fan, that's what is being used for cooling of your engine. This all application when we are looking for, they are having application for the cooling purpose. Downside, if we look at, this is what is a wind tunnel, that's what has been widely used for different testing purposes where large amount of air, that's what will be thrown through your wind tunnel.

And that's what is giving you the velocity, that's what is required at the entry of my test action. Next component if we look at, that's what is my cooling tower fan; this is what is being used for steam turbine power plants for cooling of hot water. And on the next side, if we look at this is what is representing your ventilation fan. These ventilation fans, that's what is having wide range of application ranging from, say... mining to say... your tunnels, it is for say... your Metro. So, wide range of applications we are having here.

Now all these devices what we are looking at, that's what is required a large quantity of air and small pressure rise. This is what is having the specialized requirement in different applications. So, we can say, these devices, that's what is coming in the category of axial flow fans.

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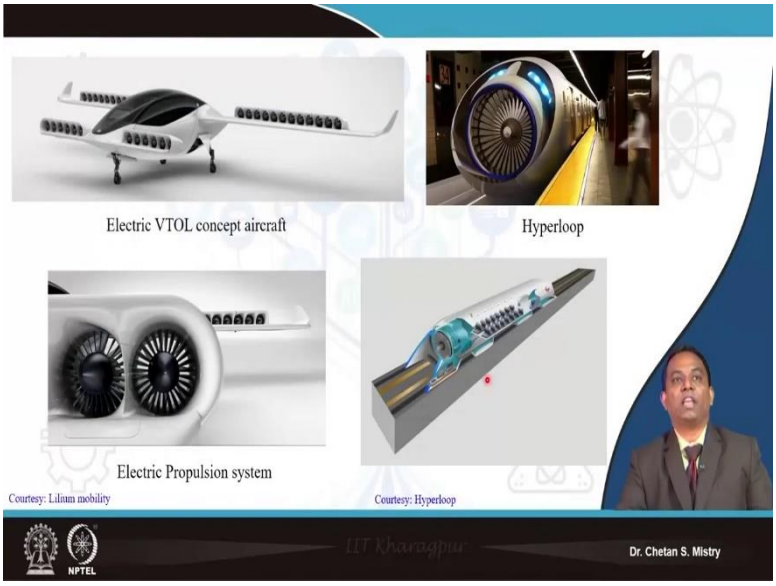

Now, let us move on to the next. If we look at here, these days, people they started talking about electrical planes! These E-planes, they are being used for using say... electrical energy,

for the generation of thrust. Here, if you look at on the wing; these people they have used, say... number of fans; they are placed in a series, on the front side as well as on the rear side. That's what is giving vertical takeoff and landing as per the requirement. When it is moving at the cruise, it will be parallel to the flow.

So, this is what is giving another kind of application, that's what these people are exploring these days. This is what is a Lilium plane; that's what was a startup company developed by, say... University of Stuttgart. Next, we are looking for, say... high speed applications for the transportation. So, this is what is a case for, say... Hyperloop! Hyperloop, that's what is working on a principle of Maglev. But here, if you look at for this Maglev, you are looking for large amount of propulsion power; and that propulsion power, that's what has been provided by this high-speed compressor. So, we can say, this is also a category of application for, say… generation of thrust in, say ... new era.

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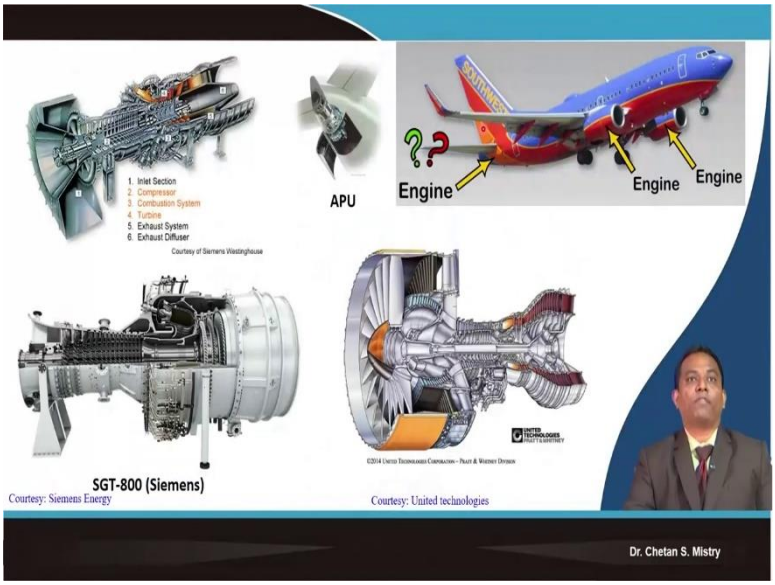

Now, after all this discussion, let us move towards the most challenging application for your axial flow compressor; that's what is for the application of your land-based power plant. So, here on this side if you look at, this is what is a device, which is defined as a gas turbine power plant that's what is used for land-based application.

So, the purpose here for this gas turbine engine, it is to generate the power for the requirements. So, the front side if you are looking at, this have number of stages, that's what is your axial flow compressor, which will be followed by the combustion chamber, and on the rear side we are having the turbines.

So, this turbine, that's what has been used to rotate your compressor. Additionally, we will be having a turbine, that's what is defined as a power turbine; which has been connected with the generator for the generation of electricity. The most promising application of Aero industry for gas turbine is, if you look at on, say... below of your wing we are having engines; on the rear side also, we are having engine.

We are focusing mainly on what engines we are fitting below this wing! So, downside if you look at, here, this is what is a cut section of Pratt and Whitney high-bypass ratio engine. So, on the front side, if you look at, this is what is a large diameter fan. That will be followed by a number of stages; this stage, that's what is, say... inter pressure compressor; rear side, that's what is say... high-pressure compressor; that's what will be run by using HP turbine and say... LP turbine.

So, here also we are having the device what we are discussing is our, say ... fan. This fan is completely different from what we are discussing for our earlier applications. Here the fan, that's what is handling large amount of mass flow rate. The purpose for providing this large diameter fan, it is for the generation of the thrust.

So, it says approximately 70 percent of your thrust, that's what has been generated by this big size fan. The pressure ratio here that's what is ranging from 1.4 to say... 2 in the range of 2; and it is handling large mass flow rate. This is what is looking like a large size, a large diameter, that's what it is named as a fan. Do not get confused, say... people they used to define in open literature with the fans, and this fan; so, do not get confused with the fan.

When I am saying, say... fan that's what is applicable to aero engine that has a special requirement. And these blades, if you look at, they are taller blades; on the later stages, when we are looking at, these blades are the shorter blades. We will be discussing about the design of such devices in these lectures.

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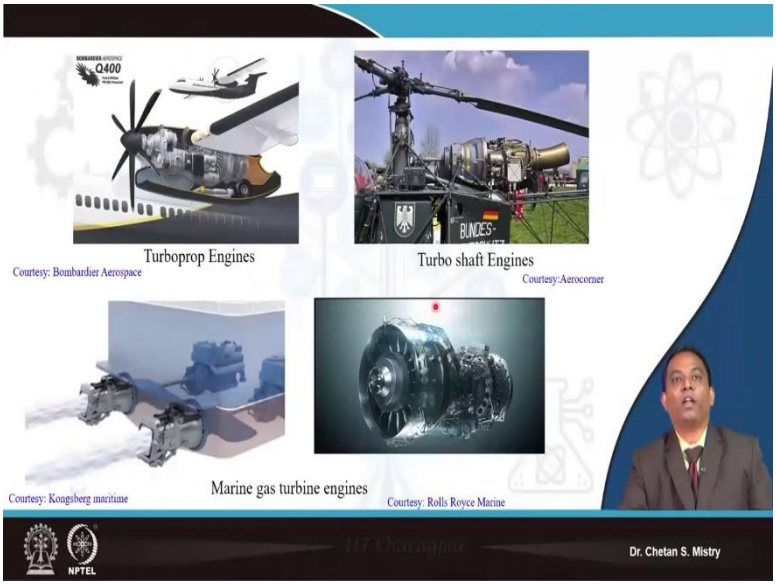

Now, this gas turbine engines they are having other kinds of applications also. So, many regional transport aircraft or say... private jets, that's what has been run by using say... your propulsion device. That's what is called propeller! This propeller, it is similar to your fan but its design approach that's what is different.

Here, the whole thrust that's what has been generated by using this propeller. Now, in order to rotate that propeller, we are looking for the power; and, that power it has been generated by your gas turbine engine. So, this gas turbine engine, that's what is similar to what we are discussing for land-based power plant. Here we are having, say... power turbine, that's what is being used to rotate these propellers.

Now, if you look at, we are having helicopter engines. In this helicopter also, that's what we are using, if you look at carefully, this is what is my turbo shaft. So, the shaft that's what is coming out from my gas turbine engine, that's what will be used in order to rotate these blades.

Now, the application that's what is not ending only for land-based power plant or say... only for say... aero application; people they are using this for marine application also. Here, if you look at, we are having this gas turbine engine, that's what is being used in order to move the propellers. So, here, this is what is in line to what we are discussing for the generation of power and this is what is used for propelling of your ships!

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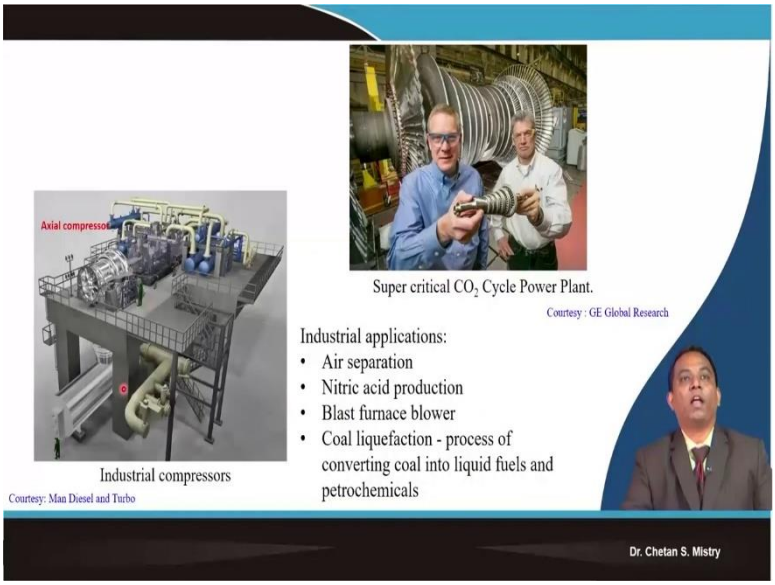

Now, these days, people they started talking of, say... development of compact engines. So, on top side if you look at, this is what is supercritical cycle power plant. So, just look at on the backside of this photograph, we are having say... large size gas turbine engine; and these persons, they are holding small size, say... gas turbine engine.

So, this is not the model, but this is what is actual engine, actual gas turbine engine. Now, we are using this supercritical CO_2; that's what is having properties similar to our steam, say ... we are having steam. And you know, it is having density in the range of water. That's what is giving you application for rotating these wheels at the high speed and that's what is providing the compactness.

Now, for the future we are moving towards the net zero. And this is what is one of the applications where we will be using, say... CO_2. That's what is been trapped in order to rotate this kind of turbines, and this kind of device. That's what is say... your gas turbines for the development of power.

Now, there are many industrial applications. Here, if you look at, this is what is my axial flow compressor that's what has been run by the steam turbine power plant; say..., we are looking at the industrial applications. These applications they are ranging for, say... air separation, nitric acid production, blast furnace blower, coal liquification. That's what is nothing, but the process of converting your coal into liquid fuel and petrochemicals.

So, we are having special application for oil and gas. So, these all are the applications what we are discussing for, say... application of gas turbine engines. So, if you look at in overall, it says

this is what is most promising industries, that's what will be giving a better future! And that's what is fulfilling our requirements for the betterment of the future in terms of fuel economy, in terms of your environment.

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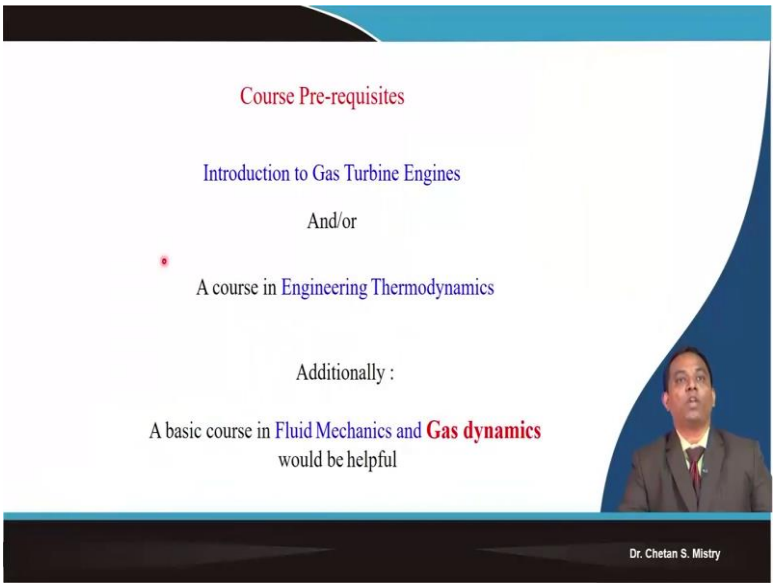

Now, in order to move forward, there are some of the prerequisites for this course, many of you are having the background of mechanical engineering, many of you are having the background of aerospace engineering. So, the introduction of gas turbine engine that's what is essential part. If you are not having this background, just go through a standard textbook, that's what we will be giving you idea of different working components.

This course also is based on the fundamentals of your engineering thermodynamics. So, the background of thermodynamics as and when required, I will be discussing this part. But, you can understand you can move with your requirements. And as and when it is required, just go through the standard literature.

Now, this aerodynamic design of compressor and fans, so you can understand your background of fluid mechanics and your background of aerodynamics, that's what is must. Okay! So, we will be talking about the three-dimensional flow through these machines. And these machines, that's what is required a special kind of attention for the background of your aerodynamics.

So, it is preferred that you just go through and refer again what all you have learned in past. We will be discussing low speed application; we will be discussing high speed application. What I mean for high speed application is, say... my flow through this machine to be transonic or supersonic, and that's what is required the background of your gas dynamics. So, this also

will be helpful in sense. So, in overall, if we say... you need to have your background of fundamentals of thermodynamics, you need to have your background of fundamentals of fluid mechanics.

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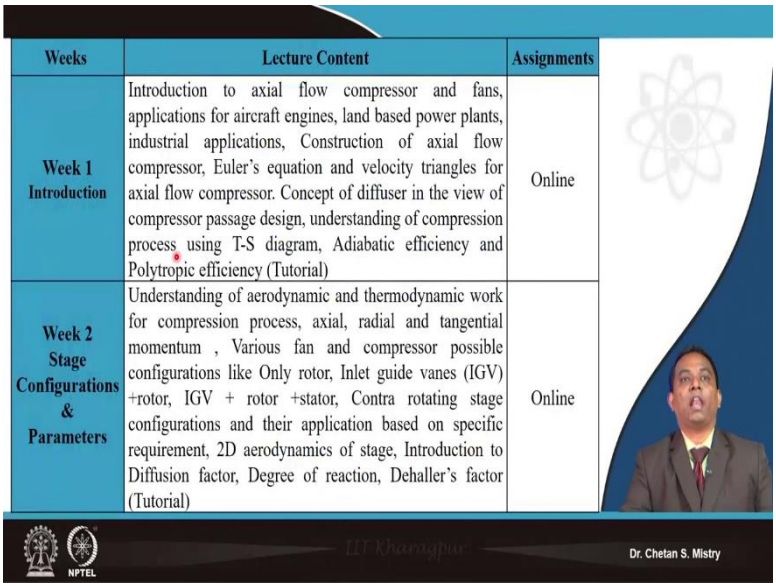

Let me move with the course structure. So, this course, it has been designed for 12 weeks. These are some of the contents for this course. And, you will be having, say... examination, because this is what is online certification course. So, that is the reason on say... right hand side, you can see, we are having say... different methods for the examination.

So, in first week, we will be discussing about the introduction of axial flow compressors and fan with their applications. We will be discussing about the say... construction details of your axial flow compressor. We also will be discussing about the fundamentals of Euler's equation and velocity triangle. That's what you might have studied in your basic course. But still, as per our requirement for the design, we will be discussing in detail.

The concept of this diffuser, so, this compressor we can it is a diffusing device. Basically, it is say... it is a fluid compressing device; and that's what is required special kind of attention in sense of aerodynamics. So, we will be discussing about that part. Then we will be representing this process or compression process on T-S diagram. We will be discussing about adiabatic efficiency, polytropic efficiency. And we will be solving one of the numerical that's what will be giving you the idea about how to use this concept for the specific requirement.

My second week that will be with the stage configuration and parameters. So, we can say... the process through this compression we can represent that as a thermodynamic process, as well

as say... your aerodynamic process. So, we will be discussing about that part. Now axial flow compressor that's what is having different kinds of configuration. You might have seen what we were discussing for different engines, that's what is having combination of say... inlet guide vanes; only rotor; inlet guide vane, rotor and stator configuration. We are having, say... future requirement that's what is say... a contra-rotating concept. All these things that's what we will be discussing in this session.

We also will be discussing very important parameter that's what is required for our design. That's what is say... diffusion factor, degree of reaction, De-Haller's factor. We will be discussing how we will be using these factors for our design purpose. Then also will be concluded with the tutorial part.

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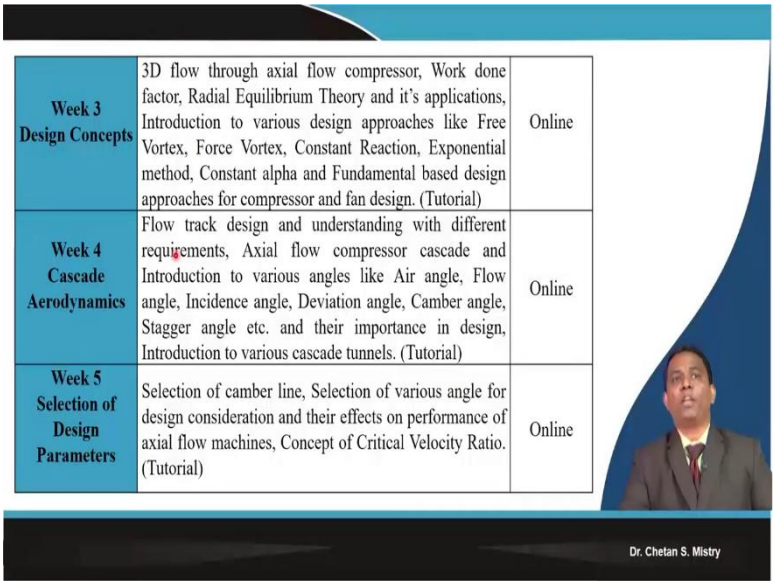

Now, coming to the design concept, you may be aware of the flow through this axial flow compressor is highly three-dimensional flow. That's what is required your fundamentals and for that, we will be discussing our fundamental theory. That's what is radial equilibrium theory and its application! We also will be discussing different design approaches; which are say... free vortex design, force vortex design, constant reaction design, exponential method, constant alpha design, your fundamental design approach for say... compressor and fan design. And that will be included with the tutorial.

So, the whole purpose here, is to discuss about the fundamentals; then we will be having explanation, that's what is related with the design and how you will be using that concept for further study. Now, when we say... our axial flow compressor, this axial flow compressors and

fans, they are made up of airfoils. So, fundamentals of your cascade aerodynamics, that's what is very important.

So, we will be discussing about, say... various angles in sense of air angle, flow angle, incidence angle, deviation angle, camber angle. We also will be discussing about the various kinds of cascade tunnels, which are available. Because this is what will be giving you other sight of say... application of these devices for, say... design.

Next, in fifth week, we will be discussing about the selection of design parameters. This design parameters will be covering what all is our requirements for the design. We also will be discussing the concept of critical velocity. You must be aware of when we are talking about, say... the gas dynamics there we have discussed about some of the parameter. This parameter that's what is very important. So, we will be discussing in detail about the application of this critical velocity ratio.

In week six, we will be discussing about different design strategies, because you need to do design that's what is required a selection of different parameters. So, how do we select these parameters! Then, we will be talking about the first cut design calculation. Then we will be discussing about the systematic approach for design of axial flow compressor based on various design approaches and different requirements. From week seven, we will be starting with the design of say... low speed compressor. We will be doing the design problem for the low speed axial flow compressor. Then later on after doing this design, we need to select, say... different kind of airfoil geometries. And that's what is for finalizing your rotor and stator blades.

So, we will be doing the design for this low speed axial flow compressor. And for assignment, we will be giving you one or two problem, that's what you need to do at your home when in order to do a satisfy your certification. Next, we will be discussing about say... design of low speed contra-rotating fan. As I told, for the future, people they are looking for high aerodynamic loading in order to meet the requirement of the compactness for the engines. And this is what is one of the concepts. Very few open literature they are discussing the design concept for this contra rotating fan. So, we will be covering that contra-rotating fan design and we also will be discussing about how do we select different airfoils for making of these two rotors, which are rotating in opposite direction!

Now, these all it is related with your low speed application; when we are moving with the application for say... aero engines, where we are looking for special kind of compressors. These

compressors are of say... transonic nature. So, we will be discussing about what all are the need of this transonic compressor. We will be discussing about how do we select these transonic airfoils and their application. Then, we will be discussing about the selection of this blade parameters which are required for say... transonic compressor.

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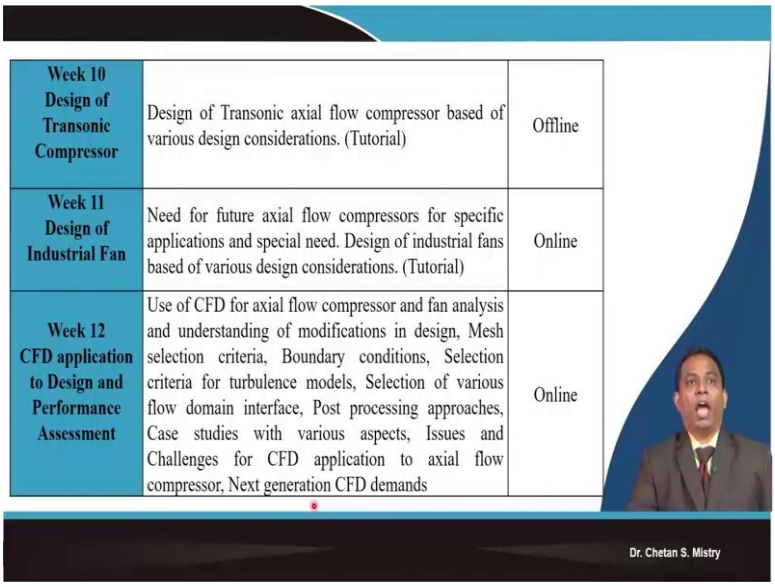

Having this background, we will be discussing, we will be doing our design for the transonic flow compressor with different design consideration. Okay! And, for that also you will be having assignment which will be for design of say... transonic compressor of your choice. Later on, as I told, we have seen many industrial applications ranging from our ceiling fan towards say... we are having say... cooling tower fan. They all are having different requirements and if you look at the size, that's what is starting from few millimeters size to few meters; maybe in the range of say... 20 millimeter size towards to 14 meter, say... height of the blade or the diameter of this blade. And if you look at this, we need to do the design for this kind of industrial application also.

Now, after doing all this design, the recent trend, that's what he is saying, the CFD application for design and performance assessment of your engine. Now, in week 12, we will be discussing about the use of your CFD, for application to axial flow compressor and fan design. We also will be discussing about say... how to do the modification of design, when we are using such tool. We will be discussing about, say... mesh selection criteria, different boundary conditions, we will be discussing about say... selection of various turbulence model, selection of flow domain interface, post processing approaches; that's what is very important. We also will be

discussing few of our own design in sense of case studies for various aspects, losses and challenges for the CFD application to your axial flow compressor.

And last, we will be discussing about the next generation CFD demands. So, if you look at carefully, the whole course, that's what has been structured in such a way that the beginners they can understand the fundamental part and they will start doing their first-hand design and slowly they will move towards the advanced stage. At the same time the working professionals, they will be getting advantage in sense of brush-up their earlier knowledge or already known knowledge and then they will think of applying that knowledge for the specific application. And, as per the requirement, they people, they will be targeting the new kind of design.

So, if we look at this is what is a course, when you are having the expectation in sense of design of axial flow fan and axial flow compressor for various applications. So, this is what is all about the course structure, what we have discussed.

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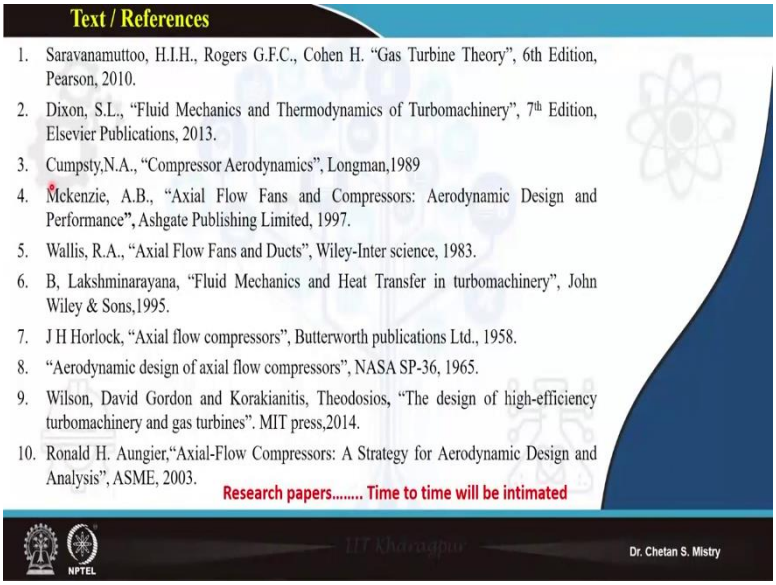

Now, let me move towards what all are the references. If you look at these are some of the books, that's what we will be discussing about, say... a very first book, that's what is by Saravanamuttoo and Cohen and Rogers. That's what is giving very good introduction to axial flow compressors. And it is giving the fundamentals part that's what is required for the design.

The book by this Dixon, that's what is talking about, say... your cascade aerodynamics in detail. So, that's what is also a good book. Very good compilation of data that's what is been given by Cumpsty, that's what is titled with Compressor Aerodynamics. It is also covering wide

range of design application, future requirements, design modification, so many prospects, they have discussed in that book.

The book by Mckenzie that is talking about design of various application. That's what is ranging from industrial application towards the aero engine application. Book by Wallis that also is talking about your cascade aerodynamics, different kinds of profiles.

Those who are interested to move forward in the direction of computational fluid dynamics, those who are interested in development of say... codes for simulating this turbomachinery device that's what is say... the axial flow compressor; this book by Lakshminarayana, that's what is giving very good understanding of basic fluid mechanics and your energy equation, momentum equation, continuity equation, and then how you will be using this equation to develop the solver; and after doing this solver, what all you will be required for doing the post processing. That is what has been covered in this book.

There is a book by Horlock, title "Axial flow Compressors". This is one of the old books, but that's what is having very good fundamentals, that's what they have discussed. The book by Wilson and Aungier, that's what is talking about the most recent approaches. Now, let me tell you, these all books, that's what has been written for last many years. This gas turbine industries, that's what is been started hundred years back!

So, you can understand there is a continuous development activity that's what is going on in order to meet the future requirements and the current requirements, okay. And, in order to meet these requirements, you need to have continuous knowledge of the development activities. So, with these all fundamentals what you learn from these books, you need additional reading; and that additional reading that will be provided by good journal papers.

So, as and when required in our course, we will be discussing about say... application of different research paper and we will be intimating you. Now this course, it has been designed for say... long experience with the compilation of whole lot of data. And that's the reason I consider that 'zeroth reference' for this course is a course material! So, you know, these all will be covering what all you are looking for, say... design - aerodynamic design of your axial flow compressors and fans. I am sure, by doing this course you will be meeting with the requirement for the future! Thank you. Thank you very much!