Aerodynamic Design of Axial Flow Compressors and Fans
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Lecture 61
Design of Industrial Fan (Contd.)

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Hello, and welcome to lecture 61. We are discussing about design of industrial fan. In last lecture, we were discussing about what all are the design goals for the compressor. So, in that we have discussed we are looking for lightweight and compactness, we are looking for high mass flow rate capacity, we are looking for higher isentropic efficiency, we are looking for large stall or surge margin, and we are looking for low noise. If you look at all these aspects, that’s what is mainly been targeted with the compressor. And, those compressors, they are applicable to say aero engines; same is a logic, that's what is applicable these days for industrial compressor also.

Now, if we look at in sense of lightweight and compactness, we have discussed, we are looking for high per stage pressure rise. Then we have realized we want to reduce the number of components, we would like to have say lighter weight blades, those all are the aspects that's what we have discussed in last lecture. Then we were looking for say high mass flow rate capacity; there we have discussed about say design flow coefficient need to be higher. If you are going for say higher design flow coefficient that time we have realized we are facing difficulty in sense of operation, that's what we say hysteresis and that's what is restricting our flow coefficient decision.

Next parameter, that's what is possible is to increase say your intake area or increase the diameter, that may be the constraint where we are applying this compressor. Suppose, if you are talking for application of commercial engines, there we may not be having such kind of limitations but if we are talking about the fighter aircrafts, where we will be having constraints with a diameter. In the same way, if we are looking for suppose say industrial compressor, the diameter of the rotor or say the diameter of the casing may not be the constraint for us. But remember, for aero engine we are looking for thrust that's what is our major parameter and for land-based power plant we are looking for power generation, that's what is say power generating capacity in sense of Megawatt, so both the aspects are different. We need to address individually as per the requirement.

Next, if we are looking at, that's what is looking for say higher isentropic efficiency and we know efficiency we are correlating with the losses, when we are able to reduce the losses then it is possible to improve the efficiency. Now, these losses, we have discussed, they are mainly our aerodynamic losses that's what is concerned with the design, selection of blade, selection of airfoil, so many parameters, that's what will be coming into the picture.

So, during 70s and 80s, people they were happy with the efficiency in the range of say 88%, 85%. These days, now we are very aggressive in sense of improvement of efficiency. People, they are claiming say, many companies they are claiming their efficiency to be in the range of say 90 to 92% as on today for say axial flow compressor. So, we can say, now we are moving more towards achieving higher isentropic efficiency. We can say, we are able to achieve high per stage efficiency. Do not forget the terms, that's what is say polytrophic efficiency, that's what we say per stage efficiency and isentropic efficiency do not make them mix.

Next, that’s what is to have say large stall and surge margin and that’s what is mainly been how we are managing our flow within the blade passage. Then we have discussed about some active and passive control mechanisms which can be used in order to improve this stall margin or the Surge margin. And noise, as we know, that’s what is very challenging aspect; these days as per say new norms as suggested by ACARE, we are looking for reduction in the noise. So, when we are doing our design that time only we will be taking care of this aspect. So that, later on when we will be making that component it will give what we are looking for in sense of their performance. So, this is what all we were discussing in sense of what are the expectations.

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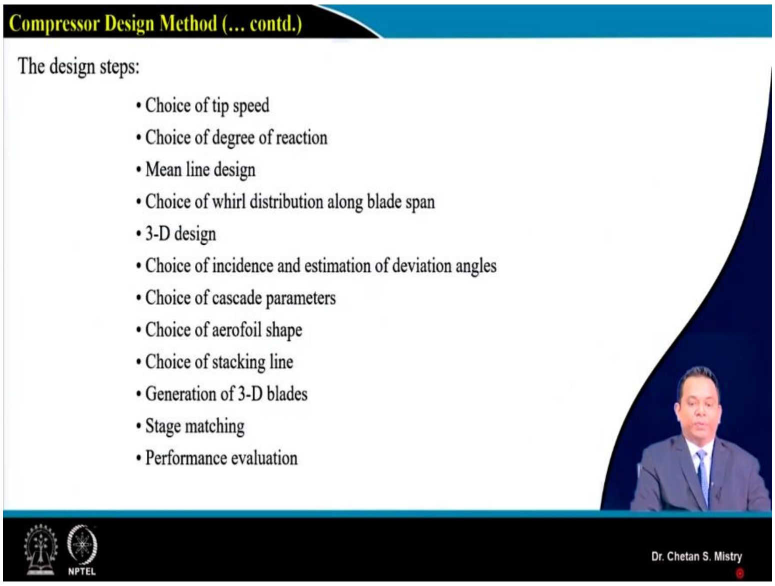

Now, in sense of design, what we have discussed up till now, that’s what is the choice of tip speed, the choice of degree of reaction. We can say when we are discussing about the tip speed, we are realizing say earlier designs where we have constraint with say tip Mach number. Later on, people, they realize by having say benefit of loss say shocks we are able to achieve higher pressure ratio and that is the reason why now this tip speed, that’s what is becoming very important parameter.

Degree of reaction, we have realized when we are discussing for low speed applications where there may be chances that near the hub region our degree of reaction may go zero or it may go negative. And, we know what is the meaning of negative degree of reaction, we know what is the meaning of degree of reaction to be zero at the hub region. So, that’s what is a choice how we want to have say diffusion to be happened in rotor and diffusion to be happened in stator that’s what is a parameter we say as a degree of reaction.

Then we were discussing about say mean line design. Suppose, if you are talking about say low speed application or say subsonic compressors for them our mean line design, that's what we are doing at 50% span, when we are discussing about supersonic compressor or say transonic compressor our mean line design, that's what will be happening at 75% of span.

Next, that's what is very important in sense of how we are doing our loading for the rotor and that's what we say choice of whirl distribution along the blade span and we have discussed about different methodology that's what is say free vortex, forced vertex, constant reaction design, fundamental design method, all those we have discussed with different applications.

So now, you are clear with what we mean by whirl distribution. Then we are achieving our three dimensional design say based on our pressure ratio, we have realized when we are talking about designing the compressor for high pressure ratio, we will be having our flow track that's what will be of decreasing diameter at the exit of the stage and that's what will lead to give the flow three dimensionality. Then we have discussed about the choice of incidence angle and estimation of deviation angle. So, by Design only at the initial stage when we are doing our design, we are giving our incidence angle, say nearly the hub we are giving incidence angle to be $+2°$, near the tip region we are giving $-2°$ and by incorporating that in our calculated blade angle, we have defined that as say blade metal angle at the entry.

Same way, this deviation, that's what we are deriving using Carter's rule initially and then after based on using computational tool or experimental results we are coming with some numbers and that's what we are incorporating in order to making of our blades and that's what we have defined as say blade metal angle. Now, it is mainly been depending on which kind of airfoil we are using. So, that is the reason the choice of airfoil that's what is becoming very important here. And, that's what we are deciding based on say earlier available cascade data.

So, number of experiments that's what was done or they were done in past, the industries those who are dealing with the design and development activity they are having their database. Database in sense of say what will be the effect of change of incidence angle, effect of change of say your chord, effect of change of thickness ratio, all those studies, that's what is already been available in their database and as and when required, they people, they are utilizing that data.

These days mainly we are moving towards say per stage pressure rise to be very high and that is the reason why we are looking for our flow through blade passage that's what will be transonic flow. And, computational tool here, that's what is helping us a lot in order to understand the detailed flow field within the blade passage and at the entry as well as at the exit.

So, that's what will give new chance for the development of new blade airfoils. So, that's what is say choice of airfoil shape, generation of 3D blades, stage matching and performance evolution. So, this all we have discussed about say our compressor design. Now, the question may arise in your mind what is the reason, why this topic at this week what we are discussing is mainly with the industrial fan and this is what we are discussing about say compressors. But you need to be clear here, there is a difference and that difference you will realize very soon when we will go ahead with the design aspects for say industrial fans. And, that is the reason why this is what is very important and that need to be discussed at this instant.

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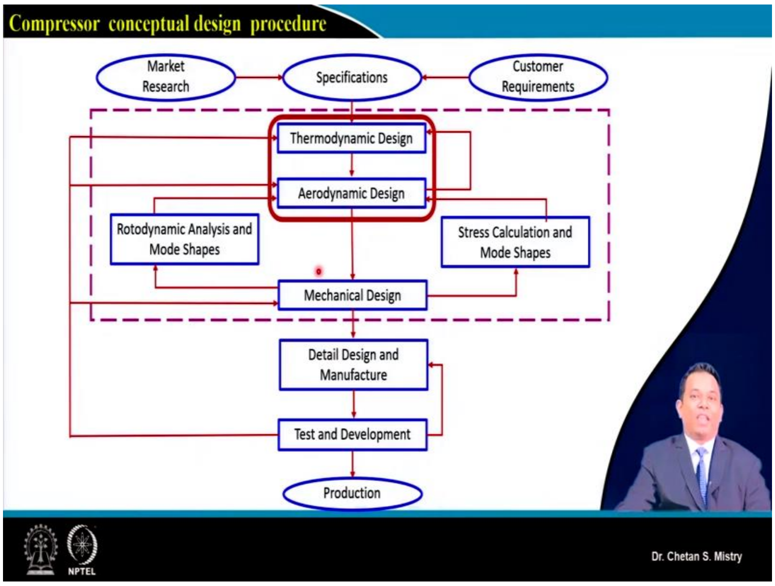

Now, when we are talking about say use or say design of compressor say what is our application, that's what we need to be a very first question. Are we using that compressor for say aerospace application or aircraft engine application? Are we designing that compressor for industrial application? Are we designing that for say power plant application? Are we designing for say turbo shaft or turboprop engines? So, all those things that need to be known to us.

Now, suppose if we consider say for aero engines, the companies those who are making their engines they are having whole lot of database that's what is available with them. And, that is the reason why they are not need of doing the market research. Though, this market research in sense what engines are existing or future coming engines by other competitive companies that's what is always required and that is where we need to go with say market survey. Then we will see, there is a requirement by the customer, say based on application. Suppose say, we are talking about say aircraft engine that's what will not be using for say commercial purpose or maybe for fighter purpose, maybe our application will be for UAV. There whole our requirement, whole our design process that's what is different; and, if you recall we have discussed such kind of designs, okay.

Then, you know, once you will be having the database from market survey as well as from say customer requirements, we will be going with the thermodynamic design and aerodynamic design. And if you recall, this is what all we have discussed throughout our course, for all 12 weeks, we are discussing mainly on say thermodynamic design as well as aerodynamic design. Now, there is one more aspect, that's what is called mechanical design that's what we are not covering in this course. Because this course is dedicated for aerodynamic design only. But at the same time when we are talking about making of rotor and stator, mechanical design is equally important. We can understand, suppose if we consider say rotor, that rotor it is fixed at say hub and other end that's what is free that means it will be acting like a cantilever beam.

Now, under that configuration it will be having different modes of deflection and that's what we have discussed as say flutter of blade. We say that as say aero elastic aspects of the blade. So, the mode shape calculation, rotor dynamic calculation, stress calculation, all those things that's what will be coming when we are talking about mechanical design. So, that aspect, that's what is totally different from what aerodynamicist, they are looking for. But at the same time, as aerodynamic designer we must have some background of this mechanical design too.

Now, once we are going with this design aspect. So, this is what is we can say is the overall design aspects, okay. Once this is what has been done then we need to go with the detailed designing. So, what all we are discussing in this class, that's what is considering say aerodynamic design of blades, we are not discussing anything about what will be the shape of my hub or how will I be fixing this blade on say rotating disc, we are not discussing anything how do we fix our stator on our casing, will it be stay cantilever type or will it be fixed both at hub as well as tip, those aspects we are not discussing; but that is also equally important. Once we are defining with this detailed design then that's what will be going to say manufacturer.

Now, manufacturer, they may be having their own constraints in sense of use of tools. Mainly, we have discussed in last lecture, those who are interested, I have shared two YouTube links that's what will be discussing about how the compressor blades are made, how the fan blades are made for aero engines. So, that's what will be giving you idea about the manufacturing process. Once this is what has been done then we need to go with say testing and the development activity. And this testing, as we have discussed, that's what is mainly with the experimental facilities available in companies or may be available in universities. And, later on once this is what is qualifying that's what is going for say production activity.

So, you can say this is what is a whole cycle and this cycle is for single compressor stage we are discussing at this moment. So, if we consider say we are having 10 number of stages, for all 10 number of stages you need to go iteratively for all these design aspects. And, finally we will be coming with the final design of compressor stage. That is the reason this is what is very challenging and that's what is asking for lot of understanding in sense of design, in sense of flow physics, in sense of performance. So, it is advisable that you just go through some of the standard books which is discussing about say how the performance of this axial flow compressor is in sense of single stage configuration as well as when we are having multi-spool configuration, okay.

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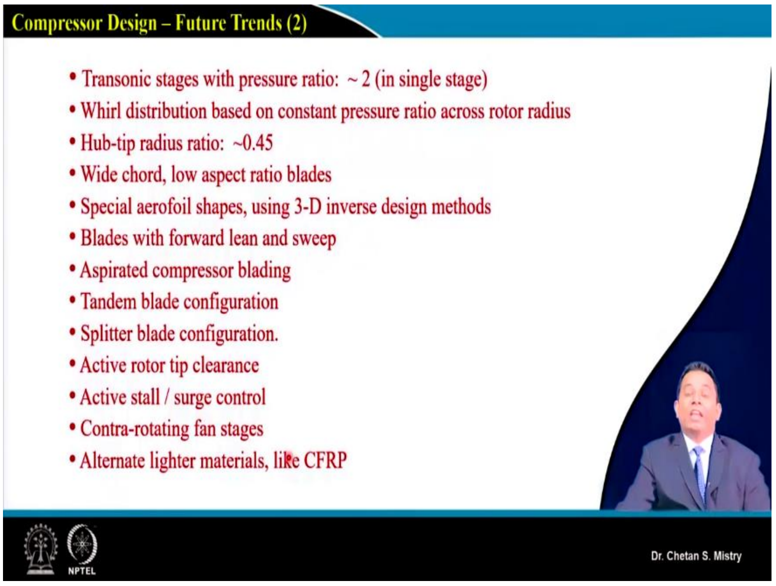

Now, the recent trends, that's what is also equally important for say future designs. When we are talking about the future expectation, what it says? People, they are looking for say transonic compressor stage, that's what will be having say pressure ratio more than two in a single stage. So, for fan as we have discussed, this is what is in the range of 1.6 to 2 at this moment. Now, later on for LP compressor also, people, they are looking for this kind of configuration, per stage pressure rise to be higher. And, we know what all are the reasons, what all are our expectations from the designer at this moment. Then, we are looking for the whirl distribution based on constant pressure ratio across the radius, okay.

So, this is what is important, what we have realized up till now, what all design methodology we are discussing where we are discussing the variation of pressure ratio at the hub, pressure ratio at the tip, this is what is depending on the design…kind of design or type of design we are adopting. So, people they are looking for say constant pressure ratio kind of configuration. And that activity, that's what is going on as on today. Now, hub to tip ratio we have constraint with say 0.8 and 0.4 that's what we have discussed.

Now, people they are looking for hub to tip ratio in the range of 0.45 and that's what is a requirement at this moment for special kind of compressors that's what is a demand for future. Now, wide chord and low aspect ratio blade, we have discussed a lot about what we mean what all are the benefits of using say wide chord blade and what all are the aspects we are looking for low aspect ratio blade.

So, this all discussions, that's what is coming into the picture and very recent engine in one of our lecture we have discussed, that's what is GE-Honda say turbo fan engine in which we are having wide chord fan and that too it is a small fan that's what is used for business jet, such kind of design configuration now it is of demand. There is a demand for say special kind of airfoils, say 3D inverse design metrology people they are opting with, that's what is very challenging to accept at this moment. In one of our lecture we have discussed, inverse design method that may be working fine when we are talking about design condition but when it will be going under off design condition that means the change of speed or change of mass flow rate then it may go may be very odd, not like your conventional compressor and that is the reason why we are…we need to look at all those aspects when we are discussing the design or when we are doing our design for the blades.

Blade with the forward lean and sweep. So, this is what will be giving you the three dimensionality to the blade and this three dimensionality basically it is improving the performance in sense of operating range. So, this is what is of demand at this moment. So, if you go through recent engines, if you are having the cut section and if you look at carefully, those blades are of highly three dimensional shape; mainly fan blades we can see the clear variation in sense of sweep as well as lean.

So, aspirated compressor that is also it is under progress when we are looking for very high pressure rise, per stage pressure rise to be very high, that time this is what is of demand. We have discussed about the tandem bladed compressor where we are looking for per stage pressure rise to be very high. So, if that's what is required higher turning of the blade and when we are looking for high turning of the blade, it is having its own design challenge.

Next, that's what is with the splitter blade configuration. So, basically the splitter concept, that's what was been adopted for centrifugal compressor. Later on, people, they have realized this is what is very good in sense of application for the rotor design, mainly transonic rotor design, that's what is giving the benefit of, you know, very high exit area. When we are having exit area to be high there are more chances for our flow to get separated from say maybe pressure surface or the suction surface of our blade.

So, by incorporating this splitter blade, that's what is permitting to go pressure rise to be even on higher side, okay. Active rotor tip clearance, say active stall and surge control, contra rotating fan concept, alternative lighter material, like you know CFRP, all those things that's what is going on in sense of development activities for the compressor.

So, in overall if you look at, this is what is a great demanding area of research and development, and this is what is giving more employability for the future engineers. Because demand, that's what is always increasing in sense of expectations and when we say our expectations are rising, that time we will be having say more research activities to be explored. And, that is the reason why at universities as well as engine making companies, these days people, they are talking about making of device and designing of the device. Because earlier, say one company they were doing whole development or engine development activity.

There is a trend in which people or special companies they are configured or they are doing only design for compressor. Few companies, they are doing only designed for turbines. So, that's what is exploring more possibility in sense of employability. So, this compressor that's what is evergreen and ever demanding and most challenging area where you can explore your future activities.

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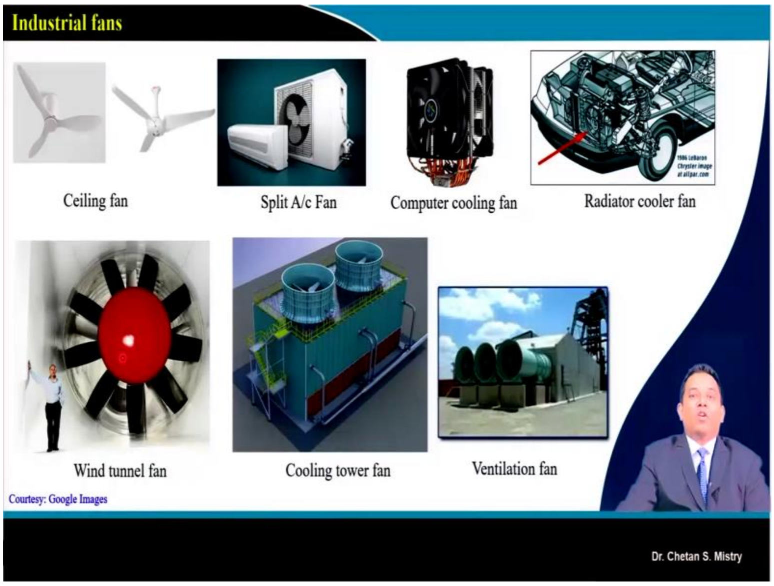

Now, with this all this background; next, that's what is very important for us to discuss is our industrial fans because that is also a booming area. We are having so many applications. What compressors we have discussed say for aero application they are very expensive in sense, but their demand that's what is limited in sense of numbers. Industrial compressor, they are also of great demand but their demand in numbers that's what is small. Say when we are talking about industrial fans, they are having say huge demand. We are having specialized area that's what is called heating, ventilation, and air conditioning. We are looking for special kind of cooling devices where this concept of design and the idea about the fan, that's what is very important and it is equally applicable there, okay.

So, suppose if we consider say ceiling fan, we can consider say ceiling fan when we are looking for competitive market say you will be getting best fan that may be costing around say 1500 rupees or maybe 1600 rupees. Now, that's what was the limit. Now, Bureau of Energy Efficiency, they have put the Restriction in sense of power consumption by these devices. And, that's what they are demanding for say highly electrical efficient fans. And in that you are having competition with different manufacturers. So, if you look at here, this is what is a new kind of fan where the blades are of airfoil shape. Conventionally earlier fans if you look at, they were the plates they have been turned or they have been machined or banned as per the required angle and that's what was serving the purpose.

Now, those fans when you are rotating at the higher speed it is making lot of noise. So, noise is also equally important aspects, people over the year now they are not tolerant to this kind of noise. So, they are looking for silent fans. And, those silent fans, we can say that's what is the demand of market, okay. So, this is what is a development activity we can say in sense of making of ceiling fans. Now, here if you look at, this fan that's what is having end winglet that's what is helping in sense of improving the aerodynamic performance as well as that's what is helping in sense of reducing the noise.

So, these all activities they have been done by the engineers only, they have been done by designers only. Here, if you look at, this is what is say the unit that's what we are putting outside for the splitter AC. Now, those splitter ACs if we look at, every year we are having new innovative designs for the fan and those fans are becoming silent. At the same time, energy as I toldm it is also equally important. So, this is what is the booming area in sense of development activity.

Now, we are having our computational facility that's what is day by day demand is increasing and we are looking for say high speed computers though we are applying or using that for say our household use but still we are looking for something that's what is high speed. When we say high speed, there are more chances for the heating because our processor will get heat up because of fast activities. Under that configuration, we are looking for special kind of cooling. And, those cooling, they have been done by force convection by using these fans. And these fans are also of great demand though they are having the cost to be lower but at the same time the requirement it is in huge number, okay. And, that's what is exploring new possibility as a designer.

We are having our cars and for car radiator, that's what need to be cooled because that's what is getting hot. For that cooling also, we are looking for fans. Now, earlier cars if you look at, they were making lot of sound because of rotation of this fan. Now, we are having silent engines, silent car, in which we are having special kind of designs that's what has been incorporated for say development. Say, this is what is a Wind Tunnel Fan, Wind Tunnel as we have discussed it has been used for testing…aerodynamic testing of different components. They are having wide variety of applications including Aerospace, building construction that's what is having application in sense of say flow field study…detailed flow study.

So, if you look this tunnel based on my test section, the size of the fan that's what has been varying. And, this fan mainly been used in order to overcome the friction losses that's what is happening in the duct. So, wind tunnel may be applicable for say open kind of configuration or closed kind of configuration. So, based on that this is what is demanding area. Now, in order to change the mass flow rate or in order to change say velocity within the test section, we are having special kind of pitching mechanism that's what has been Incorporated here, okay.

Now, this is what is with the cooling tower. If we are looking for say steam-based power plant where the water that's what will be coming out at high temperature, that is one application. There are say special kind of air conditioning system, central air conditioning system where we are having this water that's what is coming at say slightly high temperature, in order to cool down that this kind of fans, they have been used. So, that is also of demand, okay.

Now, this is what is a special application called ventilation fan; they are having application in mines, they are having application in tunnels, they are having applications in metros and this is what is of great demand where we are looking for removal of dust particles, when we are looking for particular concentration of oxygen. So, in overall if you look at, this is what is giving us a brief idea what all are the demands for industrial fan and this also need to be designed and who will be designing that? The engineers those who are having good knowledge of designing these fans they can explore that.

So, in this week we will be discussing the design for such applications that's what will give you more confidence in sense of understanding. So, we are not only focusing in sense of designing our compressors for aero engines and land-based power plant or say maybe industrial application, we also will be targeting design of this fans.

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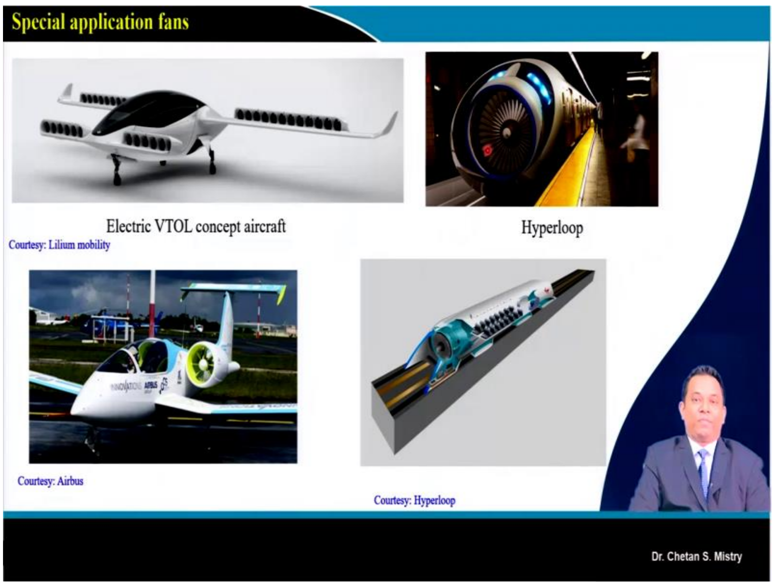

Now, along with this fan there are many special applications, that's what has been explored in last 10 years. Here if you look at, this is what is a VTOL concept that is called say Lilium, they have made this as a flying taxi. And for that flying taxi, they are looking for more number of fans which are being placed on the wing. And, these fans, that's what is generating the thrust in order to have forward movement. At the same time, the same fan, that's what will be helpful for vertical takeoff of this taxi. So, here also we are looking for the designers who will do the design for this kind of fans, this fan may be smaller and more in number; there is a logic behind that. If you will be having larger diameter of such fan, maybe few fans that will work no need for these many fans. But at the same time, the power consumption and weight that will be a major issue.

Now, what drones we are looking at, these days people, they are talking about incorporating the propellers. But these propellers are highly risky in sense of safety aspects and that is the reason why slowly the interest is moving towards the ducted fan kind of configuration. So, maybe future drones, if we look at, they will be of ducted fan. And, those ducted fans are what? We are talking of the design of this compressors and fans, the same what we are discussing.

Now, this is what is one of the application that is explored by say Airbus that's what is say E-plane. Here, in order to generate the thrust, these are the fans which are been fixed on the fuselage and these fans, they are generating the thrust. So, this is also of the future demand. So, maybe small capacity aircrafts say maybe two-seater, five-seater aircrafts, they may be having such kind of electric motors that's what will be used in order to rotate the fans and those fans are generating the thrust.

So, this is what is also one of the future application, we can say. We are talking about the transportation aspects for say Hyperloop. In this Hyperloop it is basically a vacuum tube in which this particular wagon that's what will be moving that is working on the principle of magnetism, Maglev. Now, the situation is in order to have the forward movement this kind of fans they are of need. These fans basically that's what is generating the thrust. So, this is also one of the future application for the design of this fans.

So now, what all we are discussing at this moment, we will be discussing about the design of such application. In next lecture we will be discussing the design of industrial fan where we will be discussing about what all are the aspects that's what is different from the compressor design because they are of special requirement and they are of special need. So, we will discuss about the design of industrial fan, such two fans, we will be discussing in design. So, thank you, thank you very much, see you in the next lecture!