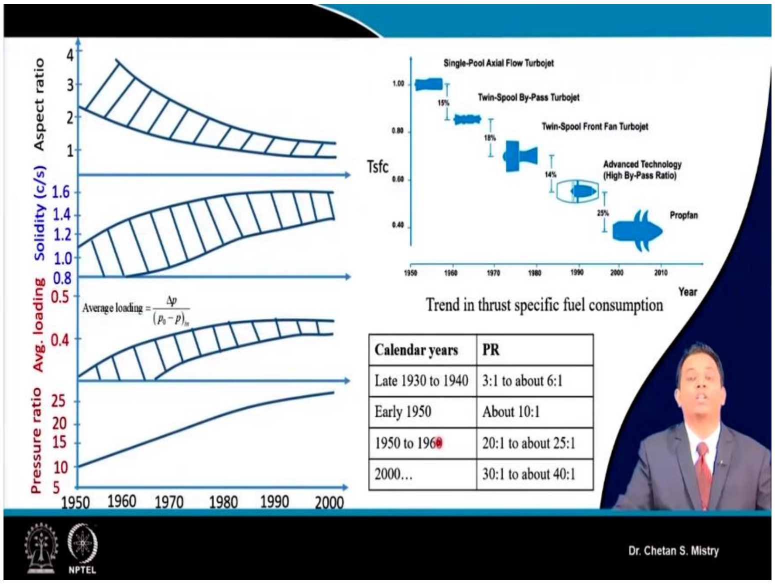
Aerodynamic Design of Axial Flow Compressors & Fans
Professor Chetankumar Sureshbhai Mistry
Department of Aerospace Engineering
Indian Institute of Technology, Kharagpur
Lecture 29
Selection of Design Parameters (Contd.)

Hello, and welcome to lecture 29. For the course on Aerodynamic Design of Axial Flow Compressors and Fans.

(Refer Slide Time: 00:36)



In last lecture, we were started discussing about selection of various parameters. Now, here if you look at, this is what is representing the global trend for the development of aero engines. So, if you look at, the major concern by aero industries, these days, that's what is mainly focusing on reduction of thrust specific fuel consumption. Parallelly we are also focusing on various environmental aspects.

We are also looking for some special kind of engines, which will be addressing the issues related to drag, which we can say we are looking for compact engines, we are looking for lightweight engines. So, this is what is representing how my global trend that's what is going on, in sense of expected pressure rise from the engines.

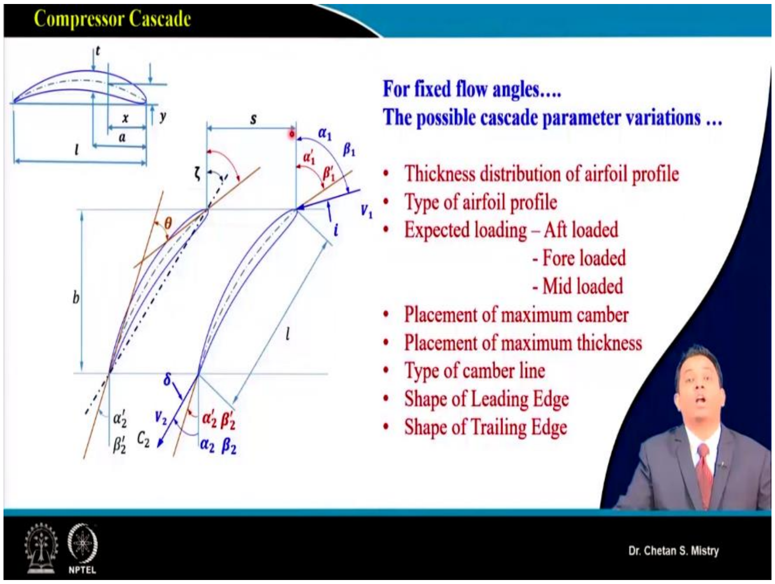
And we have discussed, say, as on today with the upcoming engines, the maximum pressure ratio, that's what has reached to above 60. So, this is what is representing how our global trend that's what is going on, in sense of rise of pressure ratio. Here I am talking about the overall pressure ratio. Now, in order to meet the special requirements, in sense of say expected thrust specific fuel consumption, we are looking for per stage pressure rise to be higher. So, here if you look at, this trend, that's what is getting towards say higher on the numbers, what it means? We are expecting per stage pressure rise to be very high. And that's what will lead to reduce the number of stages.

Now, in order to meet this requirement, one of the parameters what we have discussed earlier, that's what is called diffusion factor. And that's what is representing my aerodynamic capacity of the diffuser, okay. So, it says if you are looking for the improvement of our diffusion factor, the parameter called solidity, that's what will be coming into the picture. So, this is what is representing the improvement in sense of selection of the solidity. This solidity we are representing as say chord to pitch ratio.

It means we are looking for say higher solidity, this is what is an indication that it says we need to increase our chord or we need to increase our number of blades or we need to go with the combination of both of them. Parallelly there is an expectation in sense of height of the blade. So, this is what is representing the global trend for selection of aspect ratio.

We have introduced the aspect ratio as height of the blade to the chord of the blade and we can say, we are moving more towards the aspect ratio in the range of 0.8 to 1 and this is what is still it is getting converging. So, this is what all is giving us idea how the global trend is moving towards the development of gas turbine engines, special application to aero engines.

(Refer Slide Time: 04:01)



Now, let us move with the next step. So, here this is what is representing my compressor cascade, what we have realized? We have different parameters, that's what is coming into the picture, when I say airfoil, what we are using for our compressor blade, that's what is comprising of number of parameters. Some of them we have discussed as air angle, say my flow angle, incidence angle, deviation angle, camber angle, stagger angle, parallelly we need to look at the parameters which are related with say airfoil, okay.

Let us see what all are the parameters. If you consider say, I want to use a typical or special kind of airfoil for my compressor development, then we have our fixed flow angle. That's what we have derived based on our pen paper calculation for the flow angles based on our expected pressure rise.

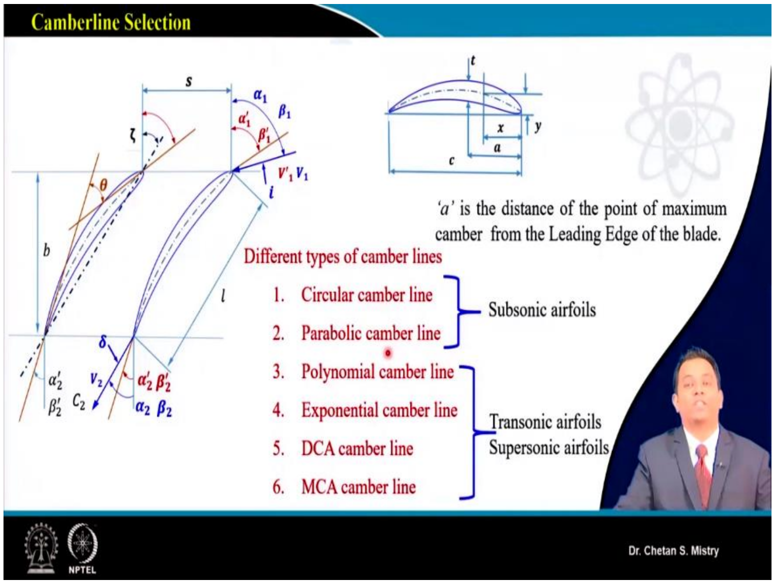
Now, here in this case, we can have different combinations for this airfoil to be possible. One of them it says the thickness distribution of this airfoil. So, how my thickness it has been distributed on my camber line, that's what is one of the important parameters. We need to realize this airfoil thickness that's what is making our blade passage and we should not forget, we are always talking in sense of diffusing passage.

So, the shape of this airfoil that's what has been decided by the thickness of my airfoil, that's what is very important. Next, that's what is different kinds of airfoil, we have discussed C4 airfoil, we have discussed NACA airfoil, we have discussed double circular arc, multiple circular arc, S type of airfoil. So, those all airfoils they are having a special application. We are expecting different kinds of loading on our airfoil or by using this airfoil; we say, we are looking for aft loaded kind of configuration, we are looking for fore loaded kind of configuration, we are looking for mid loaded kind of configuration. What all is this, we will be discussing in detail today.

Next parameter, that's what is coming is what is or where is by maximum camber, okay. So, this is what is representing location 'a' that's what is representing where I will be having maximum camber. At the same time, the location at where I will be having maximum thickness that is also equally important, okay. When I say airfoil, we should not forget the shape of our leading edge and shape have a trailing edge and as we have discussed for C4 airfoil, we are having leading edge radius to be larger compared to NACA 65 that's what is having advantages we have discussed in sense of incidence angles, okay.

Same way for trailing edge also for NACA 65, we are having sharp trailing edge and for say C4 airfoil we are having trailing edge with some radius. When we are discussing about the deviation angle, these is all parameters that's what is very important, okay. So, we can say this all are the parameters what we can play with in order to make our compressor. Now, the thing is, today we will be discussing, how do we decide with the camber lines.

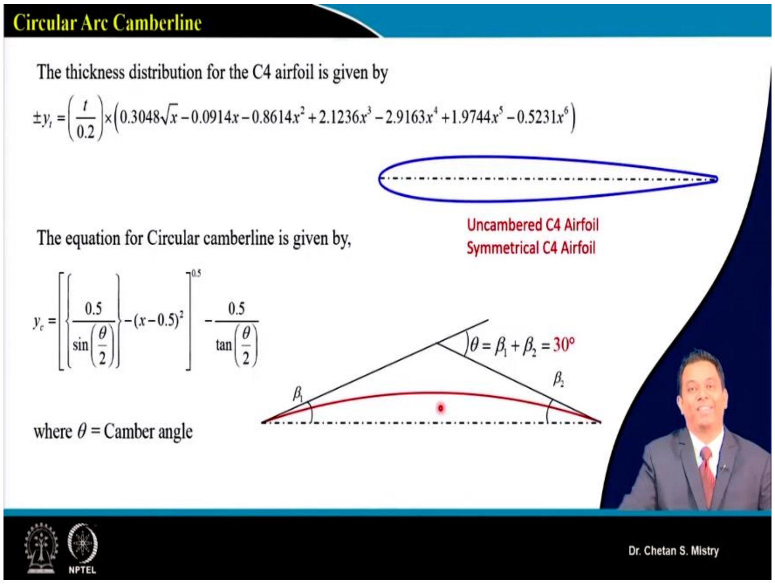
(Refer Slide Time: 07:44)



So, here if you look at, there are different types of camber lines which are people they have explored or which are available in open literature. And as on today for running engines, these all kinds of camber lines they are been in use, okay. Some of them they are say circular camber line, parabolic camber line, polynomial camber line, exponential camber line, say DCA - double circular arc camber line, multiple circular arc camber line. So, if you look at here, these two are mainly been used for subsonic airfoils, okay.

And these others, they are being used for transonic airfoil or supersonic airfoils, okay. So, we will be discussing how do we derive or how do we get with this camber lines. And once we are having this camber line, how do we put our thickness on that camber line in order to make the airfoil? Because that's what is of major concern to us, okay. What design we have done, that's what is only pen and paper calculation that is also important, but now, once you have done that part, whole your work that's what will be coming is with your airfoil, and your airfoil selection, and your airfoil placement.

(Refer Slide Time: 09:08)



So, let us see; suppose we are taking first as say circular arc camber line. So, here in this case, if you look at, this is what is representing C4 kind of airfoil, we can say it is uncambered C4 airfoil or symmetrical C4 airfoil. Now, as we have discussed, these airfoils, they are having special kind of thickness distribution. So, the thickness distribution for C4 airfoil, that's what has been given by this equation.

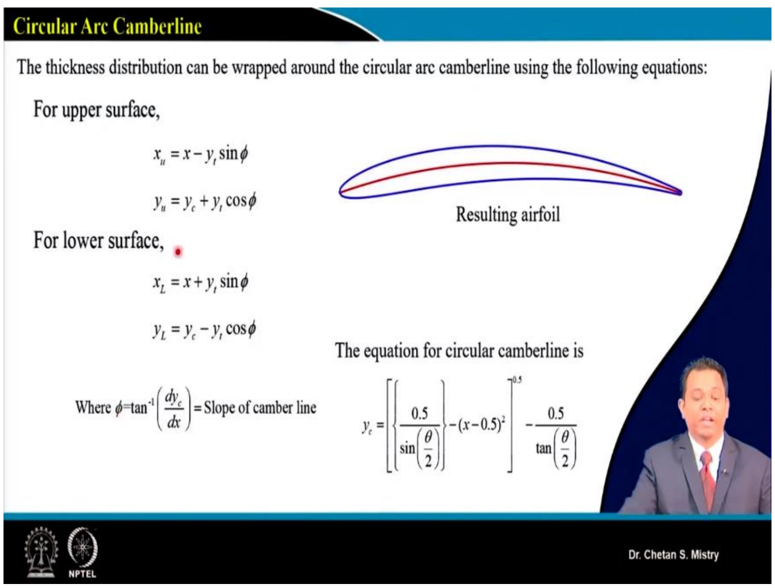
Now, as I told, few airfoils they are available in open literature. So, when you are starting with your initial design, or when you are started with your initial calculation or making of blade, you need to select those kinds of airfoils first, okay. So, suppose if you consider, say, you having the equation available for say C4 kind of airfoil, then we can say, on this…say…straight line this symmetrical airfoil, this is what is giving the variation of my thickness.

It says at 40% of my chord, I have maximum thickness. Now what we are looking for? We want to have this thickness distribution that need to be place on my camber line. So, I am looking for camber line, okay. So, suppose I say this is what is my camber line, in order to make that camber line, we need to have our angles, this angle we can say β_1 and β_2 they are nothing but my metal angles.

When I say metal angles, do not forget, we have discussed, we are having our flow angle plus or minus incidence angle on say our flow angle and my deviation angle, that's what will be giving us my entry angle and outlet angle, that's what we have defined as our metal angle. So, these are my metal angles. Now, in order to make this camber line, we need to go with the mathematical formulation. So, for circular camber line, this is what is my equation; what it says my ‘y’ coordinate for that camber line, that’s what is a function of ‘x’ and θ. This θ is nothing but that’s what is my camber angle, okay.

So, if we are putting different values of ‘x’, and if we are putting the value of my θ, that’s what will be giving me how my camber line, that’s what has been prepared. So, this is what is the formula for that, okay. So, now we are having our camber line, that’s what is ready with, okay. So, those who are good in coding, maybe you can do practice, you can make a program, that’s what we will be helping you in playing with this camber line equation, okay.

(Refer Slide Time: 12:14)



Now, let us see, now, what we are looking for is we want to have this camber line that needs to be covered with the thickness of my airfoil. So, here if you look at, this is what is my camber line, this is what is my circular arc camber line and this is what is the thickness distribution of C4 airfoil.

Now, in order to do that kind of calculation, we need to divide our surfaces in sense of upper surface, we can say, that is nothing but my suction surface; and lower surface, that’s what is my say pressure surface. Now, when I say on my suction surface, I will be calculating my ‘x’ and ‘y’ coordinate based on $x - y_t \sin\phi$. Here this is nothing but $y_c + y_t \cos\phi$.

Same way I can calculate for lower coordinates, these are the equations for lower ‘x’ and ‘y’ coordinates.

$For\ upper\ surface,$

$$x_u = x - y_t \sin\phi$$

$$y_u = y_c + y_t \cos\phi$$

$For\ upper\ surface,$

$$x_u = x - y_t \sin\phi$$

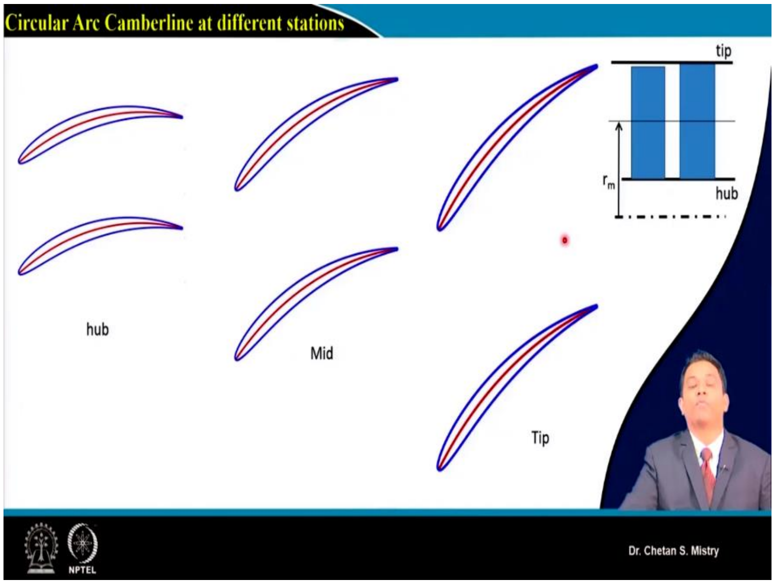
$$y_u = y_c + y_t \cos\phi$$

So, more the number of blades you will be selecting, more will be the sharper curve you will be getting or more accurate curve you will be getting, okay. Suppose say you are selecting less number of points, say you are selecting your 'x' and 'y' coordinates, that's what is less, it may be possible that you will be getting say zigzag kind of configuration for this making of this blade.

So, be careful take these points in thousands. So, that it will give the smooth curve. Again, that's what is depending on what is your chord length, okay. So here in this case, what ϕ we are looking for that is nothing but that's what is the slope of my camber line, okay. And what is my camber line? So, here if we look at, this is what is my camber line, okay.

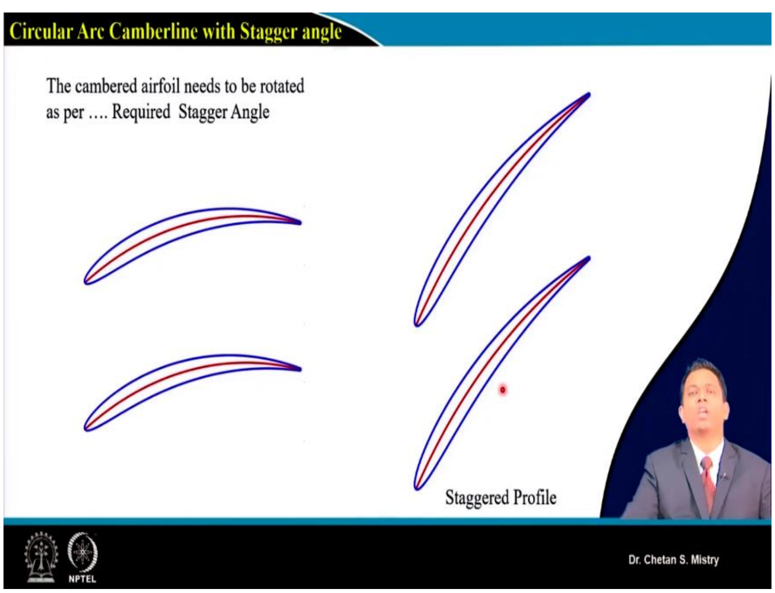
So, this is what is my equation and based on that we are calculating our ϕ at different location, be careful. Say, what we are doing? At different location, we are getting our slope, and that's what we are putting in this equation and that is how we are calculating our coordinates for upper surface, we are calculating coordinates of lower surface. So, this is how we will be making our C4 airfoil at particular station using circular camber line. I am sure you are able to understand what we are discussing of, okay. So, this is what is one kind of configuration, that's what conventionally people they are using for the initial stage calculation, okay.

(Refer Slide Time: 15:01)



Now, let us move with say what all is happening. So, here if you look at, this is what is representing, suppose if I consider, this is what is my stage, say my rotor and stator. So, for that configuration, for rotor if you look at, I will be having this kind of distribution, okay. So, you can see, we are having our diffusing passage that's what is making perfectly, entry you having lower area, at exit you are having higher area. Same way here if you look at, and this is what is representing at the tip region. So, it says you are having smooth distribution of your thickness and that's what will be giving you smooth passage, area passage, blade to blade passage we are discussing now, okay.

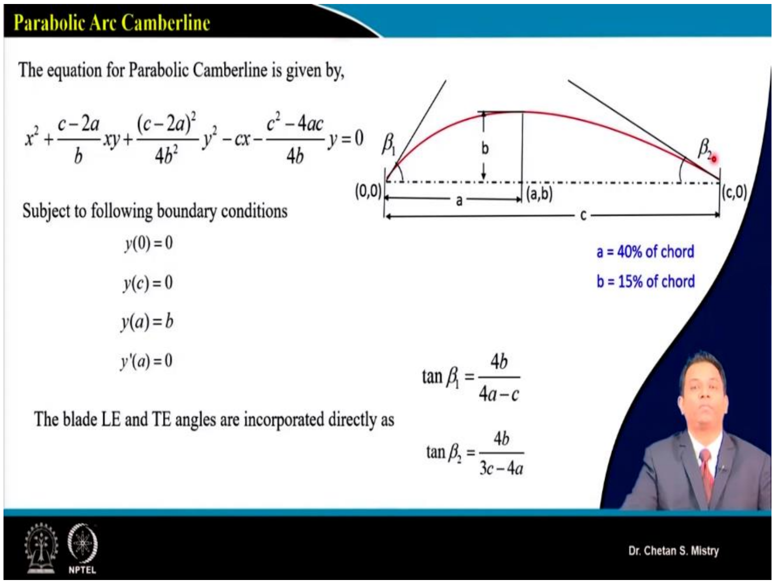
(Refer Slide Time: 15:49)



Now, we have discussed when we are discussing about the change of staggered angle; so, here if you look at, suppose say this is what is at my hub, I can set that at staggered angle, we will be discussing all these aspects when we will be discussing the design in detail. There also we will be discussing how do we calculate or how do we determine the coordinates of these blades, okay. So, this is what is representing the staggered arrangement.

So, this is what we say in sense of our circular arc camber line. So, most of the design, when we are talking about say our industrial fans, people they are preferred to go with this kind of configurations. Even when we are discussing about the HP compressor for gas turbine engines for few stages, on later stages, people they are preferred to go with this kind of camber line and C4 kind of configuration, okay.

(Refer Slide Time: 16:53)



Now, let us say suppose…say…I am looking for different other type of say camber line, where I will not be having our arc as circular one. Let us see, suppose here if you look at, this is what is having parabolic kind of configuration. So, this is what is representing my chord length say 'c' and here if you look at, this is what is representing by a/b.

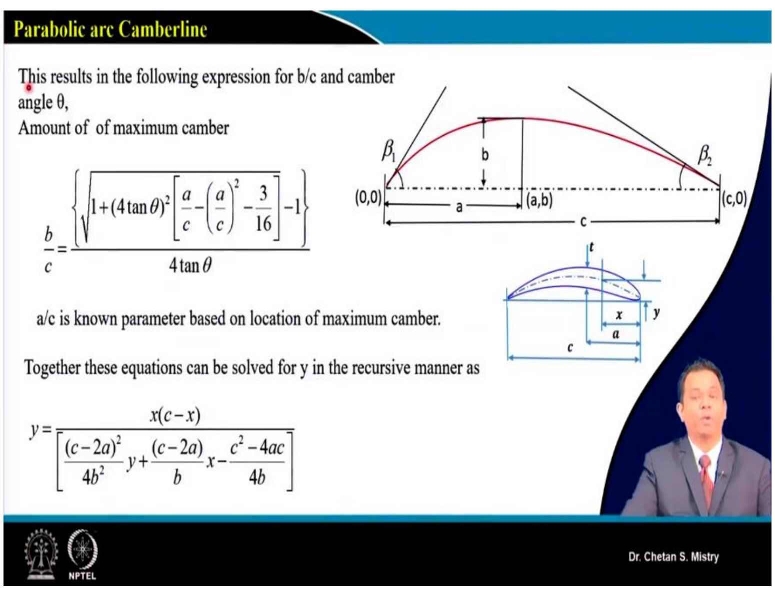
So, for parabolic configuration you can say, this is what is my location 'a' and this is what is representing my location 'b'. Again, as we have discussed, we are having angles as say my metal angle β_1, my outlet metal angle that's what is a β_2, okay. Now, in order to have this parabolic camber line, this is what is the equation that's what is available in the literature maybe you can use this equation for the calculation of say parabolic arc camber line.

Now, in order to solve this equation, we need to put certain boundary conditions. So, what are the boundary condition? Here if you look at, this is what it says (0, 0) place, this is what is representing point (a, b) and this is what is say (c, 0). So, I can say, at y(0) we will be having 0, y(c) that is also 0, y at a is my b number and $y'(a)$, that's what is equal to 0.

$$y(0) = 0$$
$$y(c) = 0$$
$$y(a) = b$$
$$y'(a) = 0$$

So, you know, if we are putting these angles into the configuration, we will be getting this equation; it says by $\tan \beta_1$, that's what is given by $\frac{4b}{4a-c}$ and $\tan \beta_2$ that's what is given by $\frac{4b}{3c-4a}$. So, this is what will be giving us idea how do we do our calculation for say different parameters, that's what is say my a, b and c.

(Refer Slide Time: 19:03)



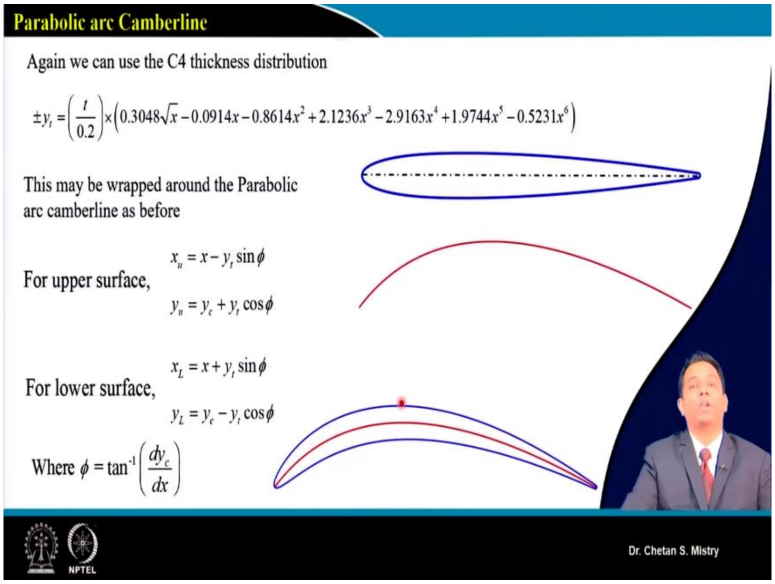
Now, what we know? If we consider, we are having we are more interested in sense of having our formula in the form of say camber angle. So, we will be considering this equation, that's what needs to be represented in the form of b/c and that's what is a function of my camber angle. So, the amount of maximum camber, so, this location what we are discussing b and c, that's what can be calculated based on this formula, okay.

So, this is what is the formula if you recall my a by c ratio, again just remember, a/c is nothing but that's what is representing my maximum camber angle configuration, okay. Now, you know, this is what is the location of my maximum camber angle here, this is what we are discussing about. And if you will be solving these equations rigorously, you will be finally coming out with the equation of say the distribution of my camber line. It says that's what is given by

$$y = \frac{x(c-x)}{\left[\frac{(c-2a)^2}{4b^2}y + \frac{(c-2a)}{b}x - \frac{c^2-4ac}{4b}\right]}$$

Now, we can understand, we are moving towards the more complexity, and that's what is always required the background of mathematics. So, we will be taking this into configuration and we will be moving with how do we use this equation for the development of our blades.

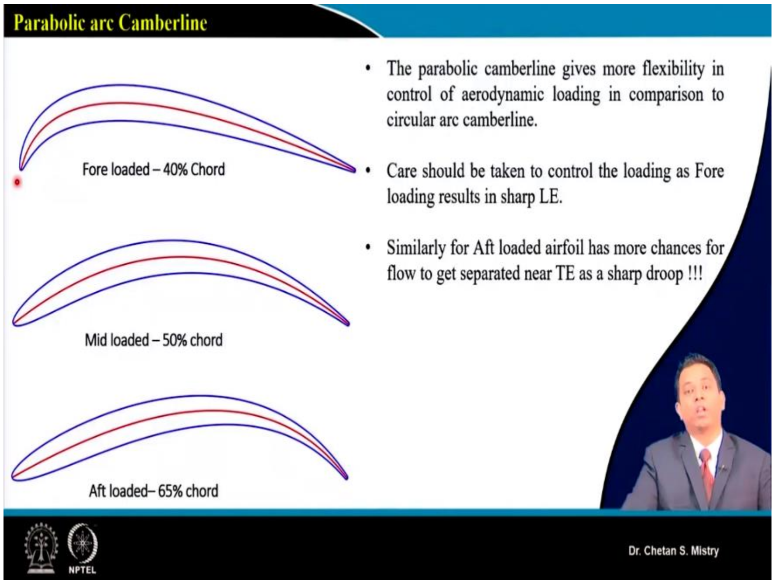
(Refer Slide Time: 20:36)



So, here in this case, again, in order to showcase what we have done, we have selected our C4 airfoil. So, this is what is representing my C4 airfoil and this is what is the thickness distribution for my C4 airfoil. Based on our formula, we have derived with this curve, that's what is representing parabolic arc camber line.

Now, on this parabolic arc camber line, I need to super imposed this thickness, okay. So, again, that's what you can use the same fundamentals, what we have used earlier; you will be calculating our upper coordinates, we will be calculating our lower coordinates. That means, suction surface coordinates, my pressure surface coordinates, and that's what based on my ϕ, I can impose them on my camber line. And that's what we will be giving us say, the blade, that's what is with required β_1, β_2 and thickness distribution, okay.

(Refer Slide Time: 21:42)



Now, what is the beauty of this camber line? Let us see. So, here if you look at, this is what is represented fore loaded kind of configuration. So, it says full loaded at 40% of chord. It has a specific meaning. So, here in this case, if you consider, we know our fundamental; suppose if I consider my flow, that's what is incident here, what is happening on our suction surface?

We will be having more acceleration that's what will be happening on my suction surface and later on after say 20% or 30% of chord, we will be having the deceleration that's what is happening on the suction surface. Now, what we are doing here, we have made this blade in such a way that, that's what is fore loaded.

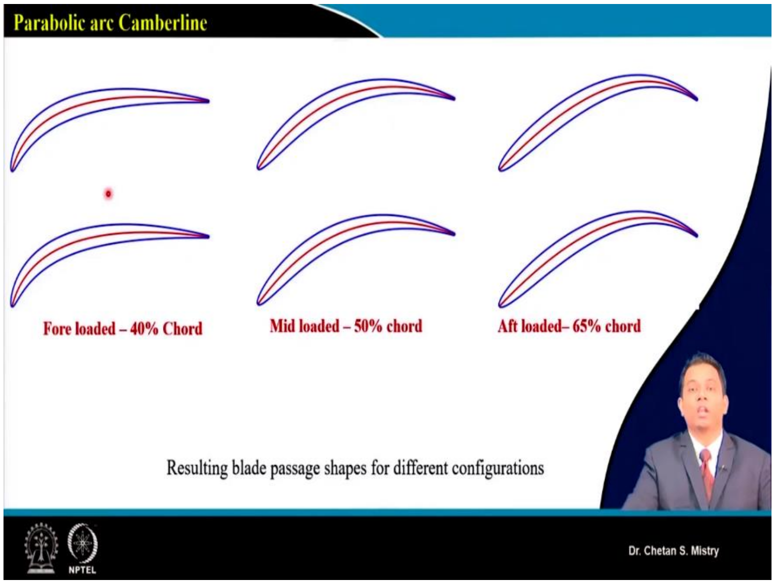
So, you will be having a whole lot of acceleration that's what will be happening on the suction surface and later on you will be having the deceleration of the flow. Now, the benefit is in sense of C_p distribution. You can understand, higher will be the acceleration on your suction surface, higher will be your area.

So, for special kind of application, for special kinds of rotor at particular location, people they are preferred to go with this kind of configuration, that's what we say as a fore loaded kind of configuration. Here if you look at, this is what is representing my mid loaded kind of configuration, it says 50% chord that's what is we are having this camber line, okay.

Now, I can change the shape of my say airfoil by using this kind of configuration; it says aft loaded. So, at 65% of my chord, I am having the turning here, okay. So, just understand like what all we were discussing about the circular arc camber line, where we are having our circular arc, that's what is not giving us any kind of flexibility in sense of changing the shape of my airfoil.

It is not giving any flexibility in sense of changing the shape of my blade at particular station. Here if you look at, this is also kind of airfoil people they are using when they are looking for say aft kind of configuration, okay. Here you can understand, if the flow is not well managed, there may be chances of flow separation to be happened near the trailing edge, okay.

(Refer Slide Time: 24:29)



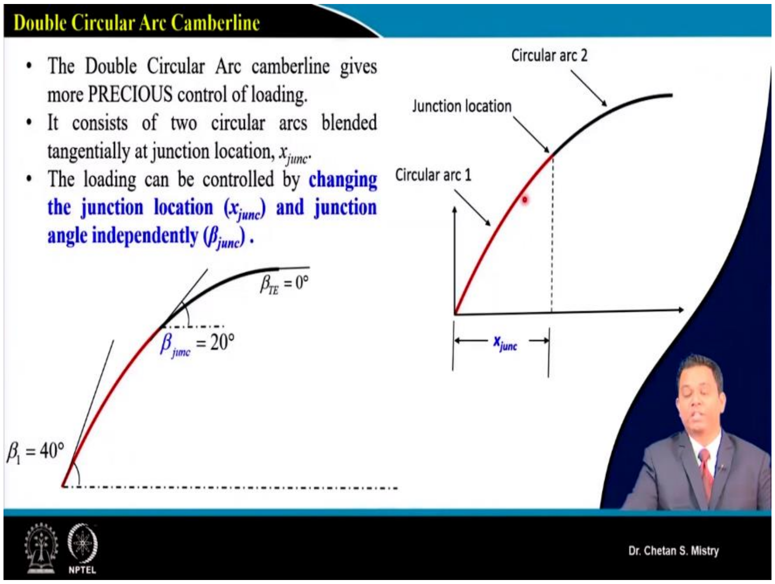
Now, this is what is representing say 40% chord say 50% chord and 65% chord; you can understand here. Now, if you recall, what we are basically looking for is we want to manage our flow within two blades. So, you can say this is my Blade-1 and Blade-2. If I will be going with what is happening with my flow, it will give me suggestion what all modifications need to be done. Let me tell you, here your computational study, that's what is coming into the picture.

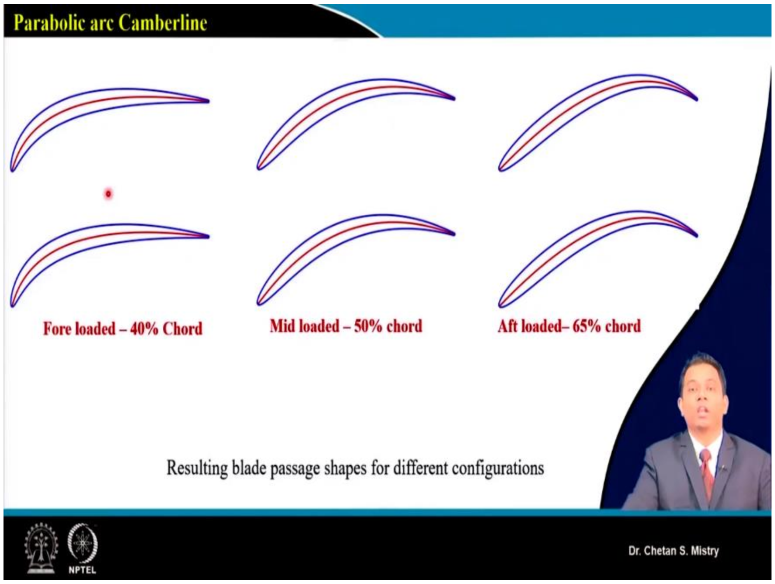
So, you are starting with say some kind of initial guess, which say circular arc camber line, then you are having say flow physics, that's what you are capturing at different span of the blade, maybe 10%, 20%, 50%, 70%, 90% span, then you are observing what is happening on my suction surface, what is happening on my pressure surface. If we are observing premature kind of flow separation, that's what will be giving us indication that there is something wrong at that particular station.

Remember one thing, when we are saying we are having say separation of flow from the suction surface that's what is acting like, you know, 0 velocity; that means 0 velocity we can say it will be acting like a solid body. So, rather at the exit we will be having our flow to be diffusing flow, it will be giving you accelerating flow.

And that is where you need to play with the shape of your airfoils. So, this is what is very important for you to learn at this moment, okay. Here if you look at, this passage area and this passage area that's what is different and here if you look at, this passage area is totally different, okay. So, we need to do systematic study, we need to use the computational tool for this help and accordingly we need to modify our shape of the airfoil. We need to modify our camber line, okay.

(Refer Slide Time: 26:47)



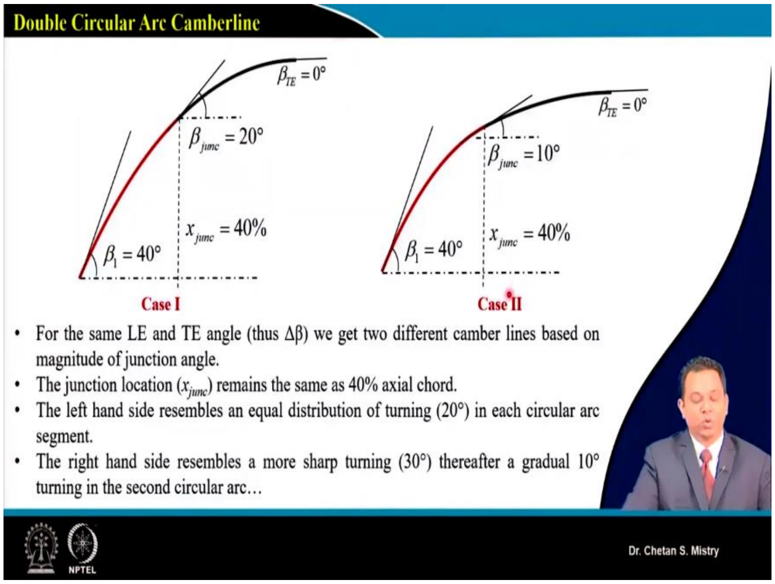


Now, with these fundamentals, people they started exploring other possibilities. So, other possibility it says, let me have flexibility; let me decide, from somewhere I will be deciding with say having the curvature of my blade or curvature of my camber line. So, here if you look at, this is what is representing double circular arc camber line, okay. Now, if you look at this double circular arc, so I am having one circular arc and this is what is my circular arc two. At some location, I will…I am defining as a junction. So, this is what is my junction point.

Now, based on our understanding, based on our knowledge for say geometry, it says we need to have the continuous curve here and that's what has been defined in sense of say junction angle. So here if you look at, this is what is representing my junction angle. So, for double circular arc, we are having more flexibility in sense of having junction point, that's what is giving us the location from where I want to change my shape of the camber line. It is also given the flexibility of changing my angle.

So, you know, are you looking for all of sudden change! Or are you looking for say no change with some reference! Suppose, here if you look at, for this kind of configuration, this is what is giving us sudden change of my say shape of the blade, okay. Now, in order to have the flexibility, we are using this double circular arc camber Line.

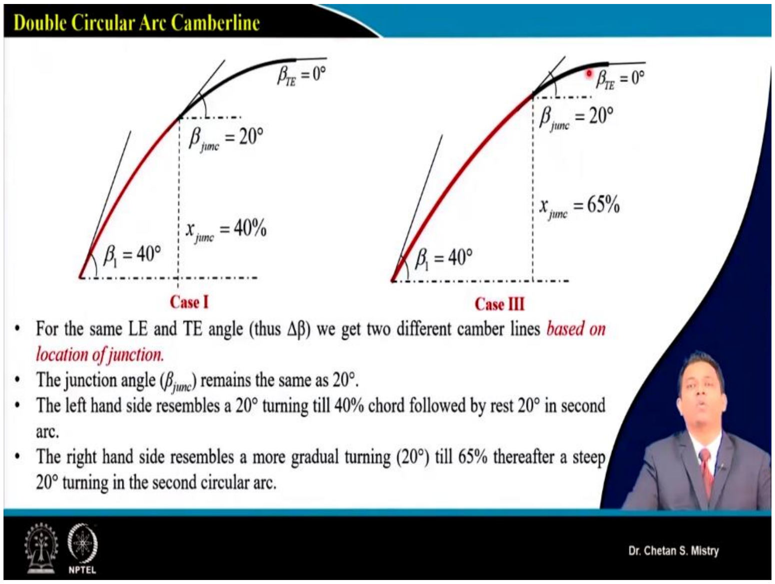
(Refer Slide Time: 28:33)



So, let us see, this is what is say two cases. We can say, case-1 and case-2. For the same leading edge and trailing edge angle, we can say, my $\Delta\beta$, that's what I am looking for same because that's what is my design requirement, okay. We are having two different camber lines or two curves. At this, that's what is present, I can say my junction point, that's what is placed at 40% of my chord, you can say this is what is my location.

So, on left hand side, if you are looking at, we are having the turning of my flow, that's what is happening at 20°, okay; and you know, that's what is say having distribution in sense of 20° and at the exit you are having 0°. Now, if you are looking at on other side, say this is what is the other kind of configuration in which we are having our flow turning, that's what is 30° and that's what is giving me my exit angle as say 0°. So, you can say, we can decide the junction point, we can decide the junction angle, and that's what will be giving us the flexibility.

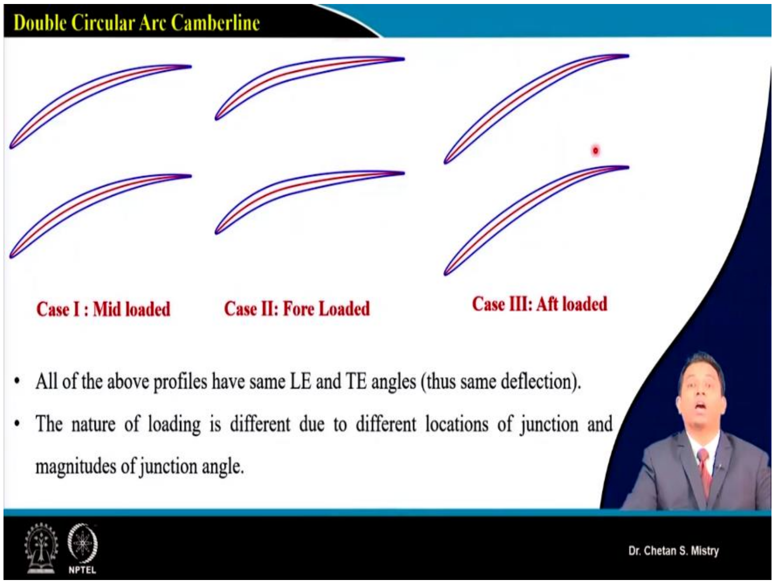
(Refer Slide Time: 29:46)



Now, here in this case, let us see, where we can take, we are having the flexibility to move with say shifting of our junction point to say 65% chord, as per our requirements. So, this is what is my case; I can give my turning in such a way that I will be having this smooth curve on 65% called location, okay.

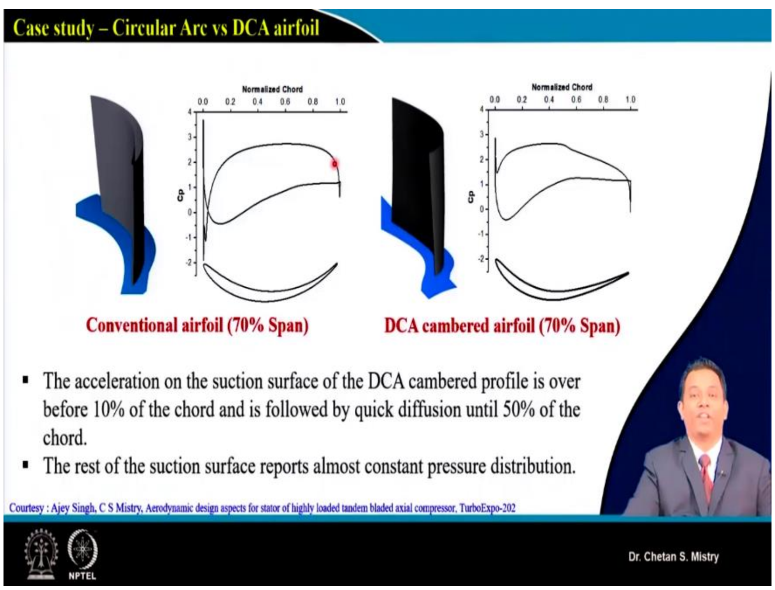
So, this is what is giving a more flexibility in sense of using the camber line, okay. So, for circular arc camber line, we are not having much flexibility for say our parabolic kind of configuration, we have little configuration, that's what is giving us to move aft load or say fore load or mid load, but here in this case, we are having too much of flexibility in sense of selection.

(Refer Slide Time: 30:40)



So, let us see, suppose if I consider, this is what is representing mid loaded kind of configuration. For the same passage area, this is what is representing say fore loaded kind of configuration. And here, if you look at, this is what is representing aft loaded kind of configuration. So, what sudden droop what we were looking for our parabolic arc camber line, that's what is now reduced, you know, you are having more control of the flow on your suction surface, you have more control of your flow on pressure surface, okay.

(Refer Slide Time: 31:18)

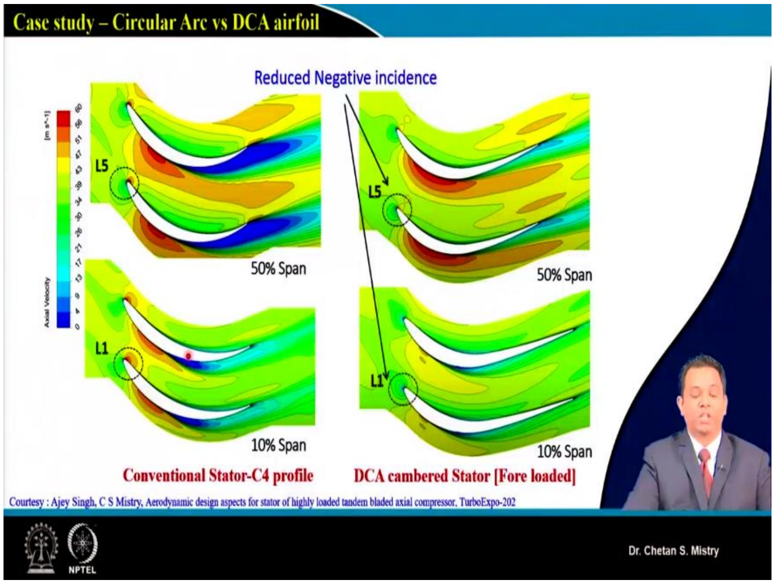


Now, this is what is one of our own case study. So, this is what we have used as a circular camber line, okay. And that's what has been distributed with say C4 profile and here if you look at, this is what is representing my C_p distribution, okay. And later on, we have done our modification, basically, this is what is representing the stator. So, at IIT Kharagpur, we are having say we are developing the test facility for highly loaded tandem bladed axial flow compressor.

Now, when we are having higher loading of, say rotor, that means I will be higher turning of my flow. And that's what we are addressing by using, say tandem configuration. Now, since this is what is my stage, the turning, that's what is coming out from my rotor that need to give me axial outlet. And that's where, my curve or say my $\Delta\beta$ or $\Delta\alpha$ for stator, that's what is coming very large.

And that's what is making the design of this stator that's what is very complex. And if you recall, we have discussed about the kind of stator or what we have made. So, there we have modified, we have used this double circular arc camber line and here if you look at, this is what is representing the distribution of C_p at 70% span. So, you know, we are having more control in sense of my pressure surface as well as on my suction surface.

(Refer Slide Time: 32:58)



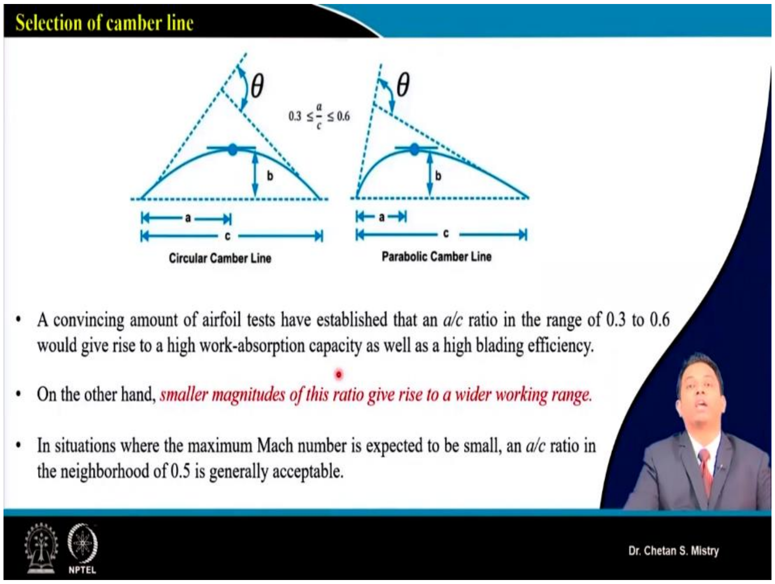
Now, this is what is based on for our understanding. So, here if you look at, this is what is representing my flow, that's what is incident on my stator at particular span, say for 10% span and 50% span. If you look at, this is what is giving me negative incidence angle, both the spans were having negative incidence angle and because of that, you will see there is a premature flow separation that’s what is happening on the suction surface of my blade. If you are moving on say upper side, that means from 10% to 50% where my flow separation is going large.

And as I was discussing, if I consider this is what is my flow separation, this particular region that’s what will be acting like a solid body and, you know, rather your flow need to diffuse, you can see my flow is getting accelerating and that’s what we are not looking for, because we want to diffuse our flow in stator also.

Under that configuration, we need to do modification with our profile. And that’s what we have done by using double circular arc cambered stator. So, here if you look at, this is what is a configuration that’s what is fore loaded kind of configuration. So, what incidence problem what we are having, that’s what has been minimized. And if you look at, if you compare these two, you can say we are having a flow to be more touching with the suction surface, and we are able to minimize the flow separation, that’s what is happening on the suction surface throughout the span.

So, this is how one need to understand and this is how one need to apply the knowledge of what all we are learning with, okay. And that’s how you will be making your new configuration. So, as I told, all compressors are unique compressors, all blades are unique blades, you cannot replace one compressor from one engine to other engine. All engines, they are having a special kind of rotor, they having special kind of stators, okay.

(Refer Slide Time: 35:16)

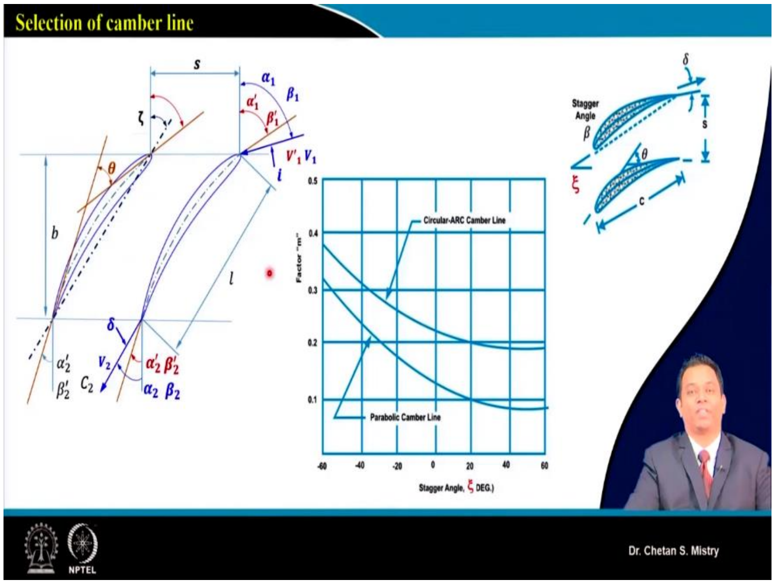


Now, this is what all we were discussing in sense of selection of circular camber line and parabolic camber line; what it says, my a by c ratio, that means my maximum camber, that's what need to be within the range of 0.3 to 0.6 ($0.3 \leq \frac{a}{c} \leq 0.6$). So, this is what is representing when we are having this in the range, that's what is giving us the high work absorption capacity as well as it is increasing our efficiency. So, when we are making our camber line, we need to take care of selecting a by c ratio, okay.

Similarly, here if you look at, if you are looking for say smaller number, if you are having a by c ratio to be lower, then that's what you need to compromise in sense of, you know, your operating range, okay. So, it says smaller range, that's what will be giving you wider operating range. So, you can understand what selection we are doing in sense of ratio of a by c, that's what is very important, okay. Now, the situation where your maximum Mach number expected is small, this a by c ratio you can take as 0.5.

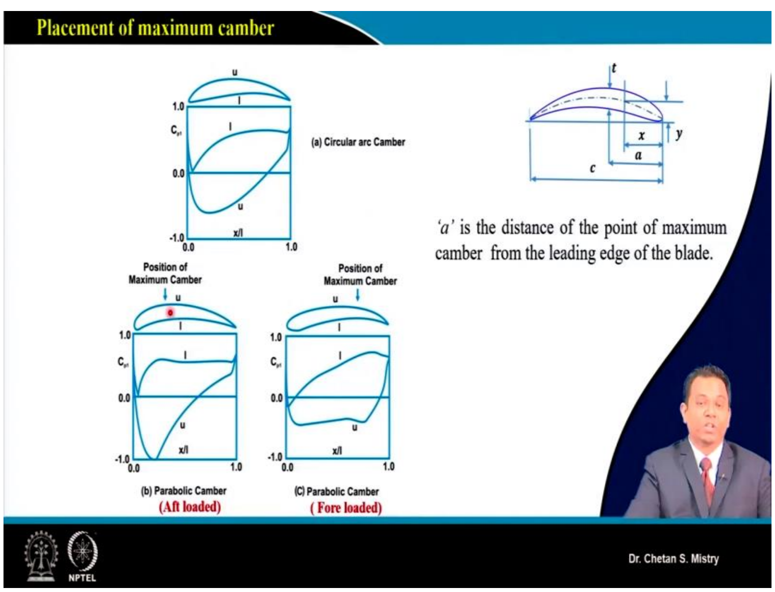
So, this is what is been given in open literature, and that's what many times we are following with and as per our requirement, as I told, we need to change that, okay. So, you know, you cannot go rigidly what say literature says or what books they are recommending. That's what is for special or typical kind of application, when you are doing your own design, that's what is a separate thing. It has nothing to do with what all that's what is available in open literature. Yes, the numbers what we are discussing, you need to stick with those numbers because that has come with a lot of experimentation, lot of experience, okay.

(Refer Slide Time: 37:19)



Now, if you recall, we were discussing about the calculation of my factor ‘m’, this factor ‘m’ that’s what we are using for the calculation of our deviation angle, okay. So, this is what is representing my circular arc camber line, this is what is representing my parabolic arc camber line with different stagger angles. So, we will be calculating our ‘m’ factor based on that, okay.

(Refer Slide Time: 37:49)



Now, we have discussed what we say in sense of say, maximum camber location. So, here, this is what is representing one of the airfoil, that's what is with say, circular arc camber line. And here if you look at, this is what is representing…my…what is happening on pressure surface, this is what is representing what is happening on my suction surface. So, for this kind of particular circular camber line, if you look at, I will be having whole lot of acceleration, that's what is happening on my upper surface and you know, then my flow is getting decelerated.

Similar to that on my say lower surface…on my pressure surface, I will be having little acceleration and then we are having say deceleration of flow, that's what is happening. Now, for same, if you will be using say parabolic camber line, just look at, this is what is representing aft loaded configuration and this is what is representing fore loaded configuration.

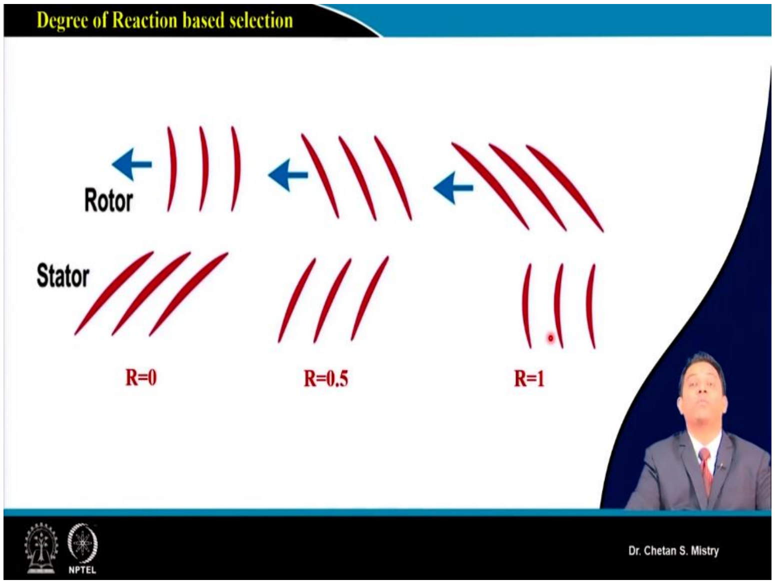
So, here if you look at, say my maximum camber position, that's what has been shifted towards the leading edge. Just compare these two, you will clearly see how my C_p distribution, that has changed. What we have done? We have just changed our camber line, our thickness is same, our angles are same, but just look at, we will be having whole lot of acceleration that's what is happening on our suction surface and that will be followed by the deceleration. And, on our lower surface or on my pressure surface, if you look at, we are having say acceleration of flow, later on with this little deceleration I will be having constant pressure kind of configuration, okay.

So, this parabolic arc camber line with aft loaded you will be having this kind of C_p distribution, okay. Similarly, suppose say if I am shifting my maximum camber on the later part, if you look at, just look this part, this is what is representing what is happening on my say upper surface or my suction surface. I will be having little acceleration, but that will be followed by constant pressure and then we will be having deceleration, that's what is happening on the later part of my blade, okay. And same way on my say lower surface or my pressure surface, I will be having flow acceleration that will be followed by say the deceleration of my flow.

So, you know, like this is what all we are looking for in sense of what we say aft loaded and fore loaded kind of configuration. Let me tell you, recent trend, that's what is going on, where people they are defining this C_p distribution. They say, this is what is my C_p distribution, I am expecting from this airfoil. And based on that, initially, they will be assuming some airfoil and they are doing inverse design. That means, here based on the shape of my airfoil, we are getting C_p distribution.

By using numerical tool, what they are doing? They are having this C_p distribution, that's what is available and then after based on that they are doing or they are developing new kinds of airfoil, that's what is called inverse design kind of configuration. That is also of hot topic for the research. People they are working on that topic since long and now, we are having again and again addition of new blade airfoils.

(Refer Slide Time: 41:44)



Now, if you recall, we have discussed different kinds of configuration; we say, we are having different kinds of degree of reaction distribution. So, here if you look at, this is what is representing my degree of reaction to be 0, my degree of reaction to be 50% and my degree of reaction to be 100%.

You will say, Sir, how we are correlating what all we learn with this degree of reaction? This degree of reaction, that's what we are looking for, what it say, my degree of reaction, that's what is 0, then I can see my diffusion is not happening in my rotor, whole lot of diffusion, that's what is happening only in my stator.

So, if you look at the shape of my airfoil, you know, this is what is a constant area kind of configuration. Now, you can say what angles we are deciding with, we are looking for the blade passage to be designed, we need to use the airfoil, that's where what all learned, that's what is helping us. So, you can see, this is what is constant area passage; here if you look at, my entry area is lower, my exit area is larger. Suppose, if you are considering say 50% kind of configuration, again we are looking for different kind of airfoils, different shape of airfoils. Same way if you look at say 100%, we are having, say a whole lot of work, that’s what is only been done by rotor and my stator, that’s what is acting like, you know, guiding the flow. So, here we are looking for constant area passage for the stator.

So, the fundamental what all we learnt about this airfoil, that’s what is straight way applicable for the design of our blade and we know this degree of reaction, that’s what is varying all the way from my hub to tip. Now, you can understand what all angles we have calculated, it may be possible that throughout my span, I will be having 100’s, 1000’s of airfoils and this all airfoils that may be having different shapes, okay. And, how do we do the modification of those shapes, that’s all what we have discussed today. I am sure, this is what will give you more clarity, more idea in sense of how do we move with the selection of airfoil, how do we move with the selection of camber line after doing our design, thank you. Thank you very much for your attention!