Aerospace Engineering Instability and Transition of Fluid Flows
Department of Aerospace Engineering
Indian Institute of Technology, Kanpur

Module No. # 01
Lecture No. # 21

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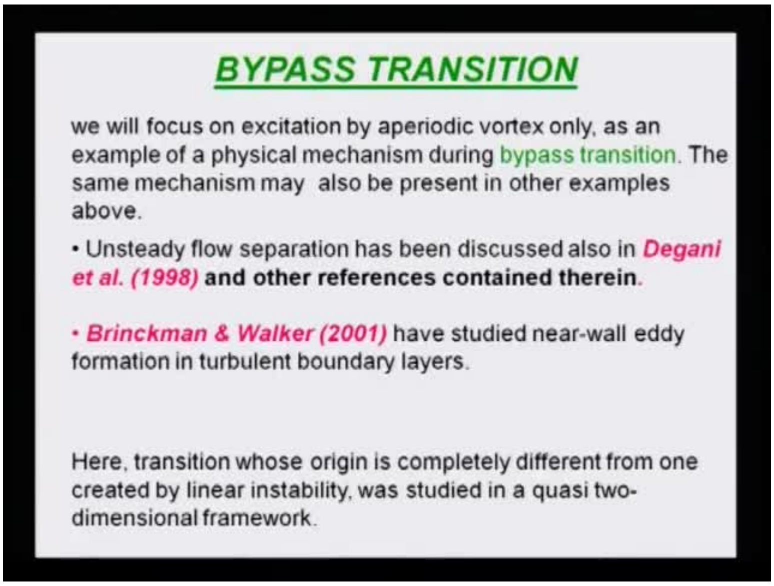

We started discussing about Bypass transition, and so far we studied about Wall excitation and Free-stream excitation with Periodic vortex strain. Today, we are going to look at another aspect where we are going to excite a shear layer by a Periodic vortex. Well, it means just a single vortex, and how does it trigger transition to turbulence without going through creating transition, Tollmien-Schlichting wave called as Bypass transition. These are the potential application areas where, you see such a thing happening.

For example, we have talked in fluid mechanics about unsteady flow separation. This is a paper Degani et al they wrote about it. This unsteady flow separation implies that, you would have separation bubbles which will grow along the surface and they also show you enhanced skin friction and significant separation ((bad video quality)) separation phenomena will club them as bypass transition.

Brinckman and Walker did similar studies where, they tried to see how eddies or vortices form near the wall, inside a turbulence boundary layer. So, what you do is, you look at the spam wise plane y, z plane. Suppose, the flow is in the x direction in the y, z plane, you postulate existence of a stream function, and you saw a steam function vortices equation.

And then, if you see there are some stream wise vortices in the spam wise plane that would create a bypass transition. So, that is what we are talking about that the transition occurs here completely different other than what we have studied so far through linear stability theory in a Quasi 2 dimensional frame work.

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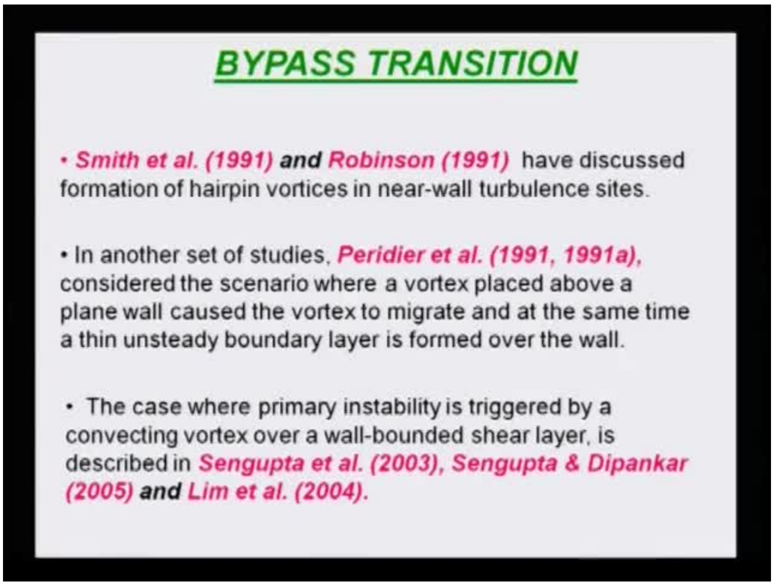

So, this is something that we would continue looking at, and this was also been discussed how similar such mechanisms, the model that we are discussing is basically a prototype model. We are just trying to see what happens to the shear layer, if a single vortex goes by this is a unit process. So, that kind of a process has been earlier postulated by Smith and his colleagues. Robinson, in his annual review paper tried to find out how air pin vortices forms inside a turbulent boundary layer. That is what we are talking about, near wall turbulence phenomena that also come about there.

There was another group of people in UK who has studied very interesting problem, that if you have a flat wall, then you bring in a vortex, and the vortex automatically starts by itself. Why?

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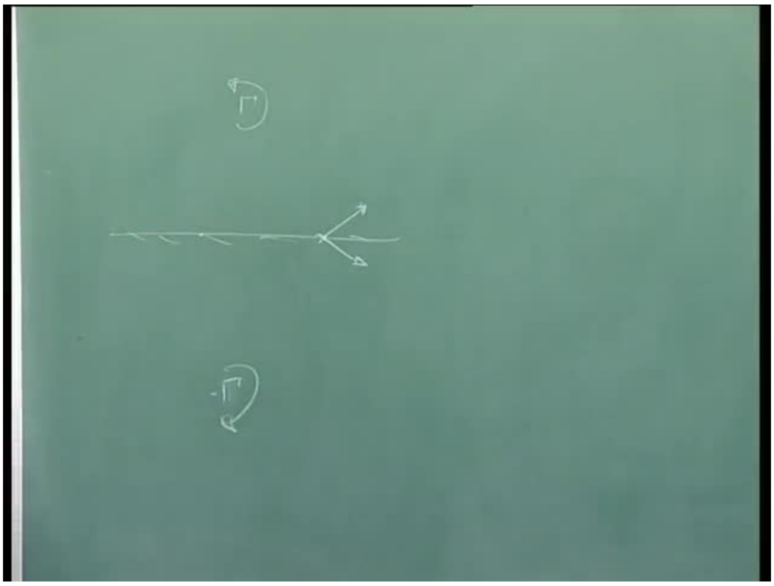

Because, that's what we discussed in the last class, if I have a wall and a vortex here, then because of the wall I would have (No audio from 3.38- 3.44) the negative sign. If I look at this point, what happens? We saw that induced velocity by these two gives a rise. So, this creates a kind of slip velocity. In addition now what can you see? That this vortex excites a force on this, and this in turn gives a force on this as a sequence both of them start moving.

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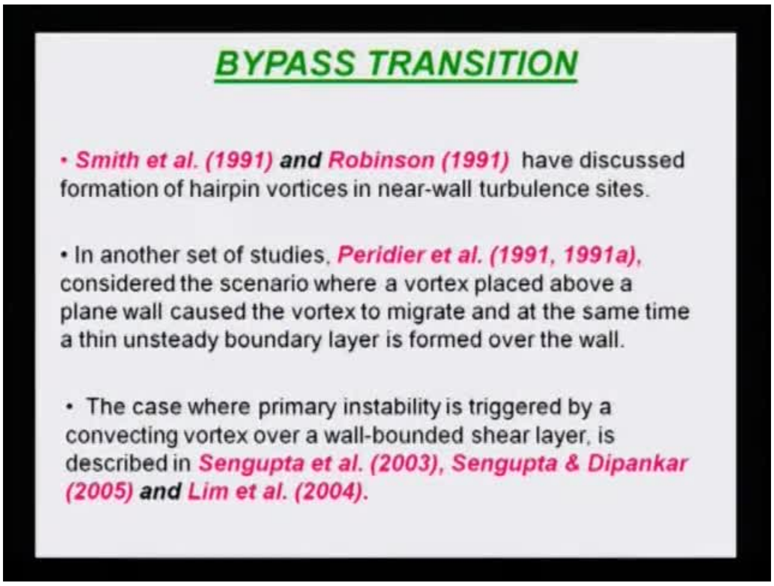

So, you start with a no flow. Just simply put it in vortex singularity, we start seeing in this vortex translating. And once this vortex starts translating, then also would be something like the complimentary flow where the vortex is stationary, but there is a flow. So, what happens is, it is kind of a similar problem that we are proposing here too, and this was investigated by Peridier Smith and Walker in couple of papers in general of fluid mechanics, and the vortex was placed above a plane wall that cause the vortex to my great, and at the same the thin unsteady boundary layer was found.

So, it will immediately start forming a boundary layer, and then this vortex will destabilize it. So, half of it just brings in a kind of a sequence of events that all starts about, by just simply keeping a single vortex in a coefficient fluid.

This is something we must understand. It is a very interesting phenomenon. The moment you put such a vortex in front of a shear layer you create a kind of a primary instability, and this we have studied a lot over the last 7- 8 years. In many scenarios we have studied it. The last paper is actually an experimental paper which we did few years ago in Singapore I will explain that work.

The first paper is where we proposed a new theory of instability based on energy. We are going to study in a great deal .And second paper in 2005 that we are looking here. We studied the instability of a flow over a wing swept back wing on the leading edge; this is what it is called as a leading edge contamination problem. That is what we have talked about in great deal too.

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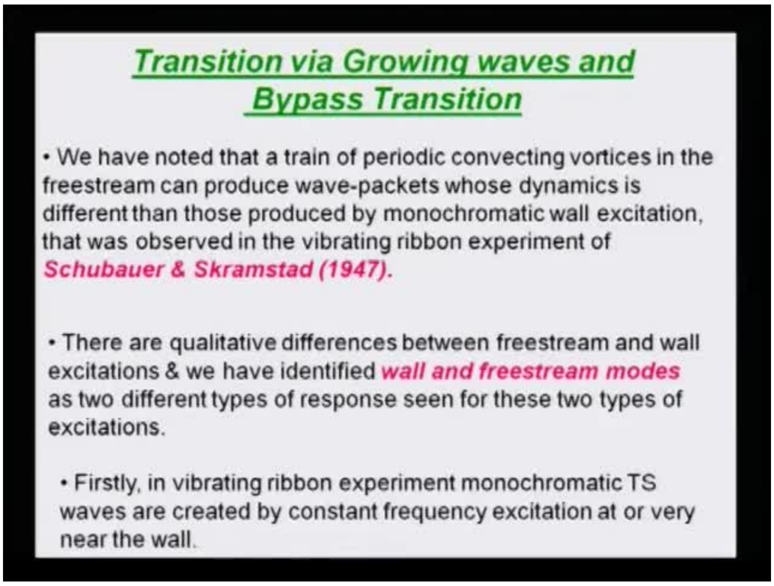

Now, we have noted already that, if we have a train of periodic vortices in the freestream that creates some kind of a wave packet whose dynamics is different than those produced by monochromatic wall excitation. The monochromatic wall excitation is a critical example of the Schuhbauer Skramstad experiment that we know.

We also noted that qualitative differences do exist between free stream and wall excitation. We talked about wall and freestream modes as two different types of response that can be created by this kind of excitation. And, we also investigated the case that, even though I create just a freestream excitation that, by itself creates an equivalent wall excitation this coupling mechanism was studied in great deal in last week.

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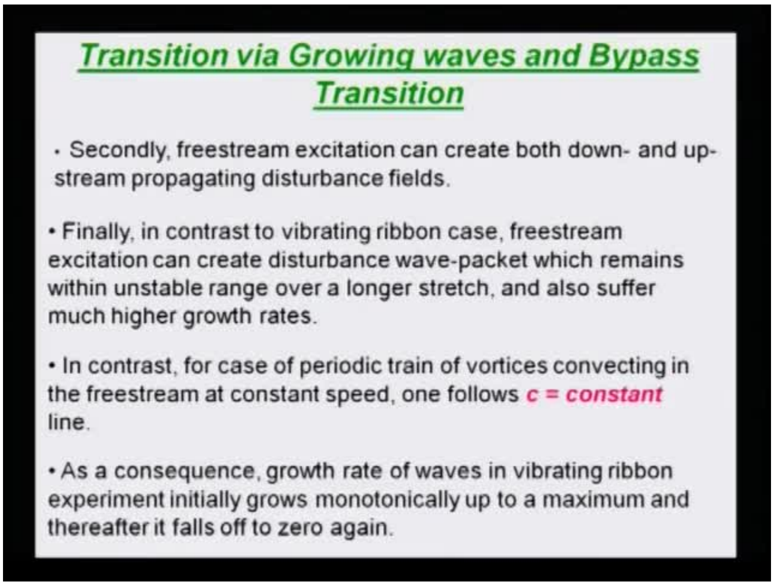

We see that, there are two types of excitation in the vibrating ribbon experiment monochromatic Tollmien-Schlichting waves are created which travels with a constant frequency, and tends to stay very near the wall itself inside the shear layer. Then, secondly, what we have also noticed that, freestream excitation can create both downstream as velocity propagating disturbances, called the downstream propagating, once at the wall mode the upstream propagating once at the freestream modes.

Finally, we noted that in contrast vibrating ribbon cases, the freestream excitation can create disturbance wave-packet which remains within the unstable bar over a longer distance and also suffer much larger growth rate. This is something that we must keep in mind. In contrast if we look at periodic train of vortices convicting in the freestream at constant speed. We do not have to follow a constant frequency, but what we should follow in that neutral curve we should follow c equal to constant y, and that is there is that we get much higher growth rate.

We said that, as a consequence growth rate of waves will much more significantly higher than what you actually generate by vibrating ribbon type of excitation.

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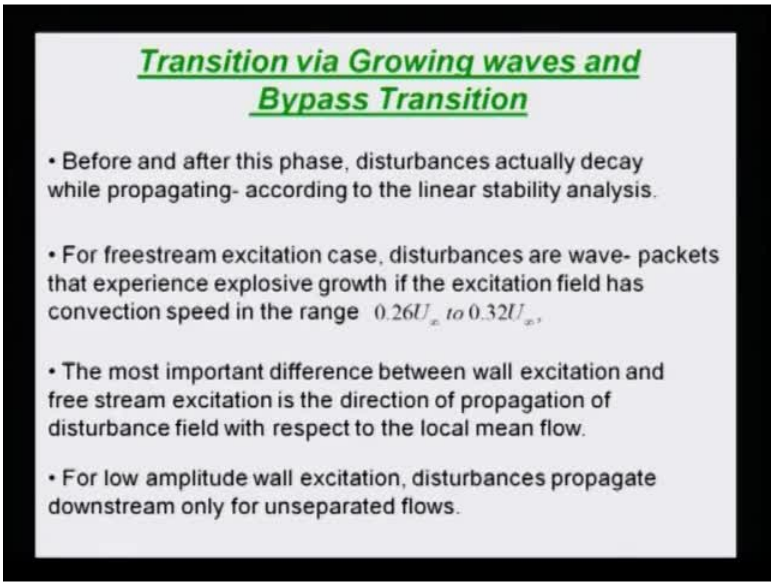

Now, what is new on plate? That is what we want to talk about, but what we noticed that for freestream excitation phase we have a band of convection speed which we actually identified, if the tunnel length is small, and then this is the weaker speed at which a vortex can go. Well, although we will revisit that what really happens and we will talk about specific mechanisms by which this kind of excitations can come about.

But, the most important difference that exists between wall and freestream excitation is the direction of prorogation of propagation of disturbance field. That we have talked, so we are emphasizing again. Free stream excitation is equivalent to upstream propagation with respect to the disturbance. So, with respect to an initial frame it still may look like going downstream, but with respect to the disturbance in the freestream it actual moves up stream.

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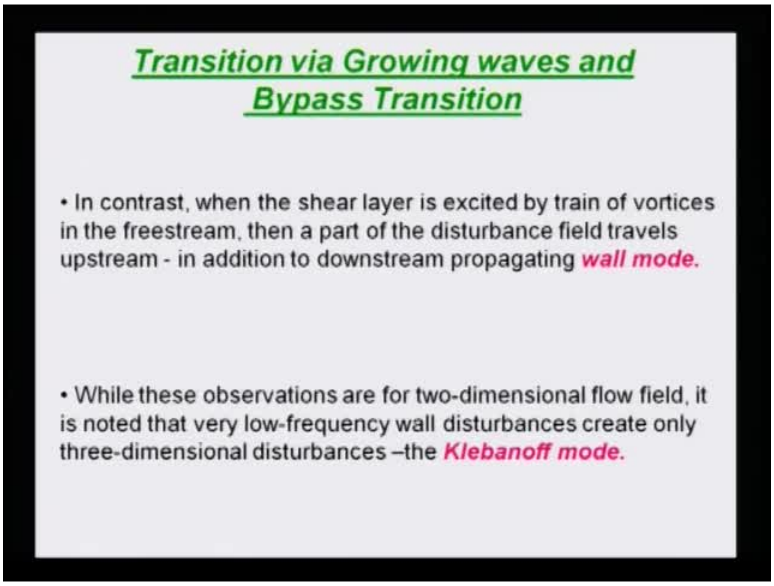

If, we just simply lower amplitude wall excitation. Then, we see that we do create those TS waves, but we also keep in mind that, if the amplitude is much larger, then we can also have a bypass event, even though we are having wall excitation. So, this wall mode that we are talking about is restricted to very small disturbance case.

Now, when shear layer is excited by train of vortices in the freestream then, a part of the disturbance field travels sub stream in addition to this wall mode. We also noted very clearly that, if we create a disturbance even inside the shear layer, but at very low frequency then we do not create any 2-dimensional disturbance field instead we create a 3-dimensional disturbance field which we called as a Breathing mode of the Klebanoff mode.

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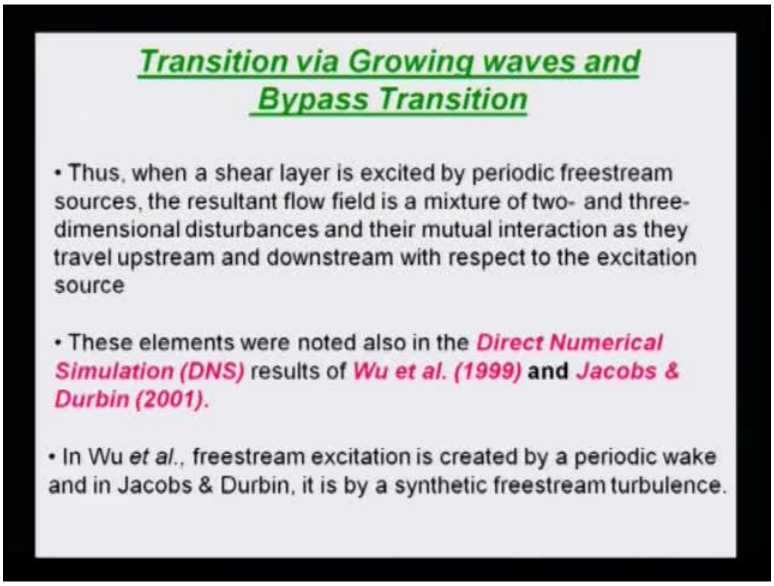

So, this is what is basically a quick summary of what we have been talking about. Now, what we are talking about, that if we just do not talk about this synthetic lab scenario where we do this vibrating ribbon business, in actual flow what will happen? The flow itself is not uniform flow that contains all kinds of things. You have periodic vortices, you have aperiodic vortices, and you know if you have periodic vortices then, you can have an equivalent wall excitation, all kinds of things. So, in a response field what do you see? It is going to be a mixture of all kinds of things ,some 2-dimensional, some 3-dimensional ,and what about the 3-dimensional disturbances we saw that could be due to the very low frequency excitation and those wave lengths could be 1000’s and 1000’s of delta star. So, that misspends the whole experimental facility and many times over.

Now, we also talked about some direct simulation our self, but in addition we also note that, they were some direct simulations, 3D simulations were done by this group at Stanford, Wu et al, Wu Jacob, and Wu Durbin and Hunt this 1990 paper. Later on, Jacob submitted his species under robin where also they talked about this DNS of this free stream excitation.

What kind of freestream excitation was considered in Wu et al? It was a periodic weight like what you would see in turbo machine, like we talked about the straighter rooter interaction. It is that kind of thing they talk about. Whereas, in Jacobs and Durbin they were created what is called as a Freestream turbulence, but please do understand, that they were basically talking about those moves are called along that alpha i axis. Remember? We talked about the anti-stokes line on the right half plane, we have alpha on the positive and alpha on the negative, we have these two kinds of things. So, this Jacobs and Durbin's what actually talked about disturbances which lie along alpha i axis and we discovered it is Eigen structure that it will not decay.

So, it is kind of a synthetic of freestream turbulence. Many of us do not agree with this way. I mean you cannot ever excite a flow like this that, the excitation goes all the way up to infinity and just it zigzags like this.

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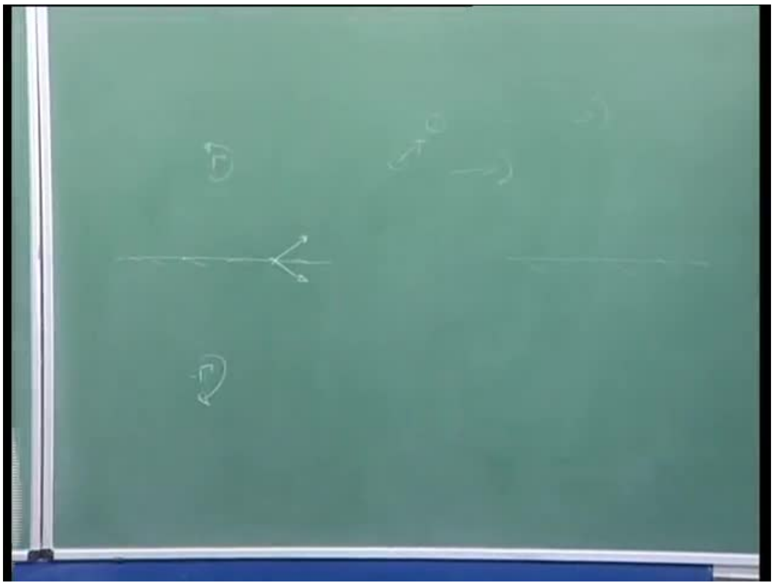

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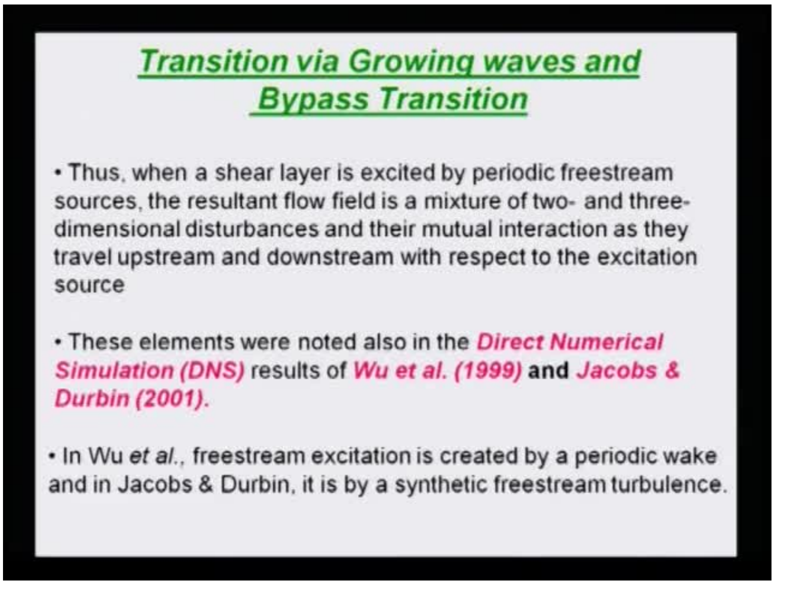

In contrast, this earlier work by Wu et al periodic way was much more realistic, that kind of depicts what happens in actual turbo machine, and if you recall that Kendall's experiment that I talked to you about where, what can I did was created a kind of a circular cylinder rotating above this, and then, it was creating vortices alternately like this and so on. That also was a kind of a prototypical model. Whether you are talking about Kendall's experiment or Wu et al's freestream excitation by periodic way. What remains in view is a kind of qualitative picture. Because, we do not have any idea about the strength of this vortices those are conflict, and we also do not know what happens to the vortex, does it goes towards the downstream plate or, does it go at a constant height or, I mean that too many unknown factors, parameters.

So, that is what we thought when we started looking at it late 90's that, we will have to design an experiment which should circumvent all of these uncertainties, and that is what we will be talking about a great deal.

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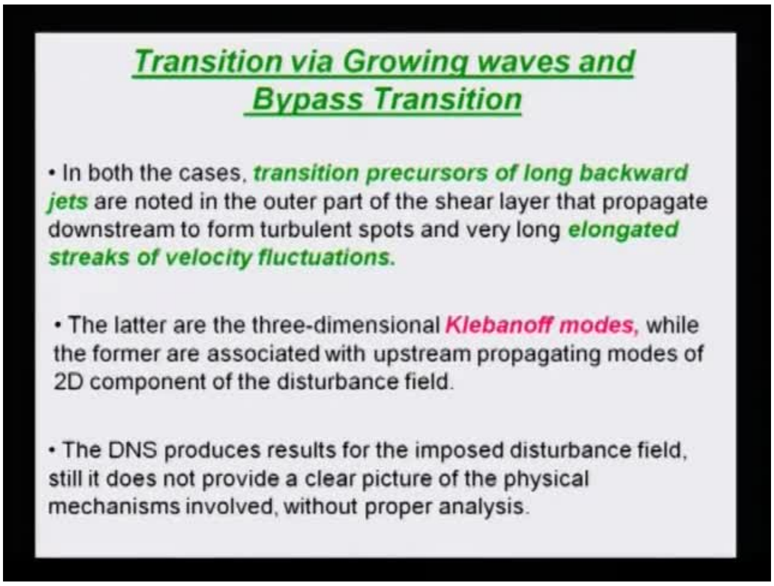

Now, what happen was those two papers those are written by Wu et al and Jacobs and Durbin they looked at some structures in your direct simulation result. What they noted is written here in green that before transition you could see some kind of structures which were propagating upstream, they look like a jet.

So, basically that is what you see in turbulence flow also, peak value structure and then, you have a stream of fluid which is going relatively faster than the other, but look at this, they were the ones first who did talk about, that there are something like backward moving flow structures, and that was computed, and it was a very brilliant piece of work however they could not give very good explanation for it.

But, now we have done that analysis our self, and we know what causes upstream propagating modes those Eigenvalues which remain on the left half plate that can give rise to this, and this make them suggest that this creates in turbo machines you do get some kind of turbulence spot's spot like wavier creates elongated streak of velocity fluctuations. So, we have peak and value structure, and they are sort of distinguishing by this feature of propagating upstream, and this was something totally new. Very few people understood and appreciated at that point of time, but when we did those calculations, we did understand what it was.

These are the level of modes, plus 2D upstream propagating modes. The upstream propagating mode as I said is a 2D component of the disturbance field.

In addition, in turbo machine you also see that, the boundary layer heaps the whole thing. That is, of course, is the signature of Klebanoff mode that we have seen. So, these are those 3-dimensional flow field disturbance fields, but we have seen its peculiarity. It's 3-dimensional, but moves along the stream wise direction, this is very quiet piece of evidence.

The DNS produces results for the imposed disturbance field, but it does not really give you a complete understanding about what is really going on. That is one of the problem with computing all is you have to understand that, it can give you lot of result, but it does not give you immediately an explanation although there are groups of people these days, they talk about artificial neural network which pretends to learn by itself without the person writing the program he or she does not have to learn, but artificial neural network learns and does lot of interesting things.

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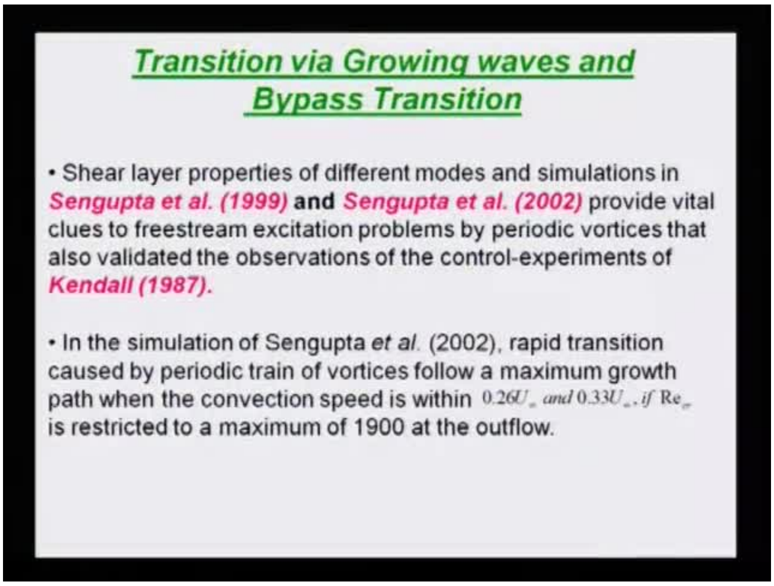

I am very spectacle about machine doing that thinking and understanding for you, but there are lots of people who are making a living (( )) So, we will not to criticize them too much .I think the numbers are growing by 1000's year by year. Look at in contrast, the kind of simulations that we reported.

Here we talked about pure convention with a prescribed velocity and times scale, but to dispersion we can actually fill up the band. That was one thing that we did, and in this work of course we did connect the wall mode and freestream mode, and we show why you get much larger growth because of this kind of a scenario.

And, we did talk about this, we looked at the shear layer where the extent of the domain started off somewhere from 150 - 99, and this is Reynolds yellow based on displacement thickness.

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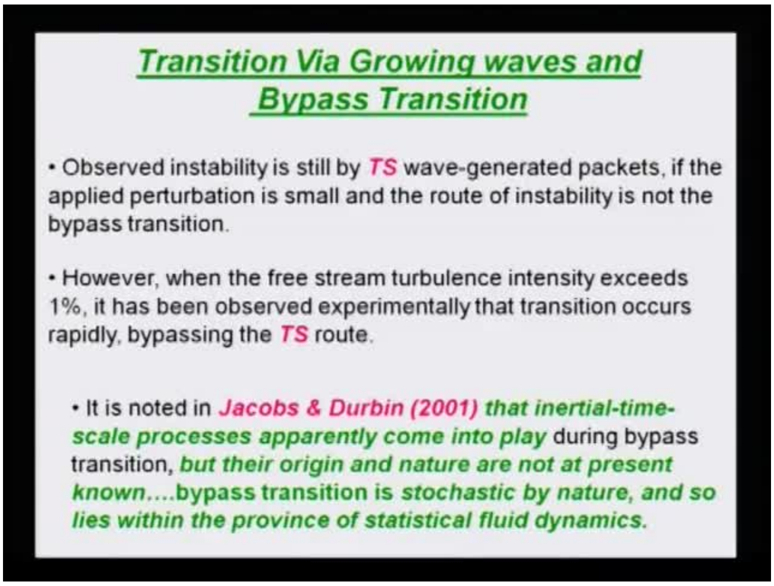

So, it was not a very longer flow field, but in recent times we are actually done much more simulations and much longer domains, and we find that this range actually depends on what to do so, what does it mean? It means that, whatever tunnel that you are using, you are going to see this selective speed slightly different, because in a sense you are creating all those waves which are restricted by the size of the tunnel so, if you have a longer tunnel then, you can create much longer length scales .So, this is something that experimentalist also should pay attention too. It is not that without knowing the theory you can do experiments and unfortunately lot of people think that way, that if you are not good in theory you should become experimentalist, which is not the case.

Whatever the instability that we have observed in all this cases where still by the Tollmien-Schlichting wave generated packets. That was true, if the perturbation is kept very small, and the root of instability is not truly the bypass transition what Markova's suggested that you do not see any TS waves.

So, these are still TS wave generated packets. However, if you keep on increasing the freestream turbulence intensity which is about 1 percent. 1 percent is quite large by pure external aerodynamics application point of view, but when you look at internal flows like flow inside a combustion champ outer turbine machines there are this may be considered even moldered immediately after the combustion chamber we could have recent turbulence level close to 2 to 5 percent, that is quite common.

And another place where external aerodynamics you could have very large freestream turbulences what you see in the wind aerodynamics now in a civil structure you talked about the dust of wind coming so in storm if we want to study let it that kind of a scenario.

So, if you have a feisty level higher than one percent, then you bypass the TS route. It is interesting that Jacobs and Durbin they makes this observation which we could not like to agree immediately what that they say that this inertial time scale process is come in to play during bypass transition irrespective of I mean you are not having a TS wave so there are additional timescale coming about. This is due to the inertial acceleration term convective acceleration term.

But they confessed that there origin and nature were not known to them for sure, and they made this observation at bypass transition is stochastic nature that is what they said, that give up the deterministic fluid mechanics and start doubling in statistical fluid dynamics and which you know that we will should not subscribe to because that is what we are going to see what happens.

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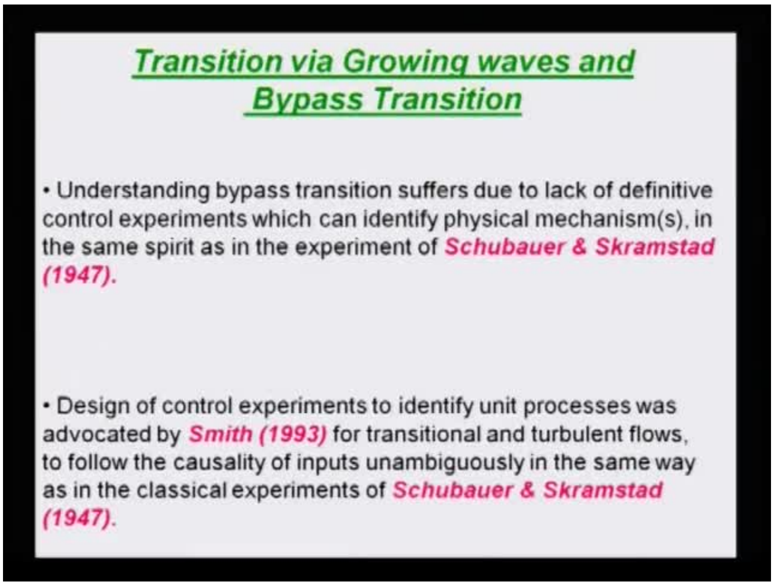

Now, understanding bypass transition actually suffer, because you have to do some experiments on which you can really control one parameter at a time . If you do not do it, then you see all this (( )) of effects together. Now we are pretty much conversion.

In actual transition scenarios so many things can simultaneously happen, if you cannot identify the cause and affect yourself, god is not going to help you. So, you have to do some definitive control experiments by which, only you can identify the physical mechanisms that you would help you the same way that Schuhbauer and Skramstad experiment established instability theory the first time.

So, this was a revolutionary piece of work. Here also you need some such good well taught out experiments, and this was clearly articulated by Professor Smith. He said that if you want to identify unit process is that goes on inside a boundary layer , whether it is either transition or nor a turbulent, then you meet to really follow the link the causality of input with response field . It should be in the same spirit as Schuhbauer and Skramstad did.

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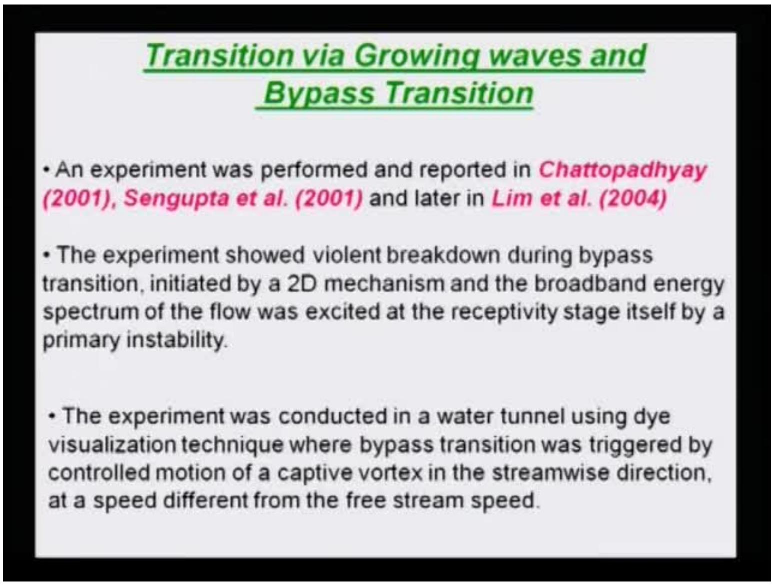

So, what do we do? Is the issue that is where we stepped in Monojit Chattopodhyay was one of my student at Singapore and (( )) was colleague so we all gathered around we thought we will design do an experiment to do some of this; what we did we did try to create bypass transition and purposely we wanted to keep those scenario very simple. So, we had to initiate something which was a really 2-dimensional mechanism.

Because if you are doing an experiment in a ventanal and if you also how transition to turbulence, and you have the side walls and you have 3-dimensional thing, then those entire reflections etcetera has going to quire the pitch completely. And that is what we decided that we will have to do something very original by which we will keep the flow essentially 2-dimensional for the disturbance flow. And then, we will see the energy spectrum, because you see now what is happening we are trying to create a single captive vortex that will go over, and that will create some instability mechanism, that will remain 2-dimensional. Too many things we tried to constraint and that is make that the design of that experiment very interesting. We were not very ambitious; we wanted to really look at the receptivity stage itself how the whole things start of the onset process.

We used a water tunnel I am telling about in (( )) I look back we spend only about 100 dollars, Singapore dollars, in doing this experiment over 2- 3 days. We just simply dependent upon a dye visualization technique.

And we are tried to create a bypass transition by first creating a captive vortex, and then, making this vortex do your bid, you wanted to go at it constant, it should do. You want to keep it strength fix, it should do that. So all that was done and we also wanted to control the speed of convection of this vortex, and what we know all that we have learn so far that it should not be a pure. If you are talking about the bypass root, then this convection speed should be different from the freestream speed.

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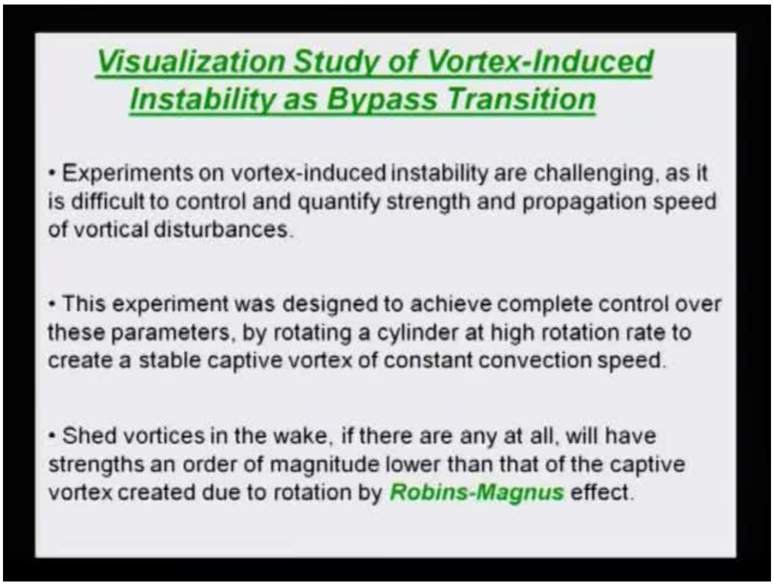

So, let us go ahead and see what we can get. Now , what we are going to get is a kind what we call as a vortex inducing instability , because that is what is happening we are making one single vortex go by and that should destabilize is the flow . So, this is quite challenging, because of those parameters that you want to control .The control parameters could be destroying, the propagation speed, the height, etcetera.

And not only have that evened the sign of the vortex. You know all order you want to create a counter clockwise rotating vortex or a clockwise rotating. How do you do it? That is what we did. We created a vortex by rotating a cylinder. You know that Robbins Magnus effect creates a very potent and coherent vortex at the center of the translating rotating cylinder. So, we did that so we said that this will do the trick, and by the rotation direction we could fix it sign, and because now your vortex is trapped inside the cylinder you have kept the height fixed, and what we did we also add a step a motor to guide its motion.

Sometimes even we can do it manually so that we can control its speed of propagation. So you see this was a very simple minded experiment, but we did not achieve quite a bit. And all these things were achieved we created a captive vortex of a particular sign, we could control it speed. We could control it height. Now you might say that you take a cylinder and then this cylinder sheared vortices that may not come on vortices.

What happens to that? This I will give you some reference as we go long earlier experiment is shown, that if your surface speed is more than twice this speed of you know surface speed imposed by rotation is more than the twice the speed of u infinity the oncoming flow than the sheared vortices are negligible. And even if there are tress amount we show visual experimental signature of those strengths are orders of magnitude lower, so you do not have to worry about. So what actually we did, we use Robbins Magnus effect to create vortex induce stability.

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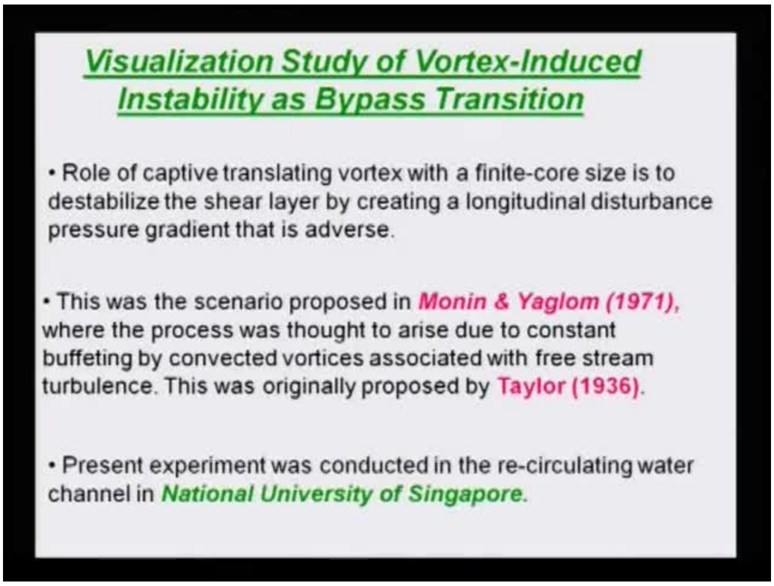

Now, when you are think of the role play by the captive translating vortex with a finite core size, Can it destabilize the shear layer? Where people have conducted about it. And no one else other than G I Taylor in 1936. He had thought about it, but what he thought was that you have these vortices going past in the free-stream and once you go there that will constantly excite.

So it is not a question of instability that they are talk about; they are talking about a first excitation. You have a constant stream of vortices is going and that keeps on of buffeting shear layer and that is what you see as the response .So, you understand that there is a qualitative bit difference between what Taylor suggested ,and which is actually given in the book by Monin and Yoglom. We can read that in the early pages that scenario is entirely different than what we considered and we did.

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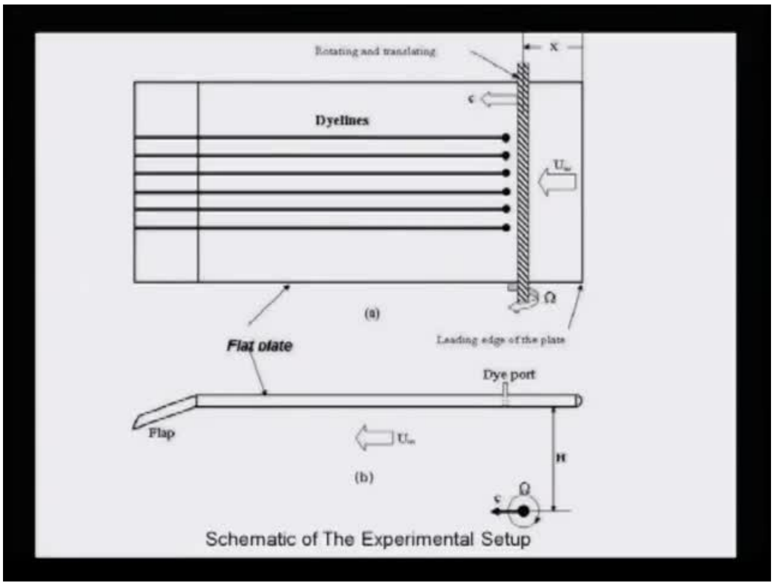

This was done in that re-circulating water tunnel in any ways. This is the sketch of the experiment .So all you needed is basically at Perspex flat plate so flow is coming from to left. And then, this a top view, so in the top view this is your rotating cylinders.

So, this is rotating with capital omega and it also convicting. Now what it does is, this is a side view, so this is the plate ,and this is the vortex that is going at a constant height edge , and the speed c is fixed by us appeal we can change our self. So we have already controlled and we also have a flat you know how your flat plate experiment that you do in tunnel you always need to have some such a flap to somehow control the flow.

Because , although you may say that that it is coming like this it really does you will always have some kind of a flow angularity etcetera , and to upset that and to create a perfect 0 pressure gradient boundary layer you need to have a sort of adjustment flap. So this is a usual trick of the train. So, what you do is you have this rotating cylinder the flow is this way, and this cylinder is made at a different speed.

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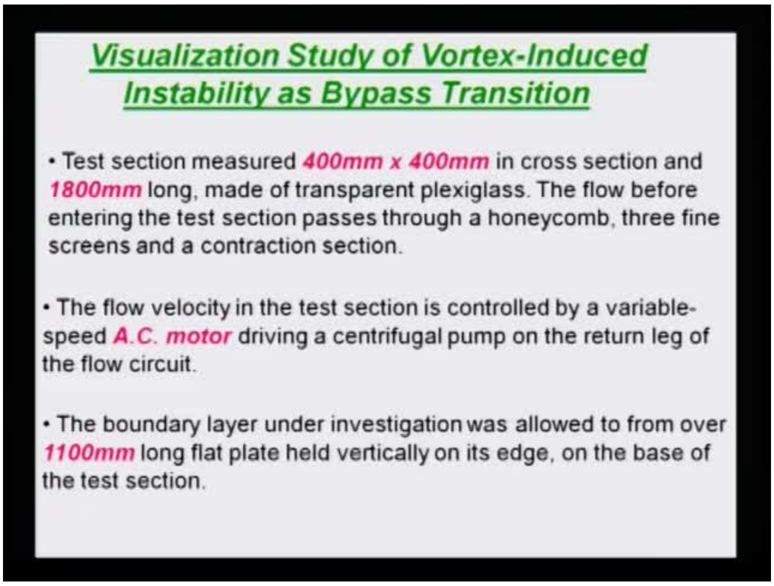

So c is not equal to infinity, and how do you visualize the flow? You create some kind of dye holes and through there we actually simple injected for dye. And what happens is? if I do not have this those dye is show as if they go in straight line, and that establishes that the flow is perfectly 2-dimensional ,and there is a low pressure gradient, and then once you start the experiment this dye will fluctuate. These dyes will suffer enhanced, mixing, catic motion all kinds of things.

And this is of these are some of the details of the tunnel .The test section was not very much it is just simple 40 centimeter and 40 centimeter. We had about 1800 mm long test section made of transparent plexiglass ,the flow was made to really be quite by passing it through a series of honeycomb and screens apart from the contraction section itself.

The flow velocity is actually controlled by AC motor which drive a centrifugal pump because it is a water turn tunnel, so we have to send a power through this AC motor that is kept on the returned limb, so it is basically not in the same say, it is a kind of a re-circulating one. So you keep it on the returned limb, and then you have all this contraction core, we have the screens, you have the honeycomb, so the time the flow enters the test section it is absolutely quite .And the plate that we are took is about 110 centimeters long and if this a channel so we kept the plane vertical so that from the side we could take pictures so that was the way.

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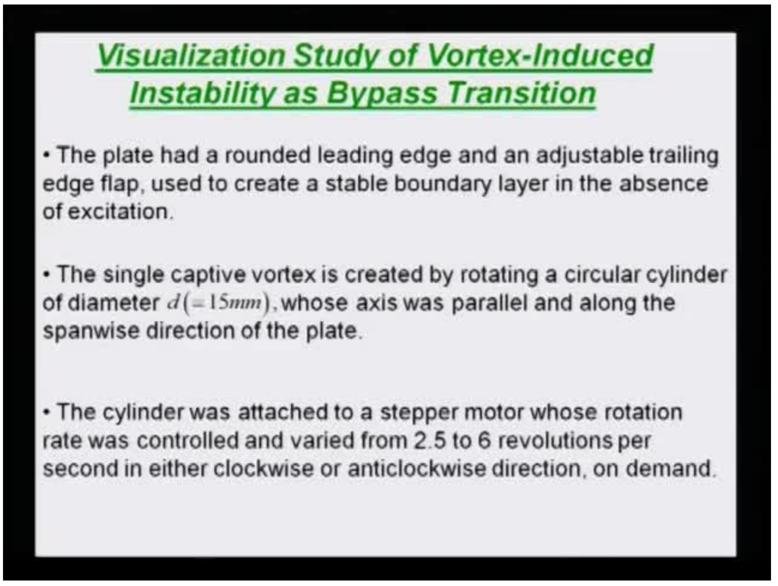

So the plate was positioned vertically on the bottom wall of the water tunnel .And as I told you the plate had a round at leading edge. Please do understand that we do talk about all kinds of .When you do theoretical analysis we say, that we have a flat plate with the sharp leading edge so that the thickness is 0. There is a problem also there, if there is a bid of flow angularity, then that sharp leading edge causes lots and lots of problem.

So, in the actual experiment you all were end of having a slight rounded leading edge. Some people will call it by super ellipse section , but essentially that is the whole idea and this adjustable trailing edge flap actually creates a stable boundary layer ,if you have low excitation .The rotating cylinder has a diameter of about 15 mm,

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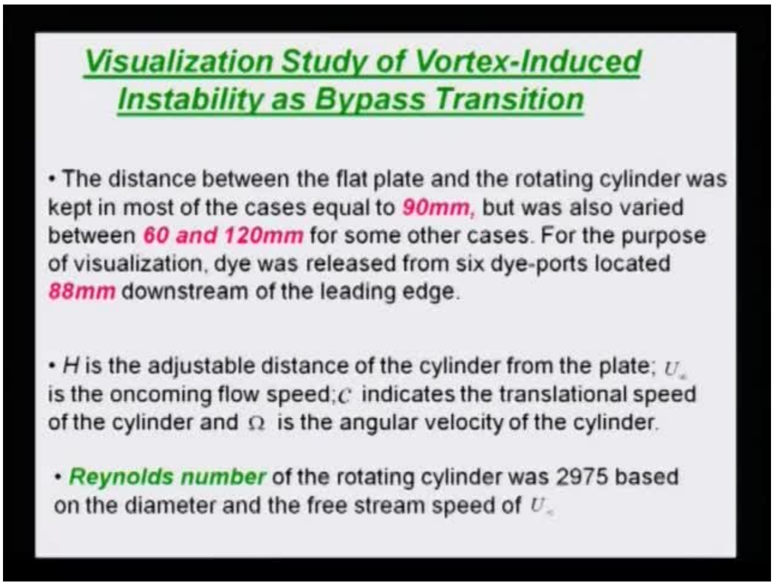

So that it hardly creates any obstruction to the flow, an axis was perfectly made parallel line in this span wise direction of the tunnel. The cylinder was attached to a stepper motor whose rotation was controlled between 2.5 to 6 rotations per second, and we could do it in either clockwise or anticlockwise direction. As we want I told you that we want to change the sign of the vortex and that is what we need to understand. Now, what happens is, we kept a distance about 90 millimeter between the flat plate and the conducting cylinder, but we could also bring it closer to 60 output take it further to 120 mm, because we wanted to see the effect of height also of this vortex.

And dye was released from 6 dye ports as we saw this was position some around 88 millimeters downstream of the leading edge. And the H was the adjustable distance of the cylinder from the plate U infinity is the oncoming flow speed C, there is a translational speed and capital omega is angular velocity.

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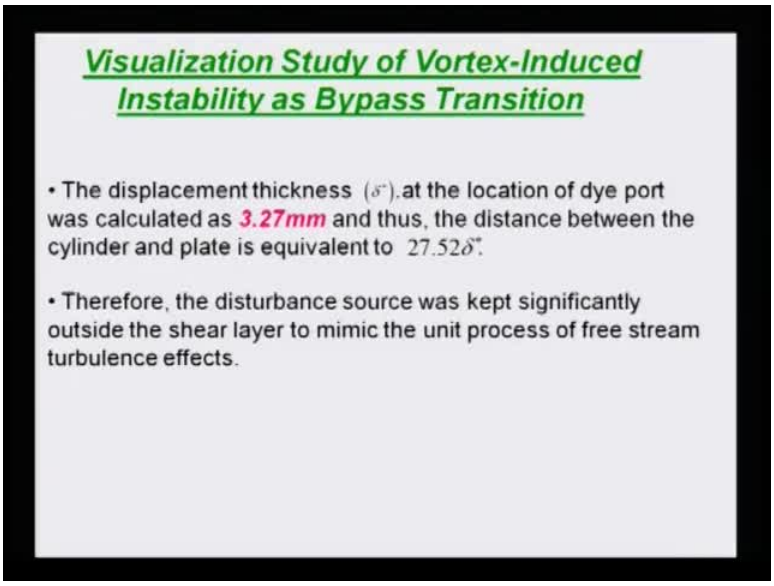

So if I look at all of these I can calculate a reynolds number further rotating cylinder based on its diameter that we talked about 15 mm, and the speed that we have said it works out to about. (( )) So this is considered slight a significantly high enough Reynolds number. And to understand what is the health of the underlying shear layer to measure the displacement thickness at the location of the dye port this is very thick about 3 millimeter.

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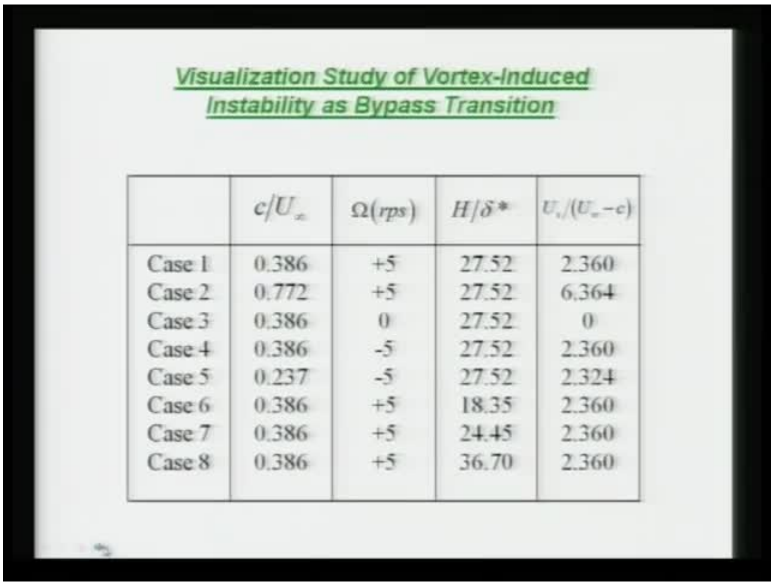

	c/U_∞	$\Omega(rps)$	H/δ^*	$U_r/(U_\infty - c)$
Case 1	0.386	+5	27.52	2.360
Case 2	0.772	+5	27.52	6.364
Case 3	0.386	0	27.52	0
Case 4	0.386	-5	27.52	2.360
Case 5	0.237	-5	27.52	2.324
Case 6	0.386	+5	18.35	2.360
Case 7	0.386	+5	24.45	2.360
Case 8	0.386	+5	36.70	2.360

So if you now calculate the distance between the bottom plate and the convicting vortex that is about thirty deltas star. So it is truly a free stream excitation when I keep it at 90 mm, if I bring it down to 60 mm it will come down, or I can take it up to 120 mm. So this is what we are saying that we want to mimic the unit process of freestream turbulence we are trying to study. So these are the following cases that we studied, 8 of them .The first column tells you the relative speed of the vortex that rotating cylinder with respect to U infinity, this was kept at various values 0.386 to 0.772 in some cases we have even to come down to even 15 percent also, but in this table you cannot see this and this rotation per second is either it was plus 5 or minus 5.

So that you the plus 5 corresponds to counter clockwise rotation of the cylinder, and the corresponding H over delta star we are kept all this like 27.52 delta star .We have actually brought it down, we brought it down to 60 mm that corresponded it to this all we could even take it out of the 36. So this is what we did and this is the factor that I told you that determine whether you are going to see some shared vortices common vortices or not. This is the surface speed U s and this is the relative speed you see the freestream is going this way the cylinder is also going this way.

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So the net speed is basically U infinity minus C. So if you are actually know the diameter you know this so you can calculate the surface speed us, and you check what this out and you can see in all these cases this is more than 2. If you guys remember common vortex stream that is Robbins Magnus (( )) that we talk about what happens if I have a cylinder like this and flow comes like this what do we get? We get a front stagnation point here and re-stagnation point here if it is a stationery cylinder. As we keep rotating it both of them, it keeps moving like this.

When you actually get this factor close to 2, then what happens is this 2 point comes like this. And anything above 2 this point actually comes down to like this. So that, you have a sort of a stream line like this. Iam drawing this it very closely run, but essentially it will be along the radical axis so it will just simply come like this. And if you keep increasing the last quantity then this keeps coming down.

So what happens is? You have a re-circulating flow inside ,if this is a stream line for a long time this was the heuristic explanation provided by Pander again ,that beyond to you cannot keep increasing the circulation because of the fact that the internal flow is shield it from outside alone a did not consider the viscous nature that is the diffusion of vorticity from inside to outside .It can actually communicate and this is what I was found out later by (( )) and we also provided strong support in that claim and we calculated there lots of a you might see in by its book or recent book in Anderson .There we have highlighted this aspect of the work that we done it here also.

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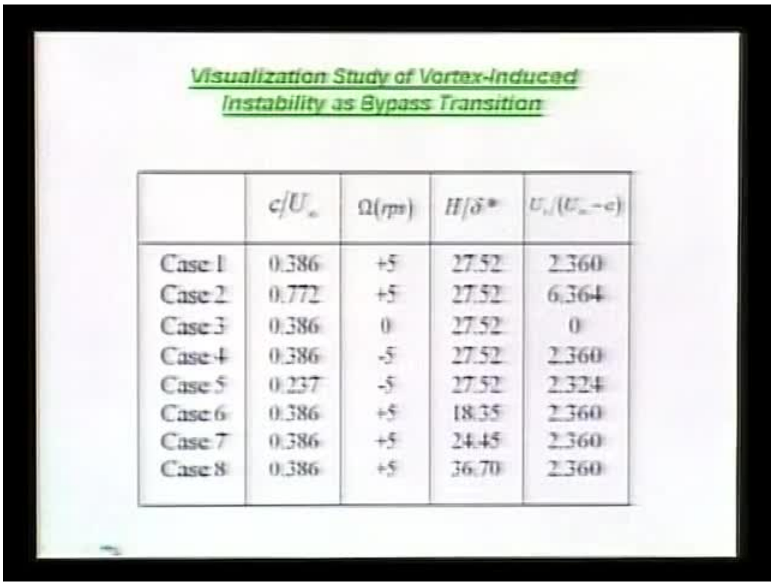
Visualization Study of Vortex-Induced Instability as Bypass Transition

	c/U_∞	$\Omega(rps)$	H/δ^*	$U_c/(U_\infty - c)$
Case 1	0.386	+5	27.52	2.360
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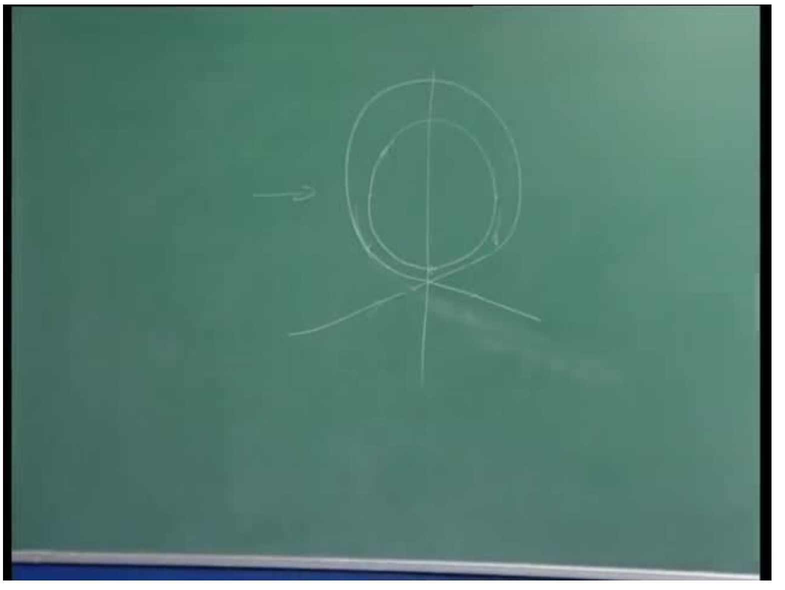

So what happens is when you have more than 2 as you see in this case , there is no way you have to see those vortices coming out. This experimentally noted so this is not something that is quite unknown.

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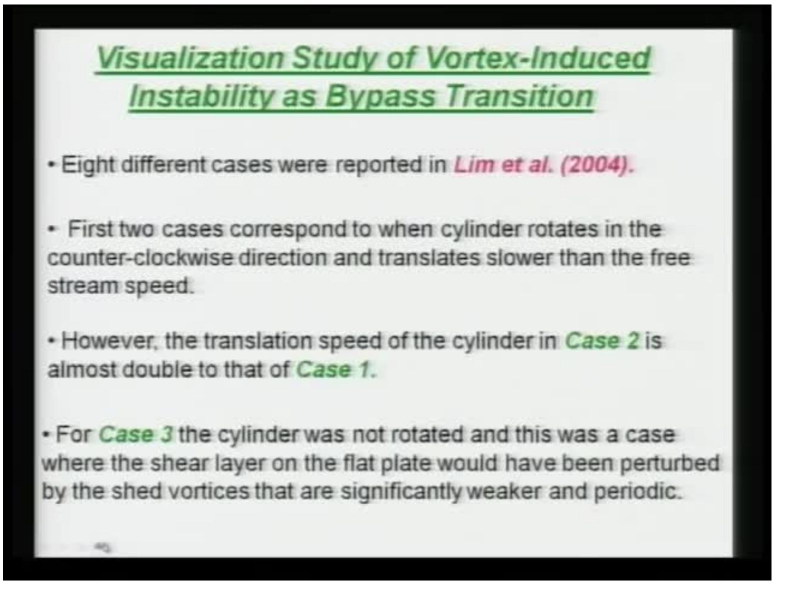

Once you do that as I showed you that the 8 cases where reported in our explanation paper , first two cases corresponded to when the cylinder rotated in a counter clockwise manner , and that translates slower than the freestream speed this of point of 386 and 0.776 or 2 or something.

However we noted that case 2 the translational speed of the vortex was significantly higher; double the of case one. Whereas, the third case was the case where the cylinder was not repeated at all. And we wanted to do that also, because we want to compare that if I have a captive vortex then what I see, and if I do not rotate then I am actually depending upon those shed vortices. Those are the shed vortices are those height can affect the flow instability or not. So that was the reason that we did this. And just to make our self-comfortable that we are not barking upon the wrong tree.

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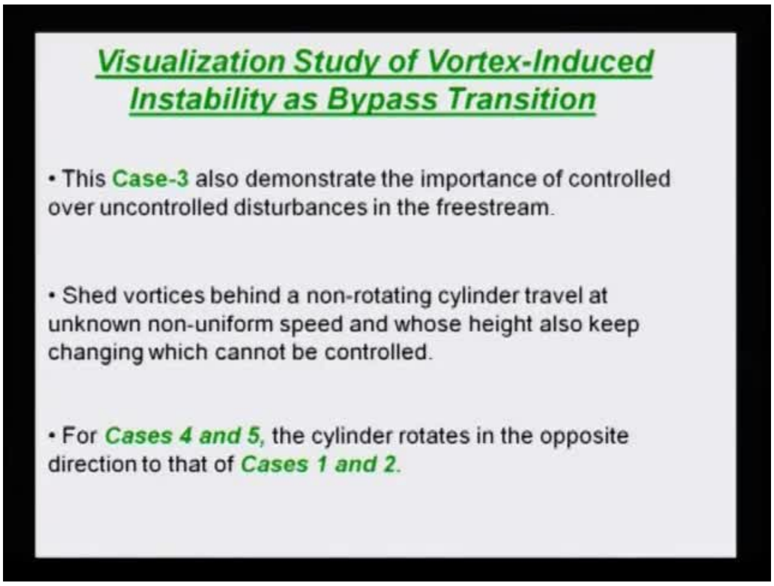

And of course, the case 3 demonstrates the importance of control over uncontrolled disturbance in the freestream are the shed vortices behind a non-rotating cylinder travels at a unknown non-uniform speed did not necessarily got a constant speed and its height also can keep changing . So all of this is a really uncontrolled case .In contrast the other experiment that you did they are the real control case .This is the reason that we did that and this cases 4 and 5 that we did was we rotated the cylinder just in the opposite direction .To that what we reported in case 1 and 2 so if we. In case 1 and 2 if we have positive vortex, for case 4 and 5 its negative vortex. That we are looking at for

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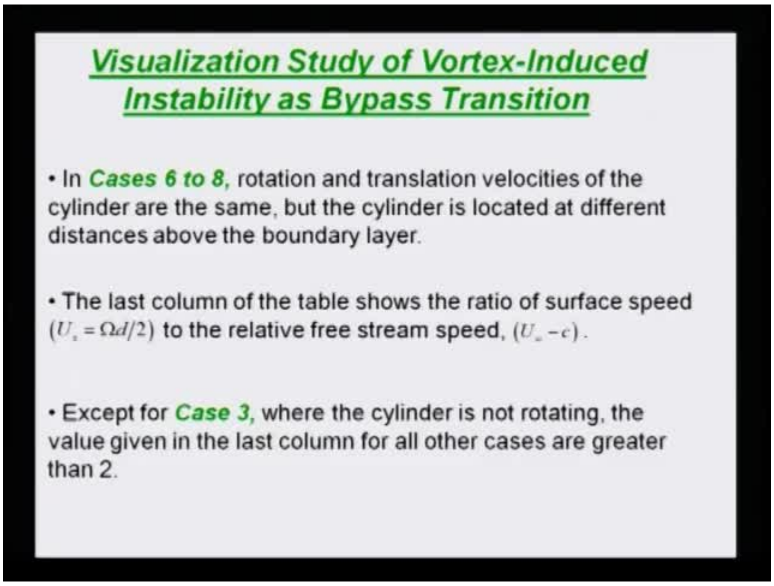

And the last three cases where of course again for positive vortices, but the cylinders were located at different height about the boundary layer. And we have talked about this ,except for case 3 these ratios kept greater than 2 .So we ensure that there were no shed vortices.

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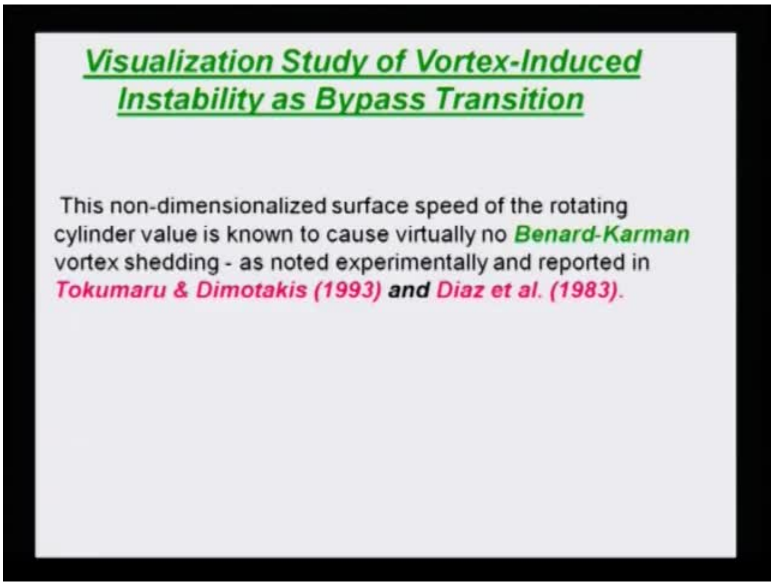

So, this was the couple of the references that I was referring to earlier , this was done by Dimotakis for a (( )) thesis. Tokumaru Professor Dimotakis is the guide and this was paper appeared in physics of fluids which really say that if you keep that nondimensional surface speed greater than twice the speed of freestream speed, then you do not see Bernard-Karman vortex shedding. This was experimentally noted also. So there was nothing new that we needed to do.

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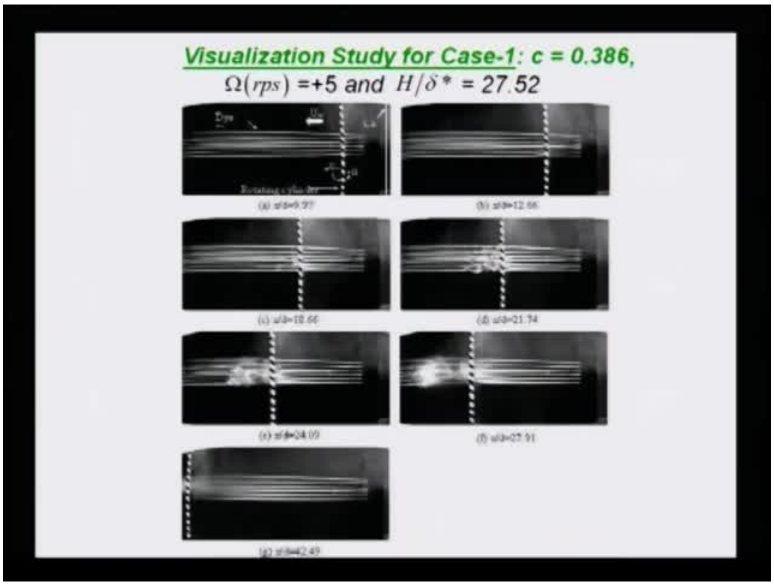

This is one such experiment visualization picture that we can see .These are the sequence for the case 1 so C is about 0.386 u infinity the rotation rate is the counter clockwise with 5 revolutions per second of the distance between the plate and this is about 27 delta star, and this is the way this is your rotating cylinder it purposely (( )) so that you can visualize it and it went like this. As you can see initially these where kind of straight and parallel of those dyes, of course there would be a lateral spreading, but you do not see much disturbances out here. But as it moves along as you can see it is moving along in this direction ,this is the first-one, this is second-one short ,this is a third short, and the fourth short. You see what happens? this is all nice, but you can start seeing some kind of perturbation coming up.

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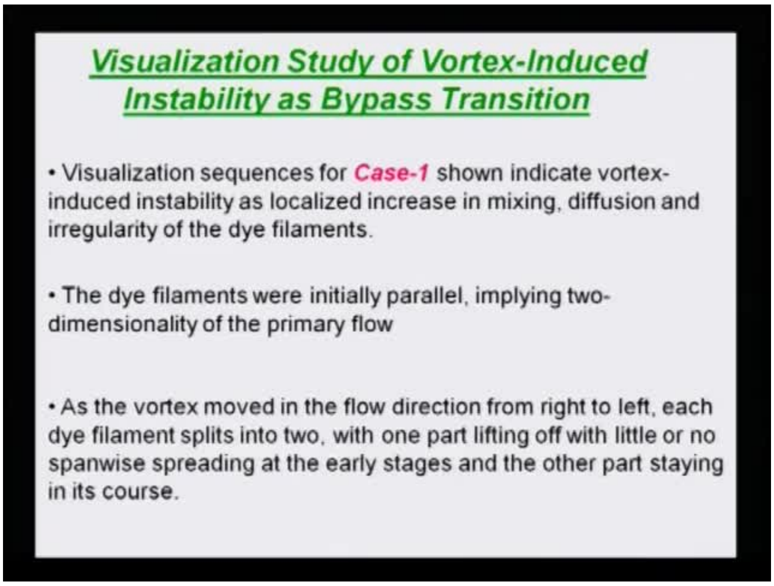

You can see what happens here. This is really it surely makes like what you might see in turbulent flow. so what happened is? You notice that the di lines are parallel so it is not like spreading out into a 3-dimensional flow , and if you notice little carefully also this dyes are basically lifted up it comes straight like this but, a part of it lifts up that is what goes outside, and then it starts mixing. So once it is lifted off also in the shear layer, then it can do this span wise mixing .And this is exactly what you would expect in a kind of a later stage transitional flow or turbulent flow where you would see lot of his kind of enhance mixing .So this is something that was a case that you did for C equal to 0.386 .So what we noticed as localized increased in mixing diffusion a regularities as the di filaments were initially parallel.

We indeed have 2-dimensional flows as the vortex moved in the flow direction from right to left. Each di filaments split into 2, one part lifting of with little ,or no spanwise spreading at the early stage, and the other part actually remain with in. So you can correlate it to what we talked about wall and freestream mode. The one that stays there ,they are like one or more the disturbances . They are embedded, but once those which go out those actually really go through all this process enhanced mixing diffusion and irregularities.

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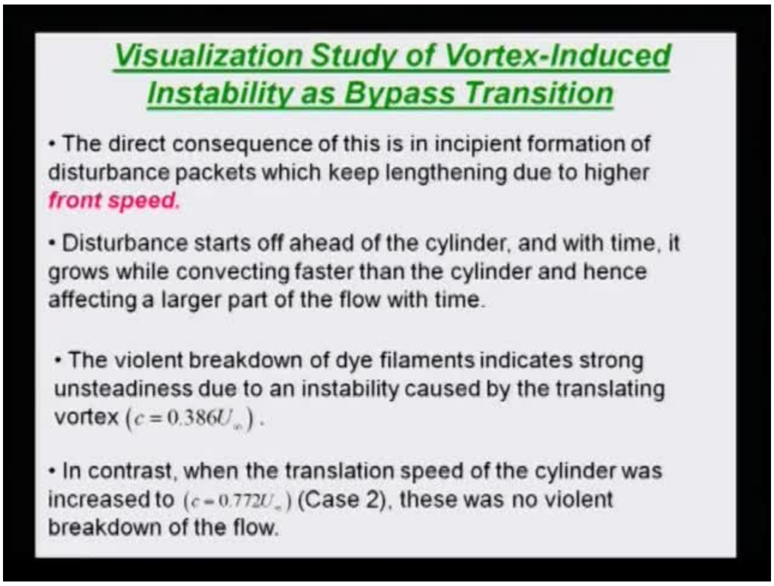

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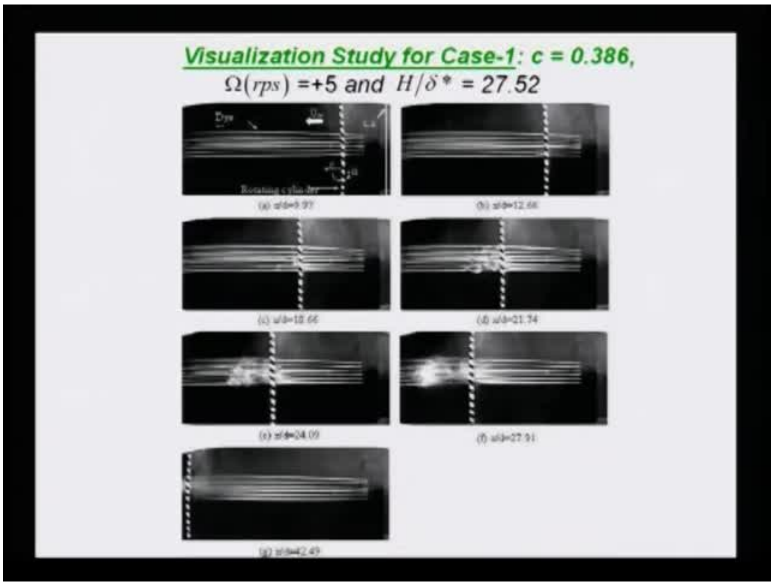

So this is something that we see for this case. Well one solve does not make a (( )) but still we will look at other cases, but before we do that what we also notice that initially the disturbance was really localized on a small region as a time progressed it expand over a longer distance. Well that is what we are basically talking about . Initially it was all very localized here , but with the passage of time you can see this whole thing is very well. The leading edge of the packet of the disturbance actually it propagates faster than the freestream speed faster than the speed of convection of this.

So you get to see very rapidly cascading effect. So you started off with this. Please do not understand it is a very simple case, it is a cylinder rotating at a study speed moving at a constant speed and that creates all kinds of unsteadiness with this curve ,taking it all the way from a laminar flow through transitional and turbulent flow .So this was something that we did achieve for this case.

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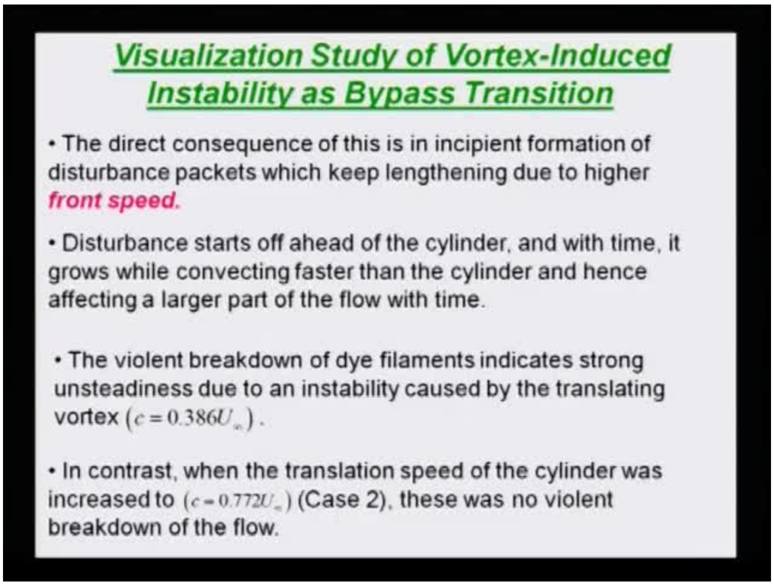

Now what also we notice that disturbance actually started off little ahead of a cylinder so if this is my location of the cylinder disturbance would happen ahead of it. We said that with time it starts effecting larger part of the flow that is what we saw, and this violent break down of dye filament indicates a very strong unsteadiness that can only come about due to an instability ,because everything was steady.

If anything has up in time scale has come about that has to be a foot print of an instability. And this was created by translating vortex growing at this kind of a speed .Now next what we do is, we increase the speed to almost double ,so that is our case 2. And we will not see much of the phenomena happening I think we will actually have to stop here over short over time we will begin in the next class almost.