Fluid Mechanics
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Lecture - 19
Conservation Equations in Fluid Flow Part – VII

Good afternoon and I welcome you all to the session of Fluid Mechanics. Now last class if we recall, we are discussing the flow through a pipe bends and the flow through a pipe bends exerts the force on the bend. And we have seen that by the analysis of finite control volumes with the application of the analysis of finite control volumes, how we can find out this forces exerted by the flow of fluid through the bends on the bends.

Now, today we will be discussing a similar type of problem with the analysis of finite control volume when the flow impinges on a surface, it may be plane surface; it may be curved surface, when a liquid, flow of liquid impinges on a surface and then flows along the surface, then what is the force exerted because of this impingement of the liquid Z on a surface. And accordingly due to that force, if the surface moves with some velocity what is the power generated; which is very important and forms the back ground of the turbo machines, principles of turbo machines.

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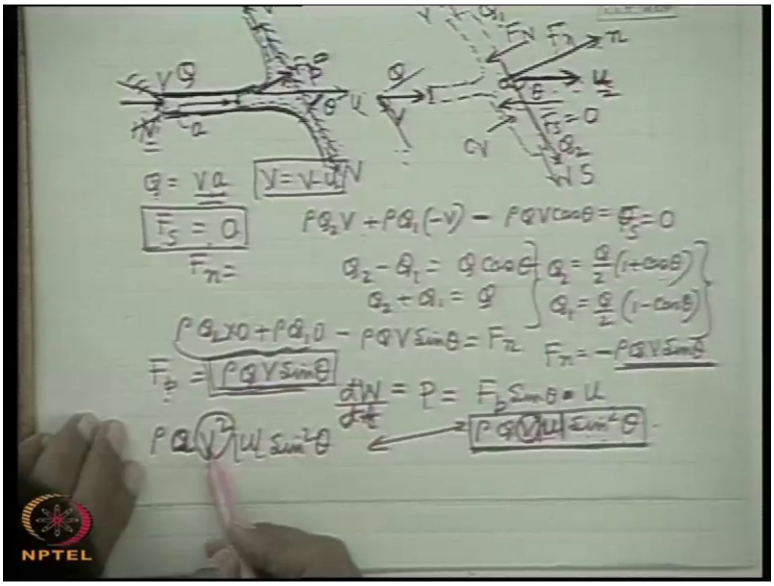

So, therefore today we will be discussing the force exerted due to the impingement, due to the impingement of a liquid Z on a surface - solid surface. First, we will restrict to plane surface. Let us see the problem, analyze the problem. Let us consider a surface like this, which is plane, in a sense that this surface is inclined with respect to the liquid Z. Let liquid z strikes the surface like this, which is being issued from a nozzle and it strikes the plate and then the Z after striking the plate, glides along the plate. Let it glide along the plate.

So, let this is the inflow and after impinging I show the liquid sheet; that flow is like this. So, liquid is flowing along the plate. And we consider, initially the angle of the plate, in general the plate is inclined with respect to the axis of the incoming fluid. Let this be the horizontal direction, then plate may be in the vertical plane, this will be in the or even the horizontal plane. It may be vertical; it may be horizontal, but this inclination angle is theta with the axis of the incoming flow.

Now, how to analyze this problem? In a sense, practically what happens? When the fluid impinges on this plate and glides along the plate, some force is being exerted on the plate. So, it is obvious, you can consider very well from practical realization that if the plate is made free, it will be moving in some direction like this depending upon the net force acting on the plate. So, therefore to keep the plate stationary against this flow of fluid impinging on it, some force has to be given on the plate.

So, therefore we can find first what is the force exerted on the fluid by the plate due to its flow through the plate. And what we do for that? As usual control volume; we can take a control volume like this. Well, we can now take a control volume of the fluid like this; a fluid element just like this. We can track a control volume of the fluid element like this. This surface of the fluid element just adhering to the plate surface and one of the face is perpendicular to the inlet flow and this face is perpendicular to the outlet flow.

Now, one thing we will have to first understand from the physical situation; that, if V is the inlet flow velocity, so the outlet flow velocities also will be V, provided certain conditions are maintained. What are those conditions? If we consider the jet is or fluid flow stream of fluid impinging on the plate throughout the pressure is atmospheric. There is no pressure change and all these things. That means, in atmosphere this fluid jet is exposed and the plate is kept at atmospheric condition and the fluid strikes; that means, throughout the pressure is same and in the atmospheric pressure. And more over if we consider the fluid to be inviscid; that means the friction between the fluid layers and also between the fluid and the solid surface to be 0. That means, considering the frictionless fluid. That means frictional interaction with the fluid or the liquid and the surface to be 0 and pressure throughout the atmospheric pressure, we can write the velocity of exit will be V.

This is because if we write the Bernoulli's equation at a point here and there at the exit, then we can see this is the pressure remains same, velocity remains same. But another assumption should be there; that if the plate is in the vertical plane, then the elevation difference from this point to this point or this point. Elevation difference from these three planes; one is the inlet plane, two are the exit planes are 0. For a surface at horizontal plane like this, then question does not arise. But for a vertical plane, the surface is at a vertical plane, then the elevation difference should be negligible.

So, in that case we can consider, we can write that the velocity at inlet and outlet are same from the Bernoulli's equation. So, therefore outlet velocities are V. well, now if we draw that here, now draw the… Well, the control volume. Now, if we draw the control volume like this, this is the control volume of the fluid, control volume.

Now, we can analyze the situation. Now, this is the inflow velocity V; this is the outflow velocity V; this is the outflow velocity V; the sheet thickness of cross section will definitely change. Because now this angle, let us consider theta because if we consider the volume flow rate as Q; where Q is equal to V into, let if we consider a small a is the cross sectional area of these jet, then V into a. Now, this Q will not be definitely distributed in the equal manner or equally distributed in both the directions. This cannot be. In general, this will be different. Then we will find it analytically that this will be different. Let Q 1 and Q 2 are the volume flow rate through these two paths, which is being divided after impinging on the plate. Now, first of all we will find out a relationship between Q 1, Q 2 and Q through the application of the momentum theorem to the control volume. And also, we will find out by this application of this same theorem to this control volume, the force acting.

Now, our next step is to choose the reference axis. Now, here one trick is there. The reference axis is not chosen parallel to the incoming jet velocity and perpendicular to that. Rather, it is chosen as parallel to the plate; that means this direction and perpendicular to that. So, this axis is n, for example. And this, I write as s; that means, let o origin at any point here. So o s, o n are the different axis which is parallel. And let this direction is the positive for this s axis and o n is perpendicular. This trick is because of the fact, with the assumption of the inviscid flow, there is no frictional interaction. And there is no frictional interaction between the plate and the liquid.

So, the net force acting along the direction of this plate on the fluid element will be 0; because net force acting in this direction when the flow is in this direction because the outlet flow, the fluid stream will be flowing along the plate. So, therefore in any force along the plate, acting on this control volume at this surface will only indicate the frictional effect; because normal force between the two contact surfaces, as you know always acts perpendicular to the surface.

So, any force acting parallel to the meeting contact surface means the frictional effect. So, if you neglect the frictional effect, the force acting on the fluid, there should not be any component of force acting on body of fluid in the direction of S. That is the main assumption and main concept.

So, we can tell the F s, the net force in the x direction has to be 0. This is not from the concept of momentum theorem from the control volume; it is simply from the physics of the problem that we take and inviscid fluid. And because of this we take the axis or choose the axis o s and o n; that means one axis parallel to the plate; that means, parallel to the flow direction and the outlet means and one is normal to that. So, this is the key point.

Now, we simply write the momentum theorem for this control volume in s direction. What is that momentum theorem? That means the net rate of momentum, efflux in the s direction from the control volume is equal to the force in the s direction to the control volume which is 0. So, I can get a constant in equation.

Now, let me see what is the net rate of momentum efflux. If Q 2 is the volume flux, so rho Q 2 into V is the momentum efflux in this direction. What is the momentum efflux due to this? This will be plus, so momentum is coming out from the control volume in both the planes rho Q 1, please tell, into minus V because this V is in the opposite direction to the coordinate axis o s taken positive in this direction. Well, so this minus, the incoming velocity of the fluid along this direction; that means, incoming momentum; that means, this direction.

So, we have chosen this direction as theta because this angle is theta. So, therefore this will be V cos theta, well, and this V cos theta is in the positive direction of the axis. So, it is plus V cos theta, but minus sign is because of the effect minus the influx efflux minus the influx. So, rho Q V cos theta is equal to 0; is equal to, rather I can write F s which is by definition from the physics of the problem is 0. So, if you write this, rho cancels out which is not 0.

So, what we get? We get Q 2 minus Q 1 is Q cos theta. Another relationship between Q 2, Q 1 and Q, we can find from which equation? Please tell me. Q 2 plus Q 1 continuity is equal to Q; simple continuity conservation of volume flow or mass flow; rho constant means the conservation of mass flow and volume flow are same. That means the volume flow rate which is coming is getting divided into two parts. So, Q 2 plus Q 1 is Q; which finally gives us… If you solve this, then what we get? Q 2 is equal to Q by 2 1 plus cos theta and Q 1 is equal to Q by 2 1 minus cos theta.

So, these are the two important relationships. That means Q 1 and Q 2 are divided like that. Depending upon this theta value, if this theta is acute and the plate is inclined in the position as shown in the figure, among Q 2 will be more than the Q 1. So, Q 2 is this; Q 1 is this. Now to find out the force, now you see from the basic Physics, we have already defined the F s is 0. So, therefore if we choose two axes like that way, so we can tell the net force acting on this control volume is only in this direction and that is equal to F n. And this F n we can find out from the application of the momentum theorem with respect to the control volume along o n axis.

Let us write it. That means the net momentum efflux from the control volume; that means, along o n. Well, so what is that? Please tell me, rho Q 2; now, velocity V, so therefore we have to find out. It is 0; it is 0. That means, 0 plus rho Q 1 0; that means, rho efflux minus the influx. What is influx? Influx is, so this component and that is in the positive direction; that means rho Q V sine theta. It is very simple and that is equal to the force acting; let F n, F s is 0, F s which is 0 is equal to F n. So, therefore we see that F n becomes equal to minus rho Q V sine theta.

So under this condition, positive value of sine theta; so this is minus. That means, the forces acting on the control volume is in the opposite direction. That means this is the F n. So, therefore the forces acting on the plate is in this direction perpendicular to the plate. In this direction F n, magnitude is rho Q V sine theta; this is negative sign indicates the value opposite to this direction. This direction is positive.

So, therefore the forces acting on the plate; that means let us write this F p. The forces acting on the plate is equal to plus… rho Q V sine theta. That means this is acting in this direction with a magnitude of rho Q V sine theta. Well. Now in this case, if we consider the plate is allowed to move or we maintain a motion of the plane in this direction with magnitude u; that means the, if the velocity of the plate in this direction is u, is a practical problem. if we maintain the plate under this force to move only with this velocity in this direction, then we can find out the work done work done.

Now, this Q is the volume flow rate. We consider this Q is the volume flow rate. So, rho Q is the mass flow rate. So, it is the rate basis. That means, work done per unit time; that means, we can write is d W d t; d with a cut you can write or del W del t because it is not a perfect differential or power developed because of this impinging fluid Z. If this plate is moving with very simple, it is the force component that direction into u. That means, it will be F p. Here better, we understand better. It is F n is, which is F p, rather you write. Now, we have given the F p. That means rho Q V sine theta. So, again we take a component in this direction. That means, again sine theta will come; that means F p sine theta into because we know into u. So, the work done is the force into displacement in this same direction. So, it is power because it is per unit time. So, therefore we can write rho Q V into u sine square theta.

So, this is the… therefore now if I take an absolute value because sometimes the plate can move in this direction, in that case the work will be done against this force and plate may be moving in this direction. Work will be done by the force applied by the liquid to the plate. But in both the cases the power consumed will be rho Q V mod of u; that is the speed of the plate times sine square theta. Clear. It is very simple. If any concept, any problem is there in the concept you tell me.

Alright, next part; if there may be a case when the plate may move with a velocity, now if the plate starts moving with a velocity, now here I have done the plate moving already. But the problem is that when the plate moves, I cannot write this. Though, now I have written this thing; V into u sine square theta, but it is not correct actually because when the plate moves with the velocity u for the force, just for your concept I have done this thing, but there is a mistake in this expression. Now, I will correct it. Because when the plate is initially moving in this direction, then when it starts moving, even if it does not move initially or if starts moving, so after the motion is set into the plate, then the force acting exerted on the fluid is not given by this expression.

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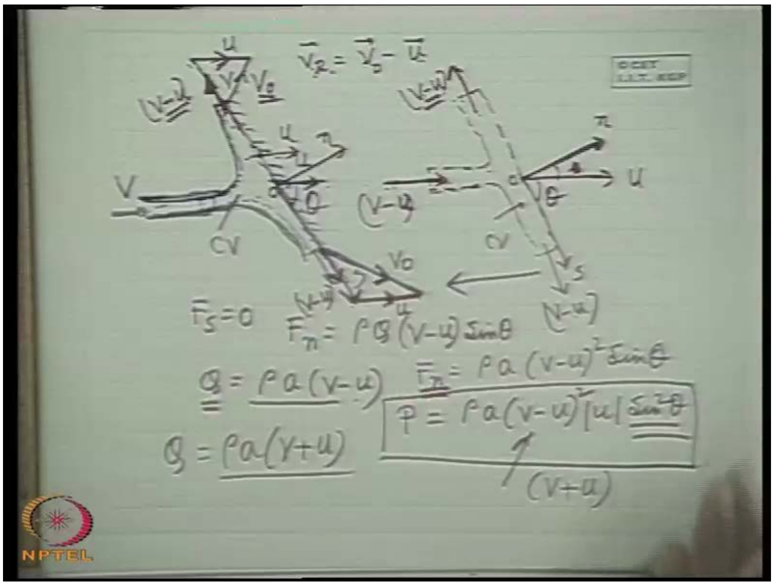

Why? Let us see that. Now, let us consider the plate is moving now with a velocity u. Just for the concept I have written that. But that is not correct in analytical expression. Let us… it is moving with u. Now, what happen? If the jet comes like this with the velocity V, that is alright; so that the pressure remains same, the velocity will remain same. But now the difference is that since the plate is moving with u the by considering fixed frame of reference from an absolute fixed reference plane; that means, if I take any coordinate axis at this point, fixed point. Say, why this is parallel and perpendicular to the plate or parallel and perpendicular to the incoming direction jet axis. It does not matter. The flow becomes unsteady; because if we consider a point here o stationary with respect to an absolute static frame of reference. So, plate will move like that. So, plate will not be fixed at that point a. After sometime plate will move, so that the flow structure here will not be same.

So, fluid jet will come here and then this thing will appear somewhere here. So, the things here will change. Or, we can tell if we consider a point here, when nothing is there no flow, flow 0, no flow field is there, after some point the flow field will gradually be developed. The jet will come and ultimately some parallel initial velocity V, then again this type of velocity vector will come; which means that, with an absolute frame of reference the flow is unsteady. But if we observe the flow; just I gave an example earlier that if we observe the flow in a river while sitting on a moving boat or a moving steamer, the flow as surrounding the boat or steamer will appear steady. Similarly, if a person observes the flow field who is moving with this plate, he will see always a steady flow field like that, in the immediate vicinity of the plane; which mathematically means that, I will take a control volume and also the axis attached to the control volume, which is moving with the plane; that means, here comes the concept of moving control volume.

That means I will consider a fixed region like this of fluid. As I take as the control volume, well, the concept is same. So this control volume, we will take the same control volume. But the control volume is moving also with this speed u. And we will fix the coordinate axis as s and n with the control volume. And control volume is moving.

That means, now I can tell the problem like that this is my control volume, so that this is my control volume. Well, this is my control volume. But this control volume is also moving with the same speed u. So, therefore to make the problem steady, we attach the coordinate axis to the control volume; that is, moving coordinate axis. Sometimes in the language of Mechanics, we can tell the coordinate axis is moving. So, you can define in that way also. With a moving frame of reference, the flow situation may remain steady. That means, though the actual flow is unsteady from an absolute frame of reference, but with a moving frame of reference, the flow will be steady.

The situation is… that if I take a moving frame of reference o s, o n, which is displaced with the same velocity u; that means with respect to this axis, the flow will be steady. That means in other words, through my control volume state or control picture of control volume, I can tell that this control volume is taken which is also moving with the… That means I consider a control volume fixed region when the plate moves, the control volume is also moving. Now, if we attach the coordinate axis with the control volume axis are moving; that means, any analysis with respect to this axis will be done, provided the parameters regarding these velocity has to be made the relative to the axis; because the analysis will be made with respect to the axis.

So, therefore this will be with respect to the control volume. That means, if we make now the control volume fixed or other way we can give an opposite direction velocity to fix that plate; that means, it will be similar to an earlier case of an absolutely static plate with changed values of these. In that case, this will be V minus u and the fluid will leave also with the velocity V minus u; fluid will also leave with the velocity V minus u.

That means the entire problem is now scaled to a static plate problem or static control volume problem, where instead actual velocity is V. Instead of V, the fluid is coming with V minus u; V minus u; V minus u and leaving with V. So, in that case we can write the F s is as usual 0; because any way there is motion, so relative velocity will be 0. And because the fluid is frictionless, there is no force acting in the s direction. Any problem? Please ask. So, now F n is equal to… in the similar analysis we got rho Q V sine theta, if you see the earlier one.

So, only thing is that instead of V, I declare V is equal to V minus u. That means, a simple one step mean that, I declare variable V as V minus u. So, therefore it will be rho Q V minus u sine theta. Now, here Q expression; if we see the earlier one Q expression was V into a; that means, what is the flow rate? That is issued by a nozzle, for example, a static nozzle; that is V into a, because this is the area of the jet issue and that is the velocity v, which is maintained constant. The same flow was received by the plate because there is no discrepancy. So, Q is V into a. But here you tell me, even if the nozzle issues the velocity V, so with how much jet water or how much flow rate is received by the moving plate u? It will be rho into, if a is the area of the cross section of the Z, a into this is moving with u, it will be V minus u. And obviously when this velocity of the plate will be equal to V or more than V, the liquid will not be able to impinge on it. Limiting case is V is u is equal to v. If the plate moves at a rate faster than the incoming jet velocity, so jet will never strike the plate. So that, you know from the common sense that Q the flow received by the plate is rho a V minus a. So, in terms of that, it is a very important concept. We can write rho a V minus u whole square sine theta. And this case only the power developed, the question of power developed comes. And in that case P will be… which we did here for an understanding that V u sine square theta.

So simply it is, V will be replaced by V minus u. and Q also V minus u will come. So, in this case we could have written this thing a pseudo expression; rho Q. So, Q is a into V.

So, a into V square u sine square theta; so in this case it will be instead of V square, V has been declared as V minus u. It will be V minus u whole square. So, therefore we can write rho a. So, automatically here also V minus u square sine square theta u into u is as usual sine square theta because this into u sine theta.

So, this is F n into sine thetas; that means the component of this is theta, sorry, this is theta. So, this component will be sine theta. So, theta is defined like this is theta. So, this is the expression for the power. Similarly, when the plate will be moving in the opposite direction, this will be substituted by V plus u. In that case, the flow rate received is more than that issued by the nozzle. So, these are the two typical cases.

Now in this case, if you are interested I can show you another one thing that, now this V minus u is actually the relative velocity of the liquid coming out from the plate. That means, this velocity in this case is V minus u. And actually for a shock less flow, the relative velocity should be parallel to the solid surface; which means that this liquid should glide along the solid. That means, with respect to solid, always liquid should glide along the solid. That means the relative velocity vector will be… That means, a person moving or sitting at the plate will see always the liquid going out at the final plane, discharge plane which is gliding along that, is parallel to surface. And this is relative velocity. We can find out what is the actual velocity. By doing so what we can do? We can, may you know the relative velocity is equal to vector is absolute velocity minus the velocity of the plate. So, therefore if we make this, we will have a velocity triangle. That means, if this is u, so this will be your V 0. So, V 0 is the absolute velocity. That means, this V minus u relative velocity and this is u.

This gives the vector notation that V 0 minus u is V R or V R plus u is V 0 V. That means, V R plus u is V 0; here, I write V 0. Similarly, here also; if this be the V minus u whose direction will be always along the plate. You will have to remember throughout afterwards in your turbo machines course also; that the relative velocity of the fluid, when a moving, when the fluid flows along a moving surface, then the relative velocity of the fluid coming out from the surface is parallel to the direction of the surface; because the fluid should glide along the surface with respect to the surface. Therefore, this is the V minus u direction. And I can make a V 0 here and this is u. So, at the outlet the velocity triangle, these are known as velocity triangle…

So, V minus u.; so this is the relative velocity. So, this is the plate velocity V 0. That means, V minus u is v 0 minus u or v minus u plus u. That is, the relative velocity plus the plate velocity with respect to which the relative velocity is defined is the absolute. That means, therefore absolutely the fluid is coming with an absolute velocity, vector is this; direction is this; magnitude is this; is direction is these magnitude is this, when these are the relative velocity.

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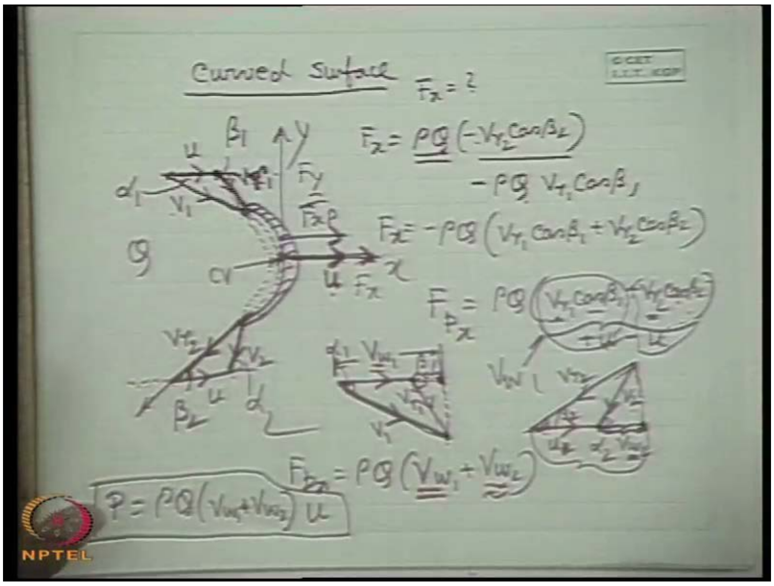

Now, we come next to the curved surface; flow through curved surfaces now; which is very important and forms the background of turbomachines. This will be again told in your Fluid Machines class. Well, curved surface I repeat it again. Now, let us have a problem like this. There is a curved surface like that. Let us have a curved surface like that a curved surface like that. And let this curved surface is moving in this direction with a velocity u. Well, so the fluid enters at this point on the curved surface and glides over this curved surface and coming out. Since the fluid is, the curved surface is moving this velocity u, so the fluid here we have a relative velocity. That is, we can have a velocity with relative to this curved surface.

Let us draw the velocity triangle. Well, u; now this diagram is… this is V R; let this one; this is u and let this is V 1; this is the absolute velocity and this is the relative velocity. Similarly, we have this relative and the absolute velocity; where V u plus V R is therefore, so this is V 2, V R and this is u. That means, we can tell that if a fluid strikes the plane here at one, section one, with a velocity V 1 and comes out with a velocity V 2, these are the absolute velocity. I have drawn the velocity triangle beforehand. So, let us first think the problem in detail. So, a liquid jet impinges at these curved surface here with a velocity V 1 and which makes an angle, this angle is alpha 1 with the direction of the motion of the curved surface and comes out with a velocity V 2, which makes an angle alpha 2 with the direction of the motion of the plate u. And let us analyze the problem. What we will do? We will take a control volume like this. Control volume of fluid touching the plane, some infinite small fluid element as the control volume, understand.

So, I am not again doing it separately. Now, this control volume will be moving with u and we fix an axis with the control volume in this direction; one in this direction which I call x; another let in this direction y. So, therefore we attach the axis with the control volume and control volume we are taking a moving control volume, moving with the uniform speed because here the system is moving with uniform speed. So, therefore the axis is moving with uniform speed.

So, therefore the axis is moving because attached to control volume. And the analysis will be made similar to the earlier problem with respect to the moving axis or moving control volume. So, therefore this will be made like that, as if the fluid is approaching the control volume with respect to the control volume or with respect to this frame of reference with a velocity V R 1 and not with V 1. Why because this is the relative velocity with respect to the control volume. That means this is a relative velocity of V 1 with respect to u; that means, we will have to vectorially subtract u from V 1. And that is done to this by, shown by this velocity triangle; vectorial subtraction.

Similarly, we will consider the fluid is not coming out with velocity V 2; rather, it is coming out with velocity V r 2. I am writing here capital R, better small r; V r 2. So, therefore it becomes a problem of a static curved surface, a static curved surface, the absolutely static surface where the fluid is now entering with V r 1 velocity and going out V r 2 velocity. For a static surface, the absolute velocity of the liquid is the relative velocity is of the liquid. There is no difference.

So, now we will solve the problem. Now, if we analyze this with the momentum theorem, now you see momentum theorem we can apply for both x and y direction. But usually we are interested to find out the force acting on this curved surface because of the flow of the liquid. So, therefore we are not much interested in finding out the force on y direction. Why? Because the curved surface is moving in this direction, so we are finding out what is the power generated or work done in this case, to cause this motion by the flow of fluid. So, therefore we are only interested in F x. F y will be there which in practical cases of turbo machines, I will tell you some hints afterwards. What happens actually in turbo machines, these are taken as general loads and supported by the bearings.

So, let us only find out F x. Well F x, now what is F x? F x is equal to the net rate of momentum efflux in that direction. Now, what is the net rate of momentum efflux? First, it is the influx V r 1. Let us define this angle. This angle is beta 1. This is the common nomenclature; that means with the direction of the motion, the relative velocity makes an angle beta one. And this relative velocity angle and the angle of the curved surface at this t must coincide. Similarly, the angle of V r 2 with this beta 2 must be equal to the angle of the curved surface at this step. That means the relative velocities of an inlet and outlet should match this angle or direction of the curved surface of the inlet and outlet.

So now F x, will you tell me what will be the F x? If I make the flow rate is Q which is same throughout. So, rho Q into, it is coming with what velocity? V r 1 cos beta 1; so this is here. Sorry, this will be here; let is this is beta 2, so V r 2 cos beta 2; that is in the opposite direction of the positive x direction. So, that will be minus V r 2 cos, clear, beta 2; efflux, mass flow into the efflux velocity. Now, efflux velocity component in this direction, positive x direction is minus V r 2 cos beta 2. This is cos beta 2; so minus V r 2 cos beta 2 because the component is in the opposite direction. Well, minus the incoming momentum or momentum influx. In this case, the component of the inlet or in coming velocity, that is, the relative velocity V r 1 is in the opposite direction of the chosen x. So, this will be simply V r 1 cos beta 1. And that minus sign, according to the formula efflux minus influx. So, this becomes simply minus rho Q into, I can write this one first V r 1 cos beta 1 plus V r 2 cos beta 2.

So, this is the force that is acting on the control volume; the control volume… by the bend. So, the force got by the plane, force x component, force acting on the plate will be just be opposite to that with a negative sign. That means the force acting on the plate will be in this direction of jet. That means, in this direction the force x component of force is acting on the plate is this direction, whose magnitude is V r 1 cos beta 1 plus V r 2 cos beta 2. Now this V r 1 cos beta 1 and V r 2 cos beta 2, if I draw the triangle separately here, it will be difficult for you to recognize from there; u, this is V 1 and this is V r 1. Let this is V r 1. So, this is beta 1; this angle and this angle is alpha 1. Well and similarly the outlet triangle if I draw it here clearly, V 2 and this is V r 2, this is u 2 and this is beta are the relative velocities angle and this is alpha 2.

Now V r 2, V r 1 cos beta and V r 2 cos beta is nothing but this is V r 1 cos beta and what is V r 2 cos beta? This is entire thing is the V r 2 cos beta; … V r 1 cos beta 1 plus V r 2 cos beta 2. Now, if I add plus u and subtract minus what happens? V r 1 cos beta 1 plus u is this component. Usually, this is known as V w 1. Of course, this terminology will be difficult for you to understand. This is known as the tangential component of the absolute velocity. Tangential means, this direction is the tangent direction. I will explain it afterwards with respect to a fluid machines application. That it is the component of the initial velocity in the direction of the plate motion. Similarly, if I deduct from V r 2 cos beta the u 2 component, this will also, then it will come like this; this is beta 2; that mean this will be again the component of the absolute velocity in the direction of plate motion. It is easier to deal with this in case of turbo machines, so that F p x is denoted as rho Q V w 1; where V w 1, V w 2 nomenclature is the component of the absolute velocity in the direction of the plate or surface motion and component of the absolute velocity at the outlet in the direction.

That means components of the absolute velocities, the inlet and outlet in the direction of the motion of the plate or surface. That is the tangential direction. That is why it is known as tangential component of absolute velocities. So, this is F p x. Now, we can find out what is the power? Power is rho Q; that is, the rate of force rho Q V w 1 plus V w 2 into simply u. So, this is the power developed because of the motion of the curved surface in this direction, due to the flow of liquid through the curved surface. This happens actually. This is...

This is like this. This is simply; I tell you that if the, first of all it is a simple geometrical consideration. You see this… triangle. From this triangle, V r 1 cos beta 1 plus u, I add u with this, subtract u from this; so V r 1 cos beta 1; that is this thing. V r 1 cos beta 1; that means this is this projection; V r 1 is this one. This component plus u, this is u.

What is this? This is u; vector diagram, this is V 1; this is V r 1. So, if you add u, so this will be this length. This is nothing but V w 1; that means the component of the absolute velocity in the direction of the motion of the surface of plate. Clear. Similarly, if we now minus, deduct from V r 2, what is V r 2 cos beta? This one is V r 2 cos, then if you take a projection, here also we take the projection. You take the projection, then this will be the V r 2 cos beta; deduct u, you will get this. This is not u 2, this is u; u 1, u 2 are same. This is u. So, therefore, this becomes this part; V r 2 cos beta minus u, this becomes. So, this plus this means, this plus this plus u minus u, if I take plus u with this, I get V w 1. If I take minus u with this, from the velocity triangle I get V w 2; where V w 1, V w 2 are the tangential component of the absolute velocities at inlet and outlet. Clear. It happens. just I tell time is mostly up.

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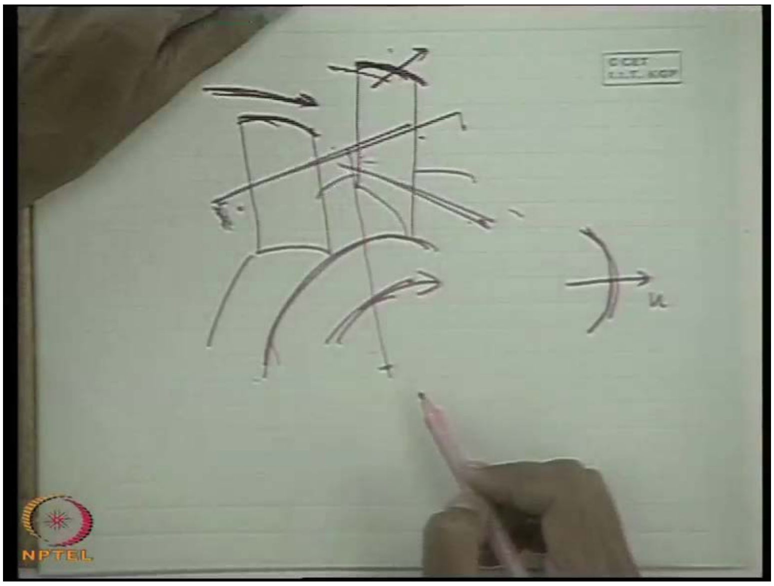

That in case of a turbo machines, you will see there is a rotor and a number of blades like this is attached like that in the rotor. A number of blades are attached. These are the rotor.

That means the fluid comes in between the passages of the blades and comes out. That means, fluid comes in and fluid goes out. So, what is done there? If we take a section and the meet section; if we take a section, we will get this curved surface; the flow of fluid to curved surface. We will take any representative section of the blade. You see from the top. Take a section; we will see this is moving in this direction; rotating in this direction, turbo machine. So, as the fluid enters in the blade passages, there are number of blades on it and goes out. This exerts a force and ultimately the turbo machine rotates in this direction.

So, therefore, if we take a section like that and we get a… This is the curved vane, curved vane like that. Then this direction motion is represented; this is the tangential direction. So, at any representative section; usually if this is the center, it is taken as the middle height. This is the basic application of turbo machine through this. Then again I tell you what happens in turbo machine. You can better understand if I tell like that.

There is rotor…to a shaft. Rotor is a disc, simple disc to a shaft, then the disc rotates. And on the periphery of the disc, number of blades with some heights are arranged and the fluid flows through this; fluid enters at some section and flows axially through this blade passages. And the power is developed and blade and the rotor move in this circular way. That means, rotates above the axis; that is the shaft. So, this is the practical application. And based on this principle of force exerted by the flow of fluid through curved surface and does the power developed, if the surface is allowed to move.

Thank you.