Fluid Mechanics
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Lecture - 03
Fluid Flow Analysis

Welcome all of you for this third lectures on fluid mechanics. So today we will cover on flow analysis of very complex flow processes, how you can solve very complex flow processes. So that is what I will discuss today.

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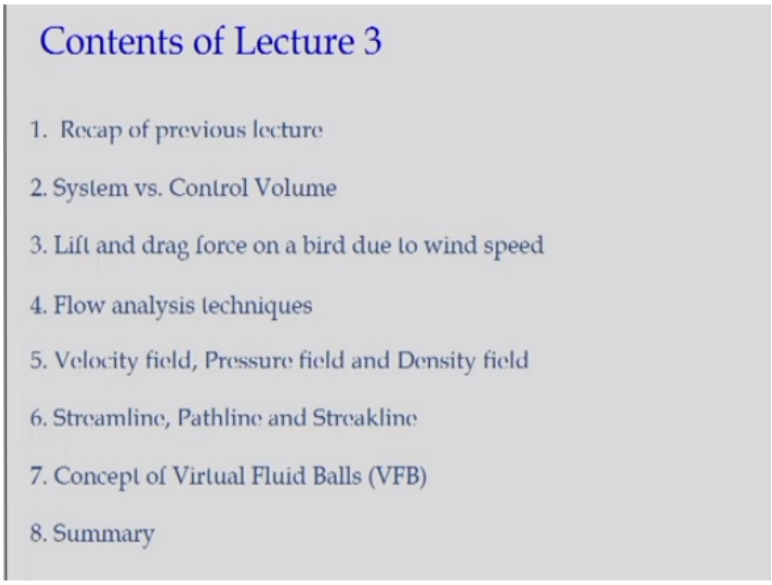

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Considering that I will cover today systems and control volumes; what is the difference between system, what is difference between control volume. Then I will give a very interesting examples of a bird under the wind flow conditions. Then we will talk about what type of flow analysis techniques are available and how we solve very complex flow problems using these analysis techniques and then I will talk about velocity field, the pressure field, density field.

And after that we will talk about very interesting part is the streamline, the path line and the streak lines which is very much required for analyzing or visualizing a fluid flow problems. Then again, I will talk about these virtual fluid ball concept what we introduced in the first class. So same things how we can use it for very complex flow problems. Considering that let me look at what so far we have discussed.

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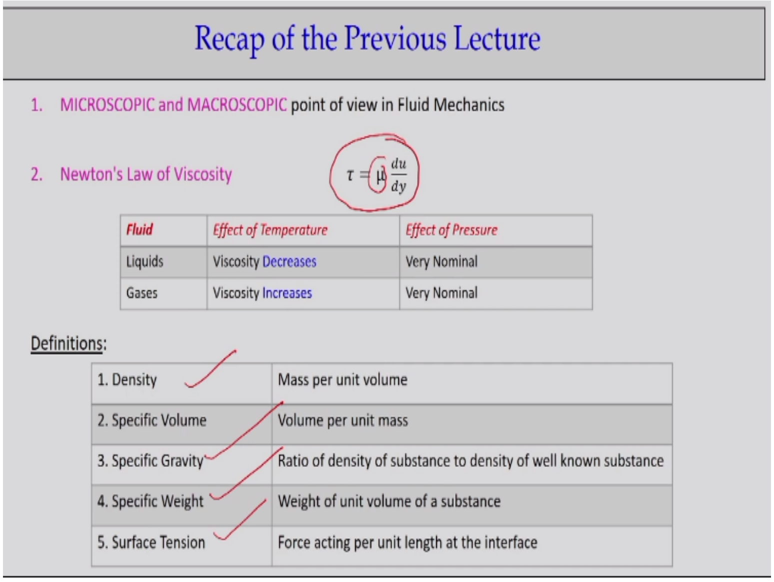

Recap of the Previous Lecture

1. MICROSCOPIC and MACROSCOPIC point of view in Fluid Mechanics

2. Newton's Law of Viscosity $\tau = \mu \frac{du}{dy}$

Fluid	Effect of Temperature	Effect of Pressure
Liquids	Viscosity Decreases	Very Nominal
Gases	Viscosity Increases	Very Nominal

Definitions:

1. Density	Mass per unit volume
2. Specific Volume	Volume per unit mass
3. Specific Gravity	Ratio of density of substance to density of well known substance
4. Specific Weight	Weight of unit volume of a substance
5. Surface Tension	Force acting per unit length at the interface

One is very basic equations of Newton's laws of viscosity which is establish a relationship between the shear stress and the shear strain rate and also we discussed about how these the mu the dynamic of viscosities depends upon the pressure and the temperatures and that relationships are different for the fluid and for the gas part and after that we just know some of the basic definitions about density, specific gravity, specific weight and the surface tension.

With this knowledge, let us go to the next level that if I have a very complex problem, fluid flow problems, how do you solve that ones.

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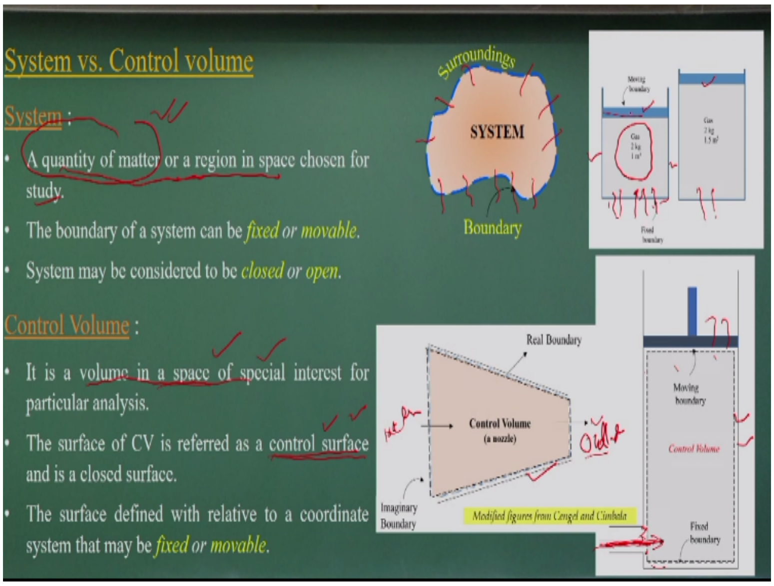

System vs. Control volume

System :

- A quantity of matter or a region in space chosen for study.
- The boundary of a system can be *fixed or movable.*
- System may be considered to be *closed or open.*

Control Volume :

- It is a volume in a space of special interest for particular analysis.
- The surface of CV is referred as a control surface and is a closed surface.
- The surface defined with relative to a coordinate system that may be *fixed or movable.*

First let us talk what is the system, what is the control volume. The system is a quantity of matter or the region in a space chosen for the study. For example I have considered a 2 kg of gas which is having 1 meter cube volumes. And if I heat this gas, if I give a temperature to this gas, then what will happen? This gas will be expanded.

So this is a system, that means we have a fixed amount of the mass of gas we consider it is a system and this system has a boundary and the surroundings. So the boundary in this case is the surface where the heat flux is coming into the gas, gas gets expanded. Because of that the boundary at this stop is a moving boundary conditions whereas other directions at the fixed boundary conditions.

So the basically when you talk about the system we have the boundary we have a surroundings. Mostly when you talk about the systems we consider a fixed mass of the fluid. And how it interacts with the boundary with respect to the heat, mass, and momentum exchange through these boundaries. That is what is called the systems.

Here very clearly say that it consider a quantity of matters or the mass components as a system. But many of the times we cannot solve the problems within system approach which in generally follow in thermodynamics. But in case of the fluid flow problems, we go for a space defined by a particular volume okay. Like for example, I have a this problem. If you look it this is what my control volume.

This is the space what I have considered as a control volume and the fluid is coming from this sites and this piston is moving in these conditions. So this is what the control volume and there is the surface confined to this control volume is called the control surface. That is what the control surface. The control surface can be a fixed surface or can be a movable boundary conditions or these control surface here the mass or momentum flux entering to this control volume.

So we have a control volume the fixed regions or the movable regions on the space that what we consider it and it is confined by the surface we call the control surface and this control surface through these control surface the fluid mass momentum exchange mass or energy mass comes into the control volumes. But if you look it another case like you have the nozzles, you have the flow is coming from the left to the right and it has consider this control volume like this okay.

So in this case, this is the inlet path and this is a outlet path. The flow is coming from the left side and it is going out the outsides. We have considered the boundary. One is the real boundary conditions another the imaginary boundary conditions. So you have considered a fixed the space in the fluid regions. Within that there may be a system of or the a fixed mass of the fluid is make enter to this control volumes.

After certain times may again go out from these control surface. So we have a two approach. One is a system approach another is a control volume approach. The mostly in the fluid mechanics problems what we will solve it we will follow the control volume approach. That means we will define a regions defined by the surface that is your control surface.

Through this control surface the fluid mass, the fluid momentum flux or the energy flux will come into this control volumes. Also will be go out across this control surface as is the outlet conditions. So the mostly in fluid mechanics we follow the control volume approach, which is easy to solve as compared to the system approach where you have to consider a fixed mass of the fluid and you track over that which is very difficult when you have a very complex problems.

Whereas if you consider a control volume that means you consider a fixed regions of the space maybe in a fixed conditions or the movable conditions. That not a big problems. Here the easy things is that there will be a very defined surface, control surface in which the momentum flux, the energy flux will come into the control volumes. Also there will be a defined surface.

On that defined surface the mass flux, momentum flux, energy flux will go out. So the reasons we define it is the control volumes and the surface what you define is it the control surface. So it is easy to solve the fluid mechanics problem using the control volume approach.

So most of my lectures I will cover through these the control volume approach as compared to the system approach which mostly follow in the problems like what I am talking about heat flow and moving boundary conditions like a piston conditions which is most of the times in thermodynamics it is followed it but in case of the fluid flow, we consider the control volume approach to solve the problems.

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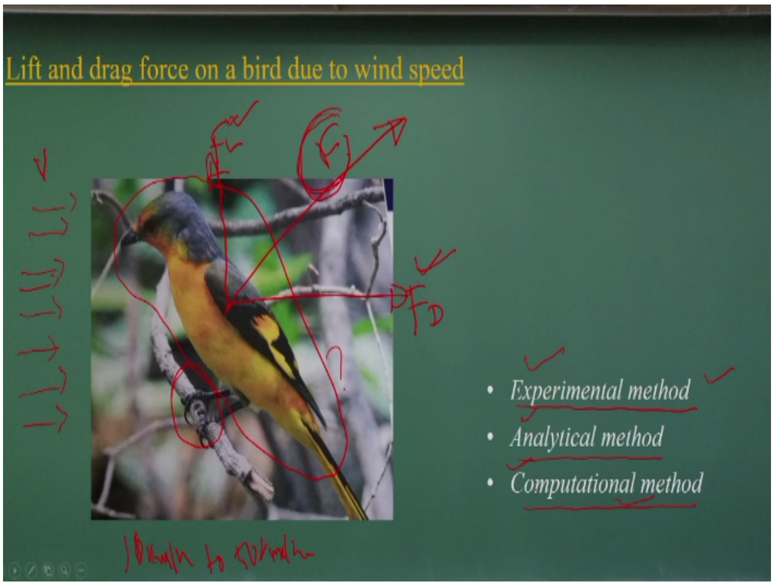

Lift and drag force on a bird due to wind speed

- Experimental method
- Analytical method
- Computational method

Now, if you look it the next very interesting problems what I have to give a illustrations to you that if you look at this very beautiful bird sitting on a branch. If there is a wind movement is coming from this and this wind movements consider let me the this speed is increasing from 10 km/hr to 50 km/hr okay. The speed of the wind is increasing from 10 km to 50 km per hour.

The question which comes it at which speed this bird cannot hold this branch. That means after that critical speed this bird has to fly from this place okay that is very interesting topic what you can understand it. That means what we are looking it that there is a fluid flow is coming from these sides is having a speed let be the V the speed is what is coming upon that.

Because of that here you are going to have a two force components okay. One will be the drag force and other will be the lift force and will have a result and ports what is occurring, because this fluid where it is passing through that that what will create a pro structure such a way that there will be a drag force there will be the lift force.

And you will have a resultant force what is occurring because this fluid which is passing through that, that what will create a flow structure such a way that there will be a drag force, there will be the lift force. Also the resultant force will react like that.

So these resultant force when you cross it the strength of the holding of the bird on this at that time, bird has to fly from these places.

So we are looking it that at which speed the force will be coming such a way that, that amount of the force this bird cannot withstand with this holding. So this if you look at that is very interesting problems. But it is also the complex problem in the safe. If you look at this, the beautiful bird shape okay. It is very interesting, the geometry what you have.

So also, as the wind flow is happening it that bird how it is responding which is a totally different aspect, we are not going to that details. So we are trying to look at how this force is going to happen it. So we can conduct the experimental way to compute it what will be the drag force, what will be the lift force, what will be the resultant forces or we can follow a analytical methods.

That means we can follow laws of conservations like mass conservation, momentum conservation, energy conservation, then we take a appropriate control volumes. Then you try to find out what could be the approximate the drag force and the lift force on this case. Or we go for very much the computational methods. The recently people has been using this the computational methods to solve these type of problems to find out what will be the drag and the lift forces.

So we have three ways to solve this problems. The experimental ways, analytical ways and also the computational ways. That means with help of the computers, by solving a set of nonlinear partial differential equations, we can find out what could be the pressure field, what could be the velocity field that what I will introduce you that. Based on that we can compute it, what will be the drag force, the lift force, and what will be the resultant force.

And at which force component this bird can withstand and beyond that it cannot. So that is what is the very interesting study can be looked upon.

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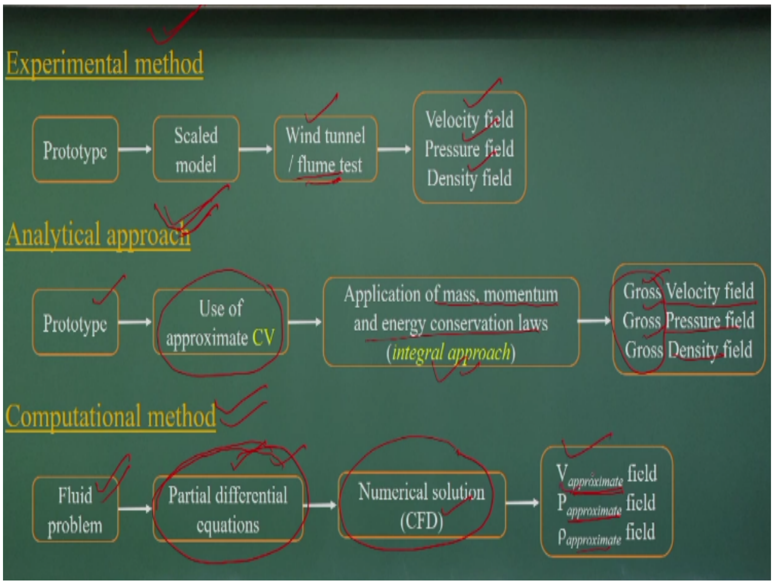
Experimental method

Prototype → Scaled model → Wind tunnel / flume test → Velocity field, Pressure field, Density field

Analytical approach

Prototype → Use of approximate CV → Application of mass, momentum and energy conservation laws (*integral approach*) → Gross Velocity field, Gross Pressure field, Gross Density field

Computational method

Fluid problem → Partial differential equations → Numerical solution (CFD) → $V_{approximate}$ field, $P_{approximate}$ field, $\rho_{approximate}$ field

So similar way, that is what I am telling it, there are three ways to do the solve the any flow complex flow problems, like you can have experimental methods. That means you can have a prototype and make a scaled models. That means you can reduce the flow and the geometry of the problem in such a way that you do a scaled model.

Then you do a wind tunnel or the flume test to measure the velocity, pressure and the density. So once you measure the velocity and pressure and density that means you solve the problems. You know, how the flow is happening in terms of velocity, in terms of pressure, and same way the density. The second approach is analytical approach which mostly in the fluid mechanics books, we will cover with the analytical approach.

In that what do we do it we have a problems. We try to use a control volumes, is a bigger control volume we try to use it. And we try to understand it where the mass flux is coming, the momentum flux is coming and which are the boundary there is no flux of mass, momentum, energy is passing through that. Equating applying this all mass, momentum, energy conservation with a integral approach we can find out the gross velocity, pressure and density.

Still I will talk about the gross. It is not the very detail distributions of the velocity the distribution on the pressure or the density we will get it. In a very average type of conditions what we can predict it as a gross characteristics what will go through this analytical methods. One is experimental methods. The second is the analytical methods. Third is which is the last one of two decades is very famous is the computational fluid dynamics.

In which what we do it any of the fluid problems okay, we define through these mass conservations and momentum, energy conservation into a set of partial differential equations. This most often is a nonlinear partial differential equations and both equations we try to solve the numerically. As we solve this numerically, we get the velocity pressure and the density distribution, but these are all approximate solution.

It is not the true solutions, because they are the numerical solution is approximation solutions to this numerical partial differential equation. So we get approximate solutions of the velocity field, the pressure field and the density field. So that in summary, I can say that we have three ways to solve the problems. One is conducting experiments to find out the velocity, pressure, and density field.

Second one is that we use appropriate control volume, apply basic conservation equations like mass conservations, momentum conservations, and energy conservation equation. Then we try to get it what is the gross velocity distributions, the pressure distributions and the density distribution. These are gross level. It is not gives a very detailed like the we get it the wind tunnel or the numerical methods.

In a computational methods as you know it now we have a lot of supercomputers, we can solve many of the complex problems, fluid flow problems, that is what we do it any of the fluid flow problems we convert to a set of partial differential equations by applying same basic principle of mass, momentum and energy. But here these the control volumes are the unit what we consider that is what is infinitely small.

And then we try to solve that equation using a numerical methods. And then we get this approximate values of velocity, pressure, and the density field. So we have a three ways to solve any complex fluid flow problems experimentally, analytically and computational way.

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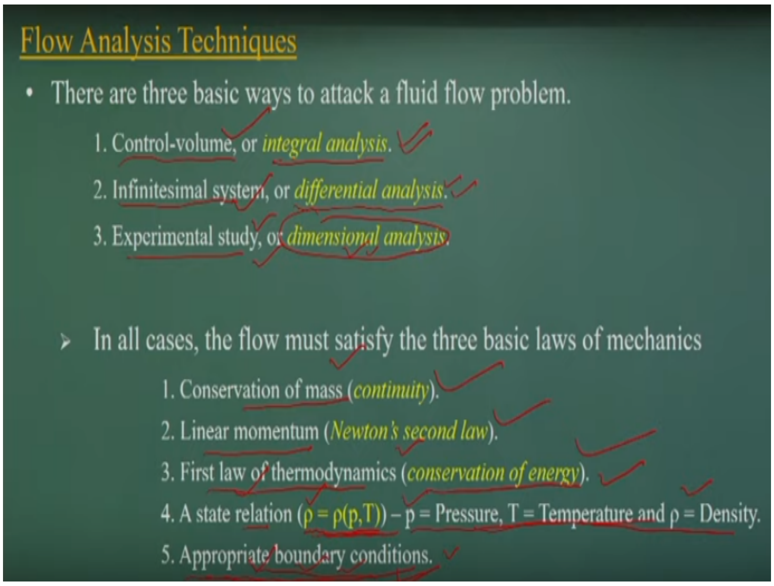

Flow Analysis Techniques

- There are three basic ways to attack a fluid flow problem.
  1. Control-volume, or *integral analysis*.
  2. Infinitesimal system, or *differential analysis*.
  3. Experimental study, or *dimensional analysis*.

- In all cases, the flow must satisfy the three basic laws of mechanics
  1. Conservation of mass (*continuity*).
  2. Linear momentum (*Newton's second law*).
  3. First law of thermodynamics (*conservation of energy*).
  4. A state relation ($\rho = \rho(p,T)$) – p = Pressure, T = Temperature and ρ = Density.
  5. Appropriate boundary conditions.

Now if you let me summarize that way, there are three basic ways to solve the problems. One is a bigger control volumes where we have an integral analysis or the analytical methods ways. You take a smaller control volume, which is very close to infinitely small. Then you get a set of a differential equation problem. So that is the reason we call differential analysis.

Then the experimental study, as I said that we need to have a scaled models. So we will discuss more in the latter half of my lecture series that there is a techniques to how to scale the models from the prototype to scaled models. How to get different geometry scale, flow scale all the similarity concept what we will discuss in later on. So that way you have control volume, infinite small systems.

That means analytical and you have a computational methods techniques, then experimental methods. And as I already said that, these three basic equations always need to be applied for any fluid flow problems. They are conservations of mass, the linear momentums or the angular momentums, the first law of the thermodynamics that is conservations of energy.

But apart from these equations we adopt a state relationship. That means a relationship between a density and the pressure and temperature, the ideal gas laws. So these type of the relationship between one variable to other the independent variable like pressure and temperatures, we can establish that relationship and that relationship is called the state relationship.

And at the last one what I can say that not only know this what type of flow problems also we should have a very good understanding how to define the boundary conditions. That means, you have to give a appropriate boundary conditions to solve the problems.

So the flow analysis techniques what is available to us with a very basic conservation equations as we apply for solid mechanics here also we follow conservation of mass, momentum, linear momentum equation, energy conservation equations. Apart from that, we look for appropriate boundary conditions and the state relationship to solve this problems.

So this is what the basic strategy to solve any fluid flow problems and a fluid specialist has to have a confidence or knowledge on how to define the boundary conditions, what type of equations to apply it and which condition he has to go for a control volume approach or the differential analysis or the experimental analysis that all it depends upon a knowledge on the fluid mechanics.

So that is my idea is that we should have a very indepth knowledge of the fluid mechanics then we can analyze a complex fluid flow problems taking appropriate analysis techniques. Now let us come to a very interesting examples here, we have given it here.

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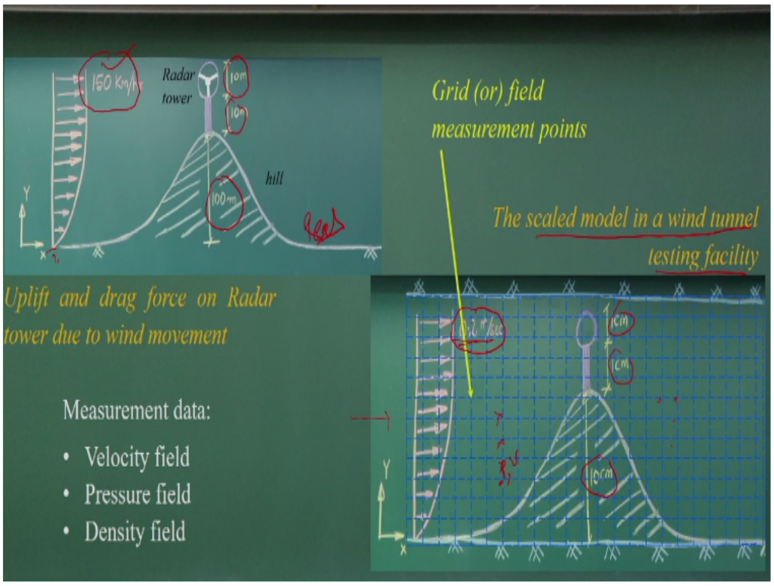

Grid (or) field measurement points

The scaled model in a wind tunnel testing facility

Uplift and drag force on Radar tower due to wind movement

Measurement data:

- Velocity field
- Pressure field
- Density field

That they let be there is a weather radar is there. You know it nowadays weather radars are there to measure the rainfall, the wind velocities and all. That is what is a on the hilltop and it has a stand of 10 meters and the weather radar tower is about 10 meters. And the wind is moving at a speed of 150 km/hr and the velocity is 0 at this point.

If you have that conditions the questions is coming to design this radar systems we need to find out what could be the maximum of split force and the drag force of this radar systems when you the wind speed is close to 150 km/hr of reaction of reaction. If that is the problems, for these type of complex problems we do not have any analytical solutions. So what we go for? We go for a scaled models in a wind tunnel, okay?

So that means in a wind tunnel, we set up the scaled models. As I say the scaled models means we reduce the dimension, we reduce the flow velocities or the densities. How to do that we will discuss that in a dimensional analysis chapters, but lets us you understand it that these are the real problems.

And we reduce to a scale models which is if you look it here is 100 meters here is 10 centimeters, the 1 centimeters, 1 centimeter. So we scale the models okay. We reduce the dimensions. Similar way we have reduced the velocity and this is the facilities is there in the wind tunnels and we have the velocity flow is going like this and at each point of this grid we will measure the pressure, velocity components okay

So if you look it that, so we have the wind tunnels and we will fix up these the scale models of the hills, the radar systems as equivalent to a spherical body and connecting part and we generate the flow systems which is you will have the flow distributions like this and with having a velocity 0.52 meter per second and each grid point will measure it what is the pressure, what is the velocity, what is the density.

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For example, if you look it that point, like the wind tunnel facilities what you have at the IIT Guwahati in the Department of Mechanical Energy. See if you can look at this wind tunnel the setups okay there is a inflow, this will be the outflow and this is what the test sections what is there and these are all the recording systems for velocity measurement and the pressure measurements.

So if you can look at these type of wind tunnels they are most of the advanced fluid mechanics labs this type of wind tunnel systems are there where we generate the wind movement through a test sections like this. If you look it this is the or the test sections okay. In the test section we generate the wind flow. To measure the velocity we have a Pitot static tubes. I will discuss more detail what is it a Pitot static tube in the later on.

So you can now know it there are the instruments which can measure the velocity, not only this one direction, it can measure the three dimensional velocity component. That means it can measure the u, v, and the w components, the three velocity distributions component can measure it. And similar way we can have a nanometer. I will discuss what is a nanometer and all the things later on.

That the instrument can use to measure the pressure. So we can measure the velocity, we can measure the pressure and this is the wind tunnels where you can the variable the speed, the speed of the winds, which will pass through these the test sections.

Then we can measure the velocity and the pressure. Similar we can have also measure the density.

So if you look it this way, that means what I am talking about that I have a scale models put into the wind tunnel facilities. Then at each point we are measuring the pressure and the velocity and the density. It is the measurement, the physical measurement of pressure and velocity and the density.

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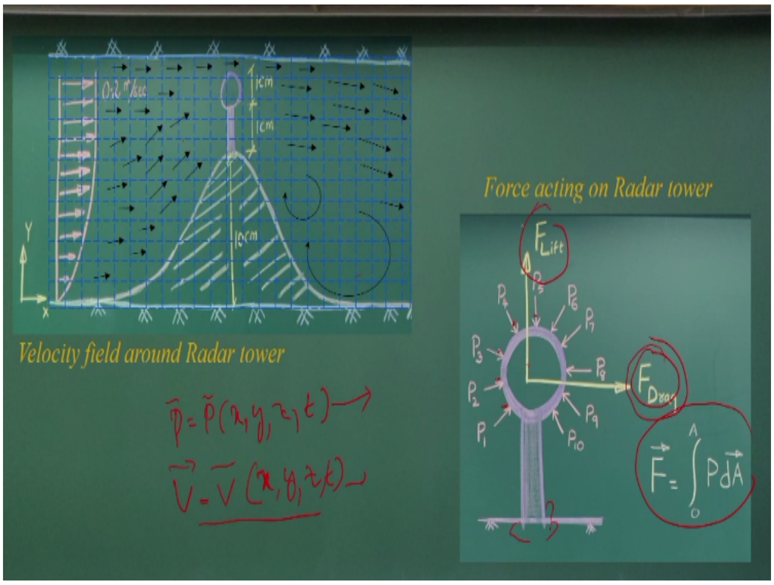

Velocity field around Radar tower

Force acting on Radar tower

$$\vec{p} = \vec{p}(x, y, z, t) \rightarrow$$

$$\vec{V} = \vec{V}(x, y, z, t)$$

$$\vec{F} = \int_0^A P\, d\vec{A}$$

Now if you look it for example, we got for each grid point this type of velocity factors. It has the directions, it has a magnitude. So we get the velocity at each points. So interestingly you can see that there will be the high velocity zones, there will be a low velocity zones and there could be a vertex formation. But that is not our interest now. We just measure the at each grid point the velocity factors, velocity magnitudes.

So that means we know u, v, w component, the scalar component of velocity we know it. That is what is called the velocity field. Now you can understand it if I take a more number of grid points the velocity field will have a more accuracy. So if I take a less number of the grid point for the measurements, I will have a less accuracy in defining the velocity field because the sampling points are less.

So that depending upon the flow problems, you can decide that how much the spacing, how much locations you should collect the velocity or the pressure or the density content and once you know these pressure components that means I know it approximately how the pressure is varying with the space and the time. I know it how it varies because these are the measurement values.

The similar way, if I have vectors, this is what I measure it the vector which is the sample point vectors, which have x and the t. So this is what called the pressure field and the velocity field. Now if you look it that my prime objective as a engineer is that I have to design what could be the lift force and the drag force because of 150 km/hr wind is blowing over these tower.

What we can do it one we can measure the pressure. That means you knew the pressure point P 1, P 2, P 4, P 5 like this. You just integrate that places you can find out what will be the drag force and the lift force components. So this drag and lift force can be used to design this the civil engineering design the structural engineering designs of this tower.

The mounting staff or the foundations will design such a way that whenever when you have a 150 km/hr the winds pass over this tower system, these structures would be in safe, okay. So that is what to make it that we should know exactly what is the drag force and the lift force is happening it.

So with this example, if you can know it, that with measurements with conducting the experiments, we can compute it the velocity field and the pressure field and knowing this pressure field and velocity field can compute it, what will be the gross or split force is going to act it and the drag force and these two force can be used to design these structures for wind speed of 150 km/hr.

So this is what is experimental way we can conduct it. But you can always think it that the conducting this type of experiment is always expensive and for that we need to have a wind tunnel facilities to solve these problems. Today's you know it there are big wind tunnel facilities are there. They full prototype of truck they simulate it.

So that is what am I pointing that the facilities nowadays the wind tunnel facility what is there in all over the world, the automobile engineers they use the full truck not the scaled models, they conduct the wind tunnel test to know it what will be the drag force, the lift force for different flow conditions like different velocity, different fix and drag confusions they try to do solve that type of problems the very complex fluid flow problems with full scale wind tunnel lab facility.

So it is possible today's it is not that difficult that to conduct the wind tunnel test, but it is expensive as compared to the other methods what we are going to discuss it.

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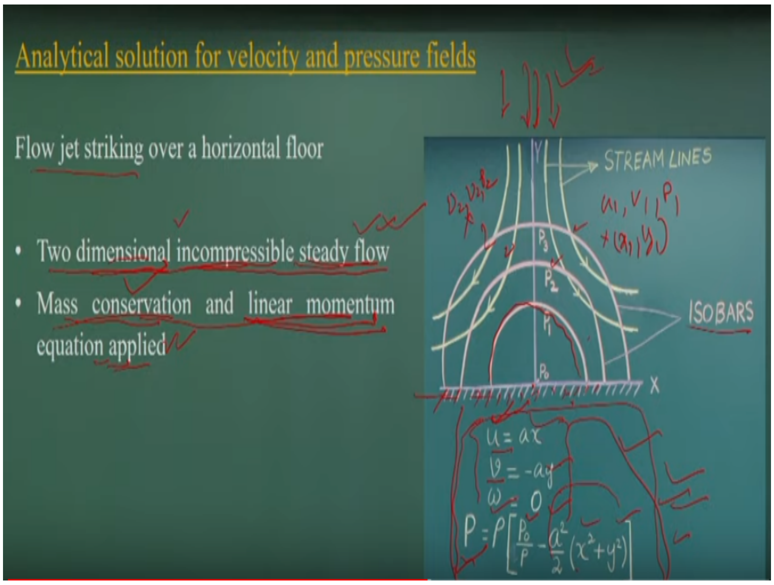

Analytical solution for velocity and pressure fields

Flow jet striking over a horizontal floor

- Two dimensional incompressible steady flow
- Mass conservation and linear momentum equation applied

Second one you know it we are looking for a analytical solutions. That means the fluid flow problems we are more or less very simplified cases like for examples, we have a flow that means flow velocity is coming from this striking on the horizontal floor here. The flow jet is coming and striking over a horizontal floor. And our interest to know it what will be the pressure distributions, what will be the velocity distributions.

These problems we can identify it is a two dimensional problems we can make it because jet direction it does not have a much component. So incompressible flow and we can simplify to a steady flow. So we have simplified the flow now okay as a two dimensional incompressible and steady flow. Because of that, we can use this the mass conservations and linear momentum equations.

Okay, I am not going more detailed. Anyway, we will discuss that how to apply the mass conservations and linear momentum equations here. Considering that if I do that, I will get a solutions of this. These are integral solutions of the scalar velocity component of u, the v as a function of ax and ay and the pressure will be function of x and y; a is constant and P naught is a pressure at this point at the where we have the regions.

The pressure at that point which called the stagnation pressure. So if I know these equations, which satisfy this conservation equations and the linear momentum equations and the boundary conditions at this point as well as this boundary conditions here, then this is what my solutions of the equations which is the analytical solutions of equations.

That means, if I take any point here, if I have a x 1 and y 1 is the coordinate I just substituting this x and y 1 I can get the u 1 component v 1 component and the P 1 component. Here the u 2 component v 2 component and P 2component. So here what we have drawn it as the water jet is coming it and tracking on the horizontal floors. As you know it that this flow is a symmetric problems.

So exactly at the center the flow velocity will be zero. That is what you can say that if you substitute x and y equal to zero v and v component will be zero. So that condition is satisfied and the pressure if you look it that it will be varied with a x square plus y square term is a equations of a circles okay it is more or less the equations of a circle.

That is the reason you will have a unit for the pressure, the constant pressures line like this, the concentric circles like that, where it will be half concentric circles. So this is what called isobar. The line of equal pressures. So you will get the equal pressure line. And if you know the u, v and that you can draw the flow stream lines. That means flow will come like this okay the pressure diagrams like that.

So for a very simple case, we can get a analytical solutions like u and v and w and the pressure and that analytical solutions can help us to know the velocity, the pressure distribution of these problems and it satisfy conservation equations, mass conservation equations, linear momentum equations. Also it satisfy the boundary conditions at the floor also flow inject what is coming it.

So that is what I say that there is a experimental way to do that thing. Very simple case, we can simplify it and we can like it a two dimensional incompressible steady flow, this is what the total simplification of problems are. These assumptions are hold good for these type of problems. Then you apply the mass conservation linear momentum equations. Then you get these solutions.

How to get this u and v equations and the pressure that what we will discuss later, but at present you know that we can get it the functional relationship of u, v with respect to a Cartesian coordinate of x, y, z and these problems becomes a steady problems. So there is no time components. So we will have the solution of u, v, w and the pressure component.

Okay, so from that two examples, one the wind flow over a weather radar setup, second is a simple flow jet impacting on the floor. We tried to understand it, the pressure field and the velocity field.

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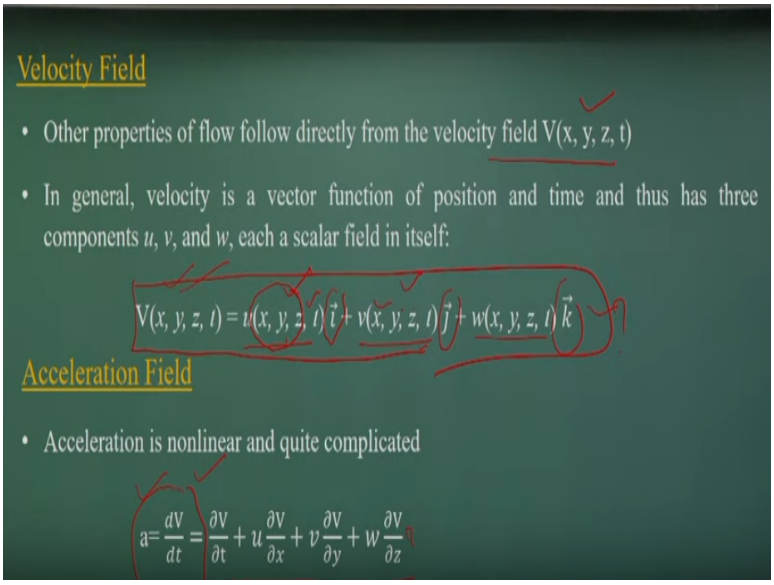

Velocity Field

- Other properties of flow follow directly from the velocity field V(x, y, z, t)
- In general, velocity is a vector function of position and time and thus has three components *u*, *v*, and *w*, each a scalar field in itself:

$$V(x, y, z, t) = u(x, y, z, t)\vec{i} + v(x, y, z, t)\vec{j} + w(x, y, z, t)\vec{k}$$

Acceleration Field

- Acceleration is nonlinear and quite complicated

$$a = \frac{dV}{dt} = \frac{\partial V}{\partial t} + u\frac{\partial V}{\partial x} + v\frac{\partial V}{\partial y} + w\frac{\partial V}{\partial z}$$

So now I am just defining them the velocity field, when we are talking about we are talking this velocity as a vector quantity, which vary in a space in case of the Cartesian coordinate system of x, y, z and the time. But most often for easy point of view, we resolve this velocity factor component into a scalar component in Cartesian coordinate systems like the i and j and k.

As you know from vector rotations of x and y, j these are the unit vectors. So you will have the u velocity components along this x directions. The v velocity components, small v velocity component in y direction and w is a velocity component z. All will have a scalar component having a functions with the space x, y, z and the time; v will be x, y, z and the time and w is that. So we define a velocity field.

That means getting a velocity field either from experimental study or analytical study. Similar way we can get it from computational methods, which later on I will introduce to more detail to you. So that way we will get a velocity field. Similar way if I know the velocity field, we can compute it what will be the acceleration, the rate of change of the velocity gradient, velocity, you know it the accelerations that the component you will get it.

About these derivations we will come it when we have fluid kinematics. We will talk about that, but you can see that any of the flow field conditions we can have a velocity field. That means we know the velocity distributions with respect to space and the time. Similar way if I know the velocity distributions, we can compute the acceleration distribution over that the fluid flow problems.

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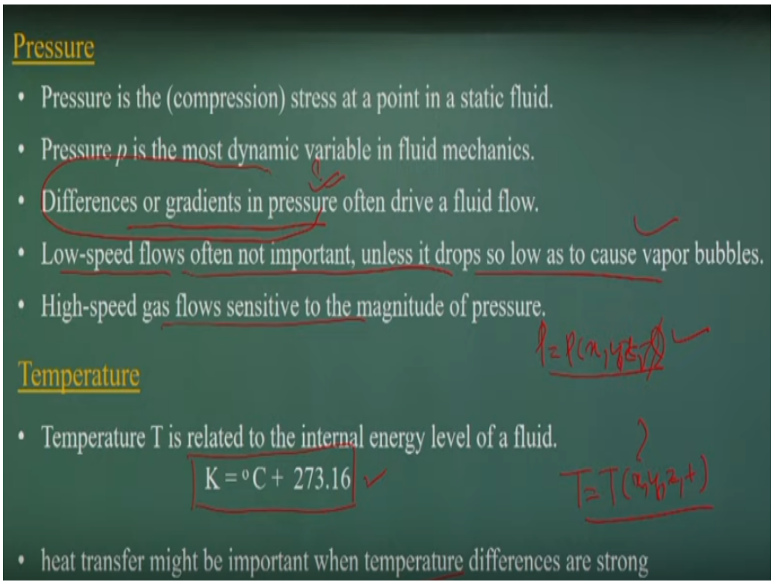

Pressure

- Pressure is the (compression) stress at a point in a static fluid.
- Pressure p is the most dynamic variable in fluid mechanics.
- Differences or gradients in pressure often drive a fluid flow.
- Low-speed flows often not important, unless it drops so low as to cause vapor bubbles.
- High-speed gas flows sensitive to the magnitude of pressure.

$p = p(x, y, z, t)$

Temperature

- Temperature T is related to the internal energy level of a fluid.

$$\boxed{K = {}^\circ C + 273.16}$$

$T = T(x, y, z, t)$

- heat transfer might be important when temperature differences are strong

Now as already I discussed that we talk about the pressures which is very dynamic variables, the pressure distribution play the major roles because as you know it the flow is come from high energy to the low energy. Many of the time this pressure the gradients indicates for us which directions flow will be there. So that is the reasons we always look at the gradient of the force which drive the flow.

Mostly this energy drive the flow, but many of the cases the other component whenever is less, the pressure gradient itself will indicate it which direction the flow is going on. So the computing the pressure and the pressure gradient that what is major component in the fluid flow problems. Some of the case studies like a is there we also very worried about the places that when it goes below a particular pressure this vapor pressure then the water converts from the liquid to the vapor.

So that is what creates the problems of gravitations. That what I will just discuss in a example problems, how the gravitation processes occurs it. So we try to look it which are the reasons we have low flow speed flow zone or the high speed flow zones, how the pressure distributions are changes it. All we can try to look it in a fluid flow problems, if I have either pressure variations if I know which varies with respect to the positions and also the time. That means is a scalar components.

It varies with a space to space, the locations to locations. Also it varies with time. So in case of steady problems, we the time component goes out. So we have the pressures which varies with space only. So if you know the velocity field that means velocity variations with space and time, the pressure variations with space and time then more or less you have solved that fluid flow problems.

But some of the cases like when you have the heat exchange is going on drastically in a fluid flow where there is a lot of temperature gradients are there, then we apply the first law of thermodynamics to get it the temperature field. So there are the, the problems here is not only the fluid flow problems there will be the heat transfer problems.

There is a lot of gradient of temperatures are there, the heat transfers are there. The same way for that fluid flow problems, we can have the temperatures is a function of the space and the time. So to solve this, we have to follow first law of thermodynamics, the heat transfer equations to solve this problem. Mostly in these fluid mechanics course I will not go more detail about these thermal flow, the heat transfer problems more, the flow due to the temperature gradients that part.

And this is as you know is very basic things that how the temperatures related to the at different centigrade to the Kelvin scale. That is what the point.

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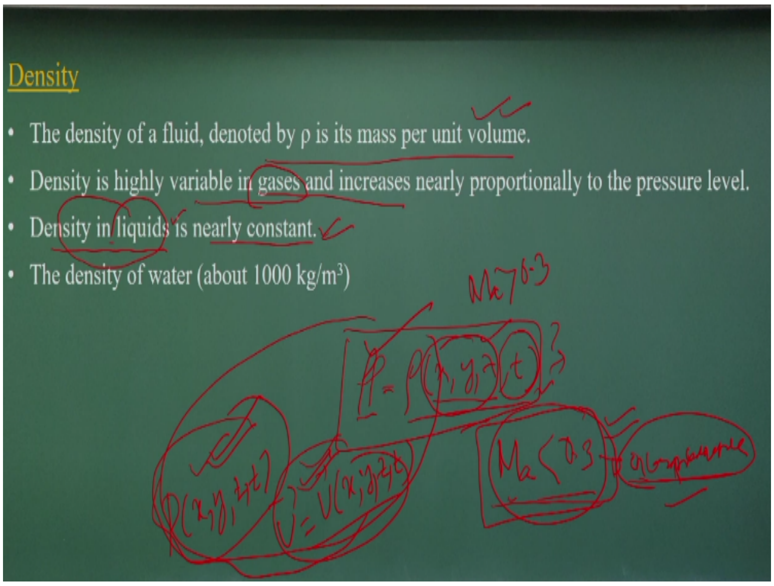

Density

- The density of a fluid, denoted by ρ is its mass per unit volume.
- Density is highly variable in gases and increases nearly proportionally to the pressure level.
- Density in liquids is nearly constant.
- The density of water (about 1000 kg/m^3)

And second point what I am to discuss is the density of the flow. You know it this mass per unit volume or it indicates the mass of the fluid and that what per unit volume we quantified it. So if you multiply the volume, you know this what is the amount of the mass is there and based on that we can find out which is a heavier mass or the lighter mass, the fluid as they have a heavier and lighter mass.

The energy, the kinetic energy, potential energy and how that is what varying it that is what is related to the mass properties. So that way the density plays a major role for us. Some of the cases when you have the flow is compressible, your density is also the significantly varies with the positions and the time.

So we can solve the problems to get these density variations with positions and the time and that is a variable for the gases, but for the density in the liquids nearly constant as most of the examples what I have I will discuss it. We will talk about the liquid flows not the gas flows. So that is the case if the density of the liquids will be really constant.

Even if in case of the gas flows also as discussed earlier, when you have a Mach number less than 0.3 also we can consider as incompressible flow. So density does not vary significant. So that way, if you look at that, as a fluid mechanics specialist, we will try to solve only two fields, pressure field and the velocity field.

Because most of the fluid flow problems what we have considered where the Mach number is less than 0.3 unless there is supersonic flow and all which is for the rocket flow and all the concept. So we need not to have a density field that for this problems, what we consider it, but the major things what we look at how the pressure field and the velocity field. How does it varies with the space and the time.

These two things are more important for us, the pressure field and velocity field. Since we consider the problems which the problem, the flow is a Mach number is less than 0.3. So flow is incompressible in nature. So we can just need to know it the pressure field and the velocity field.

If it is not, then you have to go for that means if your Mach number is more than 0.3 conditions in your flow field conditions then we have to consider the density variations which will be the varies with the space and the time component. So in that case, we will have a the pressure, the velocity, and the density variations. So three fields we need to know, define the flow when you have a flow incompressible.

But when you have the Mach number greater than 0.3 the flow is compressible. Then you need to have a density field, the pressure field, and the velocity field. These three field we need to define it when the flow is compressible. If flow is incomprehensible, that what we can get it when the Mach number is less than 0.3. In that conditions only we need a pressure field and the velocity filed.

So what I am to tell you that fluid flow problems are very interesting problems. It is a solvable problems at present. Only we need to know it how the pressure varies it, how the velocity varies it. But as I showed it two examples, one is the flow around a bird which is very complex geometry and another is the flow load on a weather towers which is looks like a spherical ball.

So if you look it that as we go for a complex problems, so getting these pressure filed, velocity field, it is not that easy. So that is the reasons we follow experimental methods, analytical methods, and numerical methods to solve the problems. In fluid mechanics problems, the a specialist who can visualize the flow better and then he can simplify the flow problems and then he can solve the problem.

The flow visualization is a major issue and how to visualize the flow. That means how to determine that how what could be a tentative flow patterns or the flow patterns are obtaining from either experimental results or analytical methods or the computational fluid dynamics methods we should try to understand what we are getting the flow patterns.

Are they correct or a fluid mechanics specialist he can looking these problems he can visualize it that this could be expected flow pattern could be there. So define these flow patterns we define technically three lines.

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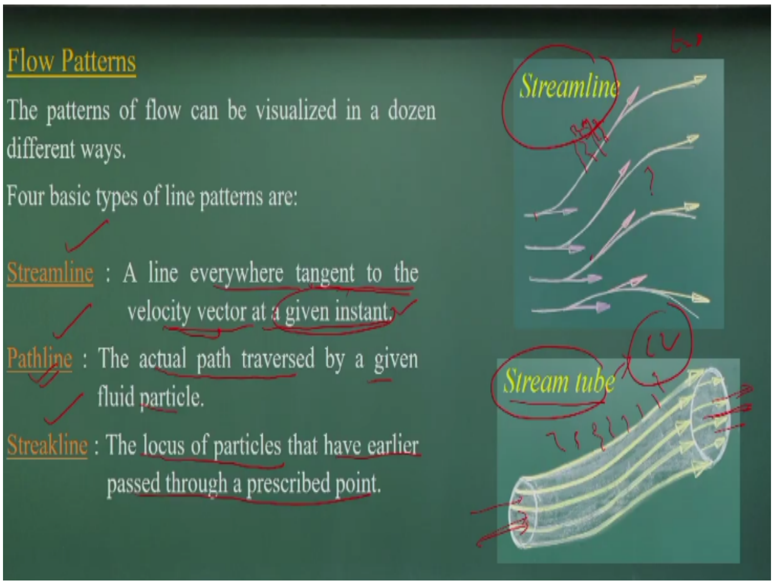

Flow Patterns

The patterns of flow can be visualized in a dozen different ways.

Four basic types of line patterns are:

Streamline : A line everywhere tangent to the velocity vector at a given instant.

Pathline : The actual path traversed by a given fluid particle.

Streakline : The locus of particles that have earlier passed through a prescribed point.

One is the streamline, pathline, and the streakline. Let us look at the definitions. The streamline, a line everywhere it is a tangent to the velocity vector at given instant. That means time equal to zero or we take a snapshot okay. And at each point, if I draw this the tangent that tangent should give a directions of the velocity vector okay. So if you look at this that as I draw this, these tangent line, this line tangent should match with the directions of the velocity.

So if that is the conditions and join that line is called the streamlines. So if you look at that one case, the streamline goes like this, one case streamlines goes like this, like this. like this. Other way round, if you have that streamlines at a point if you draw the tangent and that the tangent is a direction of the velocity. So we can find out the directions of velocity if I know the streamlines.

Or if I know this direction of the velocity by measuring any experimentally work and connecting that lines such a way that it will have a tangent to that velocity. Tangent and the velocity direction matches each other. That what will give a streamline. So we will have the streamline patterns like that.

So if you look it that the flow is going this direction, this direction, and this direction, but one of the easy things here in the streamline if you look it if this is the velocity, the direction of the velocity, that means there is no component is working on this time. There is no velocity component. The normal components is zero. The flow is going tangential to that. There is no component on this.

That means, there is no flow goes through this ones. That is the reasons of what we define it if I have draw the streamlines, and it is occupied a certain space like this the steam cube. In that case is a very simplified case is now the only the flow will be enter from the side and go out from this. Since the streamlines does not allow any flow cross through that as the definitions indicates for us.

So there will be no flow will go through these ones. So we consider a streamline, a stream tube which is composition of streamline such a way that there will be inflow and outflow and across the stream tubes, there will be no flow component. So this is what the imaginary the stream tube will generate it to solve the problems because it gives us that there is no velocity, no mass flux, no momentum flux comes into that.

So some of the times we consider the stream tube as a control volume. We solve the problems as a stream tube as a control volume, then we solve it because we get imaginary the boundary where there is no mass flux, no momentum flux. And it is easy for us to solve the problems because it is only having inflow and the outflow. So we use the stream tube concept and the streamline concept.

So again I am to repeat it the streamline is a line everywhere the tangent through the velocity vector at given instant of time, as a snapshot. You take a snapshot, at that snapshot, if you draw a line the each tangent of the line will indicate us the directions of the velocity. So that is the basic point. That is what we call the streamline. Second is the pathline.

If you can understand it that the actually path traversed by a given fluid particle. You consider a fluid particle and at different time interval you find out where that fluid particles.

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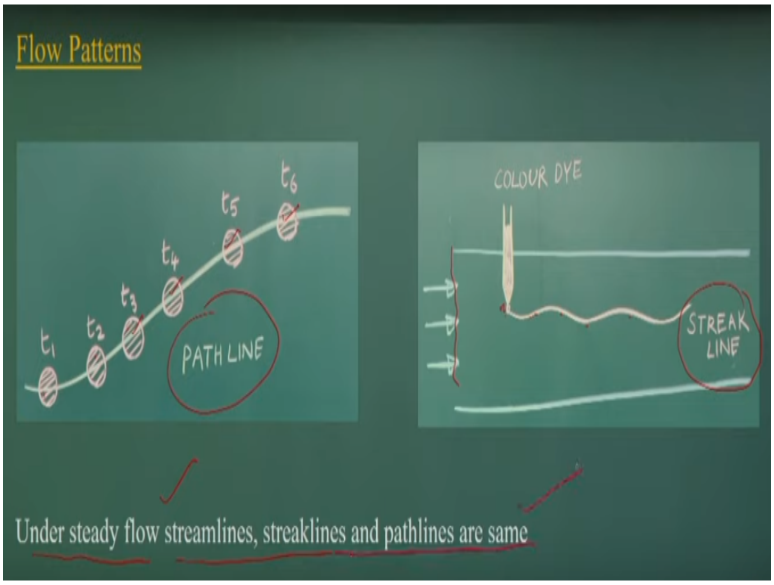
Flow Patterns

Under steady flow streamlines, streaklines and pathlines are same

Like the next examples, like I have a fluid particles at these points at the t 1 time and t 2 time, t 3 time, t 4 time, t 5 time, t 6 time. It is a different time. How from this position to this position, this positions like this. Then if I draw this line which is called the pathlines. That means we define the path of the fluid particles, but it is traced by the maybe last few minutes, last few seconds drawing that will draw the pathline.

So it is a time informations are there the how the fluid particles are passing through at different time. So we are tracking over fluid particles, we are talking about that. So how the at the different time it is moving it. This is called the pathline. Similar way if you look at this, another point is the streakline. What it says that the locus of the particles that have earlier passed through a prescribed point.

That means you have defined a point, at that point the fluid particles are passing through that. So that means the position is fixed. At that point, which are the fluid particles have already passed through that and those if you color it or those you mark it that the lines will indicate as the streakline. So if you look at these problems that let I have the flow like, this is coming from these.

We have a channels. I have at this point I have a color dye putting into there. So that means which are the fluid particles are coming to where I am making them to either a red color or the blue colors okay, any of the colors okay you can use as a color dye. So put in a color. So as after few minute if you look it these particles will move it the second particles will move it and this color dye pattern what will get it after t 1 time that what will give us the streaklines.

So try to understand there is the streamline, pathline, and the streaklines. The streamlines talks about the how presentations of the velocity vectors at a particular instant of the time. Whereas the pathlines which talk about us the path traversed by a fluid particles of a durations of t. What are the path, what is the different positions it should path it.

The streaklines what is talk about that it is a locus of the particles which have passed through a fixed points. So if you look at this way, we use a pathline for a some problems to solve it. The streaklines to solve the some problems, to visualize the problems.

Similar way we use the streamlines more upon we use the steamlines which as I try to explaining is that if you know the streamlines you know these the velocity the directions of the velocity vectors, which gives us that there is no flow cross through that and we can compose a stream tube concept as a control volume and you can solve the many problems.

So mostly in case of the analytical methods we follow the stream tube or streamlines methods more accurately, but the experimental technique when you visit either we follow for a techniques like a pathlines like we track a fluid particles at different instant of time then trace on that or we do a dye a color a series of the fluid particles then find out the color dye pattern. So that patterns will be like a streakline.

So these two most upon use for an experimental works to know it how the flow patterns or flow visualizations will do it. Then later on with wind lab experiment I will demonstrate to you how interesting flow patents we get it for different conditions. So but very interestingly that you see that if you have a steady flow okay if the flow parameters characteristics the velocity, pressure they do not change with the time then all the steamlines, streakline, pathlines are the same.

So definitely they are not will be the different the same things will happen it if you have the steady problems. That means your pressure, the velocity that they do not depend upon the time variabilities. With this let us come back to that just to have a if you look at any fluid flow problems which are very complex and most often this fluid flow in a natural systems is much more complex as compared to manmade systems like as I given a example of bird and the weather towers.

Similar way you can imagine very complex problems would it happens is that. So as I told you that we need to visualize the flow. If you visualize the flow you solve the problems.

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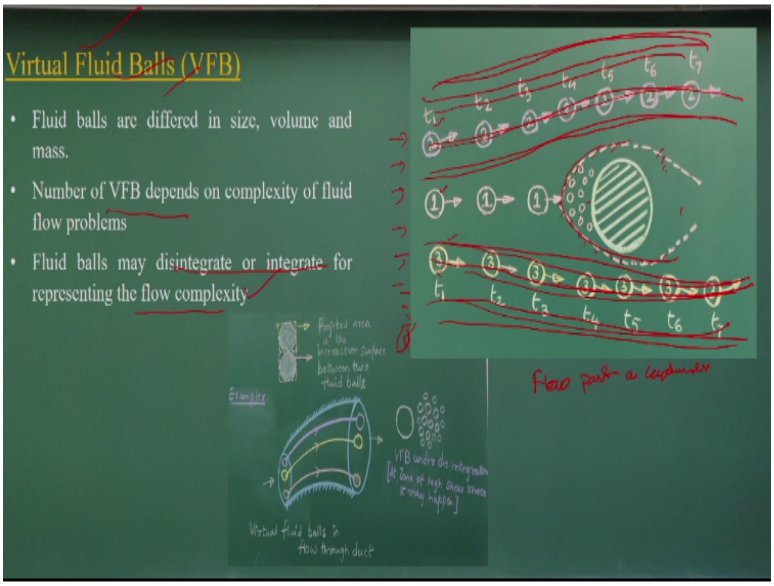

Virtual Fluid Balls (VFB)

- Fluid balls are differed in size, volume and mass.
- Number of VFB depends on complexity of fluid flow problems
- Fluid balls may disintegrate or integrate for representing the flow complexity

The for example, if I take these problems that flow past a cylinder. That means I have a cylinder, a velocity of v uniform velocity of v is passing through this okay? As I told it earlier I will have a virtual fluid balls okay it is not real fluid balls these are virtual fluid balls. I have a ball 1, 2, and 3 and this is the fixed. And these balls are having a velocity v as equal to the velocity of uniform flow.

And as you can see it very clearly that the ball 2 at t 1, t 2, t 3, t 4, t 5 will move like this, which will be defined as a streamlines in case of the steady flow it will define a streamline or pathline or streaklines. Similar way if I take a fluid flow ball is third one that what will we define it the another streamlines, pathline, streaklines like this.

So we can with help of this conceptualization we can draw it what could be the approachment the streamline conditions when flow pass a cylinder. But what it happens to the 1 which the ball is goes after certain time dash over this. As you know it at this point the velocity will be zero. So these concept what we have said it this is what approximately can draw the flow field the streamline patterns.

But when you close to the cases when you have a velocity reduces and we have a hypothesis now, that it may degenerated it make it bigger ball to smaller ball and we can find out these are what zone of influence. So if you have a art, how to draw a streamlines of a flow conditions that means you have solved many problems.

See here I am with a example of a virtual fluid ball concept, you just think it balls are rolling it and dashing over a cylinder is there. So because of the dashing there will be a regions which will have a effect, there will be regions will not have a effect. The balls of these ones will move like this. So if I can draw that, I can draw the streamlines. I can draw the streamlines.

So that means I am just hypothetically I am considering the balls are rolling with the velocity v and there is a zone of influences and those the regions the balls will be disintegrated into smaller part beyond that, they may not have a effect and that what we can move it. So just to visualize the fluid flow we have brought this concept of virtual fluid balls.

That means if you want to have a very complex problems you can change you can make a more number balls are moving it and interacting with the structures and how the zone of influence how the streamline patterns will be there, that what we can generate it and we will try to use this concept to define the laminar flow and the turbulent flow which is will be more interesting to you to visualize the flow.

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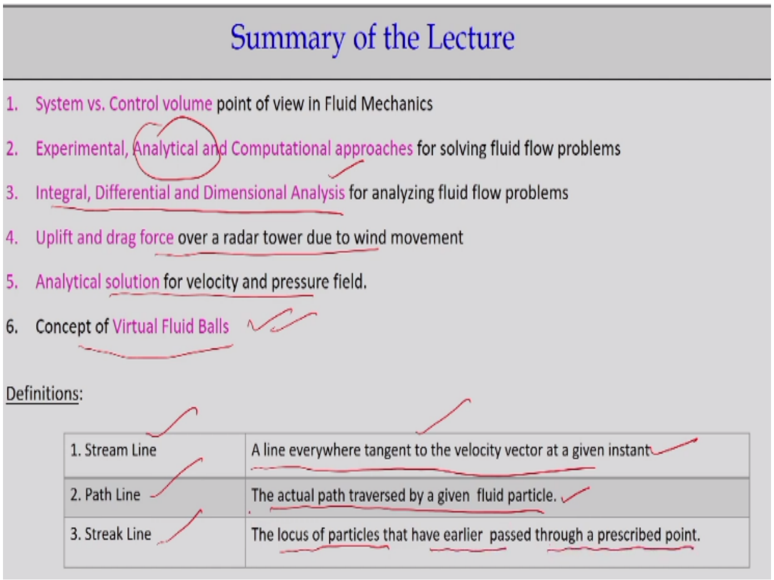

Summary of the Lecture

1. System vs. Control volume point of view in Fluid Mechanics
2. Experimental, Analytical and Computational approaches for solving fluid flow problems
3. Integral, Differential and Dimensional Analysis for analyzing fluid flow problems
4. Uplift and drag force over a radar tower due to wind movement
5. Analytical solution for velocity and pressure field.
6. Concept of Virtual Fluid Balls

Definitions:

1. Stream Line	A line everywhere tangent to the velocity vector at a given instant
2. Path Line	The actual path traversed by a given fluid particle.
3. Streak Line	The locus of particles that have earlier passed through a prescribed point.

With this let me summarize today's lectures that we define what is the systems and the control volumes and the fluid mechanics problems. There are three tools are available to us, the experimental, analytical and computational approach. The last two decades people have been using the computational methods more extensively solve very complex fluid flow problems.

Because of that, we have fuel efficient aircraft, the fuel efficient spacecraft. So all these are possible because of the use of the computational fluid dynamics. The use of the computational fluid dynamics help us to predict the weather which is also a fluid flow and heat transfer problems.

Also the parallely as I say that there are a lot of experimental facility has developed in the world that can not necessarily will we do in a scaled models can do a full prototype of models, which is used in automobile industries or the aerospace industry. They try to use the full scale models and try to look into what is space technology centers they use the full scale models to test it.

So these are not is possible. But before that as you know these analytical methods is give us a basic knowledge how the fluid flow problems happens it with the help of a control volumes with the basic energy conservation equations and mass conservation movement. And these are the three approaches. Next is integral, differential and the dimensional analysis.

As we have talked about that radar problems and the bird problems. Then very simple way I just define it the again the virtual fluid balls concept what we should try to understand it. Then we can visualize the flow and once you visualize the flow then you solve the problems very systematic way. At the end we have learned also the three lines. One is streamline, pathline, and streakline.

The streamline the line everywhere tangent to velocity vector gives at a particular instant. That means it talks about the tangents is a parallel to the directions of velocity vectors. And the actual path traversed by the fluid particle is pathline. And the locus of the particles that have the passed through the prescribed point is called the streak plane. With these definitions let me conclude this class. Thank you.