Fluid Mechanics

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Lecture - 36
Principles of Similarity Part – I

Good morning, I welcome you all to the session of fluid mechanics. Today, we will be starting a very interesting and a new section Principles of similarity and dimensional analysis. Dimensional analysis comes as a tool to the physical phenomena of principles of well, at the outset we must discuss, what is principle of similarity and where from it originates. Now, we all know that the engineering problems are very complex in nature, and in fact the theoretical solutions are sometimes impossible.

Even with the advent of computational mathematics or numerical analysis, we go for a solution of a practical problem or engineering problems. But to take care of all down towards considerations, at some instance or at some place we request the empirical information or empirical feel that is the information from experiments. And also even if we develop a theoretical model for engineering problems this has to be calibrated against experiments.

So therefore, it is a proven fact or it is true that experiments are the actual proof and most of the engineering problems are solved from the experiments. Now, at the same time we know that when you perform experiments in laboratory to solve engineering problems in practice, due to some reasons like-economic constraints, saving of time, energy, space we cannot perform the experiments under the identical set of operating conditions that actually prevail in actual problems in practice.

For an example, if you want to study the pressure drop flow rate characteristics of water flow, through a very big pipe line transporting water in a city. So, we cannot do the experiments of that particular problem in the laboratory having a pipe of very big diameter as it occurs in practice, or very big length as it occurs in practice, it transports water from some bed of river to cities where the length of pipe is very big.

For example, if we want to find out the pressure profile or the pressure distribution due to flow of air over the aircraft wing when it flies, we want to predict that from laboratory experiments. Then we cannot build an aircraft wing of the dimensions what is exactly in practice. Moreover, we cannot create that very high velocity of air in some instances as it happens in actual practice, when the aircraft moves at a very high velocity. In many instances we may not be able to do the experiments with the fluids, actual fluids in practice. This is because of cost constant, so we may use different fluids.

So therefore, the conclusion is that in laboratory due to these reasons of economic advantage, saving of time, money, energy, space requirement, we perform experiments under some altered set of conditions from the set of conditions that actually prevail in practice. Now, under this circumstances two partinian questions, two partinian questions come into our mind. Number one is under what conditions or how can we apply or can we apply, any way you see that, can we apply or how can we apply the test results from laboratory experiments to the actual problems under different set of conditions in practice, how can we apply this result.

For example, for a flow rate pressure drop test in laboratory for pipe flow, under different geometrical conditions, that means under altered geometrical shapes, under altered flow parameters like flow velocity, with experiments, with different fluids, how can we apply this results to the actual problems at another set of conditions, in practice. How? What makes us justifiable or possible to apply these results for the predictions of the actual problem performance in practice under a different set of condition? This is number one.

Second question, which comes into our mind that, when the performance parameter of any system is a function of number of independent operating parameters, has independent variables or input variables, then we have to perform a large number of experiments. Then is it possible to reduce the number of experiments to a limited one, limited numbers so that we can at the same results. That means we can predict the influences of all the independent operating parameters on the performance, by performing a limited number of experiments. That means if see that if there are ten independent parameters influencing a performance parameter, then we have to do a number of experiments to see the individual effect of each ten parameters.

But, is it possible that by a limited number of experiments, through the influence of only two independent parameters, that we vary two independent parameters, we can predict the performance of all other independent parameters on the performance parameters.

Then I am giving you a example so that you can understand. The pressure drop over through a flow of fluid through a pipe is a function of pipe diameter, pipe length, flow velocity, and the rheological properties like density and viscosity of the fluid.

So each and every parameter has got its individual influence. So, if have to express the relationship of pressure drop delta p with all this parameters, we have to do a large number of experiment, large sets of experiments. In one set of experiments we will vary the diameter of the pipe to see its influence, in one set of experiments we will vary the viscosity, one set of experiments we will vary the density, one set of experiments we will vary the flow velocity, one set of experiments we will vary the length, so that we can establish the functional relationship.

But, is it possible that if we vary one or two parameters for example, one parameter we can express the influence of all the parameter on pressure drop? It is possible. Now, we know probably from our earlier studies that why varying only the flow velocity, which is very simple, because if you vary the flow rates through the pipe the flow velocity changes. Just from one set of experiments by varying the flow velocity we are able to predict the influence of diameter, influence of density, influence of viscosity, and all these things that you know. Now, from your earlier knowledge that friction factor is a function of Reynolds number. So, Reynolds number takes the combination of all the independents parameters rho, v, d, mu. But where from it is dictated that such a parameter will take care of the variations of all the independent parameters, so this comes from that principle.

Therefore, I can say that the two partinian questions which arise under this circumstances, just I have told you has its answer in the clue, or it has a clue in its answer from the physical principles, mean the principles of physical similarity. Or we can tell the principles of physical similarity gives a clue in answer in these two questions. What is that? Yes, we can apply the test results under one set of conditions to the actual problems in practice under different set of conditions, provided the principles of physical similarity holds good.

Number two, it is because of the principles of physical similarity, we can club the different dimensional variables influencing a performance parameter into a single group, so that the influence of all the dimensional variables has operating parameters on the performance parameter, is effected through that parameter group, that is the group parameter, just like Reynolds number. This all comes from the phenomena of principles of physical similarity.

Now, let us consider what is this principle of physical similarity. The very first thing you must know that, what that physical, principle of physical similarity means that two problems under different sets of operating conditions will be physically similar, will be physically similar. Physically means in respects of its entire physical principles the physically similar, physically similar. This is basically the principle. But before that I tell you one thing, which you will not find any book except my book. I am telling that I have gone through many books but you will not find this particular word. If you see my book you will the very first line of physical similarity between two problems is like this: the physics of the problems have to be same that means they should be described by the same physics, that means if one wants to find out whether the physical similarity exists between two problems of different kind is a fool.

That means the very first requirement is that the problems will be of same physics, will be described by the same physics. For an example, the pipe flow problem cannot be made similar even under different or even under same sets of condition with a flow with a free surface, that means flow through open channels. Why? This is because the pipe flow problem is governed by pressure force, viscous force, inertia forces, whereas, the flow with a free surface is governed by the gravity forces. Similarly, any of this flow cannot be made similar to a flow of liquid vertically above through very small diameter tube, where surface tension is dominated.

Or flow of a free jet in air, which means that in this case of flows, that means free jet in air or flow of liquid through a very narrow tube, means the surface tension force is dominated. Therefore, the physics of this system changes where the flow is in one case for example, the pipe flow, flow is dominated by viscous and pressure forces, while in other case flow of a free jet the flow is dominated by surface tension forces.

So therefore, one is very essential that the physics of the two system should be same, should be described by the same physics. This will not be dictated any formula or any law. This is will be come from our intuition, this will be coming from our sense that, we will be recognizing that the two problems are of same physics or not. Now, I describe what is principles of physical similarity.

Now, a problem of same physics, described by the same physics, for example, pipe flow problem-channel flow problem. So, a class of problems, like that same class of problems, that means same problems-problems belonging to a particular class, which is defined by the same physics. So free jet problem like that a problem defined by the same physics, but under two different operating conditions, will be similar, physically similar in respect of certain specified physical quantity, with respect of a certain specified physical quantity, when the ratios of the corresponding magnitudes of that quantity between the two systems is same everywhere, is same everywhere.

Now, when this physical quantity is referred to as geometrical dimension this similarity is known as geometrical similarity. When this physical system is motion or velocity this similarity is known as kinematic similarity and when this physical system refers to forces then this is known as dynamic similarity. Therefore, we come across three types of similarity: one is geometric similarity, one is kinematic similarity, another is dynamic similarity. So, according to the definition, general definition of similarity the ratio of corresponding magnitudes of this physical quantity will be same for both the system. Now, geometrical similarity therefore insures the ratio of the geometrical dimensions, corresponding geometrical dimensions will be same for both the system. This similarity we are acquainted since our childhood. Geometrical similarity is similarity of shape that means the ratio of the corresponding dimensions between the two systems have to be same.

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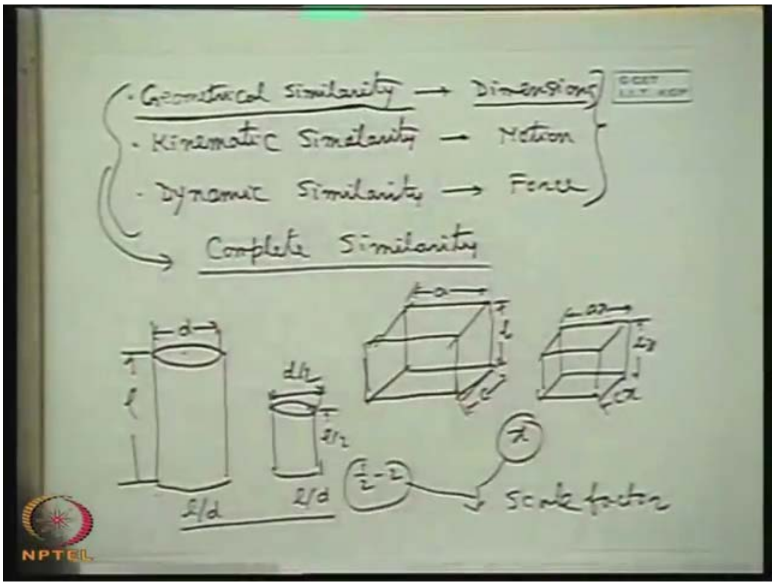

So therefore, let us see a geometrical similar, so geometrical similarity. Therefore, we come across, we come with geometrical similarity, geometrical similarity. It is similarity of geometrical dimensions. So, three types of similarity, I think we have understood this one is kinematic similarity. That is similarity of motion-kinematic similarity and another is dynamics similarity, dynamic similarity alright. So this is similarity of dimensions-geometrical dimensions, this is similarity of motion or velocity whatever you call, this is similarity of force. If these three similarity simultaneously exist, we call, that we tell the entire physical similarity or sometimes we tell complete physical similarity is achieved, is achieved between two problems of same physics, but operating under different conditions.

So, geometrical similarity means the dimensions geometrical, corresponding geometrical dimensions will be at the same ration. That means if we consider two pipes or two cylinders, for example when two cylinders are geometrically similar, when this is like this, that if this length is l, this is child job, this is d. If by half the length and half the diameter that means these are geometrically, similar because this ratio of the lengths of the two cylinder is equal to ratio of the diameters of the two cylinders or we can tell l by d is same for both this case.

Similarly, we can think of another example parallellopiped, if you take, a parallellopiped element, just geometrical similarity. That means this is a, this side is a, let this height is b, let this is c. We consider a geometrical similar parallellopiped whose side will be ax, sides will be bx, with the same ratio cx. This x is the scale factor, that means the ratio of the length ratio of the height and ratio of the here scale factor is half of two. So, this is known as scale factor, this ratio which ever you define either half or two ratio, this is known as scale factor. That means in one way we can tell geometrical similarity is the similarity of shape. That means the geometry of the equipment or the device through which the flow is taking place will be similar in nature.

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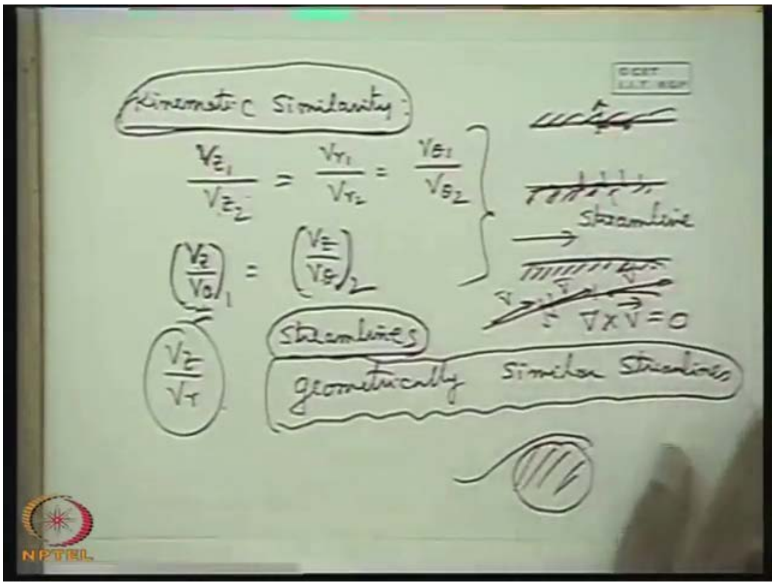

Then, next comes the kinematic similarity. Kinematic similarity is very simple, kinematic similarity is the very simple, kinematic similarity is the similarity of motion. That means the ratio of the corresponding velocities at the similar points between two systems will be equal. That means Vz in one system, the Vz in another system is equal to vr radial velocity in one system, radial velocity in other system. Tangential velocity in one system or we can represent the ratio of axial-to-tangential velocity in one system is the ratio of axial-to-tangential velocity in other system. That means the ratio of the corresponding velocities, we can tell in other way also. The ratio of the corresponding velocities or the ratio of any two velocities of one system is equal to the ratio of the corresponding velocities in other system at all similar points. Or, we can tell the ratio of a particular component of velocity at all similar points between the two systems are same with other components of velocity. So, this is the requirement of kinematic similarity.

As we know the stream lines at any instant represent the direction of flow- velocity vector in the flow. So, when the kinematic similarity is attained, it is automatically coming from common sense. So, in the ratio Vz by V theta, Vz by Vr of one system must be equal to the Vz by Vr of other system. That means the ratios of velocities are same then which means the stream lines are geometrically similar, which means geometrically similar stream lines, geometrically similar stream line. This comes with the geometry of stream lines because from the kinematic studies we have seen that the geometry that the motions are described by the stream line. So, the stream at any instant will be geometrically similar between the two systems to for kinematic similarity to be maintained. Alright?

Then comes the most important similarity is the dynamic similarity. But before that I tell you another one very important thing that is solid body passed with a fluid flow. So, either it is a plate or it is the wall of a duct or it is anybody that means when the flow takes place passed a circular cylinder. So, any impermeable solid body-what is meant that there is no porosity, that means fluid does not go into the solid body-any impermeable solid body, one thing we know that the no-sleep condition till the velocity of this fluid at the solid surface is 0, relative velocity of the fluid with respect to the solid surface is 0. So, what velocity?

This is the tangential velocity. That means along this solid. If solid is porous, so fluid will go into it, there is no more sleep conditions. So, no sleep condition is now little modified, that it is the tangential velocity, that is velocity along the solid surface, is 0 for the fluid element relative to this solid. That means if solid surface is at rest, so there is no velocity. But if the solid surface at the same time is impermeable there is no flow through it. Then solid surface is still with stream line.

Because definition of stream line is that stream line represents a line where there is no flow across the stream line. That means the velocity vector is always tangent to that one, whether the magnitude of the vector is 0 or non 0 that is not the point. There the magnitude is 0 but the velocity vector is tangential. A 0 vector, that means its magnitude is 0, that means physically there is no flow across a stream line, basic definition from which we derive the equation of stream line as del cross V is 0. There is no flow across the stream line; that means no perpendicular-no component of velocity perpendicular-to the stream line at a point. So with that definition you must remember that a solid body defines one stream line in the pattern of stream line. So, in the kinematic similarities obtained we have seen the pattern of stream lines will be geometrically similar between two flows and similarly, the two flows will be such that their boundaries will be geometrically similar.

So, another consequence we can tell for kinematicaly, kinematic similar flow or to maintain the kinematic similarity in flows, the flow should be such that, the flow should be such that they should pass over similar solid boundaries, they should pass over or they should flow over similar solid boundary. Similar means geometrically similar solid boundaries.

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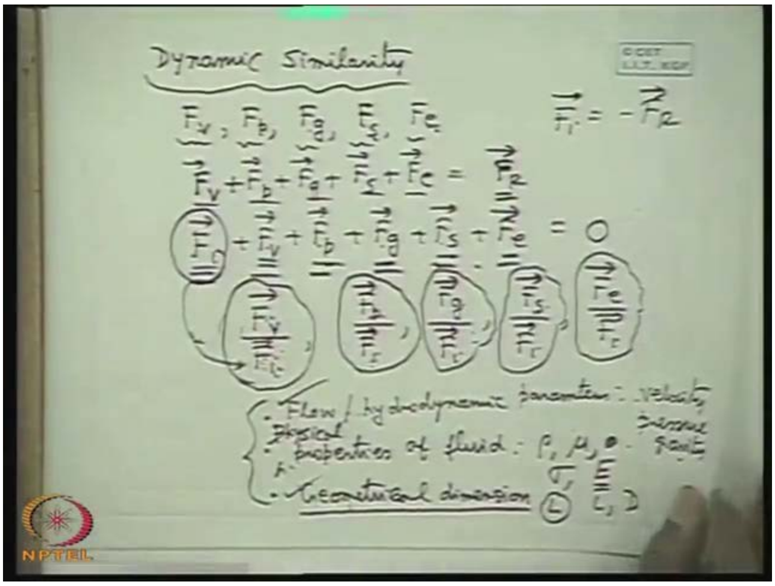

Now, after this we come to the dynamic similarity concept. Dynamic similarity concept- now it is the similarity of forces. Dynamic similarity; dynamic similarity is the similarity of forces, very important. So this can be defined as that between two systems operating or under different conditions or two systems working under different operating condition, different sets of conditions, will be set to be in dynamically similar or dynamic similarity is prevailing, provided the ratio of some forces, components of forces in one system at similar points will be same as that of the other system. That means if we take two similar points for example, the particular system is governed by pressure force and viscous force. That means consider a system of fluid flow under the influence of pressure force, viscous force, inertia force. Two such systems, two such flows, but the conditions are different, the actual geometrical dimensions of the flow are different but geometrical similarity prevails, length-diameter of the pipe may be different but l by d ratio is same.

Similarly, the fluid may be different. Flow velocities may be different. Now the thing is that the ratio of inertia force by viscous force must be same between the two. That means ratio of inertia force by viscous force in one system must be the, must be equal to the ratio of inertia force by viscous force to other system. Ratio of viscous force by pressure force in one system must be same as the ratio of viscous force by inertia force in other system, you understood, other system at all similar points.

So, this is precisely the requirement of dynamic similarity. That means the ratio of different force components at a particular point in a system must be equal to the ratios of the correspondent force components at similar points of the other system operating under different conditions. Therefore, it is the ratio of the different forces which have to be same for both the systems under different conditions is the criteria of dynamic similarity. So therefore, to go further into dynamic similarity we will have to know what are the different forces acting in general to a fluid flow problems. Let us see a fluid flow problem is generally influenced by viscous force, pressure force, gravity force. There are other forces, conventionally, we are coming across this forces in fluid flow in practice that is the surface tension force, elastics force.

In general we come across these forces in fluid flow. That means in practical cases of fluid flow, these forces are dominant. That means these forces cause the fluid to flow and if we consider in general a fluid flow under all such forces, usually we see that in a particular application all the forces are not equally important or equally dominant. But if we consider in general a fluid flow, which is being dominated or caused by all the forces then we can write that sum of the all these forces.

We consider a situation like this. Though I tell you we will see in practical situations a particular type of practical situation, all the forces are not dominating. For example, in a pipe flow only the viscous flows and pressure force are dominating for a fully developed pipe flow. But if we consider in general that a force, all the forces are dominating in a fluid flow problem then I can tell the vector some of all the forces yield to a resultant force, which is the force that dictate the flow of fluid, because the kinematics-the motion of the fluid-is ultimately dictated the force. How? Why the flow velocity is generated? This is because of the force. By definition it is the force which changes the inertial. If there was no velocity earlier the flow velocity is created by the application of the force. Therefore, it is the resultant force which dictates the motion of the fluid. Therefore, it is governed by this resultant force.

Now, as we know the definition of inertia force is the negative of the resultant forces. So, from Dalembert's principle we can write that inertia force plus all the forces with vector, that is the vector sum, is 0. So, force balance equation in general for fluid flow problems, which encounter only this type of forces can be written as like this. That means inertia force plus viscous force plus pressure force plus gravity force plus surface tension force plus elastic force, this is elastic force. I am not writing everything. This is surface tension force, which is caused by surface tension. I will come one by one, this is 0. So therefore, we have 1, 2, 3, 4, 5, 5, so we have five ratios of the forces or n number of combinations we can make. But the convention is that always we take inertia force as the reference force and we develop the different ratios with respect to that. That means the ratio of viscous force to inertia force.

Similarly, the ratio of pressure force to inertia force, similarly, ratio of gravity force to inertia force, similarly, the ratio of surface tension force to inertia force, the ratio of elastic force to inertia force. That means these are the force ration, which will be same at all similar points in two systems. That means if we perform the experiments in laboratory, we have to see that our altered conditions in the laboratory should be such that it must satisfy the ratio of the forces same as that occurring actual problems in practice. These are the ratio of viscous force to inertia force, ratio of pressure force to inertia force, ratio of gravity force to inertia force.

So, this is a common practice to take inertia force as the reference force and define the ratios with respect to this force. So, in general we get 1, 2, 3, 4, 5 ratios in general for a fluid flow problem, which is being caused by all the forces. Now, main task you have seen even in the derivation of Navier Stroke's equation that we want everything to be expressed in terms of certain known parameters. What are these parameters? Flow parameters, or sometimes we tell it as hydrodynamic parameters.

So, we want everything to be expressed by flow or hydrodynamic parameters and by that we only understand velocity and pressure, nothing more than that. Velocity and pressure. Another is the rheological properties of fluid. Rather better we write physical properties of fluid, you write physical properties of fluid. That means it is density, viscosity, other physical properties, if surface gravity acceleration due to gravity. Of course, acceleration due to gravity is not a property. Better you write gravity here, flow parameters acceleration due to gravity here, you write surface tension here, you write bulk modulus of elasticity-this property comes when elastic force is coming into picture. So, fluid properties.

Another important parameter is the geometry, geometrical dimensions. Geometrical dimensions. Depending upon the shape, the geometrical dimensions-diameter, length, height-that means geometrical dimensions of the object or the duct through which the fluid is flowing. Therefore, we want now that I do not understand much by the ratio of this force to that force, this force to that force, pressure force to inertia force, surface tension force to. I want to express this ratios always in terms of flow parameters like velocity, pressure, or acceleration due to gravity g, physical properties of the fluid and geometrical dimensions-the characteristics length l, which may be length, diameter whatever may be.

So, how to do it? This is done by equating all the forces to the parameters of proportionality. How it is done? Let us see the parameters of proportionality. So that in general, without knowing much detail about the type of the flow, we can express these ratios in terms of this known parameters, that is flow parameters, physical properties, and geometrical dimensions from a concept of proportionality. That means that a particular force is proportional to few of these parameters. So, this way we can develop the ratios. So before that therefore, what we have to do? So, ratios means one force divided by another forces. Therefore, what we do, one by one we find out the expressions for each and every force in terms of these parameters, in terms of proportionality.

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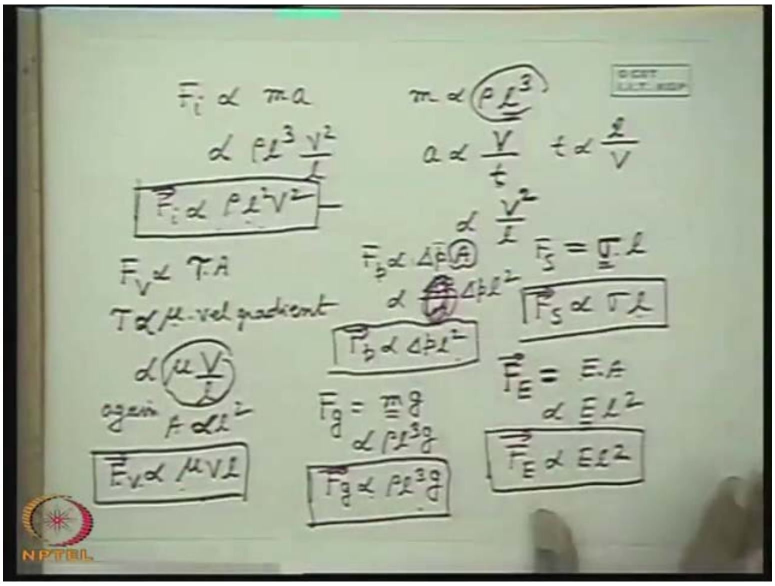

Now, let us find out that for inertia force. Now, we know the inertia force is proportional to mass times the acceleration. Ok? Now, mass is proportional to density and some characteristic length l cube, because volume is proportional to the l cube. Here l means some characteristic length of the problem, where l is some characteristic length of the problem. So, acceleration is proportional to, what it is, the rate of change of velocity, that means it will be proportional to some characteristic velocity of the problem divided by some characteristic interval of time, some characteristics velocity of the problem divided by some characteristic time. And the characteristic time will be again proportional to the characteristic length of the problem divided by the characteristic velocity.

So, we can tell that acceleration is proportional to V square by l. Obviously, we have seen this earlier also, V d v d x. That means acceleration is always proportional to square of velocity by length, this is proportionality. So that if we take care of this two we can write inertia force is proportional to V square by l that means inertia force is proportional to rho l square V square. This is the proportionality inertial force.

Similarly, we do for viscous force. Now, viscous force is proportional to what, shear stress time area. So, here we will have to think of the law. Newton’s second law tells that shear stress is proportional to mu. Now, how can we express these in terms of all these parameters we have told flow parameter and property. Then we will have to recall some law defining the shear stress. It is mu times this shear strain, which is nothing but velocity gradient, either in one dimensional flow or in multi dimensional flow. One dimensional flow the straightway velocity gradient, in multi dimensional flow it is two velocity gradient. But however, it is proportional to mu times the velocity gradient. It may be del u del y or it may be del u del y plus del v del x. Now, velocity gradient means it is proportional to V by l, some characteristic velocity divided by characteristic length of the problem. Therefore, tau is proportional to this. Again, area is proportional to l square. Therefore, Fv is proportional to this is tau and this is area is proportional to l square that means mu V l, alright, mu V l.

So, inertia force is proportional to this, viscous force is proportional to this. Let us find out other forces. Gravity forces, pressure forces. Pressure force is proportional to, how do you define the pressure forces, it is the change in pressure into area, that is the pressure force. So, it is simply because we want pressure, in terms of pressure as parameter, so do not change it. So, pressure force is proportional to delta p by l square because delta p into l square, because area is proportional to square of the characteristic length. So, this is the pressure force.

So, pressure force is proportional to delta p into l square. Now, I find out gravity force. What is the definition of gravity force? It is mass times, mass of a system times g. So, it is proportional to mass, is proportional to rho l q. So gravity force is proportional to rho l q g therefore, all the forces are now expressed in terms of a proportionality factor with the parameters as we want. That is flow parameters, physical properties of the fluid and geometrical dimension. Next is the surface tension.

Now, surface tension force occurs, you know, in certain situations of flow. For example, when the flow, vertical flow of liquid column over a narrow tube. We have recognized while discussing surface tension, the surface tension exists when there is an inter-phase between a liquid and air or between two liquids. Whenever the inter-phase between two fluids comes, surface tension comes in question. So in these categories of flow, when there is an inter-phase the surface tension comes into picture. The flow of liquid vertically have a small tube, the flow of a free jet where there is a inter-phase jet and air, the flow of a thin curved sheet in air-these certain practical classes of flow where the surface tension force comes into picture.

So therefore, if we write the surface tension force, as we know from the definition that surface tension force is equal to surface tension coefficient into some linear dimension. In terms of surface tension coefficient I can define, because this is one of the physical properties of the fluid. So, I make it unchanged. So therefore, Fa is becomes simply sigma l.

Now, what is elastic force? Elastic force comes into consideration when there is compressibility in the fluid. When the compressibility in the fluid is taken care of, then the elastic force comes into picture. When there is a substantial change in volume due to application of pressure, then the force which generate due to elasticity is known as elastic force, which is beyond the scope of this syllabus to go for the analysis of compressible flow. But you must know that in case of compressible flow the elastic force comes into picture, which is bulk modulus of elasticity into area. The force is equal to bulk modulus of elasticity into area and is proportional to E l square, E is one of the properties that bulk modulus of elasticity of the fluid. So, elastic force is proportional to E l square. You must give a vectors note sign, vector sign, vector that force is a vector. So, F E. So, F E so this way we have expressed the inertia force, viscous force, pressure force, gravity force, surface tension force, and elastic force in terms of these variables.

Now the question comes of the ratio. So, if we want to find out viscous force by inertia force, we divide this by this. We find the ratio we divide this by this. This way we can find out.

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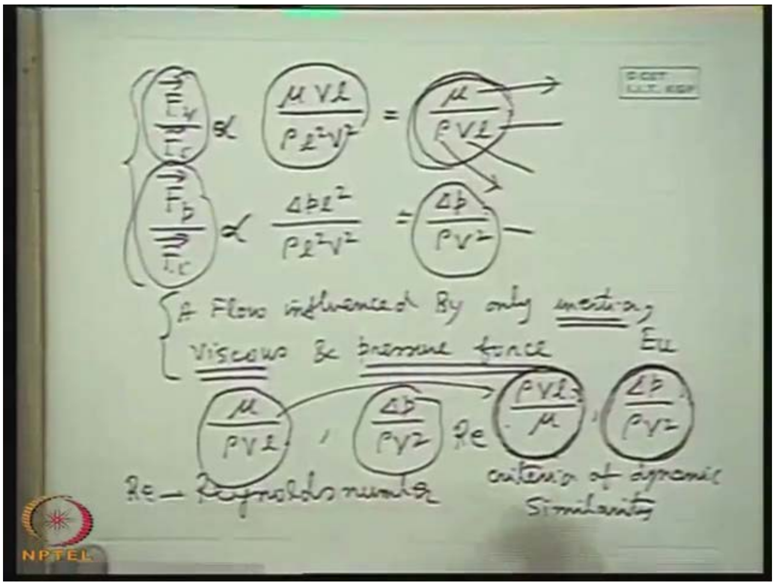

Now, let us see that how we can find out. So, if we find the, try to find out the ratio of viscous force by ratio of inertia force, what is this? This is equal to ratio of viscous force, you see your note, the viscous force is mu, is proportional-mu V l divided by, what is the inertia force, rho l square V square. So, this will be simply mu by rho V l. So, this is the ratio; ratio of viscous force, inertia force to pressure force or pressure force to inertia force, pressure force to inertia force. What is this ratio pressure force to inertia force? Please tell me from your note. Pressure force is proportional to, not is equal to, delta p l square and inertia force rho l square V square. So, this is proportional to or is equal to, same thing, is equal to delta p by rho V square.

Now I see, that viscous to inertia force is proportional to mu by rho V l pressure to inertia force. Now, I have told that if practical situations, a flow does not, is not being influenced by all the forces. So, consider a flow influenced by, only influenced by, only inertia, viscous and pressure forces. You may ask me, sir how do I know? There is no formula! This I tell you that there is a limit where you cannot ask any thing by the formula or by the laws in the book, that you will have to find out from your intelligence.

So, you will have to first detect the physics of the problem that is this problem is guided by only. This, we will have to find from your brain. In that case, so only two ratios come into picture, that means mu by rho V l. And this two dimensionless term, now one thing these terms are dimensionless because it is the ratio of the forces, so while it is expressed in terms of the physical parameter this is proportional to mu V l. This is proportional to rho l square V square. That means this will be a dimensionless, so this is a dimensionless parameter. You can check by putting the dimensions of each and every dimensional quantity, it is dimensionless.

Similarly, delta p by rho V square is dimensionless. So, these dimensionless parameters represent the ratio of force. Conventionally this is defined, that means the reverse rho V l by mu. This convention, this is the ratio of viscous to inertia force and this is as usual. That means these two dimensionless parameters become the criteria of, criteria of dynamic similarity. Why? Because the dynamic similarity criteria is that the ratio of forces will be same in two systems, ratio of governing forces.

That means that if the ratio of inertia to viscous force between two systems have to be same that means this dimensionless parameters have to be same. If the ratio of pressure to inertia force is between two systems have to be same, then this parameter has to be same. This parameter is named as Reynolds number and this parameter is named as Euler number. Re is Reynolds number, Reynolds number and this delta p by rho V square this is known as Euler number, after the scientist who first discovered it.

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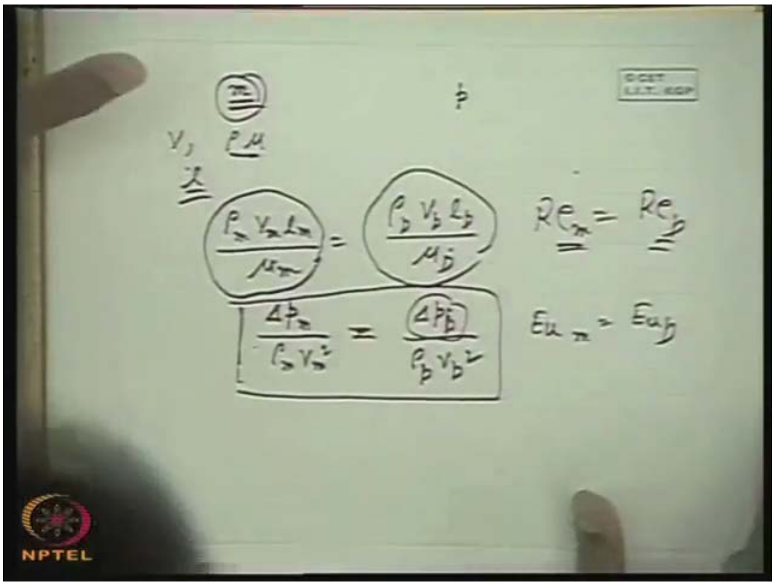

So therefore, in two systems governed by viscous, inertia and pressure force, the Euler number and Reynolds number have to be same. That means if we consider the two systems: one in laboratory, another in practice, usually they are denoted as model.

Laboratory experiment is known as model experiment and actual case is prototype, if we define by two suffix. Therefore, we can write. I must do the experiments in laboratory under different set of conditions, that I can choose different velocity, I can choose different fluid having rho mu from that in actual practice, I can choose different characteristics length for the problem, but such a way that rho V l, that means rho Vm lm by mu m, all must be equal to rho p Vp lp by mu p.

And similarly, delta Pm by rho m Vm square is equal to delta Pp. This criteria, that means this conditions, I have to satisfy. That means I will have to choose the variable such a way that for model that means rho V l by mu for model must be equal to that for the prototype. That means Re must be same for both model and prototype, that means two systems at different condition and equality of Euler number should hold good.

Actually, we fixed this. Do the experiments and from the equality of Euler number we predict the pressure drop in practice from the results of the pressure drop in model. So, model pressure drop will be always low than the practice pressure drop. Because the conditions are different, conditions are reduced. But if we equal the equality from equality we can predict this. So, this is basically principle. I will explain this again with respect to other classes of problem, governed by other types of forces, not the viscous, inertia, and pressure forces.

Thank you.