Similitude And Approximations In Engineering,

Vijay Gupta
Applied Mechanics
Indian Institute of Technology Delhi

Week - 01
Lecture – 04

Welcome back. In this unit, we will discuss the nature of quantitative investigations, what does it consist of, what are the uniquity parameters in quantitative investigations, and we will introduce the concept of similitude. All physical quantities can be classified on two different parameters, whether they are independent or dependent. Independent quantities are those which are in the control of the experimenter. They are something that do not even depend upon the phenomena. The dependent quantities on the other hand are those which are the results of the phenomena. I will elaborate with examples just now.

The other way to classify physical quantities is to classify them as variables or parameters. Variables are those quantities that change from point to point or from instant to instant in a given experiment, in a given phenomenon. While the parameters are those values which are fixed for a given experiments and do not change from point to point or from one instant to another. They are invariant for a given experiment.

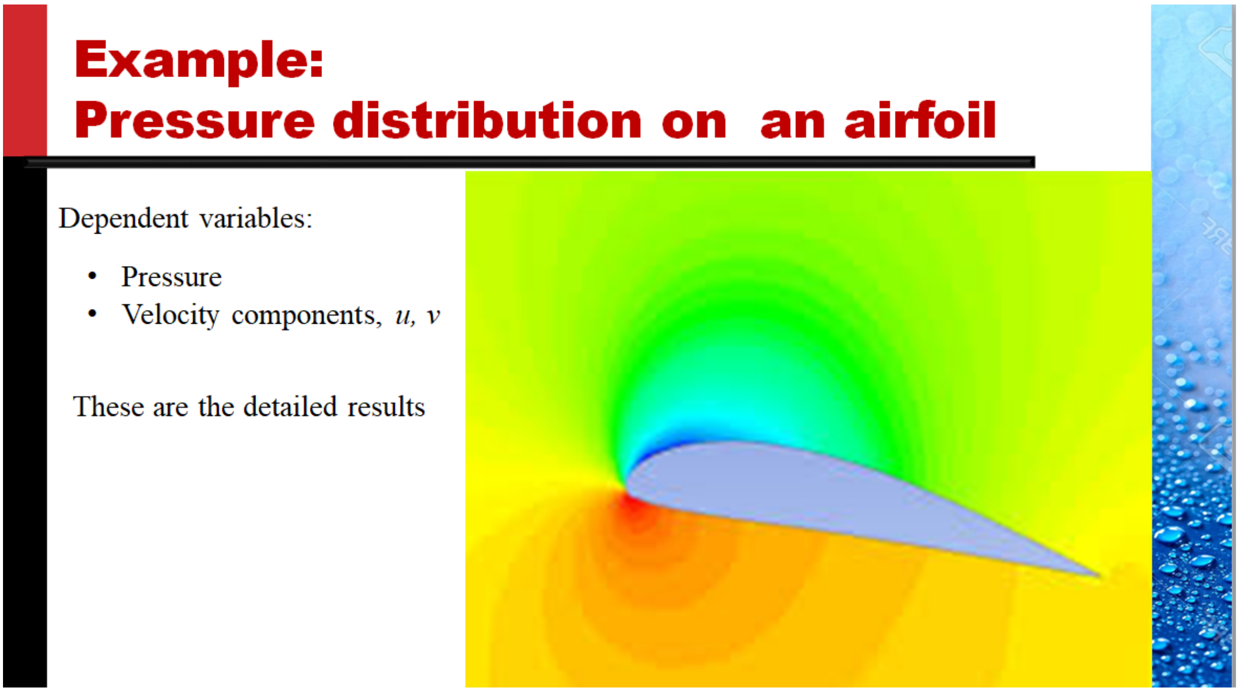
Based on this classification, we can have four types of physical quantities: independent variables, independent parameters, independent variables and dependent parameters. We will give examples to elaborate what we mean by them and what is the significance. Consider that the problem we are interested in is in finding the pressure distribution on an aerofoil, when it moves in the air. Similarly, the independent parameters, the parameters on which the experimenter has control are something like this: The geometry and the shape of the aerofoil, angle of attack of the aerofoil, the forward velocity of the aerofoil. These are all independent parameter. They do not change from point to point. They are not variable in a given experiment, in a given situation, in a given problem. Material properties, the air density, the air in which the aerofoil is moving, the viscosity of air, the ambient atmospheric pressure, these are all independent parameters.

They do not depend upon the phenomena. They are not results, they are inputs. So, parameters are inputs. We choose the atmospheric pressure that the working with, or if we do an experiment, we measure what the atmospheric pressure is and this is an independent parameter that does not depend upon the phenomena. All these parameters uniquely define the problems.

If we have defined each one of these parameters, we have uniquely defined the problem. The problem definition is complete. The situation of the problem has been completely identified. If we change any one of these parameters, the experiment has changed, whether it is a numerical experiment, analytical experiment or a physical experiment. It is for these reasons that these independent parameters are termed as uniquity parameters. They uniquely define a problem or there is a unique set for a given problem. The values of these would define a problem completely.

Now let us look at independent variables. We are interested in pressure distribution. So the location of the point along the surface is an independent variable, location x, y of the point along the surface of the airfoil.

If the flow is unsteady, then time also would be independent variable. The location does not depend upon the phenomena. It does not have anything to do with the fluid that you are dealing with. So these are independent variables. They change within an experiment. Different points, different times.



Now let us look at dependent variables. Clearly the pressure and the velocity components u and v on the surface of the airfoil. They change from point to point on the airfoil. They change with time in unsteady flow.

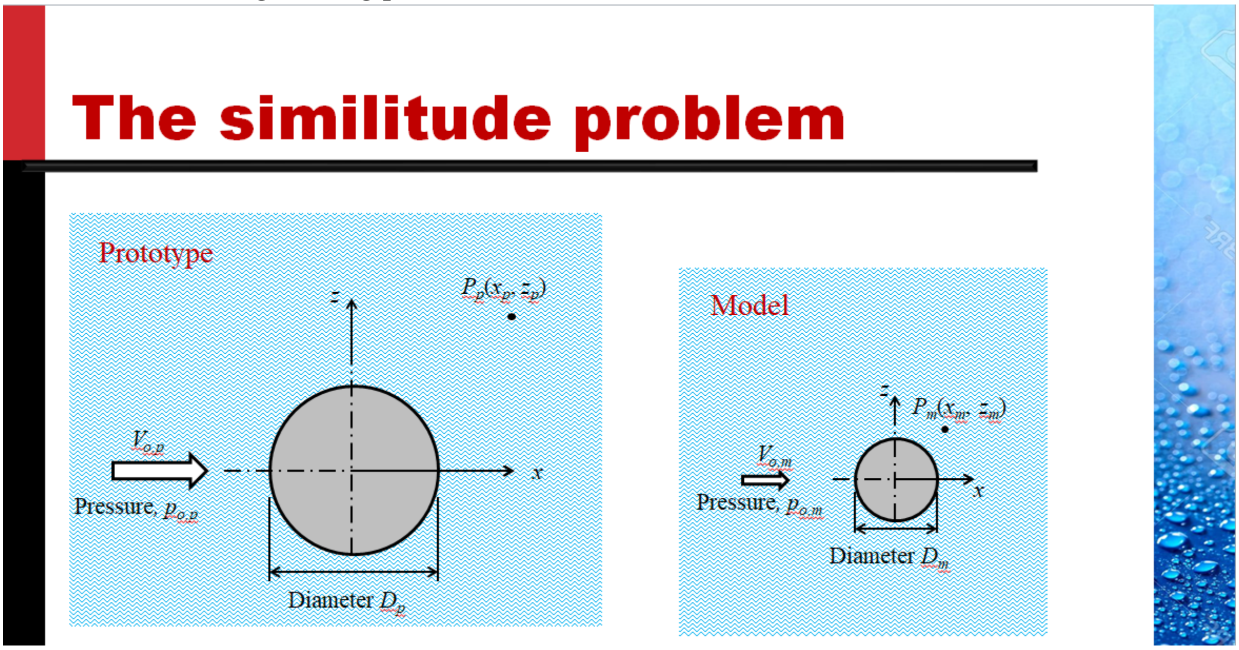
So these are dependent variables. And these produce detailed results. They give us at every point what the pressure is, at every point what the shear stress is, at every point what the velocity component is on the surface of the airfoil, or even anywhere in the flow field. Dependent variables: they are variables and they are dependent. They depend upon the nature of the fluid motion. They are the results of the fluid motion.

And then let us talk about the last category, the dependent parameters. Parameters are unique values for a given experiment. The total lift, there is only one value for the experiment in a steady flow. So it is a dependent parameter. It depends upon the phenomena. It is a result, so dependent. Total lift, total drag, a total pitching moment, we can define similar other quantities, lift by drag ratio, they are all dependent parameters. They are the results, and they are parameters, one value for a given experiment.

What is an engineering problem? How does an engineering problem look like? The engineering problem is to determine a dependent variable or a dependent parameter as a function of independent variables and the uniquity parameters. Dependent variables are functions of independent variables and the uniquity parameters. The uniquity parameters define the problem and independent variables are results at different points. Those are the independent variables. So a dependent variable is a function of independent variables and uniquity parameters.

Or if you are interested, a dependent parameter. A dependent parameter does not depend upon independent variables. A dependent parameter is function only of the uniquity parameters. To give an example: so to determine pressure as a function x and y, the location of the point on the aerofoil, we separate by a semicolon and then list the uniquity parameters. The shape of the aerofoil, the velocity far away, alpha, the angle of attack, the density rho, viscosity mu of the fluid, and p atmospheric, the atmospheric pressure.

These are all independent parameters. Similarly, the velocity u could be a function of the same set of independent variables and independent unique parameters. Or if the result desired is a dependent parameter like lift, the lift force L is a function of the shape v dot alpha etcetera. Function only of the unique parameters, the independent variables are not in this list. This is the nature of the engineering problem.



We can solve it by writing the governing equations and the applicable boundary conditions and initial condition and solve them analytically. This is the method of engineering problem solving that has been introduced to you in your high school and in early part of your engineering curricula; or by writing a computer program. And when we write a program, we have to give in the specific values of the uniquity parameters. We have to define an experiment. We cannot find the result in terms of V_o, the free stream velocity.

We have to give in the velocity V_o, and the result will be a number. So that is why many scientists call a numerical calculation as a numerical experiment because we are doing it for one set of uniquity parameters at a time. The third method is we can do physical experiments for specific values of the uniquity parameters and make actual measurement using appropriate sensors and instruments. Thus, we could make the aircraft. The wing flies with this aerofoil, have ports on the wings along the cord, along the surface of the wing, connect each of these holes, these ports to a pressure measuring instrument and measure the pressure when you fly the aircraft at a given speed in a given atmosphere with a given density, with a given viscosity and so on.

Now what is a similitude problem that is this course is all about? The whole business of similitude is to determine the conditions under which we can predict the values of dependent quantities, variables or parameters; for one set of independent parameters that is the uniquity parameters for one set of uniquity parameters from those obtained from an experiment physical accommodation with different though related values of the independent parameters. That is for example, we have to find the pressure distribution in the flow field of the flow pass this prototype cylinder with a given velocity $V_{o,p}$, with a given pressure $p_{o,p}$ and etcetera, etcetera. We do an experiment on a model, we do not work with this but we work with a model of a different sized geometrically similar with a different velocity, different pressure, could be different density, could be different viscosity. Can we predict the results for the prototype experiments from the result obtained from model? Of course we can, but only under very restrictive conditions. The uniquity parameters of this problem must be related to the uniquity parameters of this problem by a set of rules which are known as modeling rules.

And then if those modeling rules are satisfied, we can obtain the results of this problem from the results of this problem by using appropriate prediction rules which are also developed in the theory of similitude. This in brief is this basic problem that we will deal with, the core problem that we will deal with in this course to find the modeling rules and to find the prediction rules. Modeling rules, so that the two problems are similar, and the prediction rule so that we can make the required prediction.

Thank you.