Introduction to Fluid Mechanics and Fluid Engineering
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Lecture – 01
Introductory Concepts

Welcome to the course of introduction to fluid mechanics and fluids engineering. This particular course will be spread into various lectures and today we will have the lecture 1. Before going into the course, I think what is important for all of us, is to recognize that there is a motivation behind learning fluid mechanics. So, we will first go through few examples that we (()) (00:54) us the motivation and then we will get into the fundamental topics that we intend to cover.

Now, fluid mechanics is almost everywhere in human life and let me give you some examples to illustrate what are the important applications of fluid mechanics.

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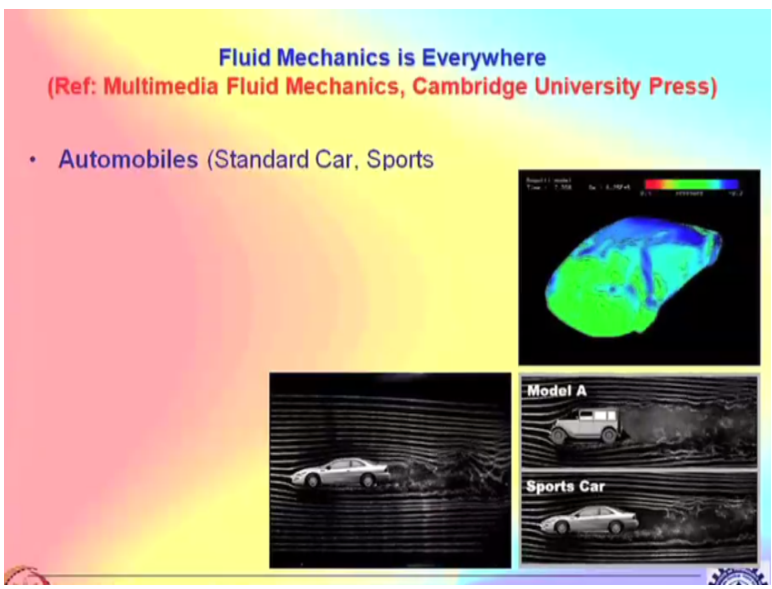

Let us think of automobiles. When we think of automobiles, I mean automobiles are the basic elements which many times motivate young minds to study fluid mechanics and really there is whole lot of challenge in designing automobiles based on the requirements of fluid mechanics, based on the constraints given by some considerations of fluid mechanics. For example, if you want to design the shape of a car, the shape of the car should be such that it should minimize the drag force or the resistance force.

We will come into what is drag force and how it can minimize later on in our course, but it gives one of the important motivations.

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Now when we think of vehicles not just automobiles which run on land are important, but we have also water crafts, boats, and ships, and as you can see here in this visualization that there can be nice flow patterns, very interesting flow patterns that can be generated as the water crafts are propelling in water, and there can be again a whole lot of analysis that can go on in the background to make sure that one can minimize the resistances against the motion of the water craft.

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Now, we come to a third example, which deals with spacecrafts. Spacecrafts are the most fascinating of all the examples that we intend to highlight and you can clearly see that let us say that when an air craft is taking off or landing or when a space shuttle is moving, so you can see nice visualization of flow and these nice visualization of flow is a very natural way of visualizing the flow.

So what is happening is that the smokes are products of combustion are coming out and these are basically highlighting the flow patterns that are surrounding the aircraft or the spacecraft. So this is a very nice way of visualizing the flow not just qualitatively, but one can get quantitative insight on the details of the fluid flow that is taking place and again the very basic principles of motion of these aircrafts or spacecrafts rely on fluid mechanics.

Many times again the issue of not just a drag force, but a lift force that is important, because the lift force pulls the aircraft up in the sky and many times one may need to use fundamental considerations like say laugh, conservation of linear momentum and some other basic principles or Newton's laws of motion and some modified versions of these which can be used for fluid flow analysis.

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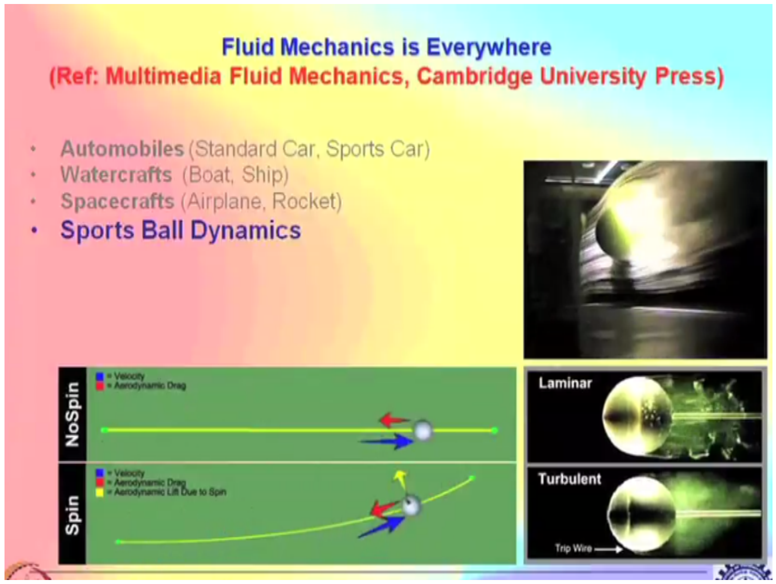

Now similar to the concept of flow around automobiles and watercrafts and aircrafts, we can have interesting interaction between fluid flow and sports balls and all of us experience that sports balls under certain conditions can spin or can swing and there is an interesting fluid dynamics that goes behind the swing or spin of sports balls. It is a very involved topic and in one of the lectures later on in this course we will discuss in details about the sports ball dynamics.

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Coming to the material world, I mean in engineering, we deal with lots of industries and industries many times are basically comprising various plants, power plants, and process plants, for example. So you can see that there can be interesting flow patterns that can be observed because of emissions of products of combustion from the chimney that you can see in one case and may be also similar flows can be visualized in process plants as well like a fluid treatment plants.

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Now fluid dynamics it is not just in the material world of automobiles and power plants and process plants like that. Fluid dynamics is there in nature and it is such a beautiful pattern or gallery of patterns of fluid flow that can be visualized if we really observe nature in a vivid way and what you can see here is that in Tornado, in rivers, in raindrops what interesting flow patterns can be observed.

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Now nature is not just made of inanimate objects. So there are animate objects like animals and you can see interesting flow around butterfly, snake, fish, and all these are really giving rise to very intriguing fluid flow patterns, which can be observed in nature.

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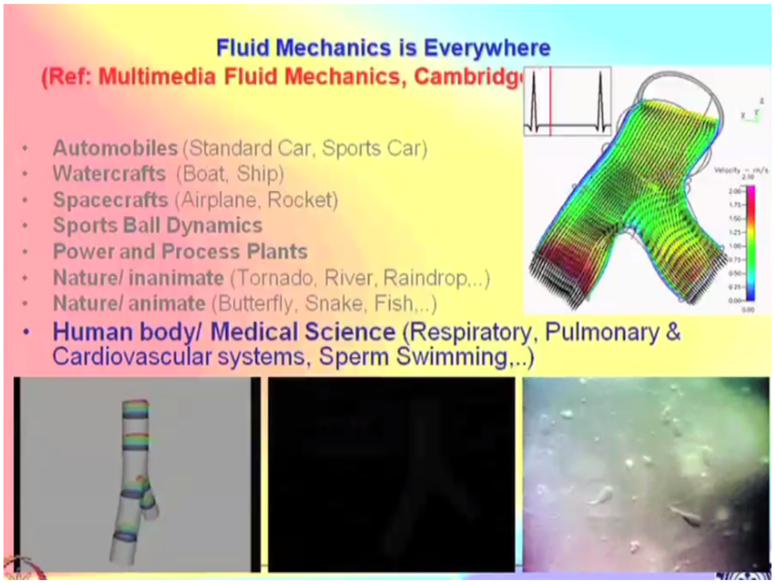

Now when we discuss about nature, I mean we basically come into the domain of biological sciences and life sciences and one of the important follow up is science of human bodies or science of living systems or medical science. The human body for example is a paradise for fluid mechanics to make their own analysis for studying the respiratory system, pulmonary system, cardiovascular system, swimming of sperms, and all these are very intricate.

And if one gets a complete understanding of these it gives rise to not only a fundamental physical insight, but also may be strategies to combat various life threatening diseases and I will just give you one example to illustrate the complicacy involve. Like, let us think of flow of blood through arteries and veins. This is a very common thing in human body mechanics. Now think off and analogue in an industrial system like flow of water through pipes.

Now can you tell, what are the basic differences between flow of water through pipes and flow of blood through arteries and veins? You will immediately come up with some obvious differences like blood is a much more complex fluid than water, but the complexity of blood as a fluid is not a mystery now. I mean it is somewhat appreciated and understood not to the fullest extent, but to some extent it has been well understood, but the problem is that it is not just the issue of blood as a complex fluid, but think of blood vessels.

These blood vessels are flexible. Their diameters vary with local blood pressure and till now it is of mystery in fundamental science that how the diameter of blood vessels should vary with locally with blood pressure. This is not yet fundamentally completely understood. I mean one can go through empirical formula to express this, but it is not yet fundamentally well understood. So you can well appreciate that an apparently and illusively simple problem like flow of blood through arteries and veins can give rise to very complicated considerations in fluid dynamics.

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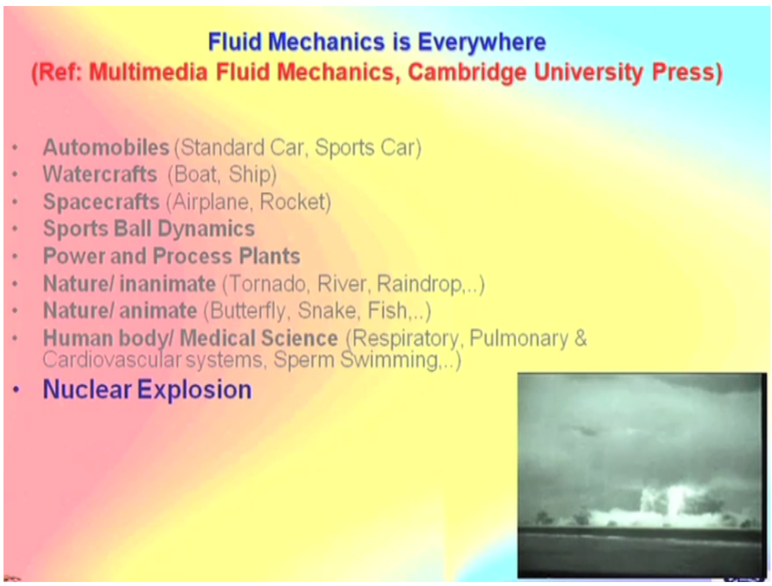

Now coming from human body mechanics to something let us consider as an example of not so humanistic like nuclear explosion. So, you can see and example like of the flow that is taking place because of nuclear explosion in the view graft that is being presented and then like when there is a fluid there is also an interacting structure that is interacting with the fluid. So, there is often a very interesting interaction between fluid and structure and critical situations may occur when there is a fluid.

Let us say wind blowing passed a bridge with an imposed frequency that imposed frequency matches with the natural frequency of the structure. Then there is something called as resonance and because of this resonance the structure may oscillate or vibrate vigorously and there can be failure of the structure in this example the bridge has totally collapsed and eventually it is going to collapse in this figure in this view graft and that collapsing of the bridge, collapsing of the structure is because of the intricate interaction between the fluid and the structure so fluid structure interaction is also a very important and interesting modern day topic.

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Let us come to more common day to day examples like food or drinks of course we need to understand that, I mean this issue we will discuss later on that sometimes it is very difficult to demarcate between a food and a drink whether it is a fluid or it is a solid or if something in between fluid and solid these kind of questions come and hard demarcations are many times difficult. For example, gel like matters.

Now what we call them, should we call then fluids, would we call them solids, I mean of course there are very standard descriptions and theories to describe these matters, but these are important and interesting topics in fluid mechanics and which deal with the constitutive behaviour or the behaviour of the substance as it is and typically it belongs to the study of rheology of fluid flows.

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Even something not so fluid. Now looking into this, particular view graph that is being shown can you tell what does it represent? Yes, you are correct. It is the traffic. If you visualize the traffic from altitude, you will see that the traffic in a typical city will be moving like this. So traffic flow although it is not the physical flow of a fluid has some resemblance with the physical flow of a fluid and there is lot of research that is currently going on and has in the past being going on in the area of traffic flow.

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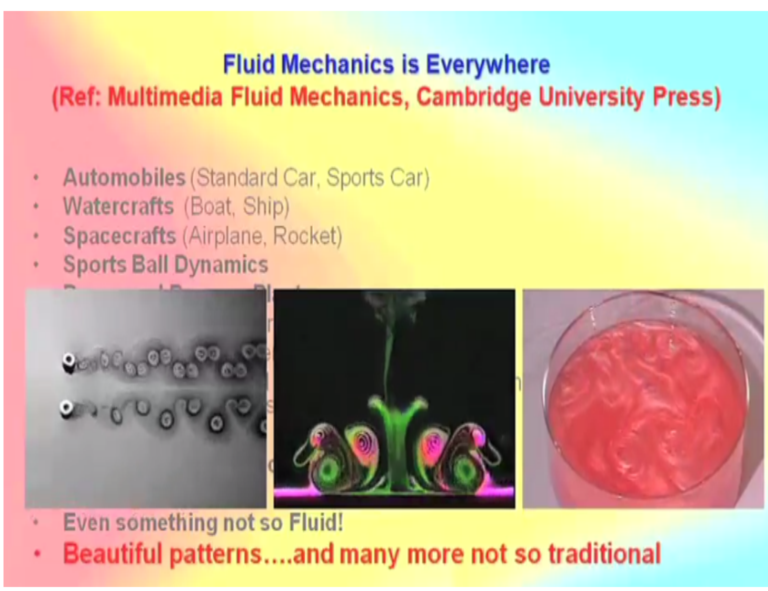

Now the issue is that should we study fluid mechanics just because there are so many applications in the industry, in the nature, and so on. But, sometimes we may study fluid mechanics just because we are fascinated with beautiful flow patterns. So you can see these examples, these flow patterns which are being demonstrated here. These flow patterns are so interesting and so fascinating that if one is interested to study the structures of these flow patterns demonstrates these flow patterns through experiments, it is like fluid mechanics gives us a structured way of understanding these patterns.

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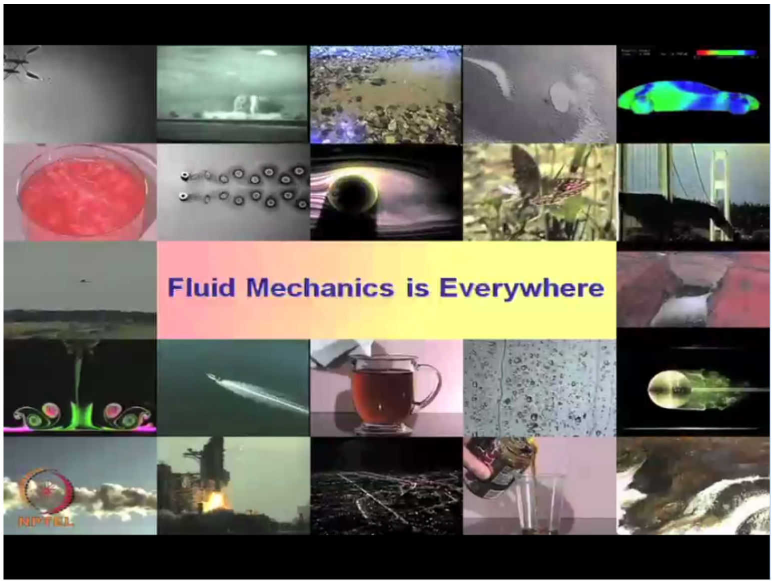

So to summarize the discussion that we had so far, we can conclude that fluid mechanics is everywhere. Fluid mechanics is not just in inanimate objects, or in animals, but fluid mechanics is everywhere in the world. So there is a lot of motivation in studying and understanding fluid mechanics.

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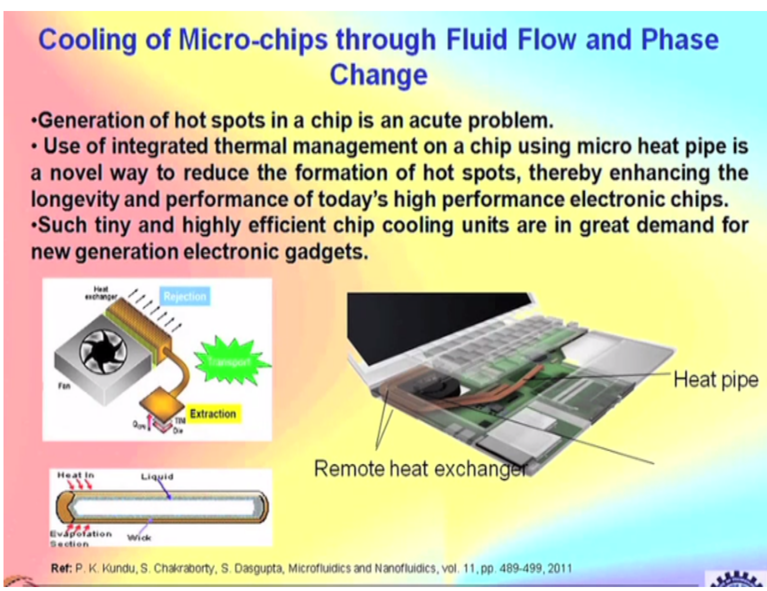

Now when we say fluid mechanics is everywhere and we have given certain examples, the examples that we have given so far are somewhat traditional. Now we can give some more examples where fluid mechanics in a different way is relevant for modern day applications. Like the first example that I want to give you is cooling of microchips through fluid flow and phase change. The motivation of this is as follows:

As we have come to the modern era what we find is that the sizes of the electronic devices are getting smaller and smaller. Despite the fact that sizes of the electronic devices are getting smaller and smaller, the power dissipation is not getting progressively reduced. So what it means is that the power dissipation per unit volume is getting significantly increased because of reduction in volume and that makes the devices over heated.

So you may not be surprised to know that many of the electronic devices actually fail not because of the failure in electronic design, but failure in thermal design that is those materials cannot withstand that high temperature. So how can we address this? Of course you may say that we can employ a fan, but yes, we have to understand that if you have a small miniaturized device your entire purpose of miniaturization will be lost if you have a very small device and to cool that small device you require a large fan.

So you require a compatible cooling arrangement. So what you can do you can for example employ various strategies. One particular strategy is you can employ change of phase. So you can have a liquid which takes heat from hot spots of the electronic device and can change its phase. The liquid can flow through a microchannel which is a very small channel, the channel of the order of micrometer dimensions and then when this liquid gets evaporated, the evaporated fluid moves to a different place in the channel and can get condensed.

So there can be an evaporation, condensation simultaneously going on to complete the loop and this mechanism is used in even industrial applications. This is known as heat pipe and in a miniaturized environment this is known as micro-heat pipe. So there is a lot of interesting fluid mechanics that goes behind. We do not have scope for discussing that at this moment, but it is just to let you know that these kinds of interesting applications do exist.

There is also another technology which is called as droplet based microfluidics. So what you can do? Basically, you take small droplets. You arrange for small droplets and these droplets will go and sit on hot spots on the electronic device and observe heat from that hot spot and so it is very interesting to design the movement of droplet so that they can move in an optimal part and in the shortest time, they go and sit on the right hot spot and take away heat from that hot spot.

We have to understand that fluid dynamics is so interdisciplinary as a subject that it is not a subject just within the jurisdiction of mechanical engineering, chemical engineering, aerospace engineering, civil engineering like that. If you are interested to design an optimal path and make chips for transmission of the droplet according to that optimal path design, then you require to interphase with electrical engineers and computer scientist. So it is really emerging as an interdisciplinary subject.

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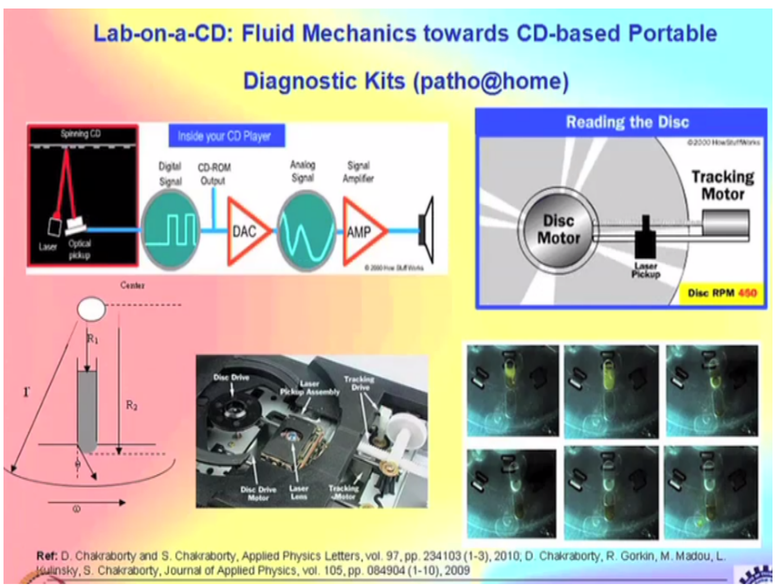

Now, I will give you couple of more interesting applications and these applications essentially deal with health care engineering. Now what is health care engineering? Health care engineering is an interphase of health care with engineering and let us see that how fluid mechanics plays a role towards that. So in health care engineering, many times what we require is rapid diagnosis of a disease and this is a classical problem.

It is a problem relevant in many countries especially in the underdeveloped countries that you know that let us say that a person is suspected to have a certain disease. Now the person cannot go to a pathological laboratory because he or she does not have access to high class pathological laboratories. So it takes time to take the blood sample. Let us say as an example and that blood sample is tested in a sophisticated laboratory.

By that time, the result of that test comes and it is quite expensive to get the result of the test and it is time consuming and by the time the result of the test comes the patient may be under very serious conditions. So as an alternative one can go for various technologies. So, one can have small devices which are called as lab on a chip or a device which is like a rotating disc that is called as lab-on-a-CD. It is like the compact disc for external data storage in a computer.

So what we can do is you can have micro-channels or small channels are cut in the disc and you put a droplet of blood just a small droplet of blood, not a huge volume of blood drawn from the patient and then you spin the disc in a small motor and that is a portable system so that can be taken to the patient itself. this is called as point of care way of handling medical diagnostics and then this blood sample is dropped and then within the channels, there are various reactants.

And because of reactions there can be for example change of colour of the blood sample and a particular change of colour can give rise to the indication of a particular disease and here fluid mechanics comes in a big way because you need to have a proper design of what is the rotational speed of the compact disc for most efficient transport of the blood sample. So this is one example.

There can be several other examples given and then once the test results come, immediately these test result can be conveyed to a medical doctor may be through SMS in the mobile phone system and then the medical doctor can immediately advise for a treatment and this entire process can take place within a few minutes and so it is very rapid, it is inexpensive, it is portable and if this kind of system comes into the market it can really solve some of the challenging problems in medical diagnostics in many places in the world.

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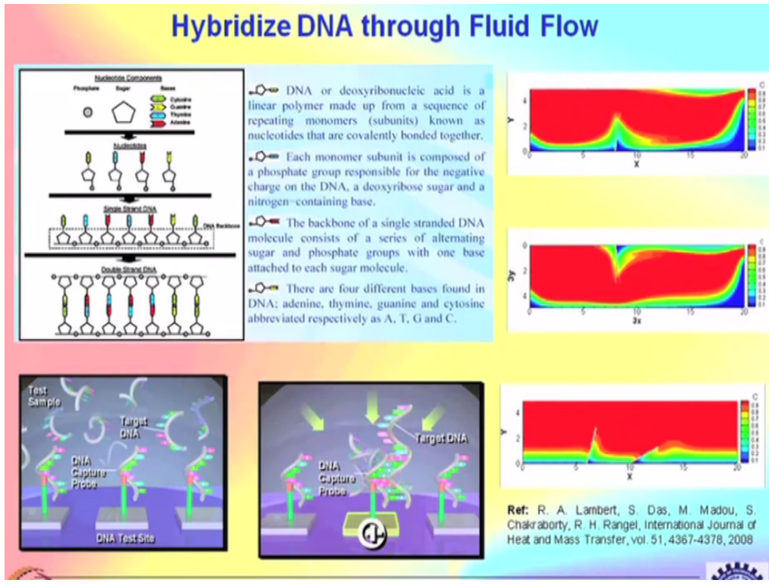

Another example like which is related to the medical science is DNA hybridization and DNA hybridization basically refers to like identification of a particular sequence of bases in a DNA which can indicate the existence of a certain disease. Like all of us know that DNA is a linear polymer made up of a sequence of repeating units known as nucleotides and each monomer is composed of a phosphate group which is schematically shown in the view graph which is responsible for a negative charge in the DNA. deoxyribose sugar and a nitrogen containing base.

So there are four different bases found in DNA A, T, C, and G. So if you want to identify a particular disease it may be related to the sequence of base, a particular sequence of bases like AA, TT, GG, CC like that and it is known that A and T want to get combined with the help of hydrogen bond and G wants to get combined with C with the help of hydrogen bond. So A is complementary to T and G is complementary to C.

So if you want to identify whether a particular sequence of DNA bases is present in a DNA sample then what you can do, you can put a complement of that interrogating sequence on the wall of a small channel and pump a DNA sample with single strands. So what you can do is that first you break the cell which is called a cell lyses and bring the DNA out of it and then you heat the DNA sample so that the double-stranded DNA gets broken into single strands.

Then you pass the sample through a fluid flow. So when you pass the sample through a fluid flow there is an interesting interaction between fluid dynamics and the transport of DNA and that can control effectively that how fast you can achieve these hybridization reactions and if you can achieve these hybridization reactions fast then it is possible to like get an answer whether a particular DNA sample base sequence is there in a DNA sample are not, and rapid diagnosis of certain diseases can be made.

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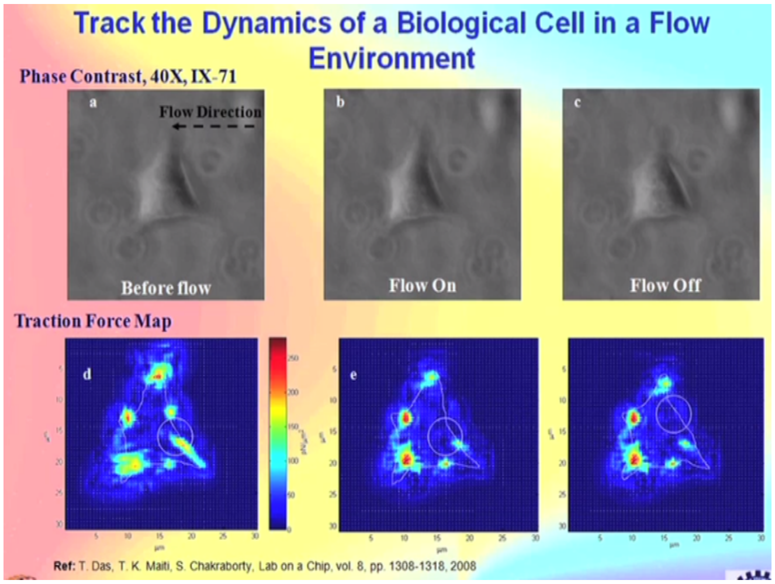

Next, example is to tract the dynamics of a biological cell. Now biological cell is a very interesting object in general and there are several motivations of studying biological cells in a small confinement. In human bodies there are hierarchical structures of blood vessels. You have large arteries, large veins, small arteries, small veins, arterioles, venules, and micro capillaries.

The micro capillaries are of the order of micrometer dimensions and cells are also of the order of micrometer dimensions like typical length scale of a cell in a human body may be around 10 micron. So when these cells are moving through human bodies let us say, let us think of a challenging problem of like how to understand cancer progression. So, one of the lethal stages of cancer progression comes when a cancer cell from its origin moves to a distant location within the human body moving across the blood vessels.

So when it moves across the blood vessels, it has to also move through microcapillaries and there is a tremendous resistance that comes from fluid dynamic considerations for moving against moving of cells through microcapillaries. Despite that cancer cells are able to survive under that stressful conditions were normal cells are not able to survive. So can fluid dynamics give an answer to this question that why cancer cells can survive effectively in a microfluidic confinement where the normal cells are not able to do?

So there are several possible answers and some of the answers, I am not going into the answer. This is not a research presentation. So I am not going into the answer to this question or possibly answer to this question. I am just giving you some clues where fluid dynamics find this relevance in this application. So the cell membrane if you look into the cell, the cell membrane in its composition is somewhat fluidic in nature.

So, the fluidity of the cell membrane has something to do with the malleability of the cell and the manner in which a cell membrane can control its fluidity based on that it depends on whether a cell can adapt or adjust its shape effectively to withstand a stressful condition and a cancer cell possibly does it in a much more better way than a normal cell.

So that is how a cancer cell survives in a stressful condition and it is a very important and interesting area of research because if one understands the proper fluid dynamic mechanism that goes in and around the cancer cell which controls the adaptation of cancer cell then possibly newer and newer drops can be discovered that can inhibit the survival capacity of cancer cells in a stressful environment.

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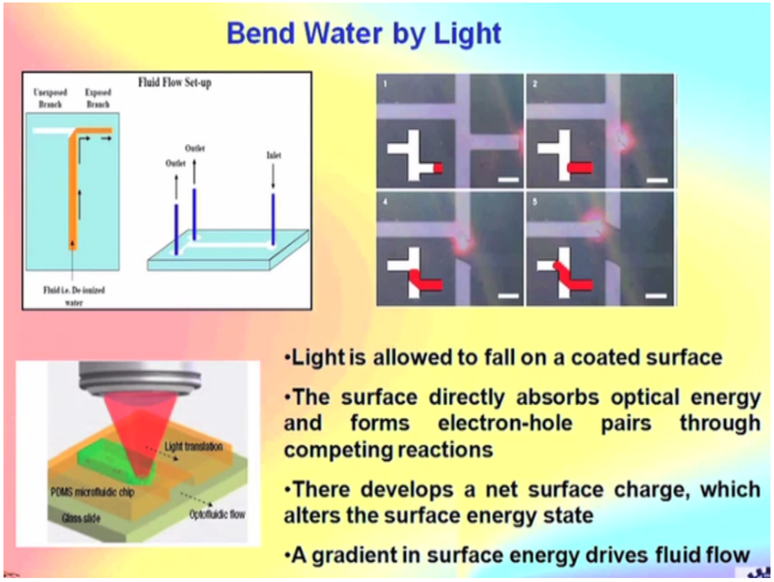

Coming from a biological example I will give you another example which does illustrates that fluid dynamics can be multi-physics. So multi-physics means that you just do not require only flow physics. The flow physics may need to be combined with electrohydrodynamics, magenetohydrodynamics that is electrical sciences or electromagnetic (())(30:53) or sometimes optics.

So this is called as multi-physics where physics from multiple disciplines need to be converge together to solve a fluid dynamics problem. Like let us look into this slide, where we intend to show that, you can bend water or move water by using light. So what is the strategy briefly the strategy is as follows: You coat the surface of a channel with a metal oxide semiconductor say titanium dioxide or zinc oxide and you shine ultraviolet light on that.

So, when you shine ultraviolet on that so because of the typical energy gap you have its compatible energies that is provided by the ultraviolet radiation and immediately electron whole reactions will start. So based on that the surface will either acquire a positive charge or a negative charge depending on whether it will have excess holes or excess electrons. I am not going to the exact details what happens in this specific case.

But the net effect is that the surface energy gets altered. Because the surface energy gets alter a surface which was earlier disliking water may start liking water, that is from so called hydrophobic it becomes hydrophilic and water will move into that direction. So you do not require a physical pump to drive water. You just require a source of light to drive water and you can even bend water by light.

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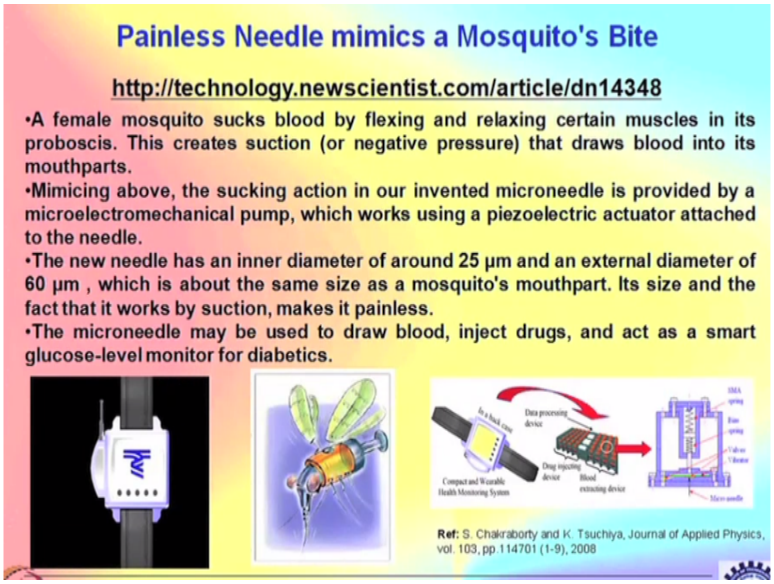

I will come to another very fascinating example just to illustrate the kind of importance that fluid dynamics may have not just in medical diagnostics, but also in medical treatment or in a combined package of diagnostics and treatment. So we can think of like injection for sucking blood, for testing the blood sample, for example may be for testing for sugar level in a diabetes patient and then transferring insulin to the same person based on the prevailing level of blood sugar.

So this is a very common procedure that many patients have to undergo throughout their life and it is not a very comfortable process. So one of the alternatives that one can think of is instead of a traditional needle one can think of a microneedle, very small needle and the typical microneedle may be designed by mimicking the act of a mosquito's bite. This is called as biomimetics. Like this biomimetics, it does not mean that we just copy what is there in nature.

It is impossible to copy what is there in nature, but we can get some lessons out of it for example when a mosquito sucks blood it typically creates a suction pressure or a negative pressure that draws blood into its mouthparts. So you mimicking the above the sucking action in a microneedle may be provided by a microelectromechanical pump and it can draw the blood very small volume of blood then there can be testing of the blood.

Let us for example say a metal oxide based semiconductor or Mosfet not a metal oxide semiconductor but a Mosfet based blood glucose sensor and then based on that we can immediately get a result that whether what is the amount of glucose that is there in the blood sample. So that the Mosfet-based sensor gives that answer and then based on that there can be a smart insulin delivery system and this entire process can be built in a package which looks like a wrist watch which is shown in this view graph.

So this is just to say that one can have small needle and the needle really can make sure that you can have a very smart painless testing of blood sample to get the amount of glucose and deliver the insulin accordingly. How does it work? One of course is the like creation of the suction pressure, but the design of the microneedle is based on the fact that in the microscale in fact mosquito's labium is also of micrometer scale like typical 25 micron to 50 micron diameter and in the typical micrometer scale surface tension works beautifully.

There are certain forces which are not that important in the large scale, but may be important in the small scale and surface tension is one such force. So because of the surface tension working beautifully the droplet of blood which is sucked from the bottom of the skin can be transmitted easily with a very little indentation force and that makes the device to work in a painless manner.

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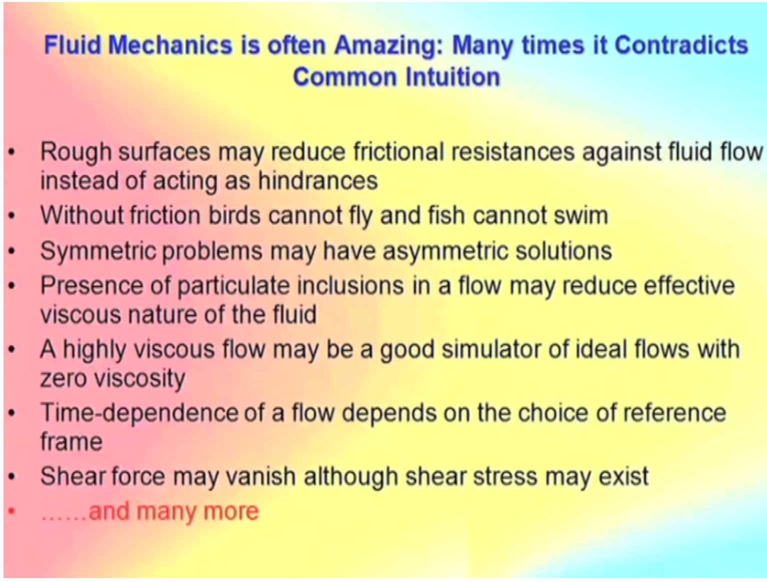

Fluid mechanics is often amazing. So I can go on giving you examples, but I just do not want to like overburden you with examples. I just want to let you make you feel that fluid dynamics is not just the traditional automobiles or aircrafts, or power plants or process plants that we can think of, but fluid dynamics is just in all aspects of modern science and technology and it is often amazing because many times it contradicts common intuition like rough surfaces may reduce frictional resistances against fluid flow instead of acting as hindrances.

Without friction birds cannot fly and fish cannot swim. Symmetric problems may have asymmetric solutions. Presence of particulate inclusions in a flow may reduce effective viscous nature of the fluid. A highly viscous flow may be a good simulator of ideal flows with zero viscosity and time-dependence of a flow depends on the choice of a reference frame like you cannot say whether the flow is steady or unsteady until and unless you specify a reference frame.

Shear force may vanish although shear stress may exist. So these are certain very interesting phenomena and many more which contradict common intuition and this is what is important alike from my perspective what I can shear my own perspective or philosophy with you that all of us are born with certain intuitions like even if you put even if there is a very little child who puts his or her finger in fire he or she knows that it will burn.

So this is something which is intuitive and this intuition is correct, but while going through experience in life one understands that there are many natural and physical phenomena which do not go by intuition and then to get an explanation to that to me that is the proper learning of science.

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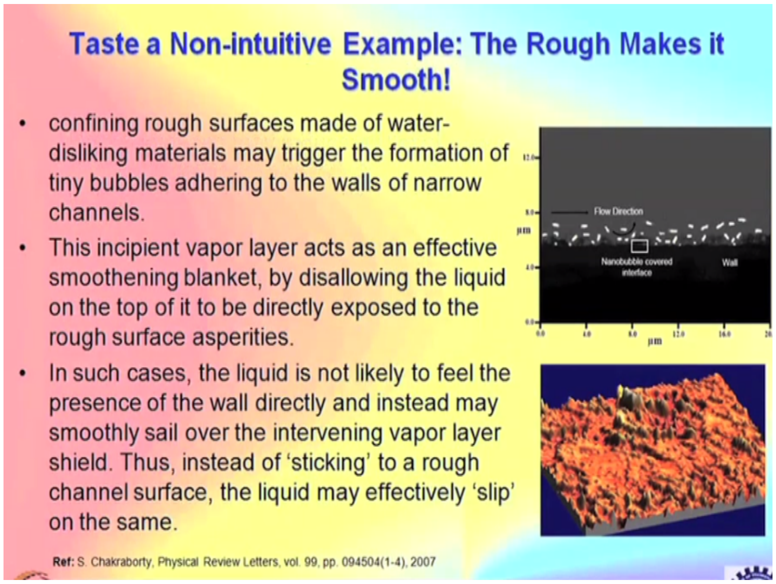

So I can give you a non-intuitive example that if you have rough surfaces, the rough surface is suppose to create more hindrance against fluid flow, but under certain cases it can be shown that the rough surface may reduce friction, not explicitly, but implicitly. What it can do that if you have a rough hydrophobic surface in a small confinement, then this surface can give rise to small bubbles nanometer scale bubbles and the liquid which is flowing on the rough surface is not directly feeling the effect of the rough wall, what it is doing?

It is gliding on the cushion layer of the bubbles. So we can say that it is a rough that makes it smooth because the roughness of the surface is one of the key factors that has triggered the formation of these nanoscale bubbles and the liquid water that is moving on the bubbles this is just flowing in an apparently frictionless manner because it is not inter phasing with the rough surfaces directly.

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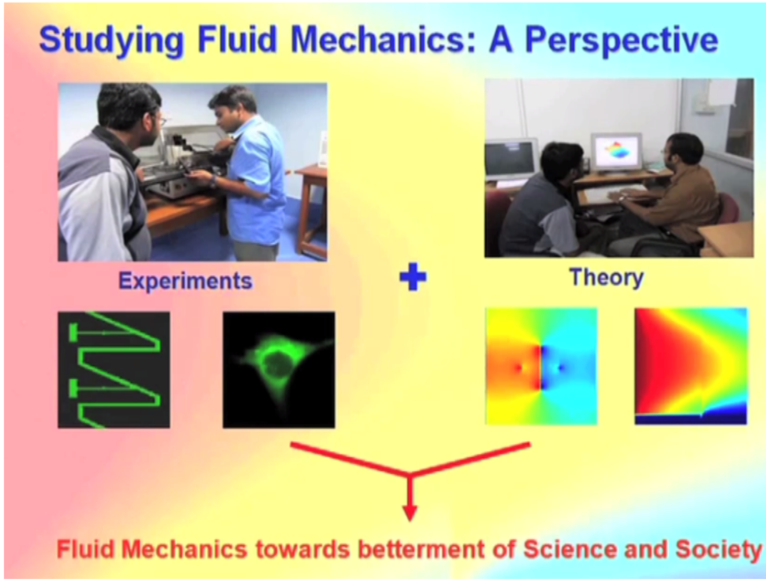

So studying fluid mechanics we can give a perspective although this is primarily a theoretical course, but we will have several video demonstrations to make it like actual experimental environment, but we will be mostly discussing on theory and experiments and theory need to go together to for us to learn fluid mechanics and from the various examples that I have illustrated my emphasis is that like fluid mechanics can really be used to understand not just fundamental scientific issues, but to help towards the betterment of the society.

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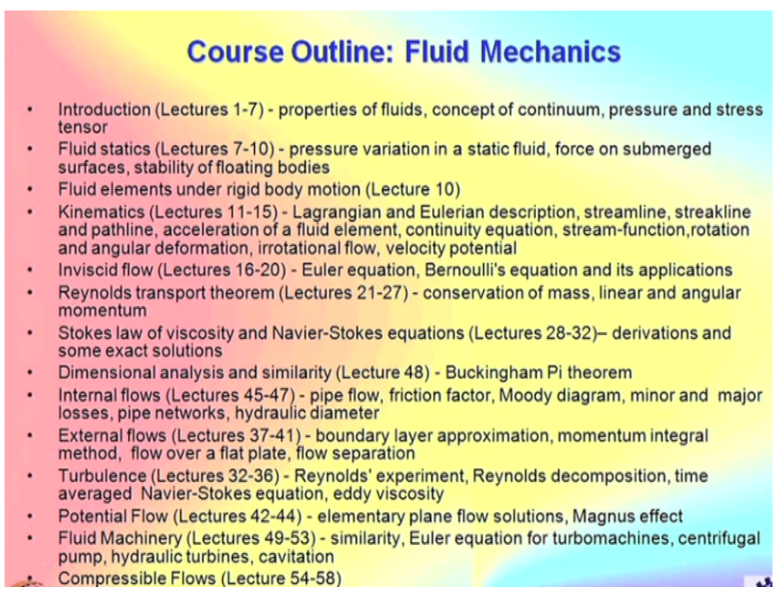

This is the course outline that we will be following. I mean that this is a tentative lecture wise breakup and hopefully we will be able to like follow these break up more or less what is indicated here and this is a standard fluid dynamics course. We will have sort of crash course on fluid mechanics to fluid machines towards the end of this introductory course of fluid mechanics and we will be also having some lectures on compressible flows. So the detailed course structure is here and we will be having a text document that will be shared with you that contains the same information.

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We have a video reference for this course. So many of the videos that we will be demonstrating these are videos taken from collection known as multimedia fluid mechanics published by the Cambridge University press and we acknowledge gratefully that we are happy to like show some of the very interesting like interviewing videos in the multimedia fluid mechanics we have already shown some of those in the introductory part of this particular lecture.

But there will also be several other chapters where we will be showing demonstrating various videos and in this various videos many of these videos are taken from the multimedia fluid mechanics published by the Cambridge University press. So with this little bit of introductory mark, we will move on to an issue which we want to discuss before discussing what is a fluid? That in fluid mechanics the initial discussion will typically always start with what is a fluid.

It is a very involved question, but it is also important to understand that many times we have an intuitive idea of what is a fluid, but like before that we will try to see that even if you know what is a fluid? Question is what is the perspective in which we are going to analyze the motion of it? To come into more concrete terms, we will consider a gas.

When we consider a gas we are definite that like it is a fluid, because there is certain substance, there are certain substances which fall in the interphase of a fluid and a solid so we are not going into liquids at this moment and we are just concentrating on gases because all of us agree that it is a fluid by the sense that like it conveys to us from a common sense. Now let us say that there is a container.

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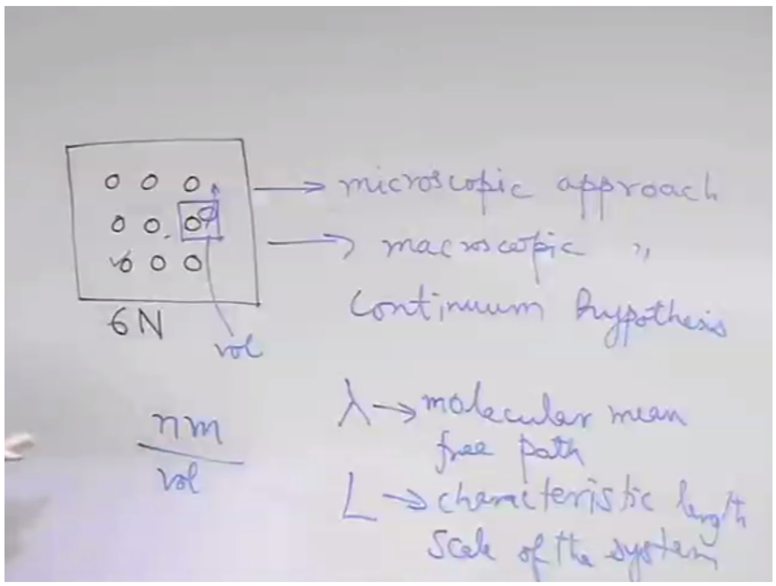

In this container there are some gas molecules. Question is that how do we analyze this system? One possibility is that we write the equations of motion for each of these molecules. When we say that we are interested to write equations of motions for each of these molecules think about a situation. Each molecule may have 3 transitional degrees of freedom and 3 rotational degrees of freedom that means, 6 independent equations for each molecule into the number of molecule.

And the number of molecule I think of just 1 mole and 1 mole really a small quantity we will have Avogadro number of molecules. So think of a realistic system so how many of unknowns you have and you will have this number of matching equations of motion and you have to solve for that to get a physical picture of the molecular motion. So it is a fundamental way of analyzing the motion and is known as molecular dynamics, but one has to understand that it has practical limitations that it cannot really address a very large system.

It can address only a small system with number of molecules not significantly large depending on the computational resources it may be 1000 or more, but it cannot be prohibitively large. So what is the alternative? There are a couple of alternative. One alternative is that instead of addressing individual molecules you can make a statistical average of many molecules. So what you can do is instead of directly simulating the molecules you statistically represent a group of molecules by statistical properties, and that is what is commonly done in kinetic theory of gases.

So in kinetic theory of gases what you do you address the behaviour of a gas statistically and it is because you do it statistically you really do not have to simulate individual molecules in a real sense you have to just simulate the statistical behaviour of molecules in a stochastic sense. So that makes the analysis computationally little bit more convenient and that is known as microscopic approach.

Now we have to understand that microscopic approach being convenient it may carry some of its important implications. For example, if you want to make a measurement, let us say you want to make a measurement of pressure of a gas so microscopic approach really does not give you a clue of how to go about that instead of that you may have a more convenient approach you just have a device which measures the time average normal force over a given area and divide the force by the area to get what is known as pressure.

In the microscopic approach, you will find pressure because of as a consequence of change in molecular momentum as it encounters a collision, but in a macroscopic approach you just do not care about all those but you just find time average force over a given area. So that is called as macroscopic approach. If the macroscopic approach is working, then that is best for us because then you can treat the fluid as a continuous medium disregarding the discontinuities.

So you can think of that the fluid is like a continuous medium and that is known as continuum and the hypothesis that tells that the fluid can be considered as a continuous medium disregarding the discontinuities inside following the macroscopic approach is known as continuum hypothesis. So question is does the continuum hypothesis always work? Or it may not work.

The thing is that if the continuum hypothesis works it is the most convenient to use because we can use well known rules of differential calculus to calculate the gradients of properties. So we can express the behaviour through well known differential equations of fundamental physics, classical physics to represent the property variations within the fluid, but the issue is that can we do it for all cases.

To get more detailed insight on that let us say that we are interested to calculate the density of a gas. To calculate the density of a gas what we need to do, we need to basically identify an elemental volume we find out the number of molecules in that elemental volume. Let us say that m is the mass of each molecule so this is the total mass/volume. So far so good, but how small the volume should be.

To get a real point-to-point variation this volume should be as small as possible but not tending to 0. It can tend to a critical volume up to which the continuum hypothesis will be valid, not below that. Why not below that? Because then the interrogating volume may really have a very few number of molecules. If it has a very few number of molecules then what will happen, then these molecules remember they are in random motion.

So what is going to happen is that let us say there is one there are 2 molecules and suddenly 1 molecule is out of this which is a very common thing that can happen, then it can give rise to an error like which is like a 100% type of error that it can give rise to or 50% type of error depending on how you are measuring the error. So when you have this high percentage of error then that means that is because of the uncertainties in the molecular occupancy of the chosen interrogating volume.

So when can that happen? That can happen if the balloon is very small or the volume may not be the small, but the system has a few number of molecules that is called as a rarified system. So we can understand that because of uncertainties with regard to the number of molecules when it has a large number of molecules it is fine, but if the volume has 2 larger number of molecules then if the balloon is itself is large to handle that then we do not get point to point variation of properties.

So what we really what is the small volume? but that should contain sufficient number of molecules and that means it is a rarified system. The next question comes what is sufficient number of molecules? How many number of molecules you say that it should be sufficient or when do you say that the system is larger, the system is smaller, when do you say that to understand that, we will come into more quantitative terms, because smallness or largeness is qualitative.

If we say that the system is small you may say that it is small to you, but it is large to me so it is always important to make a quantitative assessment of the smallness or largeness. To understand that what we can do is we use one of the important quantities, which is lambda. What is lambda? Lambda is the mean molecular mean free path. Molecular mean free path is what molecular mean free path is the average distance that a molecule will traverse before encountering a collision.

So that is the molecular mean free path. Now system is relatively rarified if the molecular mean free path is large that means there are few molecules so that a molecule before encountering another collision has to traverse a large distance, but large and small as compared to what. So we compare lambda with something called as L which is called as the characteristics length scale of the system. So what is the characteristics length scale? A characteristics length scale is a distance over which characteristics changes can take place.

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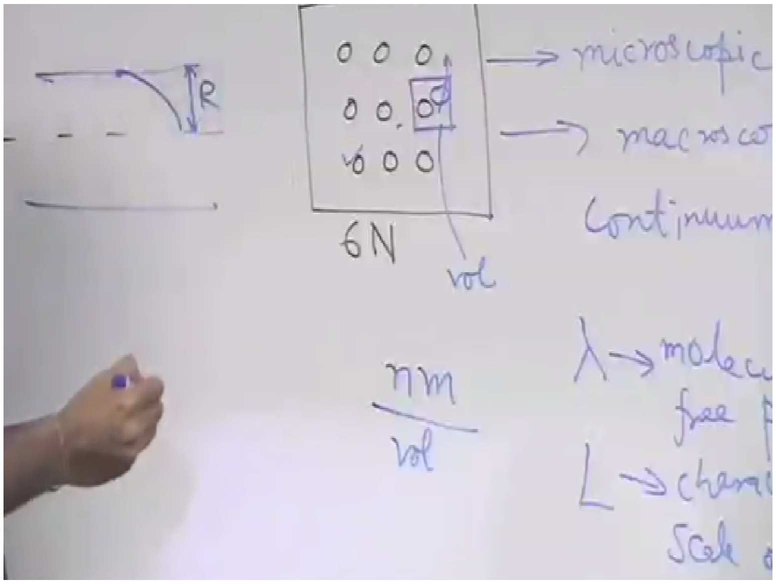

For example, like if you have a flow of gas through a pipe. So you can see that characteristics changes take place from the volume where the velocity is 0 to the center line, where the velocity is maximum. So the characteristics length can be the radius of the pipe, but in engineering typically it is considered as the diameter of the pipe with an understanding that it does not change the order like diameter is just 2 times the radius.

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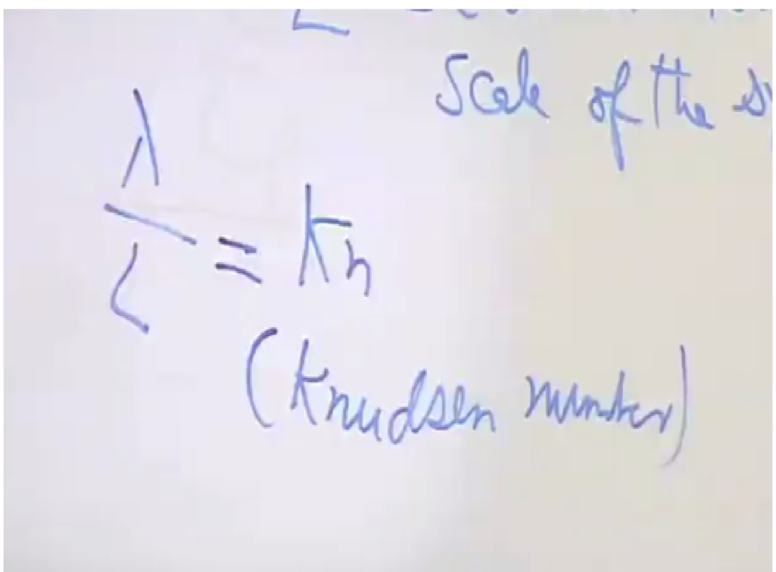

So if we compare lambda with L. If lambda is large compared to L then we say that it is a rarified system, but if lambda is small as compared to L we say there is not a rarified system. So it is not just the lambda that is important it is not just the L that is important, but lambda/L is a very important parameter that talks about the rarification of the system. So this is known as a non-dimensional number. This is the ratio of 2 lengths, so it is non-dimensional.

This is called as Knudsen number. So, a small Knudsen number means the system is not that rarified and continuum hypothesis can be used, but if the Knudsen number is large that means that the system has relative rarification that means that continuum hypothesis cannot be used and one has to go for either statistical approach through microscopic approach or may be molecular dynamics to analyze the problem.

So to summarize what we can say is that there are several approaches, one is the molecular dynamics approach to analyze the fluid flow, which is the most intuitive, but computationally most challenging and there is a compromise one can go for statistically average behaviour of many molecules which is the statistical mechanics approach and the most convenient is the macroscopic approach based on continuum view point.

Where we consider the fluid as a continuous medium disregarding the discontinuities and the continuum hypothesis can be used only under certain conditions typically govern by this Knudsen number. So if the continuum hypothesis can be used then it is very convenient because we can use the well known rules of differential calculus for solving the problems and because this is a very introductory course.

We will be mostly dealing with fluid dynamics, where continuum hypothesis can be safely used. So we will be encountering situations and solving problems which we will address through the use of continuum hypothesis and from the next lecture onwards, we will continue with the discussion with which we are living today and thank you very much.