Fundamentals of Aerospace Propulsion

Prof. D. P. Mishra
Department of Aerospace Engineering
Indian Institute of Technology, Kanpur

Lecture - 05

Let us start this lecture with the third process given by Max Planck.

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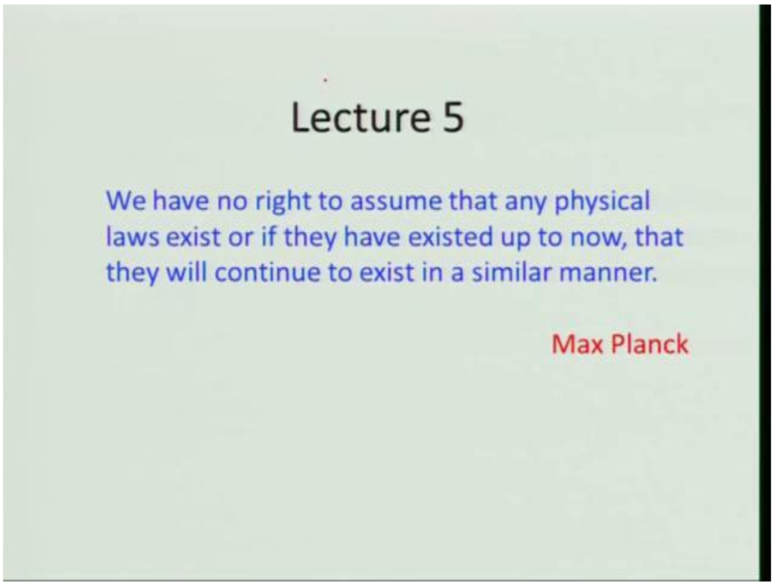

Who states that we have no right to assume that any physical laws exist or if they have existed up to now, that they will continue to exist in similar manner. What a performed statement is given by Max Planck and we always look at the laws as a gospel of a Bible or a Quran, but however we need to always keep in mind that those are subjected to scrutiny. For example, in the last lecture we discuss about four laws of thermodynamics of course, we started with a various definitions and concepts about thermodynamics. For example, the control mass system, control volume system and also we have talked about an isolated system.

Then we discuss about various other concepts like equilibrium I call that a system will be an equilibrium dynamically only when the it can be in equilibrium mechanically and chemically and thermally and also in the phase equilibrium must be existing. Then only it can be said to be in thermodynamic equilibrium and then we discuss about other concepts like kind of what do we call the equilibrium concept we discuss about. Then we moved into the laws of thermodynamics as I told that JP Joule who conducted series of experiment for over four years and put forward a law which is known as the first law of thermodynamics.

And we states that whenever a system undergoes a cyclic change, however the complex cycle may be then the work interaction or cycle integral of the work will be proportional to the cycle integral of heat. Then after that we discuss about what do we call apply the first law of thermodynamics for control mass system which is nothing but d e is equal to d q minus d w.

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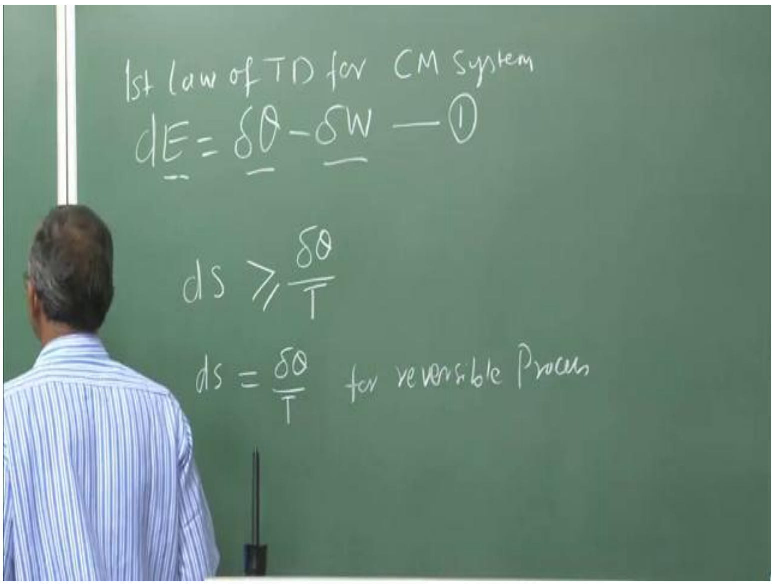

And this is basically first law of thermodynamics for a control mass system if you look at in this case this E is basically the total energy and which will be consist of both macroscopic and microscopic form of energy. Whereas, this macroscopic form of energy which we always put in terms of internal energy and macros, we form we are considering only two kinds one is potential energy other is kinetic energy, but beside this there are several other forms of energy as well.

And keep in mind that energy is a property of the system whereas, the heat interaction and the work interaction is basically not the property of the system rather is consider to be energy in tangent. Then we derive an expression for control volume system right and which will be using for analyzing the propulsive devices. Then we moved into second law of thermodynamics and where we have arrived at a terminology that is change in entropy is basically equal to del q by t which stems from the Clausius inequality.

What is Clausius inequality if would call that which states that whenever a system under goes a cyclic change. However the complex cycle maybe the heat interaction at the algebraic some of the heat interaction divided by the respective temperature at absolute or the kelvin is less than equal to 0. And from that we have derived and if you look at d s is equal to del q by t for reversible process.

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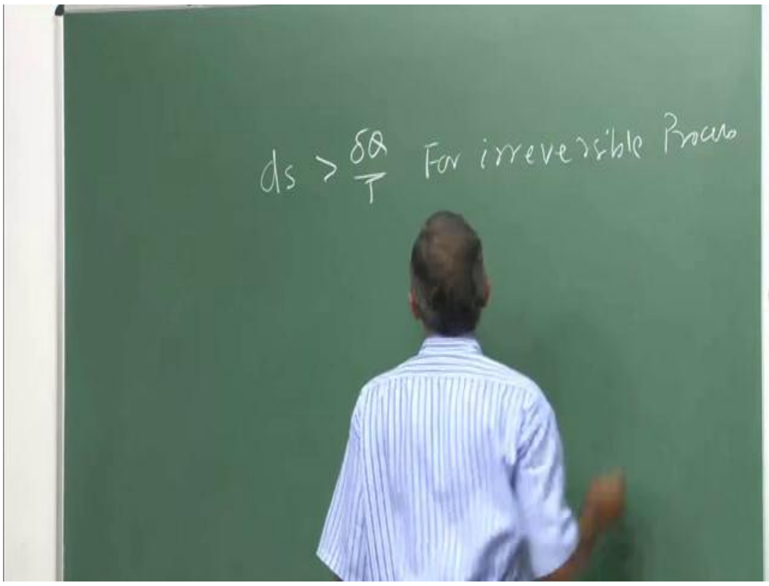

Whereas, d s is greater than del q by t is for irreversible process now then and this equation if you look at is basically valid for control mass system for control volume systems. We have derived or rather we have stated about a equation which I asked you people to derive it yourself, and if you find difficulties then we will look at it. And today what will be doing we will be looking at the fluid mechanics part and look at how it can be helpful. And what are the concepts involve in fluid mechanics, and about how we can use it for analyzing the propulsive devices.

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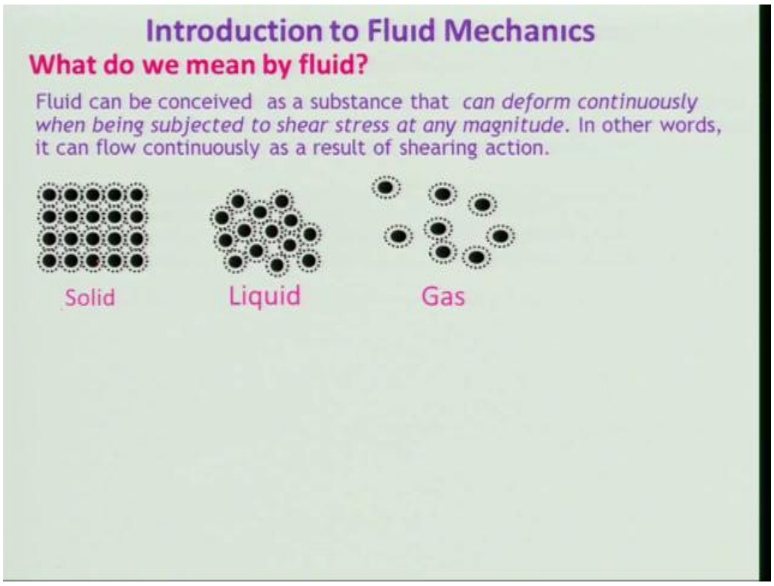

Let me ask a very simple question what do you mean by fluid can anybody answer what do you mean by fluid.

Student: A substance that have tendency to flow heavily.

You are saying that which can flow right that you call it as a fluid, but let us before answering this questions let us look at what are the kind of matter we are having. The matter if you look at it is basically is a having a solid and in case of solid these are the molecules which are quite compact. And there is a inter molecular forces which will be there and it is in a particular order we know that in case of solid in case of liquid, what will be happening this molecules are little apart and they can move the way it can be or it will be taking the shape of the place where it container.

Whereas, the gas it will be moving in a very freely as compare to the liquid and the solid, now if this is there like let say I will apply a force to a solid. For example, if I take this pen and apply a force what happens to the molecules, it will be trying to resist the force. And however there might be some deformation which will be taking place, if I remove this force then what will happen to deformation, deformation may you will come back to the original one.

That means, the stress right the deformation we call it as a basically strain which is change in the length in this example per unit length and the stress which will be experience by the molecules of this solid object right and this stress is proportional to the strain of course, within the elastic regime. Whereas, if I apply the same with the liquid certain force what will happen it will continuously deforming that means we cannot really say that it is stress. Of course, a stress will be cause by the fluid stress will be experience by the fluid molecules, but however it is not proportional to the strain rather it is proportional to the rate of strain similarly for the gas which will be happening.

So therefore, we can define a fluid as a substance that it can deform continuously when being subjected to a shear stress at any magnitude. In other words it can flow continuously as a result of shearing action right that we call it in to the fluid that means the fluid can have a more freedom to move around. And whenever it is moving around what is happening it will be moving means, it will be subjected to a force and it can move from one place to other and it will be interacting with each other.

That means molecule in the fluid will be interacting with each other and when it is interacting with each other then what happens there will be change in the momentum due to collision. There will be change in the temperature depending on the whether energy interaction is taking place or not. Now, if there is a fluid and which is moving around and I want to know what is the summation effect of this momentum which will be taking place?

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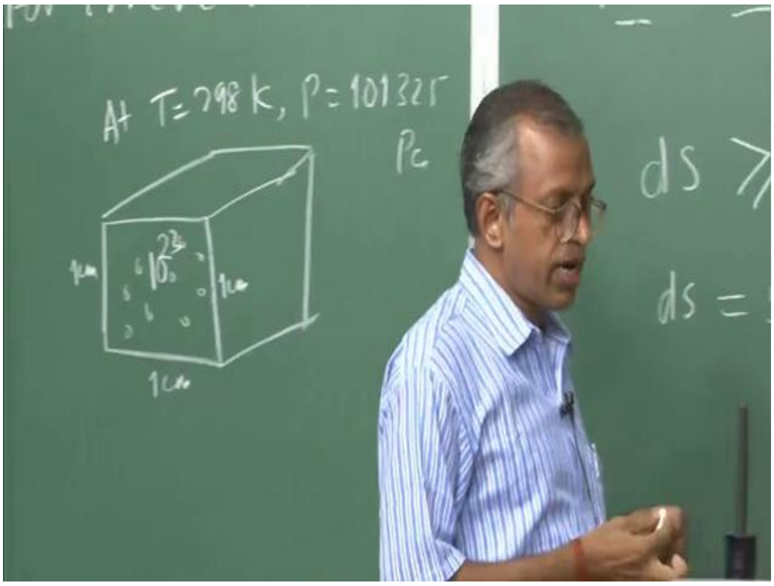

For example, if I take a small cube right of 1 centimeter and 1 centimeter right and at ambient temperature and pressure temperature of 298 Kelvin and pressure of 101325 Pascal. What will be the number of molecules which will be there inside this can anybody tell me what will be the number of molecules what is that that will be around 10 power to the 23 and 6.023, 10 power 23 like large amount of molecule which will be colliding each other. And if I will take that and put a kind of a sensor and look at what will be happening to the molecules or if I put a surface a sensor who surface area will be around let say 10 what we call 10 mm or something or may be 5 mm kind of thing right.

If I take a what we call let me consider a pipe which is having through who is the flow is taking place the pipe diameter is around 10 centimeter I will put a probe of 1 centimeter at 10 mm. So, what will happening to the pressure if I want to measure right that means the molecule will be bombarding over here and then it will be having what we call the surface on which it will be impacting. And then you will get a sensing it and then you get, but now that is effect what do we call it as macroscopic effect.

But, however if I am interested to look at the each molecules how it is interacting if I take something 10 power to the 23 number of molecules. That means each molecule I will have to track and look at about its mass how what is each individual velocity how it is imparting. And then it will be colliding and the force which is being transfer, then the number of equations and what it will be very high it will be quite difficult.

Now, naturally we need not to really worry about it, but how to handle that you can handle in a statistic results because it is a quite enormous number of equations one can think of. Whereas, when you will go and to a larger scale length then what do we call we call it as a macroscopic effect as I told that you take a probe of something 10 mm in a pipe of 10 centimeter kind of things. And you will be looking at a pressure or a due to the impact of molecules you will get that is what do we call that is known as a macroscopic effect, but when it will be possible.

For example, if I if the pressure is very low it is not atmospheric pressure it is a vacuum almost like in a space then is it the molecule will come and impact that way or if I put another question that suppose my probe is very, very small the size is something let say 1 nanometer. Then the molecule will be in angstroms sometimes the molecule will be coming and heating 1 molecule, 2 molecule may be 5 molecules not a large number of molecules. So, how to go about and use it because in our day to day life we will be considering a macroscopic.

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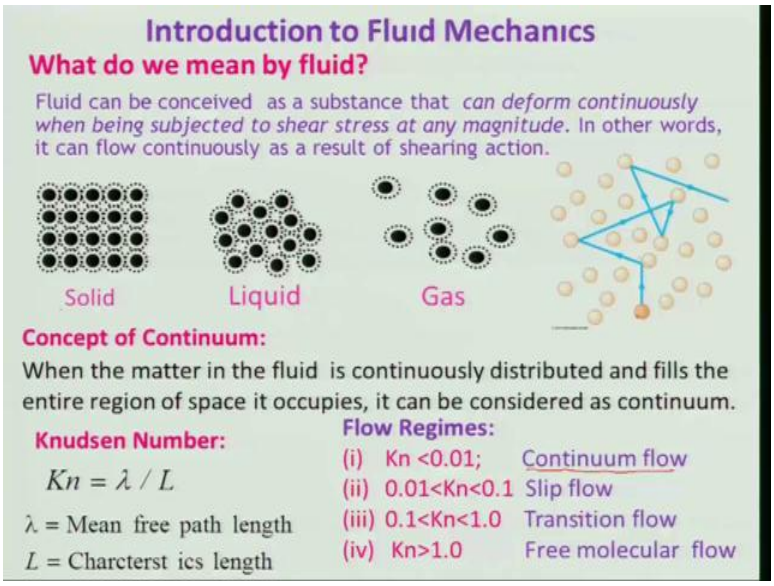

And that microscopic effect which will be giving rise to a concept known as continuum and what is that continuum is basically when matter in the fluid is continuously distributed and feels the entire region of the space it occupies and can be consider as a continuum. If you look at I will give one example like suppose in a CD we all together a lot of people leaves right they will be interacting and other each other.

And whereas, in the village people will be apart although in certain village at particular northern India they will be staying in a group. But if you go to the Kerala where each individual will be staying away apart from each other may be a 200 meters, or maybe 500 meters away from each other and they are not concentrated in one place then interaction will.

So, if you look at one is macroscopic that you look at all the people and other is a discrete where it will be going on. So, that means we can call it as a continuum when the people are continuously distributed and kind, but when we can call it as a continuum. In a fluid mechanics it is a important question has to be answered because that will give you a macroscopic way. That means all the properties like pressure, temperature, volume what do you call it as a macroscopic way of looking at can be handled. Otherwise it is quite difficult to handle when you talk about each molecules and how it is working.

For that let us look at the gas what it will be having, suppose I say that this one molecule is impacting with another or have being plan in to another molecule there will be a collision and this distance. What do we call between the collision travel by a molecule is known as mean free path and this molecule can be moving here there wherever is getting something will be you know colliding. And then transferring the momentum and the energy depending on its motion.

So therefore, this is the one length scale one can think of while talking about whether it is a continuum flow or other things right or a whether we can treat the flow has a macroscopically or not. Now, the other which will be coming into is that scale what is happening because for example, if I am considering a pipe in which the flow is taking place. And as I told you it is something 10 centimeter and in that if the fluid is there which is flowing and at certain velocities.

Of course, in a pipe and it is move also the molecule will be colliding and mean be front will be very, very small as compare to the scale for example, if it is something may be 1 mm in a 10 centimeter what to call diameter pipe. So, naturally it will be much smaller there will be several collision which will be taking place within the diameter of 10 centimeter so then at that point we can call it as a continuum flow. So therefore, we will define a number which is nothing but ratio of mean free path and the length scale characteristic length scale and which is known as the Knudsen number.

So, if the Knudsen number is less than 1 percent right we call it as a continuum flow that means in this case we can look at macroscopically and look at the properties and we can call it as a continuum flow, but if the Knudsen number is less than 0.01 that is basically 1 percent and 10 percent then we call it as a slip flow. That means the molecules will be slipping from where it will be slipping whenever it will coming on the solid surface in our case in the continuum flow, if the flat plate is there fluid is there then it will be sticking to the solid surface. That means there will be a no slip condition at the surface of the solid over which it is flowing and in the slip flow, then you know it will be quite difficult to handle. And when the Knudsen number will be between 1 percent and 1 then we call it as a transition flow.

And when the Knudsen number is greater than 1 this is known as a free molecular flow right. That means the molecules will be free separate each other and you need to look at and it is if you look at in our applications of aerospace propulsion we will be mostly dealing with the continuum flow. But however when your space cavity will go to the deep space then can we really apply you cannot really apply, but however if I look at my system it is a rocket engines or something then I can say it is a continuum, but outside it will be difficult.

And it is a quite a very hot topic even if today because it is still to be evolve and that is a very beautiful book written by G A Bird is known as molecular gas dynamics, if you have people who are interested in you can look at that book. And keep in mind that this continuum flow which will be dealing with will be governed by a number Knudsen number and which must be less than 1 percent or 1.01 and it can be related to what then can be related to certain properties any of you are aware about that. It will be related to 2 non-dimensional rather 3 non-dimensional variables, which I will be leaving for you to look at it may be as you go along, we will discuss and that can be derived by using molecular theory of gases.

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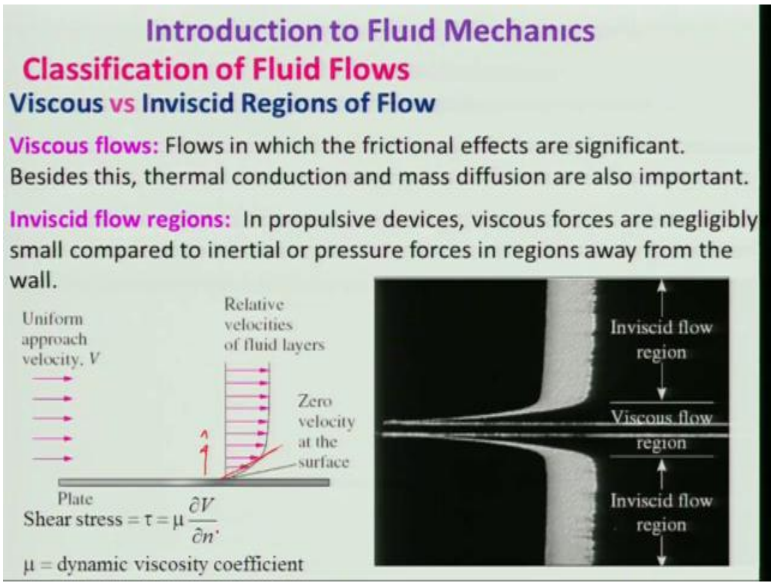

So, let us look at like when you talk about this fluid how to classify the fluid flows because we will be more interested in the fluid flow in case of this aerospace applications. How because how this fluid flow will be helpful it can be helpful in two ways one way that whenever, fluid is flowing through a duct or over a surface it will be experiencing what we call certain force will be applied, or certain force, or the thrust you know will be generated. Beside this whenever we are converting sub energy into the thrust force we need to pass through what we call a mixing.

That means some energy conversion will be taking place some chemical reaction will be taking place as we are using the fuel as a energy source, and then there will be some diffusion and mixing will be taking place. So therefore, fluid is very important fluid flow is very important for our what we call aerospace applications particularly. For example, I can have a motion in a peddle cycle, but is it really we need any fluid there we do not need we are applying the force mechanically and using, but if I want to travel in a air or if I want to travel make a object to move in the water the naturally fluid flow comes into picture. And if we want to go at a higher speed the naturally we will have to use the fluid devices.

So therefore, it is very important to understand the fluid mechanics and concept about it. And as I told that we will be dealing with the continuum flow, where the fluid will be adhering to the solid surface, and as a result there will be some viscous or kind of things which will be taking place. And the fluid flow can be classified into viscous and inviscid region of flow.

So, viscous flow is one in which the frictional effects are significant for example, if there is a solid surface and let us say this is solid surface and the fluid is going over it, then what will happened the fluid will be trying to retard on the surface of the plate or the surface on which it is moving. And the friction if you look at we all experience friction for example, if this is a surface I am rubbing it so what I am getting I am trying to rub it and get a friction and it is resisting that means you know. So therefore, that is the generally the viscous flow is consider only when it is having a frictional effects, which is quite significant in comparison to what in comparison to the inertia.

And beside this there will be some thermal conduction, conduction means some heat transfer will be taking place. And also the mass diffusion like in your combustors where the fuel and air has to be mixed. And then it will be you know reacting then you will get you know transfer this what we call chemical energy into the kinetic energy and other things. So, there also we call it as a viscous flow, but although in fluid mechanics people do not talk about it generally and beside this whenever is viscous effect is negligibly small then we can call it as a inviscid flow. And where the viscous forces will be neglected can be neglecting as compare to the inertial or the pressure force.

And keep in mind that we will be use in this inviscid flow analysis for our propulsive devices because of the bounder layer which will becoming will be discussing a little later on that will be very, very small. And let us consider that the flow over a flat plate which is having a uniform flow and then when it is flowing through it you will see that as it would then the flow gets retard on the surface of the solid. As a result it is a having a fluid the velocity profile which is you know 0 velocity at the solid surface and it goes on increasing at certain distance along with the y direction if I say this is the y direction. And this will give you basically the resistance or the boundary layer a layer will be coming into pictures.

Let us look at that a visual pictures or a that you can see that that full this is the velocity profile and with the viscous flow region is very, very small. And whereas, the inviscid flow region is quite large and wherever it will be you know and therefore, we can apply this inviscid you know analysis for this region. Whereas, whenever we want to find out what will be the drag or the kind of things we need to consider this kind of viscous region for analysis.

And if you look at the shears stress we can evaluate at this region if you look at from this taking this point here, that it will be shear stress will be proportional to change in the velocity with respect to this is my normal direction n and dou v by dou n. And when it is proportional to the rate of strain then this is tau you can be express the tau is equal to the mu in d v by n where, mu is the dynamic viscosity coefficient.

Keep in mind that this will be valid or we is for Newtonian fluid that means the shear stress is proportional to the rate of strain, but however there will be some other fluid like a viscous fluid. Like your what do we call lubricating oil or even in your paste which are not which would not be following these Newtonian concept of fluid but, in our what we call analysis or in this course we will be restricting our self to the Newtonian fluid only.

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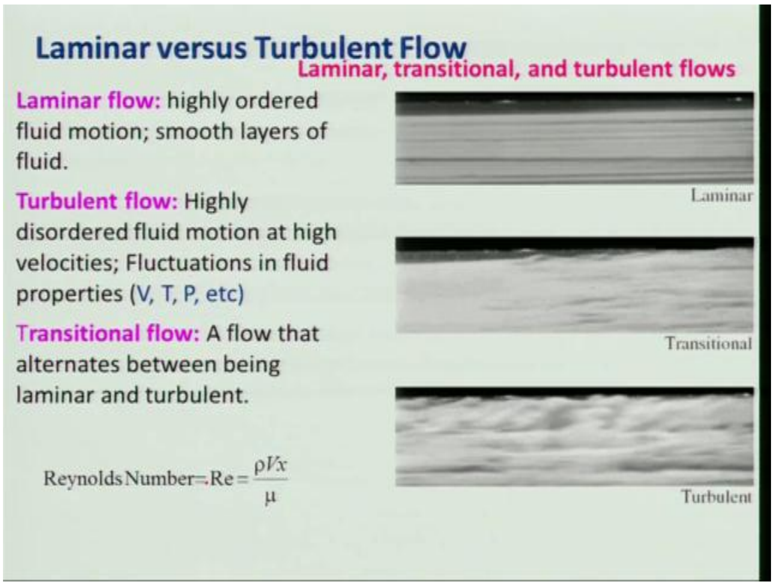

Let us look at about the laminar versus the turbulent flow if I ask a question what do you mean by laminar the name indicates that it will be layer by layer and it will be quite smooth and orderly manner the fluid will be there. For example, if I take this flow over a flat plate you can see that fluid layers by laminar layer by layer kind of things moving without intermingling with each other. For example, I will give an example let say in an army the soldiers are moving they will be moving in a very orderly manner that means they are quite discipline nature.

Some of you might of take an NCC you know you will be going in a row kind of things so that you can call it as a laminar and which is and in contrast the turbulent flow will be quite this order it will be intermingling each other. As a result the velocity or the temperature or the pressure which are the fluid properties it will be changing with respect to time. And if you look at our you know in Kanpur that traffic it will be more towards turbulent sometimes I feel it is not turbulent rather it will be transition, it will be in between kind of region what I have shown.

So, in order to talk about this laminar turbulent we always think about the whether it is the we need to define a number which is known as Reynolds number, which is a ratio of inertia force divided by viscous force in this case rho V x divided by mu where, rho is the density, V is the fluid velocity and x is the characteristic distance. And this x in case of a flow over a flat plate will be the length from the leading age can be measure and mu is the viscosity. That is your basically and this will be decided by the Reynolds number will decide whether the laminar flow is laminar or turbulent in case of flat plate, we know that critical Reynolds number will be around 5 into 10 power to 5.

Whereas, for a pipe flow for a critical Reynolds number will be around 2300 and keep in mind this is a non-dimensional number which dictates, whether the flow is laminar and turbulent and the transition flow is between the laminar and turbulent. I always feel that you know give one example laminar means, I know when you look at your mind. Particularly when you are a small baby you do not really bother about rather things, it will be in laminar regime.

When you are youth your mind will be vacillating and more confusing here and there then it will be like a transition because it is very difficult to predict. Similarly, transition flow is quite difficult to predict therefore, lot of research is going on today to understand the transition behavior of the flow. And similarly, turbulent will be the later age what one can think of.

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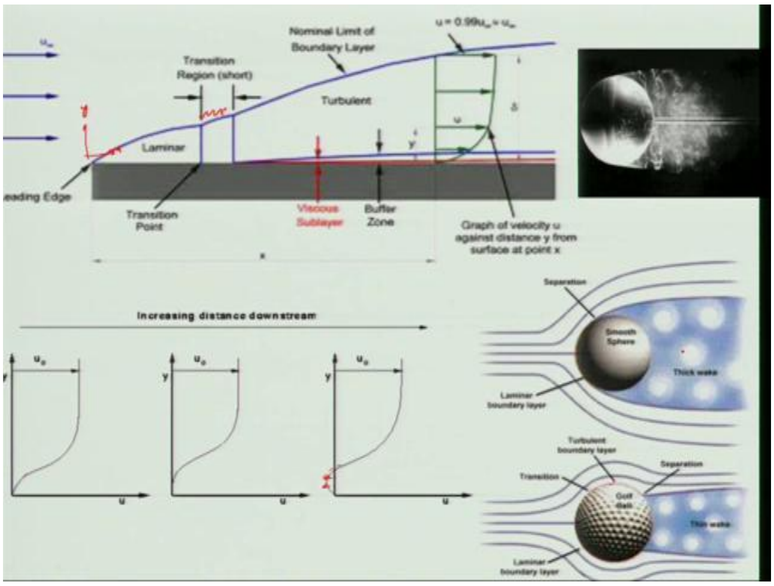

So, let us look at a flow over a flat plate and if you look at this is the your laminar regime in this case as I told that as a x increases your Reynolds number what we call increases although the your off stream velocity, u infinity it is remaining same. So, also the viscosity because it is a same fluid and there is transition regime where it will be having a fluctuation I mean generally people talk. About there is a mark like this that indicates a transition flow. Of course, after that bounder layer although grows and then it will be turbulent regime.

In this regime there is a viscous sub layer where it will be flow will be almost like a kind of viscous and then there will be a momentum transfer from this region to the wall which will be taking place. And however this will be going this the boundary layer which is define as a velocity of 0.99 percent of the free steam velocity because it will be asymptotically velocity will be increasing. So, at that point we defined and keep in mind this is the head of way of doing it because where we will define and we have taken as a practically 0.99 percent as of free steam velocity.

So, if you look at this is a the bounder layers sticking to the what we call the solid surface and there might be a way where the boundary layer will be separated from the solid surface. And that depends on what it will be dependent on the type of surface what we are and also in other words it will be dependent on what pressure gradient. So, let us consider a ball here and in this case this place of course, fluid is coming which is not shown here in this case the fluid is almost laminar and then it get separated and it is re circulated mingle and the flow became turbulent in the weak region. This is known weak region and this flow separation will be dependent on whether the flow is laminar or turbulent and this is a simple ball which I have taken.

Now, as I told earlier that this case the velocity profile is parabolic in nature and when the pressure gradient increases suppose I will be having adverse pressure gradient at the downstream what will happen the velocity profile will be like that. That means it become a coming you know flow will be retard more in this region as compare to this because of adverse pressure gradient. Somebody is trying not allowing the fluid molecules to move forward, so then it will get a inflection point will be almost 0 for certain you know this thing along the y direction, that means this is my y direction this is my x direction right.

So therefore, as the pressure gradient increase further what happen the fluid will be moving what we call towards that and then it is opposite direction of the fluid. That means it will be opposite to the x direction is the negative x direction therefore, the flow will be separating. So, that means flow separation occurs whenever there is a pressure adverse pressure gradient you know occurs in the flow. And that may be due to the safe and due to the some other you know back pressure and depending on the situation.

Now, if you look at the laminar flow will be causing more separation in a body as compare to the solid at comparison to the turbulent flow, I will take an one example this is a smooth sphere like a ball you can say and flow is laminar here. And of course, the flow becomes separated and this occur the like having a thick weak region, but if I make this ball as a dimple like a gal ball you know this is intentionally made some dimple like this kind of shears being made indentation kind of thing. And then what happen this became transition and then that flow separated, you know like become turbulent. However the separation become in occurs at the downstream of the ball as compare to the here it occurs very you know very early.

And however the as a result the thick the weak region is very thin as compare to the thick here. So, what it indicates it indicates the turbulence deters the separation of the flow so if we look at turbulence always people wants to avoid right in some situations, but here it is advantage. That means whichever is a negative things can be converted into a potential tool for achieving something. So, which is very important in life as well so we need to understand our self and find out ways and means of using those negative aspects for getting a positive thing.

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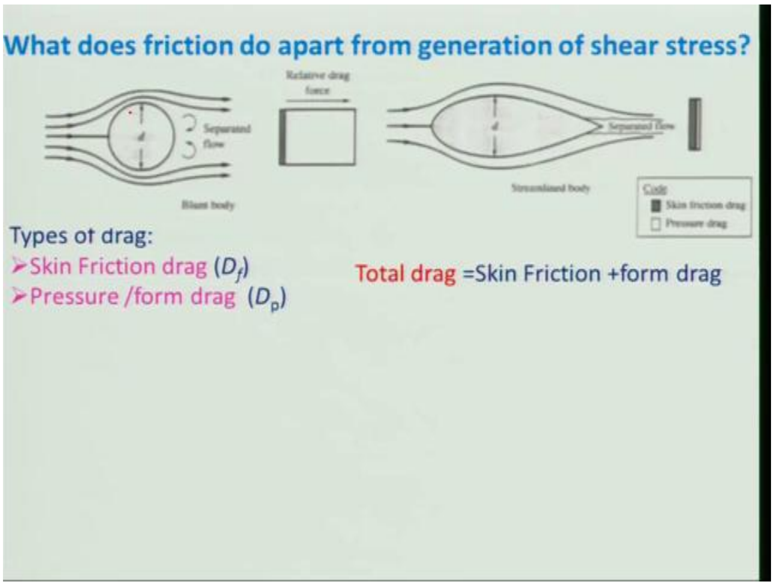

So, question as a just we are discussing about the viscous or inviscid fluid then we talk about laminar, and turbulent and what we are doing we are looking at basically the friction effect. And we have seen that it is basically generating a shear stress right and then this flow separation other things are coming, but is there any other things it can do. In other words what does friction do apart from generation of shear stress can anybody tell me it will be generating heat under what condition it can generate heat.

Student: Relative machine.

Relative machine why it will really generate the heat whenever there is a relative motion what is the reason.

Student: Momentum.

Momentum.

So, momentum what momentum means it will be a force so how it will come into picture.

Student: ((Refer Time: 38:55))

Right so that means if the rubbing of the surface is taking place there will be some kind of a dissipation which we will be discussing about it beside this what else it can do. Let us consider the flow separation in a the ball what we are discussing here fluid is coming over and then it is get separated at certain region, this is separated flow. And whenever this flow is separated what happens to the pressure in the weak region it is being reduce and when it reduce then what will happen. It will be trying to drag this ball along with the fluid more as compare to the as what we call apart from dragging due to the friction because if ball is moving it will be also due to the friction it moves.

So, that means it will be helping in that and if I want to reduce this drag force it will be dragging. That means dragging can occur due to what due to two thing, one is your skin friction due to the viscosity or due to this thing and other is due to the separation of the flow. There will be a pressure drag also, but if I want to what to call reduce the drag then what I let do I will make the body to be steam line. That means the shape of the body in such that the flow will be gliding over without really much you know way to separate from the solid surface. However, in this case I have shown there is a little surface here so if you look at you are getting the drag due to the skin friction and also pressure drag.

So, to summarize the types of the drag will be one will be skin friction drag and other is the pressure or the form drag, so the total drag will be skin friction and form drag. Keep in mind that always we want to design you know a surface in aerospace like a aero foil kind of things is basically steam line body to reduce the pressure drag. But is there any place where we will be using you know a blab body, like if you look at this is a in this case I have written here as a bland body. Even we known as the blab body which is a non-stream line body can we really we use somewhere.

Student: Space ship.

Space shuttle.

Student: Re-entry.

Re-entry will give steam line body value of course, that depends upon the what kind of way when other interaction because this steam line body this there it will be different, but what I am saying is we can use a non-stream line body in some place which will be beneficial for achieving certain thing. For example, blab body is a non-steam line like a I have put it a circular or a flat plate over the flow like.

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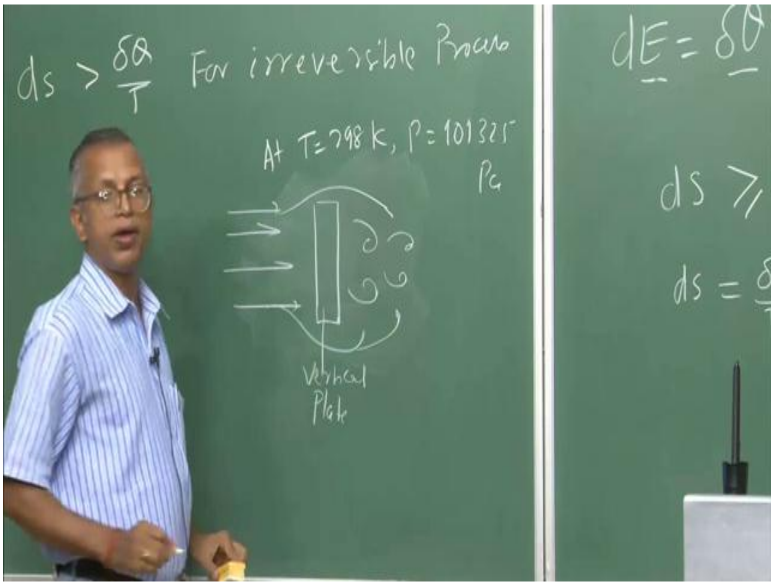

For example, if I take what we call if I take a blab body over a flow at just a flat plate let say this flow is coming this way and I put a body like this. Then what will happen there will be re circulation you know region and this is a plate vertical plate, can I use some where is this to achieve something in my propulsive devices. We will see that we will be using this for in combustor for getting a fuel air mixing better mixing and also stabilizing the flame. So, whichever is the problem in some place it can be used as a solution to overcome the problem, so that is the very important point one should look at it and we will be using this concepts in while talking about the propulsive devices.

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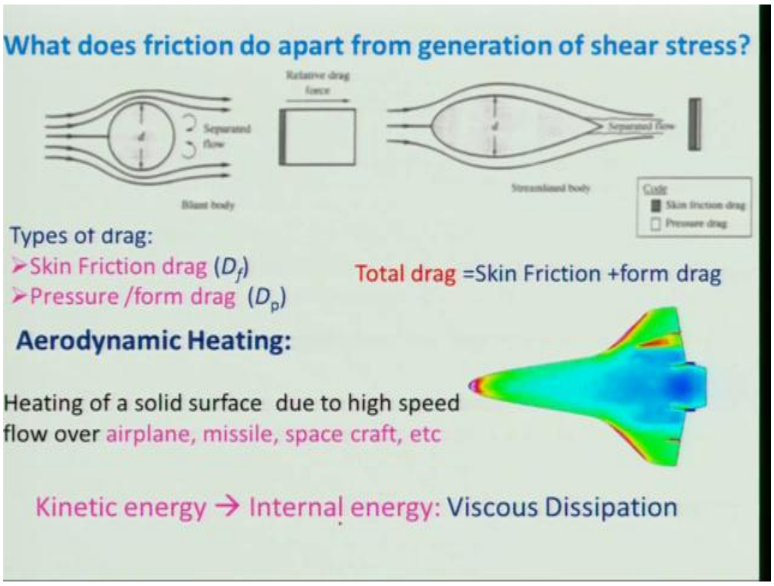

And as we have already discuss that is a some of you told that because of whenever the vehicle or a body is moving or fluid is moving at a high speed over a body, I mean it can be vice versa. Then what will happen there will be lot of kinetic energy which will be converted into in to the internal energy. That means aerodynamic heating which will be experiencing by the solid surface due to high speed flow over like airplane, or missile or a space craft to give some example or any other surface whichever is coming.

And then that heating has to be taken care you know otherwise your vehicle like will be in trouble. For example, if a aircraft which is moving at a very high speed, keep in mind it is having a delta V we says that it is applied it is you know can fly at a very high speed. In the nose region you will get a very high you know heating portions and so also in this edges of the delta V right and some places here as well. So, that means you need to take care of these whenever you are talking about a designing a aircraft or any other things.

And similar situation may occur in your gas turbine application particular turbo machinery, when you are going for a kind of a high speed or the flow over a turbine blades kind of thing. So therefore, one has to worry about this aero dynamic again keep in mind that kinetic energy in this case is convert internal energy. And as a result there will be increase in temperature and which is known as viscous dissipation because it will be dissipated, you cannot get it back and one has to also take care of this thing when designing any devices of that.

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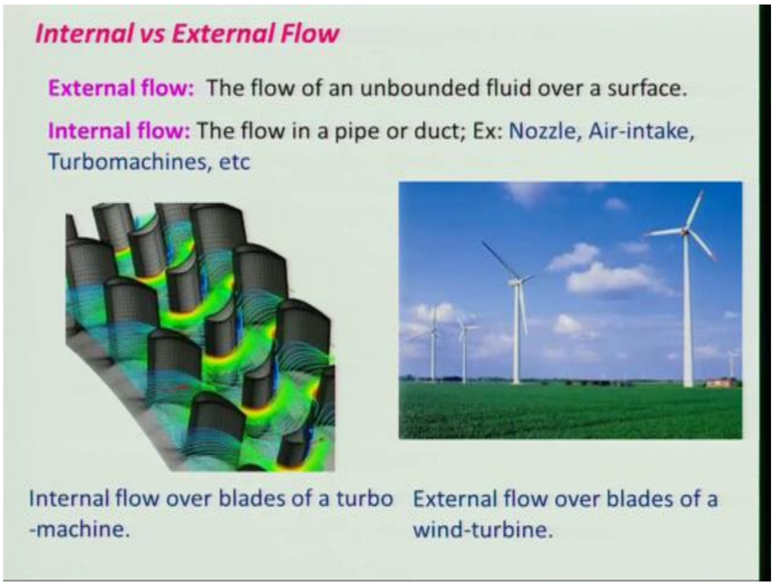

So, now we have talked about basically internal versus the external, external force and we need to understand what do you mean by internal flows and external flow. The flow of an unbounded fluid over a surface like a flow over a plot plate, flow over an aero foil flow over an aircraft or a missile all those things will be external flow. And the flow in a pipe or a duct particularly example you can nozzle air-intake and turbo machines will be internal flow. But however in case of the what we call a turbo machine which I have shown there is having a rows of blades, if you look at the flow is here is basically internal flow.

However, on the surface of it we can call it as a, what you call external flow kind of things because it is far away from. That means blades are being faraway then only otherwise we will call it as a internal flow. So whereas, the external flow if you look at if I take a turbine wind-turbine right which is also a one another kind of turbo machine the naturally the flow will be external in nature.

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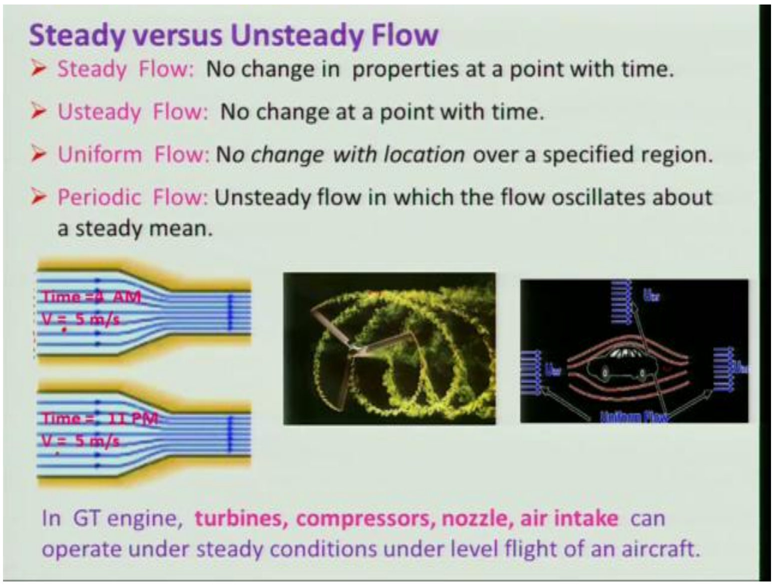

So, what we have we will be discussing now basically the steady and unsteady flow. An steady flow that in which there would not be any change in properties at any point of time. For example, if the flow is taking place in a nozzle which has shown here at the time 4 AM the velocity is 5 meter let say at this point. If I consider that at the same point and at the time 11 PM, that means several hours have being passed the velocity is almost 5 meter per second. It cannot be you know it you cannot say it is exactly 5, if it is 4.9 or may be 5.1 and some average you know you can say it has a steady flow.

And which is likely to occur provided if you keep the flow is the same continuous manner you may ask a question, suppose when it will occur if my engine is in the test bed and there is a nozzle to each flow is taking place. During the hour of operation it will be remaining constant provided I am keeping it as a constant. If I will tattle or vary it the naturally it will be different. So whereas, the unsteady flow there will be what you call change at a point with time that means the properties will be changing at a particular point in time.

For example, if I look at this a what we call a rotor or blades which is rotating if you look at each point it is you know moving so that it will be different. That means if I consider a point and then look at the properties like pressure, temperature, velocity it will be changing. Of course, in this case it would not be temperature would not be changing, but velocity and pressure will be changing with the respect to time. So therefore, we call can call it as an unsteady flow and there is a also the uniform flow in which case the velocity, or the fluid properties would not be changing along a cross sectional area over a specified region.

For example, in this case these are the places I am keeping what we call fluid velocity has a uniform you can see from this steam line. Similarly, it is very important whenever we need to identify where the flow is uniform we will be doing that particularly when we will be deriving an expression for a thrust force. Then we need to identify a uniform velocity you know that means because to have to simplify our analysis. In this case if we look at this is there a car the flow is taking place over it. If you look at these are the steam lines which is being not you know curved one which indicate that is uniform, but if I go for away from away from this we will find the flow is uniform.

Similarly, if I go away from this the weak region of the car this is the weak region then I will get uniform and of course, inlet you can have a uniform provided it is in a V internal or somewhere. You cannot get a uniform flow very exactly or accurately when it is moving because that might have several other things vehicle will be coming. So, we need to understand this very important aspect because we will be looking for using it for simplifying analysis in some several places.

So, there is also known as periodic flow like a where unsteady flow will be there, but the flow oscillation will be varying about a steady mean. For example, if I am keeping this RPM of the blade at a constant I am looking at a particular thing I will find that as the RPM is remaining constant it will be coming periodic, it will be coming and going coming and going. So, that way it will be periodic in nature and which will be useful particularly when you are analyzing the turbo machinery.

And in gas turbine engines the turbines you know several components like turbines compressor, nozzle, air intakes can be consider to be operated under steady state condition particularly under level flight of an aircraft. Suppose, you are at flight level not like your fighter air craft where you need to change you know change means you will have to need the change thrust as well. So, the condition inside the gas turbine will be changing therefore, we cannot, but however in the very simplifications or in under certain situation like level flight one can consider to be a steady flow and which will be using most of the times unless otherwise being state.

So, with this we will stop over before that let us summarize what we have learnt can anybody tell me what are the things we have discuss till now. Let me tell that like we have started a discussion about the fluid mechanics defining how it is different than the solid. And then we talked about a Newtonian fluid and how it is different than the non-Newtonian fluid and then we discuss about continuum concept and how it will be useful, and it will be differentiated from the other flows by a number known as Knudsen number.

Then we moved into what we call the laminar and turbulent flows, and then we have looked at this effect of the viscosity and apart from what we call the viscous effects or the shear stress being generated. Then it can also produce the drag and then we talk about the total drag is basically some of the skin friction drag and pressure drag. Then we talked about aerodynamics heating effects and then we looked at steady and unsteady flow.

In the next class we will be discussing about various aspects of fluid mechanics, then we will be looking at governing equations, then we will be moving to the compressible flow which is quite import and for analyzing the your propulsive devices. Is there any other question you people are having you can ask me.

Thank you very much.