Introduction to Atmosphere and Space Science
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Lecture – 10
Forces and their Classifications

Hello, dear students. So, in today's class we will try to understand various types of forces which are responsible for movement or motion of the atmosphere. These forces are the basic driving mechanism for the transfer of air or the atmospheric mass from one point to another point. In our discussions pertaining to atmospheric circulation we have seen that warm air rises from the equator and it will go towards the poles, then this builds up a convection cell which will may be mainly responsible for the atmospheric motion right.

Now, we have seen that the temperature of the atmosphere that is driven by the sun is basically builds up this circulation right. So, in today's class we will try to understand what are the different types of forces which we need to understand in order to be able to and in order to be able to successfully understand the motion of air from one point to another point what are the different types of forces. So, let us say to begin with. So, force; any force I mean forces can broadly be classified into two types.

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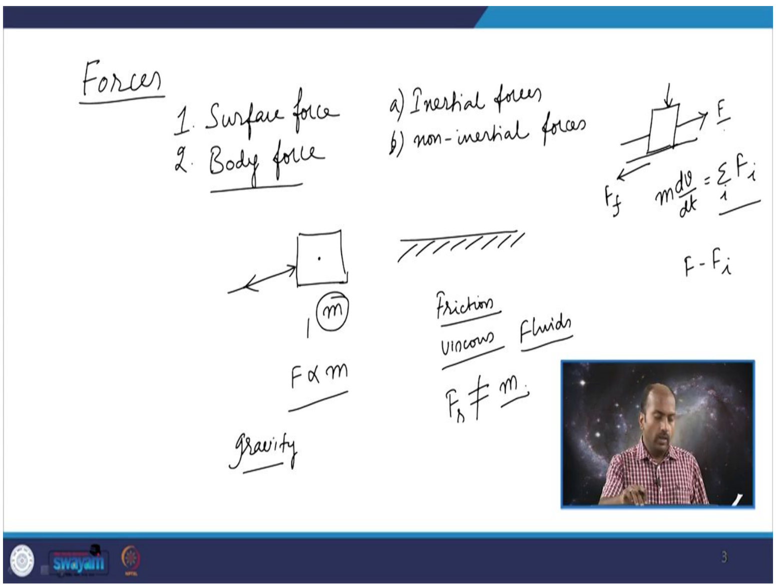

Let us say so, today's discussion is going to be about Forces. So, these forces or the discussion that is going to be done in this class is pertaining to the Earth's atmosphere let us say or more precisely forces that will act on fluid mainly let us say ok. So, basically forces can be broadly classified into two types. Let us say 1 and 2; one is surface forces and the second is body force.

So, you must have known about all these different types of forces, but let us try to derive mathematical expressions for each of them so that we can combinedly say that our objective let us say what is our objective behind the discussion of this class, behind the discussion of this forces let us say for example.

Generally, when you invoke the second law of motion what you realize is that any object let us say if any object is moving let us say from rest and if it is moving. The rate of change of velocity let us say mdv by dt of this object is equals to the sum of all the forces let us say sum over i f i. So, the objective is if this if the motion of this object is to be understood, then the rate at which the velocity of the object changes is equal to the sum of all the forces.

So, this the sum of all forces can be many many types of, different types of forces can exist. Let us say, if you are pulling this object with certain amount of force let us say f, there is this amount of force that is trying to displace this object from the rest or increase its velocity from one value to another value or change its magnitude right, the point is when this is not the only force let us say.

So, in this case if there is no friction absolutely, no friction on this side that the rate of change of velocity of this object of this object can simply be written as equal to the sum as equal to this force that you apply externally. But, if there is a force due to the friction which is acting in the opposite direction then you have to let us say you call this force as the force due to friction then you will say that the sum of all these forces is let us say F minus let us say F i right.

Now, the rate at which the velocity of this object changes with respect to time will depend on both the forces. So, this is a simple picture in which you can be able to understand what is the importance of understanding or having relations for the different types of forces ok.

So, this is a basic this is the basic idea. So, what we are going to do at the end of this class is that we will be able to figure out how many different types of forces exist in the Earths atmospheric system let us say and what is the role of each of these force in governing the atmospheric movement from one point to another point. We know very well.

There are let us say before the surface force or body force we have another type of characterization this is let us say let us call this is a is let us say these are inertial forces inertial forces and b is non-inertial forces ok. So, there are different characterizations of forces let us say. Surface force; now let us define what is surface force and what is body force. Body force is the one which acts at the center of mass of the object.

Let us consider an object let us say. So, this body force will always act towards the center of mass of the object or away from the center of mass of the object. So, obviously, the body force will depend so, it will depend on the mass of the object. So, the amount of force is will depend on the mass of the object.

So, this body force the basic definition of body force is such that it will act at this on the center of mass of the object and the magnitude of the force will be proportional to the mass of the object. So, this force will be proportional to the mass of the object. So, let us say for example, if you are trying to push or if you are trying to pull. So, you are the you the force is acted upon the centre of mass of the object that you are trying to move and the amount of force that you apply whether to pull or push will always be dependent on the mass of the object itself ok.

So here so, one example for a body force could be gravity; gravity is a very good example for gravity for the body force ok. So, then the surface force: surface force is the force which acts at the boundary of the object. So, surface forces generally act across the boundary separating two let us say two media or whatever ok.

So, surface force is the one which acts across the boundary. Let us say for example, so, what is a good example? A good example is friction. Friction in the case of solid objects, let us say and let us say we can viscous force could be an example for fluids. So, friction which will act across the boundary of the object.

So, surface force is the one which will act across the boundary and body force is the one which acts towards or away from the center of mass of the object right. Then what else? So, the body force will the magnitude of body force will obviously, depend on the mass of the object and the magnitude of let us say the surface force will not depend on the mass ok. So, this is the basic characterization by which you can we can characterize the fundamental nature of the force.

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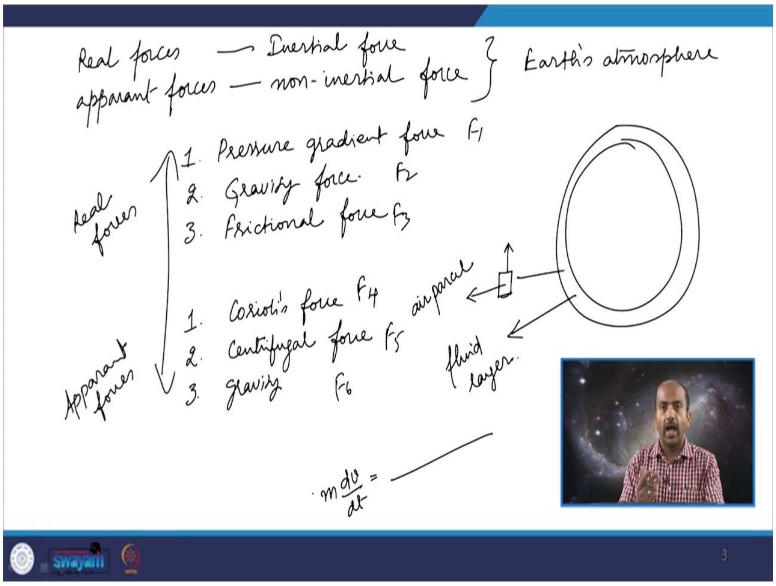

Now, in addition to this let us say most easy characterization is let us say real forces real forces and apparent forces or real forces are generally the inertial forces and the apparent forces are generally the non-inertial force. So, generally with your basic understanding of your earlier physics courses you must be able to tell what is the inertial force and what is the non-inertial force.

So, whenever there is the frame of reference that you are talking about or the object the frame of reference in which the object is there if it is an inertial frame of reference, then the forces will be called as; the forces in that particular picture will be called as inertial forces. And, if the frame of reference is being accelerated let us say if it is a rotating frame of reference, so, rotating frame of reference may although move with a constant velocity satisfying the inertial nature to an extent, but if it is rotating this velocity is changing angularly right.

So, that means, that its direction is changing. So, it is an accelerated frame of reference. So, when it is an accelerated frame of reference you talk about non inertial forces ok. So, it is very important for us to understand that in this picture, in the Earth's atmosphere let us say both of this. So, our system is the Earth's atmosphere the Earth's atmosphere itself. In the Earths atmospheric system both of these forces are very much relevant and both of these forces will be existing to various degrees.

Now, what is the real force? The real force is the one whose effect you can directly feel, but apparent force is the one you see an effect and you do not see generally a force that is causing the effect. Then, what you would say is that in order to be able to understand this effect you say that there is a force which is acting and this force which is called as apparent force ok. So, there can be.

So, the real forces examples for real forces are let us say one the real forces the real forces are number 1 example is pressure gradient force; number 2 is gravity; number 3 frictional force. And, the apparent forces – number 1 is the Coriolis force; number 2 is centrifugal force; the 3 is gravity. We will see how these forces can be real forces and apparent forces.

Now, what we will do today in our class is that we will try to derive expressions for these various forces let us say. So, fundamentally what I want to achieve is that if you consider the Earth you have the Earth's atmosphere surrounding it. So, what is this atmosphere? This atmosphere is nothing, but a fluid layer; this is just a fluid layer ok.

Now, in order to understand this fluid layer what we do is we consider an infinitesimally small volume of air, this air volume is going to be called as the air parcel. So, what we will do is we will try to understand the movement of this air parcel this the movement of this air parcel. Now, if this air parcel is moving let us say its movement has to be attributed to several different types of forces.

So, in various cases in different examples we will realize that this air parcel is air parcel's movement is subject to one or all of these forces that I have mentioned here ok. So, now in order to write an equation of motion for this air parcel so, my objective is going to be like I want to write an equation of motion like this for the air parcel. Now, the right hand side is obviously, different types of forces. So, let us call this as F1, F2, F3, F4, F5 and F6.

So, my objective is to be; I used to be able to write equation of motion in various situations by combining this F 1 to F 6 in many different ways. So, that is my objective ok. So, fundamentally I want to have mathematical expressions which will represent the nature of this force and which will also allow me to calculate the magnitude of these forces right let us say. Let us go one by one. So, the first force which is fundamentally the most important force in the Earths atmospheric system is called as the pressure gradient force.

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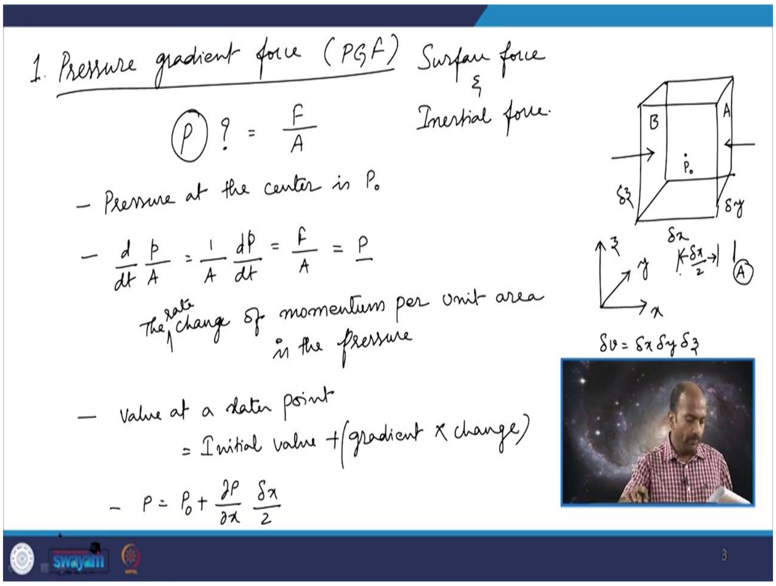

So, this is called as the pressure gradient force this is generally called as PGF ok. Now, let us say in order to understand let us consider a volume of air let us consider a volume of air, a 3-dimensional volume we take the sides to be of certain dimension let us say. Let us say our coordinate system is like this is x, this is y and this is z. Let us say this side is going to be delta x, this side is going to be delta y, and this side is going to be delta z.

Let us consider a point P at the center of this volume let us say this side is being called as A and this side, the opposite side is called as B ok. Now, let us say this is one direction and this is another direction now. So, what are we trying to do? We are trying to derive an expression for the pressure gradient force. So, in order to say this is the pressure gradient force is a surface force, is not a body force. So, the what is this is a surface force and what type of force it is? It is an inertial force. So, it is a inertial force right.

Now, let us say so, what is the idea of force here? I mean there are there are atoms and molecules inside this gas volume right and they collide and they do some momentum transfer with the walls or among themselves. So, let us say for example, if there is a momentum transfer with the walls, now this volume; what is the volume of this what is the volume of this air parcel? The volume is delta x delta y delta z. So, what this is going to be called as delta v; delta v is delta x delta y delta z ok.

Now, if I want this volume to be constant with respect to time; that means, if the volume does not change with respect to time what is the condition that I should imply on this a parcel. I will say that see the gas molecules inside this volume are exerting some pressure on the boundary; let us say let us the boundaries are A and B in this case there are other boundaries as well. So, the amount of pressure that the gas molecules exert on this on these sides should always be equal to the amount of pressure that the gas exerts from the outside.

So, as long as this condition is met the volume will stay as it is; I mean the magnitude of this, the number delta x delta y delta z will remain a constant right. So, that is kind of an equilibrium situation where the molecules inside the gas parcel, the air parcel are executing the same amount of pressure as the gas outside this air parcel right.

So, let us say what is the idea of pressure here I mean fundamentally we have to what we have to identify what is the idea of pressure, how does the pressure come into picture? So, pressure we know very well that force per unit area is the idea of pressure right. Now, where do we start? We start from the momentum transfer let us say. So, let us say the pressure at the center of the volume this center of volume. So, pressure at the center at the center is P naught let us say. Now, the transfer of momentum per unit area and per unit time; what is the momentum transfer? Let us say d by dt per unit area momentum is let say small p by per unit area per unit time is going to be written as 1 by A dp by dt which is nothing, but the rate of change of momentum is a force and force per unit area is the pressure.

So, P let us say here P is the pressure and the small p that I have written is the momentum. So, what is the idea force? The transfer the rate the change of the rate of change of momentum, the rate of change of momentum per unit area is the pressure. The rate of change of momentum per unit area is the pressure right the rate of change of momentum per unit area is the pressure. So, why is the momentum changing because of the collisions right.

So, the momentum that is imparted per unit area per unit time is the pressure that is exerted by the gas on the fluid parcel. The momentum imparted per unit area per unit time is the pressure that is exerted by the surrounding air on the fluid volume delta v ok. So, if let us say if the pressure. So, here the pressure at the center is indicated as P naught right now how do you calculate the pressure at a certain point if you know the if you know this is to be the pressure at the center of the air parcel as P naught, how can you calculate the pressure at a subsequent point?

Let us say I want to calculate the pressure at the point A, how do you do that? Generally, let us say the simple idea of let us say if you know the changes differentials what do you do? So, let us say the value at a subsequent point, let us say at a later point is in terms of let us say. So, I am just writing the relation for your understanding. So, a value at a later point is equals to the is the initial value at the beginning plus gradient times the change ok. So, this is the basic idea.

So, in that way I can write the pressure at the boundary A as P is equals to P naught plus dou P by dou x along the x direction that you are calculating the gradient and how much you have traveled delta x by 2 right. So, this is along the x axis. So, the side of the this is delta. So, this is this small dimension is delta x by 2 right so, in that way.

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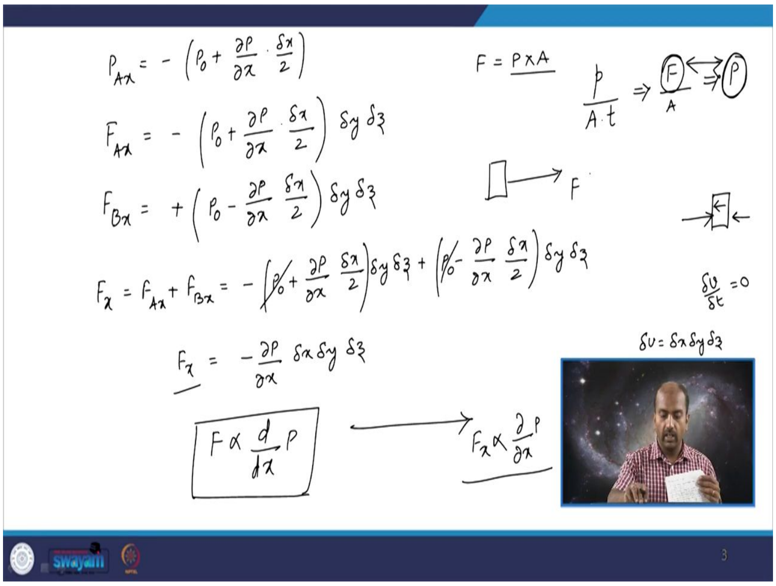

So, equilibrium can exist as long as the volume that you have taken delta v. So, again delta v is going to be written as delta x delta y delta z; if you want delta v by delta t to be 0. You would require that equal amount of pressure acts from the outside and the inside ok. So, let us say the pressure at the so, pressure at this let us say we call it as P Ax and we call it as P Bx and the on the surface B and on the surface A which can be written as.

So, P Ax P Ax is the amount of pressure that is exerted by the gas on the wall and what is that you have calculated? So, P this is let us say this is P A, P A is the pressure that is exerted by the gas on the wall from the inside. So, if you want the volume to be constant this value has to be same as this value right now. So, what will be that? Exactly opposite. So, P Ax has to be minus P naught plus dou P by dou x into delta x by 2 right now similarly.

So, what is the so, this is the pressure; the force that is acting here since you have a unit area is simply minus P naught plus dou P by dou x into delta x by 2 times delta y delta z so, because force is equal to pressure times area. So, the area that is going to be relevant here is simply this one delta x and delta y delta x and delta y. No this is delta y and delta z. So, this is the area of this plate is delta y and delta z right delta y delta z yes.

So, similarly let us say so, pressure that is acting or the force that is acting on the other side is simply plus P naught minus dou P by dou x into delta x by 2 times delta y delta z ok. Now, this is the net this is the x component of the force. So, here the basically coming back so, this is the net component of force. So, the force that is existing due to the molecules inside is exactly balanced by the force that is that the boundary of this volume experience is due to the gas molecules outside.

So, if you balance the forces from inside and outside on both the sides you will realize that the net force that acts along the x direction F x is nothing, but F Ax plus F Bx which is equals to minus P naught plus dou P by dou x into delta x by 2 times delta y delta z plus P naught minus dou P by dou x into delta x by 2 times delta y delta z.

So, then it will get cancelled you can write. So, this will get cancelled. We can write minus dou P by dou x into delta x delta y delta z. So, the net force acting in the x direction does not depend on the pressure; that means the force that is acting on. So, what is the basic idea we started from the momentum transfer per unit area per unit time gave us the force right force per unit area we call it as pressure right.

Now, what you realize is that the force is not proportional to the pressure as it is force and pressure are not directly proportional rather force is proportional to the change of the grade change of the pressure. So, here so, force is proportional to the change of the pressure, but not our or let us say the gradient of pressure along the x direction, but not the pressure directly. So, it will not depend on the magnitude of pressure as it is, but it will depend on the change the rate at which; the no not the rate; the change the gradient of pressure along this direction.

So, we have force that is acting on the x axis along the x axis is proportional to the rate at which the pressure changes across the x axis ok. This is a very important relation I mean it is not the pressure which drives the motion of air from one point on the point. So, this fundamental reading is leading to the concept that let us say if you consider air mass at some point, this air mass moves from one point to another point. Generally, air mass moves from a high pressure point to a low pressure point it is natural right.

So, but here it is not the so, if you want some movement ultimately this moment has to be attributed to the force. So, there is a force which pushes the air parcel from high pressure to low pressure. So, this force is not proportional to the magnitude of high pressure or the magnitude of low pressure how high is it or how low is it, rather the force how much amount of force pushes this air parcel.

And, how much amount of velocity does this force attribute to the air parcel depends on how high is the pressure in comparison to the low pressure. So, this is the force depends on the change of pressure with respect to the x axis, but not the absolute magnitude of the pressure along the x axis.

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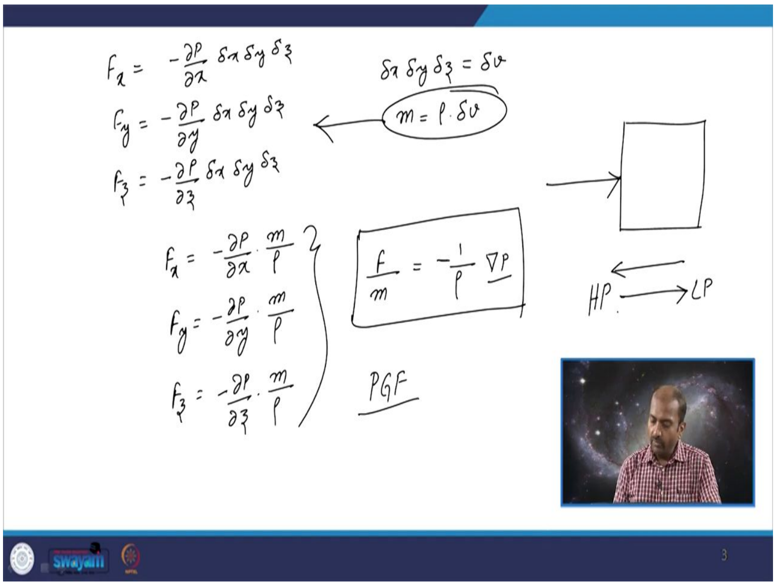

Now, let us say similarly we can we can derive I mean in the same approach we can also follow for y and z axis and we can write let us say we can write F x as let us say my already written minus dou P by dou x into delta x delta y delta z. Similarly, you can write F y as minus dou P by dou y delta x delta y delta z; F z as minus dou P by dou z delta x delta y delta z. You can combine these three equations and you can simply write you can simply write.

So, now here delta x delta y delta z is the volume right. Now, we can write mass of this air parcel as density times the volume right. So, using this into this three equation we can see we can write them in terms of mass is equals to minus dou P by dou x times m by rho; F y as minus dou P by dou y times m by rho and F z as minus dou P by dou z into m by rho.

Combining these three we can write, force per unit mass is equals to minus 1 by rho times del P. So, what is this force? This force is called as the pressure gradient force ok. So, force per unit mass, so, you have considered an air parcel the force that acts on this air parcel per unit mass will be proportional to the gradient of the pressure, but not the pressure itself. So, density also comes into picture ok.

So, this is a very very important relation which we will need at several instances during this course. So, pressure gradient force per unit mass will depend on the gradient of the force now, very very important example let us say you have a high pressure system when we have a low pressure system; there is a reason why there is a minus here right. So, high pressure the movement is from the high pressure to low pressure right and the gradient is in this direction right.

So, pressure gradient is in this direction and the movement is in this direction. So, the direction of force will be opposite to the gradient, but will be proportional to the gradient that is the idea. So, pressure gradient force let us say is the basic reason why a air mass moves from one point to another point. So, this is a basic idea of pressure gradient force which is responsible for the movement of air mass from high pressure to low pressure ok.

So, we will discuss about the remaining types of forces in the subsequent classes.