Introduction to Aerospace Propulsion

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Module No. # 01

Lecture No. # 04

Introduction to Thermodynamics, Scope and Method, Basic Concepts: System, Surroundings, Property, Intensive and Extensive, State, Equilibrium and State Postulate, Process, Path and Cycle

Hello. Starting from today's lecture series, what we are going to study about is a very fundamental and very important aspect of engineering analysis.

Over the next several lectures, what we are going to understand is about thermodynamics. Thermodynamics is a very fundamental subject, which plays a very significant role in understanding of engineering systems. In this course that we are currently studying about is on introduction to aerospace propulsion. Thermodynamics is a very fundamental science that needs to be understood very carefully.

It is very important that we understand some of the very fundamental aspects of thermodynamics because thermodynamics forms the basis for understanding and also design and development of engineering systems. In the kind of systems that we are going to study in this course that is related to aerospace propulsion thermodynamics is the basic subject that needs to be understood thoroughly. So, let us take a look at what we are going to study or understand in this particular lecture.

This lecture is on very fundamental aspects of thermodynamics. We shall get introduced to basic aspects of thermodynamics. Introduction to thermodynamics, its significance and some of the basic terminology that we are going to use in thermodynamics is what we shall cover in this course.

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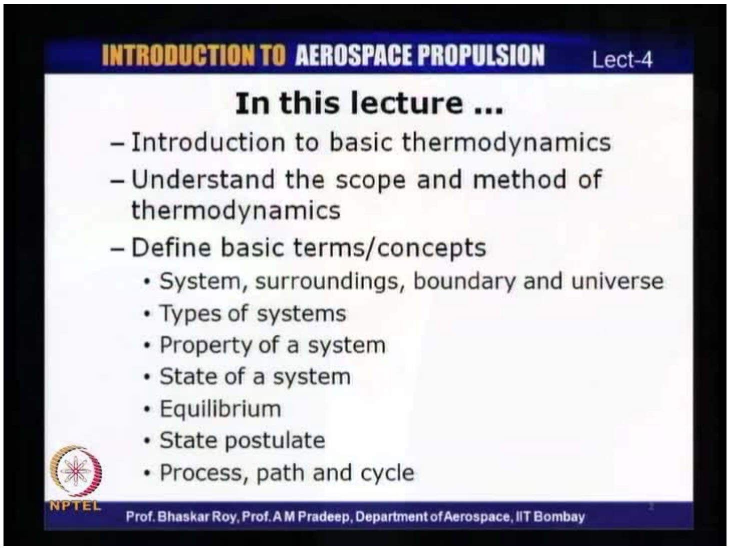

If we take a look at what are the contents of this particular lecture: we shall first get introduced to basic thermodynamics; we shall understand the scope and method of thermodynamics; we shall define basic terms and concepts; Some of the basic concepts that we shall be understanding and studying in this course will include system, surroundings, boundary and the universe. We shall then analyze the different types of systems that are in existence or that you can define for a particular system under investigation. We shall understand property of a system and what we mean by property of a particular system. We shall also understand the state of a system and about equilibrium of a system and its state.

We shall also understand a very basic concept known as the state postulate, which helps us in defining the property of a system. Towards end of the lecture, we shall understand and explore a few basic terms like process, path and cycle for any particular system.

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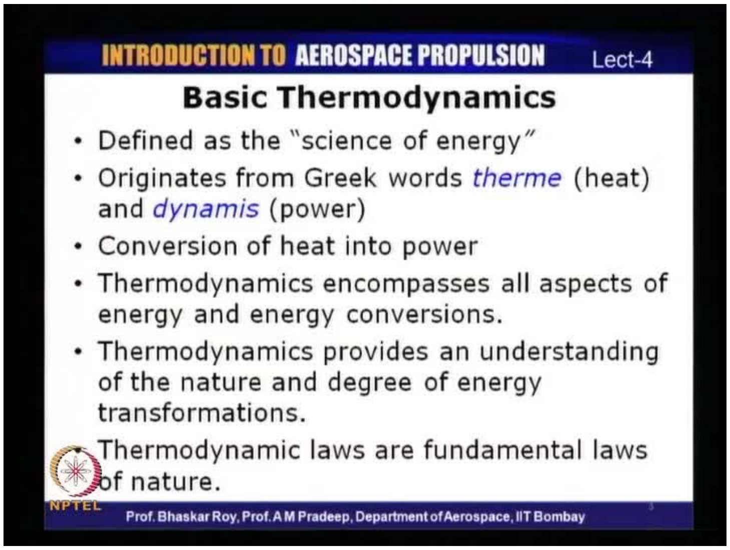

Thermodynamics is a very old subject; probably as old as existence of mankind itself. The basic reason is that man has always wanted to convert available heat into power and this has been an endeavor of mankind since time immemorial.

As of today, thermodynamics is defined as the science of energy. The basic reason for this is that thermodynamics as a word originates from two Greek words known as therme and dynamis. Therme means heat in English and dynamis means power. So, this means that thermodynamics implies conversion of heat into power. This is a very basic requirement that man has always been endeavoring towards to convert heat into power and in a very efficient way.

Thermodynamics is a science, which deals with the conversion of heat into power. That is why it is a very basic science in itself. For example, the particular course that we are currently undergoing deals with introduction to aerospace propulsion. So, propulsion means providing power to a particular vehicle. This power would involve conversion of one form of energy into another and that is what thermodynamic deals with.

Thermodynamics is a tool or a mechanism by which you can understand a system, which is converting heat energy into power. Therefore, thermodynamics in one sense encompasses all forms of heat conversion into power. What we shall try to understand over the next several lectures is that - what are the different ways by which you can understand a particular system, which is trying to convert one form of energy into another. So, thermodynamics helps us in providing an understanding of the nature and the degree of energy transformations.

Towards the end of this lecture series on thermodynamics, we shall be able to analyze a particular system, which is trying to convert heat into power output. Another very important aspect of thermodynamics is that thermodynamic laws as we shall see little later are fundamental laws of nature. These are like the laws of a Newton, which are also considered to be fundamental laws of nature. Therefore, it is very important that we understand the meaning and the implications of the different laws of thermodynamics.

As we shall see later on, there are four laws of thermodynamics that we shall study named: zeroth law, the first law of thermodynamics, the second law of thermodynamics and the third law of thermodynamics. These four laws of thermodynamics are very fundamental in nature. Therefore, they are also considered to be fundamental laws of nature, which has to be followed and cannot be violated. So, these fundamental thermodynamic laws cannot be violated. This is the basic reason why it is important that we understand the implications of thermodynamic laws. Also, this is because very often one comes across different systems, which are being proposed by different people and can convert heat into power. However, in some sense or the other, they violate one of these thermodynamic laws. Therefore, these systems are by themselves and by their very design are not feasible. A thorough understanding of thermodynamic principles and its laws are important in our understanding of engineering systems and also to evaluate the feasibility of new concepts and designs.

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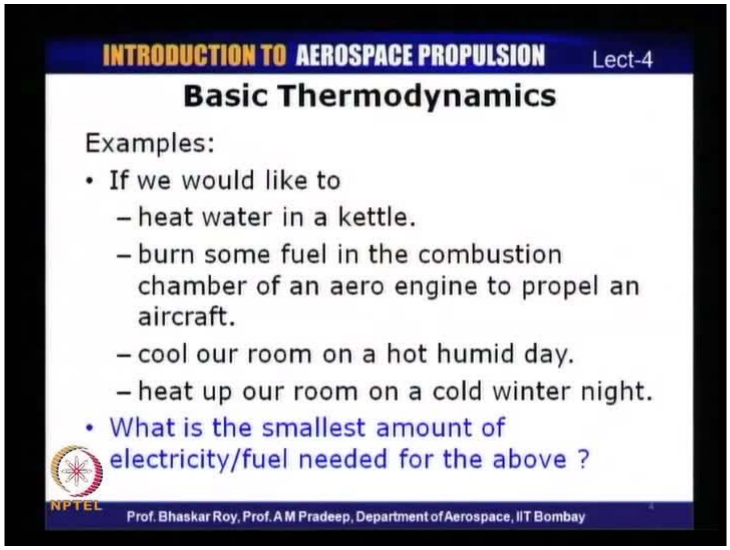

Let us take a few examples of thermodynamic systems. For example, if we would like to heat water in a kettle or burn some fuel in a combustion chamber of an aero engine to propel an aircraft or cool a room on a hot humid day or perhaps heat up your room on a cold winter night. These are examples of common occurrences in daily life. So, in all of them, you would be interested in knowing what is the smallest amount of electricity or fuel that will be needed to carry out the above.

These are very simple examples. There could be numerous of that examples like: For example, driving a car – you are converting fuel; it could be petrol or diesel into power output for driving the car forward. For example, preparing a particular dish in a pressure cooker – you are converting energy into a different form. So, you are dealing with conversions of energy day in and day out.

Another very important example of a thermodynamic system is a human body. All human bodies convert energy in some form into another form. So, the energy that we take in is the food that we take. This food is converted to energy in some other form, which enables us to walk or run and do daily activities in a normal way. So, the human body itself is a very complex thermodynamic system. We shall understand some of these aspects as we progress along these lecture series.

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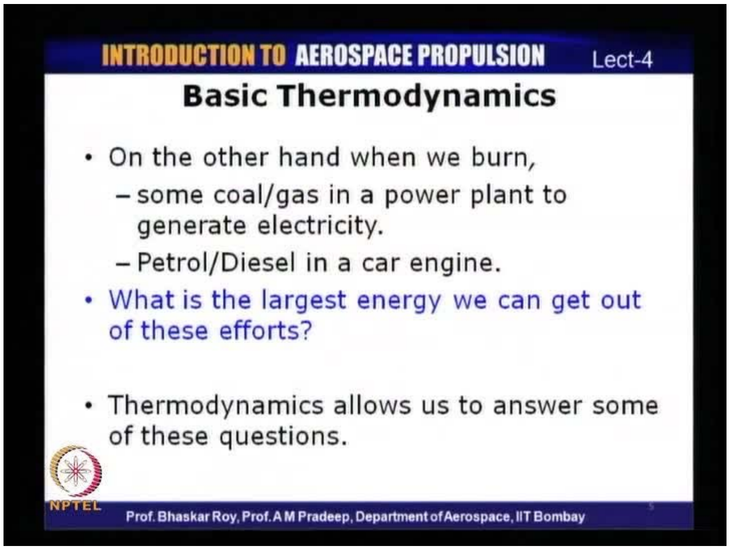

Let us take a look at some more examples of thermodynamic systems. When we burn some fuel as I was mentioning a little while ago - burning some power that is coal or gas in a power plant to generate electricity; or you burn petrol or diesel in a car engine. What is the largest amount of energy that we can get out of these efforts? You would be very much interested in efficient conversion of fuel into power output. That is one of the major goals of an engineer in a modern day. This is because he would like to have his system as efficient as possible that converts the amount of available energy into work output in a most efficient way. So, thermodynamics is a science which allows us in answering many of these questions.

In the current day scenario, it is very important that we are able to design systems, which are as efficient as possible. Thermodynamics is a basic science, which helps us in converting fuel into power output. For that matter involving any other energy conversion, it is important to understand the basic thermodynamic principles.

Let us move on further and understand some of the basic terminologies that we shall use throughout this course. There are two different ways in which you can analyze a thermodynamic system. One of them is known as the macroscopic approach, which is also referred to as the classical thermodynamics. So, the thermodynamic science or the approach, which deals with a macroscopic science of systems, is referred to as the classical thermodynamics.

The advantage of a macroscopic approach is that it does not require the knowledge of the molecular level of the system. You can analyze a system as a whole. You do not need to know the behavior of individual molecules in a system, which can be quite complicated. So, macroscopic approach does not require knowledge of the molecular level. Macroscopic approach is an easier approach. It is a more direct approach especially in the case of engineering systems, where you would not really want to bother about the molecular level dynamics. However, you would like to analyze a system as a whole as a group of molecules rather than at their individual level. It is because of this reason that we are going to follow the classical approach or the macroscopic approach or classical thermodynamics in this course.

The other approach on the other hand is the microscopic approach. So, microscopic approach involves deeper understanding of the molecular level of a system and taking a look at the individual behavior of molecules. Therefore, as we understand the molecular level dynamics, it is far more complicated and it extensibly uses the kinetic theory of gases. This particular approach is also known as the statistical thermodynamics. As the name itself refers to statistical thermodynamics, obviously will involve exhaustive use of statistical principles. This is because you are understanding or trying to understand the system on a molecular level. So, in this course, we are not going to approach thermodynamics in a statistical sense, but we are going to take the macroscopic approach or the classical thermodynamics approach.

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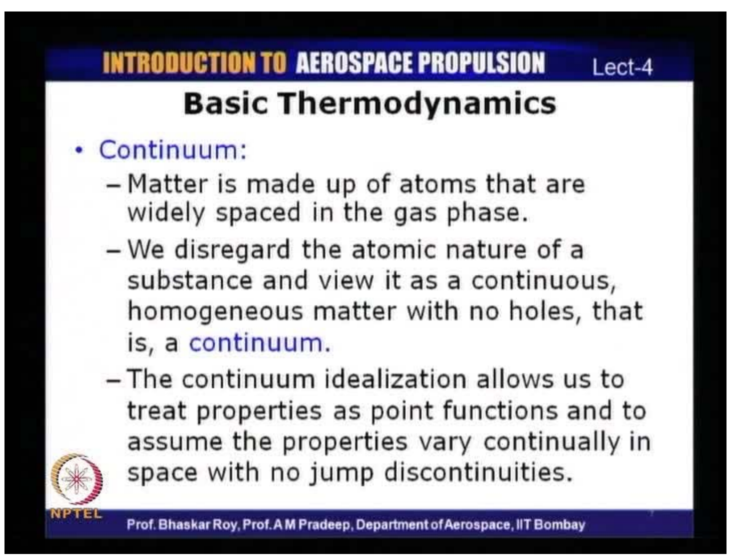

The other principle or the assumption that we are going to make is known as continuum. Continuum refers to the continuity within a system. I will explain that shortly. As we are all aware, matter is made up of atoms, which are widely spaced especially when it comes to the gaseous phase. In classical thermodynamics, we would want to disregard the atomic nature of a substance and view it as a continuous, homogeneous matter with no holes or void, that is, it is a continuum.

This is what I was mentioning a little while earlier that in classical approach, you do not want to look at the molecular level of a system, but you would like to look at the system as a whole. So, the continuum approach is what we shall be following. Continuum idealization allows us to treat properties as point functions and to assume that the properties will vary continuously in space with no jump or discontinuities. What is a point function and its implications? We shall understand this a little later when we look at properties and systems.

Continuum approach is the approach that we are going to follow in this particular course because we are looking at the classical thermodynamics approach and not the statistical thermodynamics approach.

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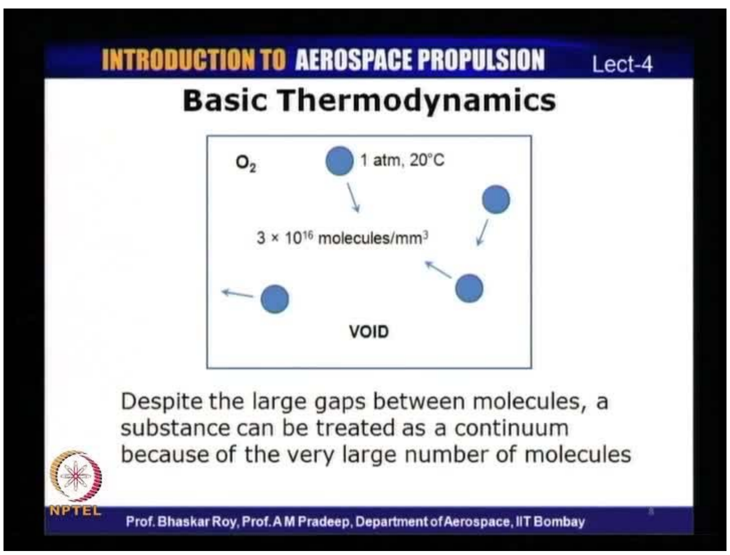

Let me explain what we mean by the continuum approach with a small example. For example, if you look at oxygen as a particular gas that we are interested in - as you see here in this bounding box, we have oxygen as the medium present there. We know that -

in the gaseous phase, there is a lot of random motion or Brownian motion of the molecules; for oxygen, which is at pressure of 1 atmosphere and 20 degree Celsius, there are estimated to be 3 into 10 raise to 16 molecules per millimeter cube of volume.

You can see that there are so many number of molecules in a very small volume of oxygen. However, in spite of that, as this illustration show, which is obviously highly exaggerated; between the molecules of oxygen you can still see a lot of void or free space. However, the good thing here is that in spite of the presence of these large gap between the molecules, there are enough number of molecules within a very small volume to enable us to consider this as a continuum. Therefore, in classical thermodynamics, we shall be dealing with systems, which are in continuum. We shall not look at the verified aspects of a system, which is a different study on its own that is usually covered using statistical thermodynamics. So, continuum approach is yet another assumption that we are going to take in thermodynamics.

What we going to do over the next several slides, which we shall explore today is to understand some basic terms, which we shall be using very continuously, quite often in this course and in subsequent courses. So, it is very important for us to understand the basic meaning of these terms. One such term that we shall use very frequently is a system.

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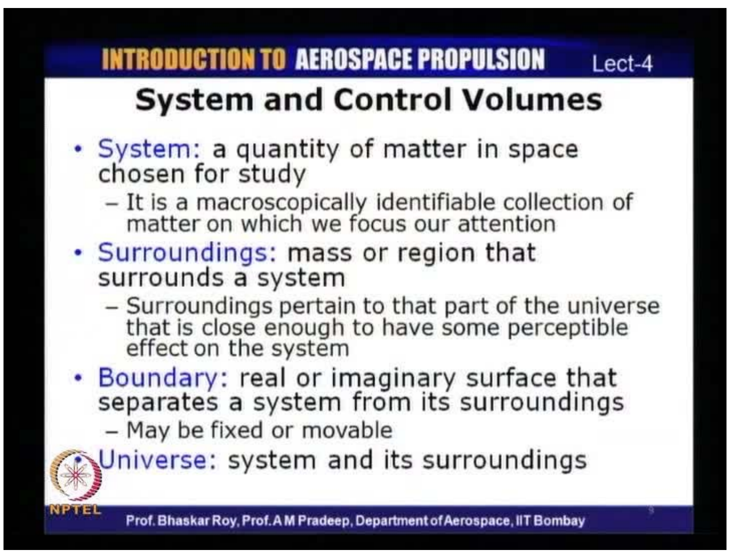

What do we mean by a system? System by definition is a quantity of matter, which we have chosen for study. Since we are dealing with macroscopic approach, it is a macroscopically identifiable collection of matter on which we focus our attention. So, system is a quantity of matter in space, which we have chosen for our study. For example, if we are trying to analyze an aircraft engine, to see the thermodynamics of an aircraft engine, we would like to choose the engine as the thermodynamic system. This is because that is the quantity of matter in the space, which we are interested in at the moment. So, we would like to choose that particular system, which is the aircraft engine in this example as the system, which is under consideration.

What is around the system is referred to as the surroundings. So, surroundings is the matter, which are in the immediate vicinity of the system and which have some amount of perceptible effect on the system. That is, if the system we are considering - let us say the aircraft engine for example, the air, which is just in the vicinity of the aircraft engine is referred to as the surroundings. What separates the system from the surroundings is referred to as the boundary of the system. So, a boundary of a system demarcates or separates the system from its surroundings.

There could be boundaries, which are of different types. As we shall see some examples a little later that a boundary could be either fixed or it could be movable. You could also have boundaries, which are real that is physical boundaries or you could also have an imaginary boundary depending upon the convenience of analysis. The system, the surroundings and the boundary put together constitute what is known as the universe.

System refers to this matter or in space, which is of interest to us and which we are considering for our analysis. Surroundings is the environment or mass or region, which surrounds a system, which is in the immediate vicinity of the system and which has some perceptible effect on the system. Boundary is one which separates the system from its surroundings. Universe is the system and its surroundings including the boundary; put together is referred to as the universe.

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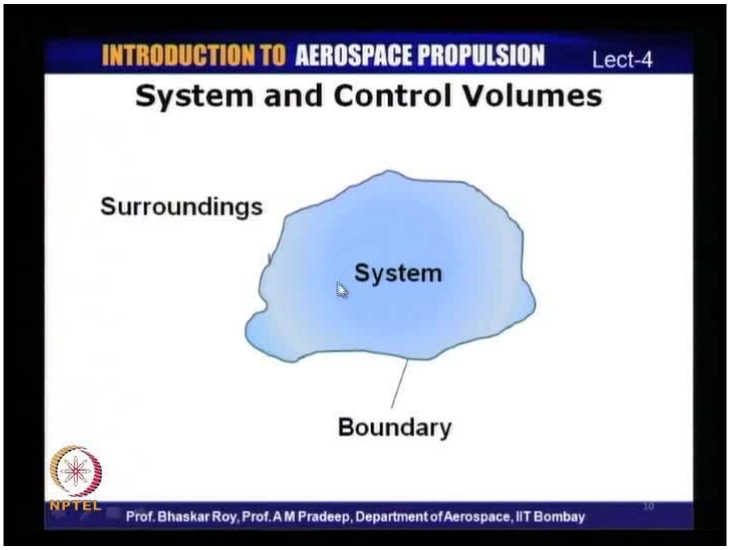

Now, let us look at an example here. What is shown here is a system, which is demarcated by its boundary. So, what you see here indicates the boundary of the system. This boundary separates the system from the surroundings. So, surroundings refer to that matter of space, which is in the vicinity of the system and which has some perceptible effect on the system. Boundary is the one, which separates the system from its surroundings.

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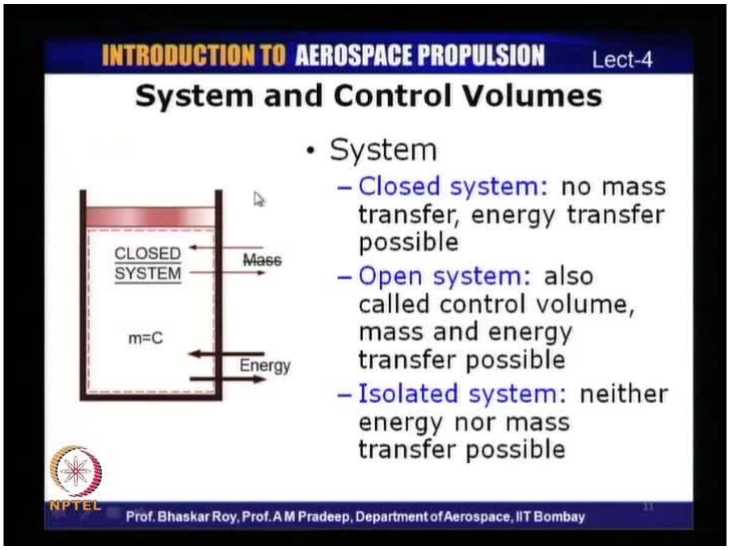

A system could be of different types depending upon the nature of the system itself. Depending upon what type of system it is it could be classified as a closed system. A closed system is one, where there is no mass transfer but, there is an energy transfer that is possible. Closed system is what is shown here in the example. What you see here is what we shall see this example very often in thermodynamics. This is referred to as a piston and cylinder assembly. So, what is seen here bounded by these lines is the cylinder and what is seen here is the piston. A piston and cylinder assembly is a system, which we shall refer to very often in this course.

As we shall see little later after several lectures is that this is very similar to what you see in automobile engines. Automobile engines operating on either spark ignition system or compression ignition systems would have a piston and cylinder assembly. That is an example, which we shall refer to very often because that is one of the common types of systems that we are familiar with, which generate a power output.

A closed system is one across the system boundaries of which there can be only energy transfer, but there cannot be any mass transfer across the system boundaries. An open system on the other hand is one across which there could be both mass transfer as well as energy transfer. So, open system involves the interaction of the system with its surroundings through mass as well as energy. An isolated system is one across the system boundaries of which there could be either no mass transfer as well as no energy transfer. So, an isolated system does not interact with its surroundings through mass or energy interactions. These are the different types of systems that are possible. Closed system - only mass transfer not allowed, but energy transfer is allowed in a closed system. Open system – both mass as well as energy transfer is permissible. If a system has no mass or energy transfer such a system is known as an isolated system.

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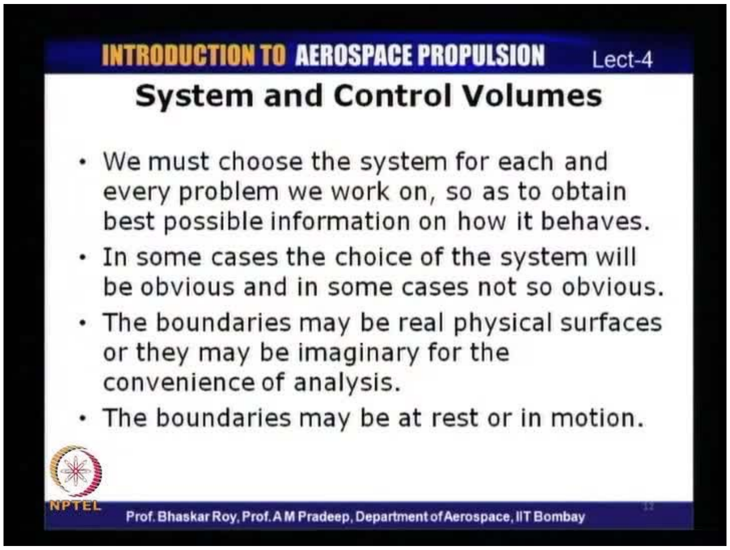

Now, we shall look at some examples of systems, which fall in either of these categories. We shall take a look at those examples after we understand how we choose a particular system. We must choose a system for each and every problem that we are interested in. This is important because if we choose a system very carefully, it will help us in obtaining as much information about the system as possible. So, it is very important that we choose a system, which is appropriate for the particular problem that we are interested in. This means that choice of a system would be quite obvious in some cases, but in some cases obviously it will not be that clear in the beginning. So, a system must be chosen; in case the system choice is not very obvious, it must be chosen carefully depending upon what is the purpose of this particular thermodynamic analysis.

When we choose a system, the boundaries of the system could be either real boundaries or physical boundaries or it could be imaginary boundaries. So, that again depends upon what is it that we are trying to analyze from a particular system. The other aspect of boundaries is that you could have boundaries, which are either stationary or fixed; or you could have boundaries, which are movable or which are in motion. So, you could have a system, which could have a combination of these different properties – that it could have a boundary, which is fixed or it could have a boundary, which is movable; it could have a real boundary or a physical boundary or it could have a boundary, which is imaginary in nature. We shall get more information on these aspects of a system as we take a look at some examples, which will help us in explaining what these actually mean.

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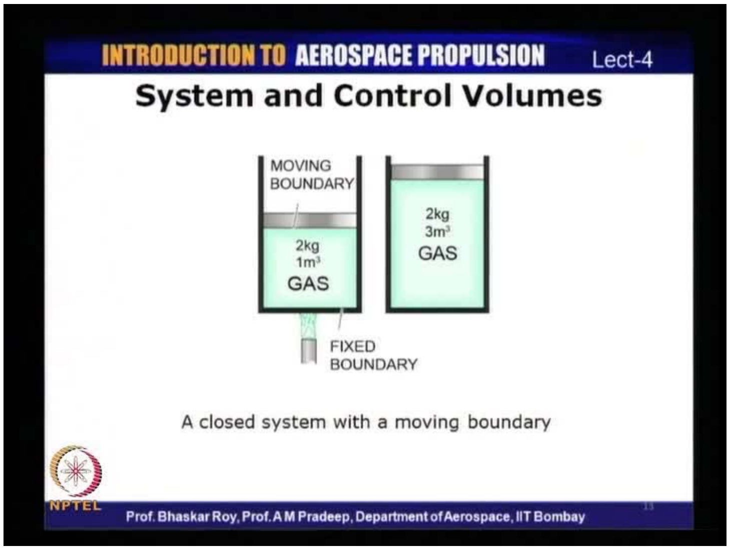

Let us look at one example of a closed system, which has a movable boundary. What you see here is a closed system. It is a closed system because there can be only energy transfer across the system boundaries. There is no mass transfer across the system boundaries and therefore, it is a closed system.

What you see here are fixed boundaries of the piston-cylinder arrangement. Remember - I had mentioned about the piston-cylinder example, which we shall see very often. So, this is a same piston-cylinder example we are coming across. This cylinder consists of a particular gas, which has a particular mass of 2 kgs. Let us say a volume of 1 meter cube.

The cylinder boundaries are fixed because they do not move. Now, if you were to add energy across a system boundaries, remember - a closed system, it is possible to have energy interaction across the system boundaries. There is energy transfer because you are heating up the cylinder. So, there is an energy interaction across system boundaries.

The piston on the other hand forms the movable boundary. As you add heat to the system, it causes the gas to expand. As you can see here, the mass of the gas still remain 2 kgs because there is no mass transfer across the system boundaries. However, yes, the volume of the gas increases because you are adding energy. As the volume of the gas increases, the piston has moved to a new location. Therefore, this constitutes a moving boundary of the system and the cylinder walls form the fixed boundary of a system.

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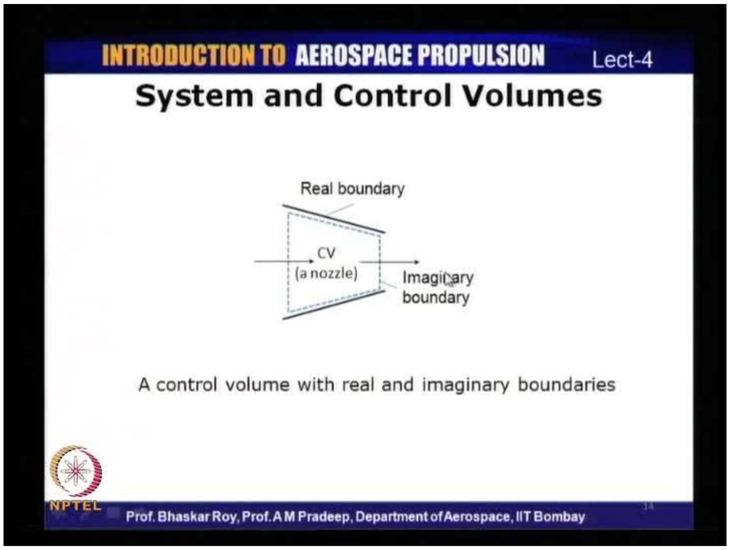

Yet another example: here we have an example of a control volume, which is an open system, which has both real as well as imaginary boundaries. The example that is shown here is that of a nozzle. A nozzle is a section, which is again very often used in engineering systems and is a system, which is used for accelerating a flow in a subsonic mach number flow.

What is sub sonic will become clear little later. In subsonic flows, a nozzle, which of the geometry, which is shown here can lead to acceleration of the flow. In this nozzle, the walls of the nozzle form the real boundaries; indicated by this dark black lines form the real boundaries. What about the inlet and exit of the nozzle? At the inlet and exit of the nozzle, we can define imaginary boundaries. So, what you see here are the imaginary boundaries of the nozzle. These form the imaginary boundaries of the nozzle, which bound the controlled volume. The real boundaries are shown by these dark lines, which are on the periphery of the nozzle. This is an example of an open system. An open system is also very usually referred to as control volume. A control volume with which has both the real as well as imaginary boundaries.

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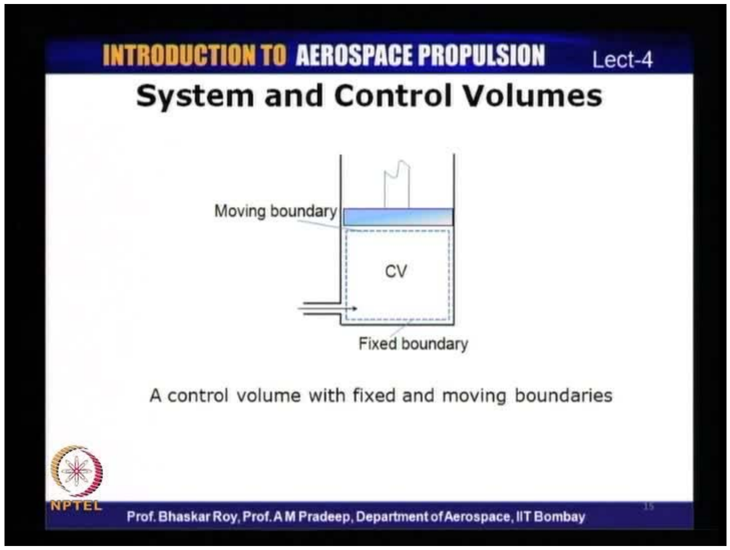

Let us look at an example, which combines the previous example as well as this example in some sense because you have an open system here with a moving boundary. We had already seen an example of an open system, which has real and imaginary boundaries. Here we have an example, which has often open system that is a control volume, which has both fixed boundary as well as a moving boundary.

The cylinder volume as I had mentioned earlier - walls of the cylinder constitutes the fixed boundary of the system and the piston on this side constitutes the moving boundary. This is a control volume that is an open system because there is mass transfer across the system boundaries in addition to energy transfer. This is an example of an open system, which has a fixed boundary as well as a moving boundary.

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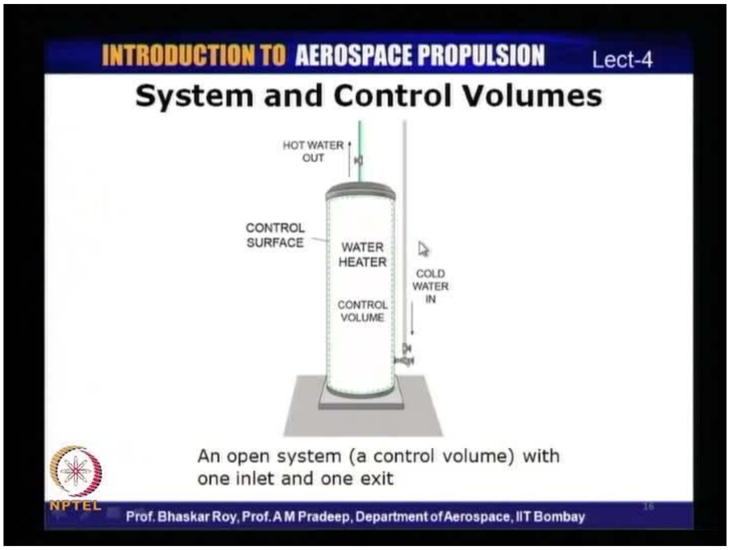

Yet another open system here. This is an example of let us say a storage water heater, which is used for heating water. In this case, we have water, which is cold water coming in from one side of the control volume. Hot water, which gets heated up inside the water heater comes out through another outlet. Now, you can see that there is mass transfer across the system boundaries and there is also heat addition inside the system. Therefore, it qualifies to be called an open system or a control volume. What bounds the control volume is referred to as the control surface. Control surface acts as the boundary of a control volume. This is an example of a control volume. An open system, which has one inlet and one exit. So, it is obviously possible that there are control volumes or control systems, which have multiple inlets and multiple outlets.

We shall see many of these examples as we analyze different engineering systems especially in aircraft engine. That is an engineering system, which is of interest to us in this course. We shall understand the working of such engineering systems through thermodynamic analysis, which will require us to use many of these concepts of defining the system, its boundaries and its surroundings. Moving on, we shall understand what is meant by a property of a system.

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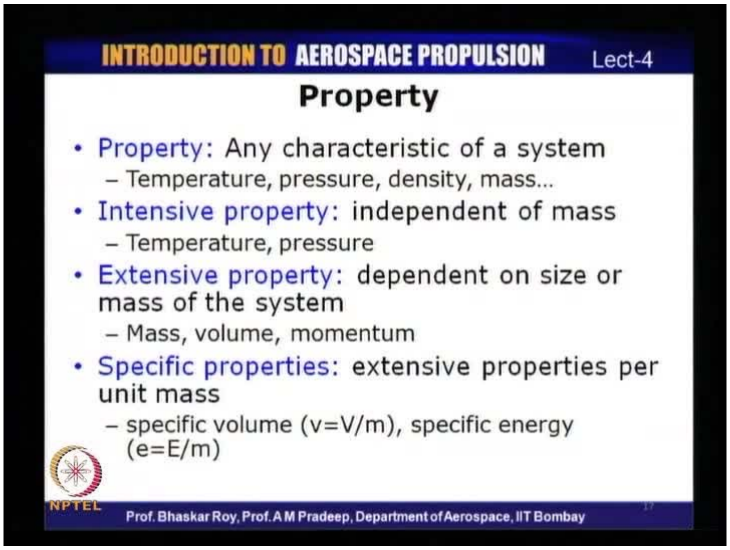

If we were to define a particular system,… We have understood how we can define a particular system. Each engineering system requires to be defined in terms of its boundaries and its surroundings. How do you characterize this particular system? A property refers to any particular characteristic of a system. There are different ways in which you can define a property. A property is any characteristic that defines a particular system. The property could be temperature of the system, pressure, density or mass and so on. Therefore, these are properties, which characterize a particular system.

The defined properties could either be intensive property or it could be an extensive property. The property could be intensive if the particular property is independent of mass. For example, temperature or pressure – these are properties, which do not depend upon the mass or size of the system. Therefore, they are referred to as intensive properties. On the other hand, extensive properties are those properties, which depend upon the mass or size of the system.

Some examples of extensive properties are mass itself; obviously, it depends upon the size of the system. Volume of a system is again an extensive property because it depends upon the mass or size of the system. Momentum associated with a particular system again depends upon the mass. Therefore, that is also classified as an extensive property. There are properties, which are extensive properties taken per unit mass are also referred to as specific properties. For example, volume, which is an extensive property taken per unit mass is referred to as specific volume. Energy for example, is again an extensive property. Energy per unit mass is referred to as specific energy; that is again a specific property. So, these are extensive properties per unit mass referred to as specific quantities or specific parameters.

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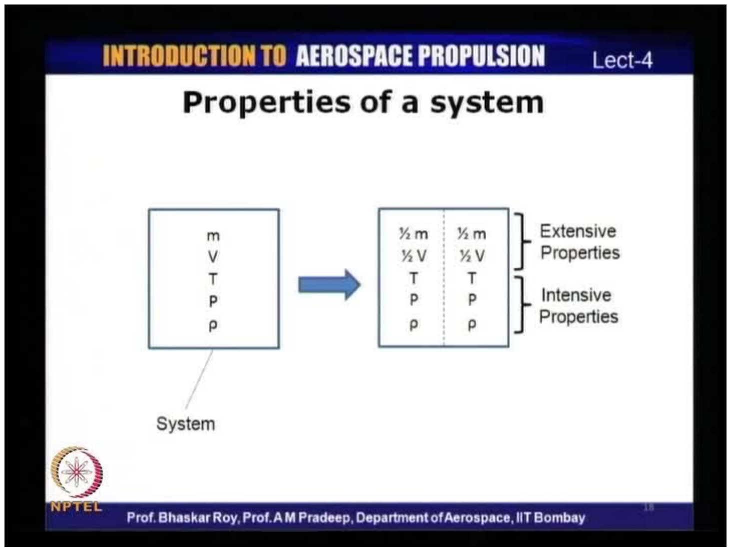

Now, let us look at an example, which will help us in explaining what are intensive and extensive properties. What is shown here in this example is a system, which has different properties, which have been defined here in terms of its mass, volume, temperature, pressure, density, etcetera. If we were to split the system exactly into half like what is shown here on the right hand side, we have a splitter, which splits the system exactly in to half.

Now, let us look at what happens to the different properties of the system. There are certain properties of this system, which could now change and certain properties, which will remain the same. Those properties, which change are the mass and volume. As you split the system into half, the mass of the systems become half and volume also becomes half. However, if you look at temperature, pressure, or density, these do not change even if you have split the system into half. These are referred to as intensive properties because they are independent of the size or mass of the system. Whereas, mass or volume are extensive properties because as you split the system into different portions, the mass or volume of the system also changes. So, this is an example of a system, which has been defined in terms of both intensive as well as extensive properties.

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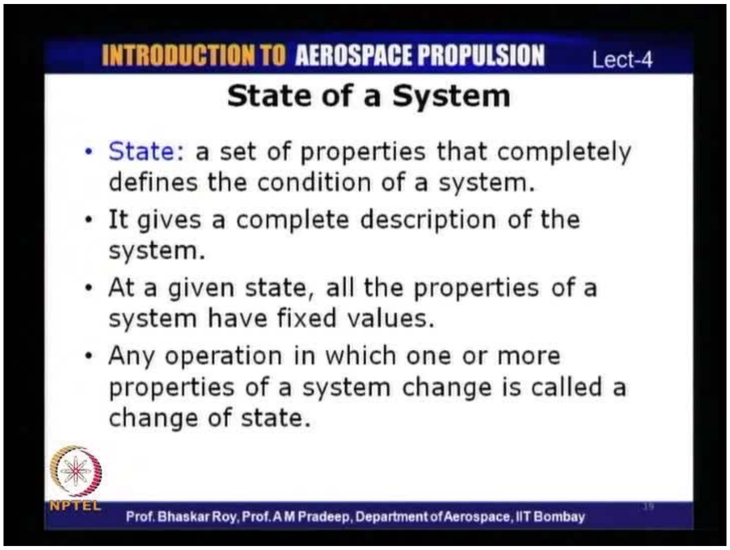

Very often you would have to define a system by using some of these properties. In fact, you will need a certain set of properties as we shall see little later; that are required to completely define the condition of the system. A set of properties, which define the condition of a particular system at a particular instant of time is referred to as state of a system. A state of a system gives complete description about what is this condition of that particular system at an instant of time.

At a given state, all the properties of the system would have fixed states or fixed values. That is, if you have defined a state of a system with certain properties, these properties will remain fixed for that particular state. If one or more of these properties change, then this operation is known as change of state. So, any operation, which involves change of one or more properties of a system, is referred to as change of state of the system.

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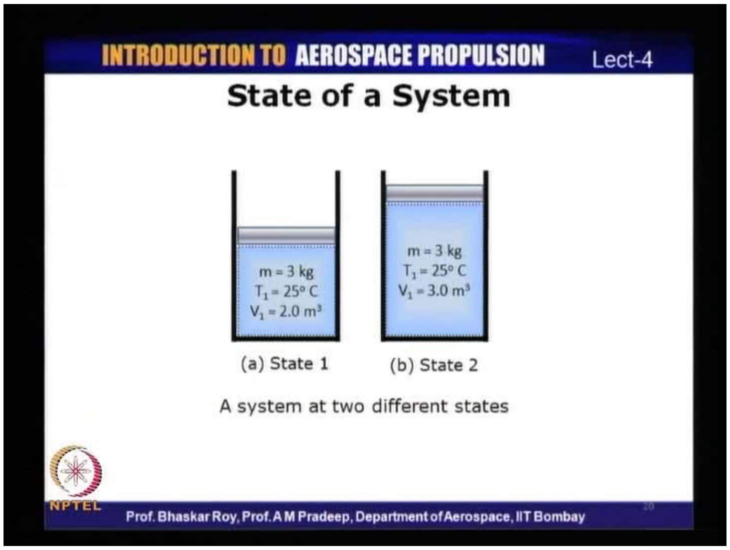

Let us look at an example, which will help us in understanding this. Here we have the piston-cylinder example again. On the left hand side, we have the system which has let us say - a mass of about 3 kgs, temperature of 25 degree Celsius, a volume of 2 meter cube. This defines the state of this particular system at particular instant of time.

If one or more of these properties were to be changed, then that defines another state of the system. On the right hand side, what we can see is that the mass of the system is fixed because it is a closed system. So, mass does not change. In this example, let us say the temperature is also fixed, but because the piston has moved away from its initial state, the volume has changed. Because the volume has changed, the system has now moved on to a new state. So, this right hand side shows the system at a different state than what it was previously. This is an example of the same system, which is existing in two different states by virtue of change of one of its properties; that was the volume in this particular example.

In thermodynamics, when we analyze different systems and what the state of the system is, etcetera, we would be dealing with equilibrium states.

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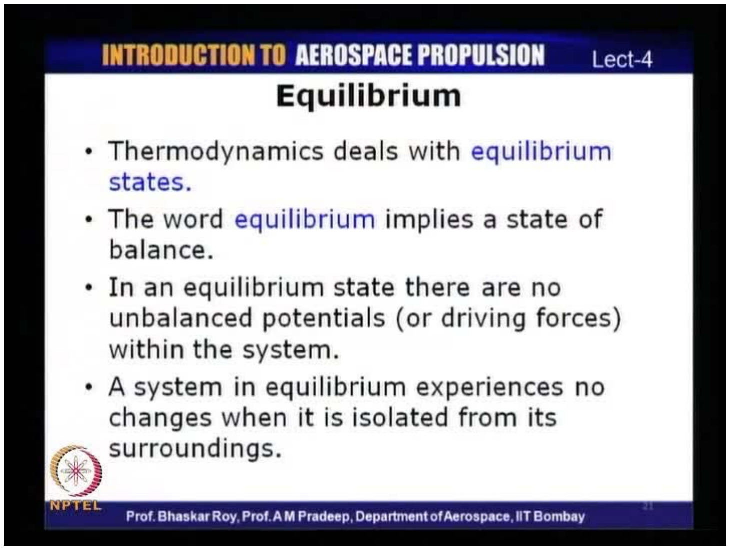

Equilibrium is implying that the state of the system is in a particular balance. The word equilibrium implies a state of balance. For a system to be in a state of balance, it is essential that there are no unbalanced potentials or driving forces within the system. For an equilibrium state, the system does not experience any change when it is isolated from its surroundings. So, a system that is in complete equilibrium will not undergo any change when it is isolated from the surroundings.

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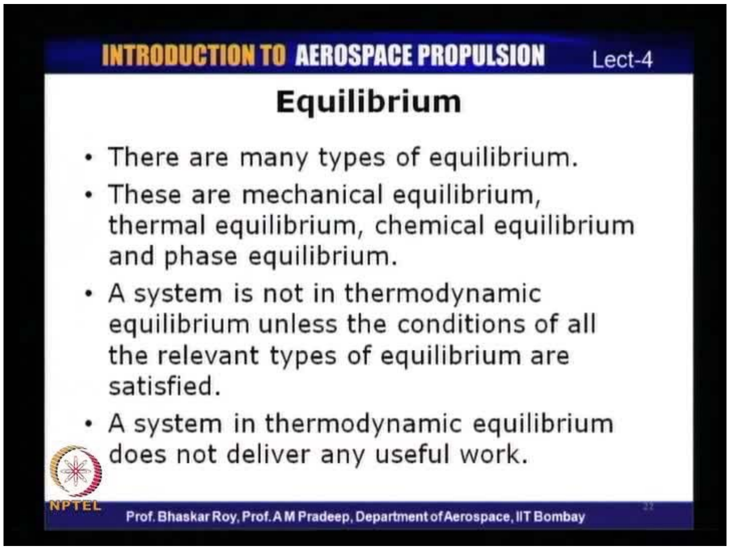

In thermodynamics, we shall be dealing with different types of equilibrium. A system could be in mechanical equilibrium, thermal equilibrium, chemical equilibrium and/or phase equilibrium. A system is referred to be in thermodynamic equilibrium, if all these conditions are satisfied. Unless all the conditions of equilibrium in terms of mechanical, thermal, chemical or phase are not satisfied, a system is not said to be in thermodynamic equilibrium.

A system, which is in thermodynamic equilibrium does not deliver any useful work. This may come as a surprise because you would excep t that if a system is in thermodynamic equilibrium, it should perform very efficiently. That necessarily does not happen because when a system is in thermodynamic equilibrium as we have seen earlier, there are no more driving forces or driving potentials. So, in the absence of any driving potentials or driving forces, there is no possibility of generation of work output. This statement will be more clear as we understand more concepts like work and heat transfer of a system. We shall be able to appreciate this point better as we understand work and heat transfer little later in further lectures.

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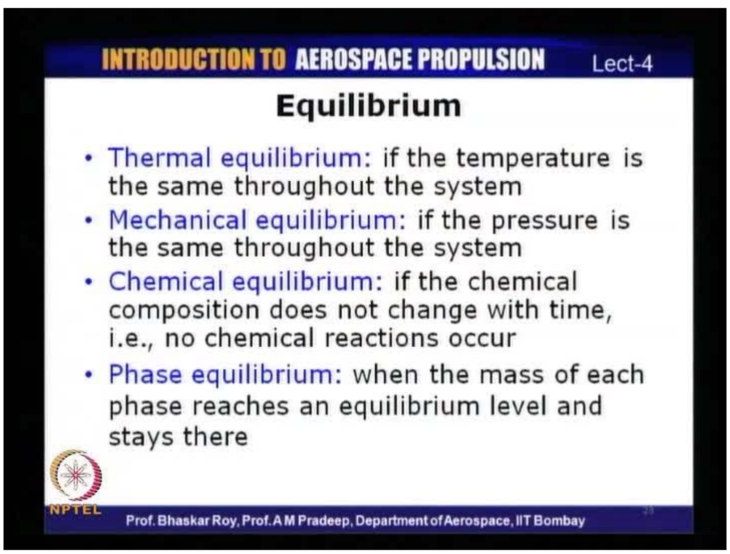

Now, let us look at what are the types of equilibrium. I mentioned that there are four different types of equilibrium that are possible. Thermal equilibrium - a system is said to be in thermal equilibrium, if the temperature of the system is the same throughout the system. On the other hand, a system is said to be in mechanical equilibrium, if the pressure is the same throughout the system. That is, if the pressure within the system is same everywhere, it is said to be in mechanical equilibrium. If the chemical composition does not change with time; that is, there are no chemical reactions taking place, then it is referred to be in chemical equilibrium.

If the system consists of different phases let say – a solid phase and a gaseous phase; when the mass of each of these phases reaches an equilibrium level, then it is referred to be in phase equilibrium. That is, for multiphase systems wherein you have different phases of the same system, either liquid gas or solid gas or all the 3 phases together. If the mass of each of these phases remains constant or it reaches an equilibrium level, it is said to have been in phase equilibrium. A system, which has all these different types of equilibrium conditions satisfied is said to be in thermodynamic equilibrium.

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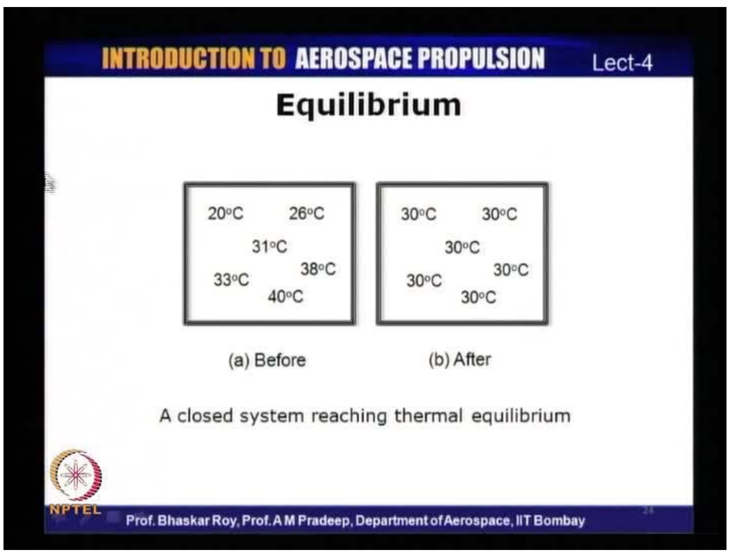

Now, let us look at one example of a system, which is initially not an equilibrium and then it has become come to an equilibrium state. The example shown here is that of a system, which was initially having different temperatures in different parts of the system. You can see that the system has different temperatures ranging from 20 degree Celsius to 40 degree Celsius and that keeps changing across the system. For the system to be in thermal equilibrium, the temperature has to be the same throughout the system. So, after the system reaches thermal equilibrium, the temperatures as you can see here (Refer Slide Time: 41:51) are the same; it is 30 degree Celsius everywhere.

In this example, which is shown is that the system is in thermal equilibrium. This does not mean that the system is in thermodynamic equilibrium. For this system to be in thermodynamic equilibrium in addition to the temperature being same everywhere, it also has to satisfy the conditions for: mechanical equilibrium, which means the same pressure throughout the system; or chemical equilibrium, which means no chemical reactions occurring as well as phase equilibrium; that is, if the system constitutes different phases, all the phases should be in equilibrium. This particular example, which is shown is that of a system, which is in thermal equilibrium.

In thermodynamics, we shall be always dealing with equilibrium states of a system and which means that it need not be essentially in thermodynamic equilibrium. However, it could be in one of the different forms of equilibrium; it could be either in thermal equilibrium or in mechanical equilibrium and so on.

If you recall, I had mentioned little earlier that we need a certain number of properties to define the state of a particular system. How do we know what number of properties are needed to define a particular state? It is not required that we define all the properties of a particular system. If you define certain properties of a system, certain number of properties, that itself will define the state of a system in totality.

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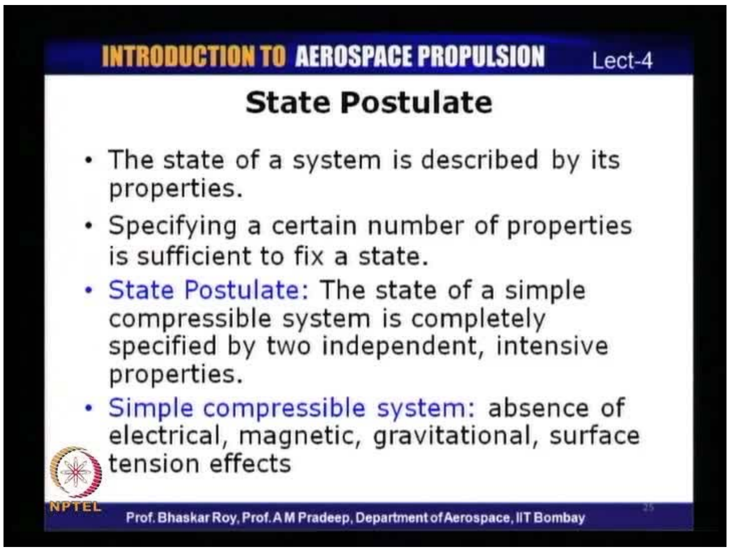

It is necessary for us to know what is the minimum number of properties that you would need to define a particular state of a system. This is explained by what is known as the state postulate. State postulates states that you can completely define the state of a simple compressible system by specifying two independent and intensive properties.

We have a new term here - simple compressible system. A simple compressible system refers to a system wherein there are no effects of gravity, electrical, magnetic fields or surface tension effects. That is, a system wherein there are no effects of electrical forces or magnetic forces, gravity effects or surface tension effects, is referred to as a simple compressible system.

According to the state postulate for such a system, which is a simple compressible system, it is possible to completely define such a system by specifying just two properties, which are independent and intensive. We have already seen what are intensive properties. Intensive properties are those properties, which do not depend upon the mass or size of a system. Independent properties are those in which you can change one of those properties without affecting the other. That means each of these properties are independent or mutually exclusive. So, according to state postulate, you can define the state of a system completely by just defining two properties, which are independent and intensive. Now, let us explain this point further by an example.

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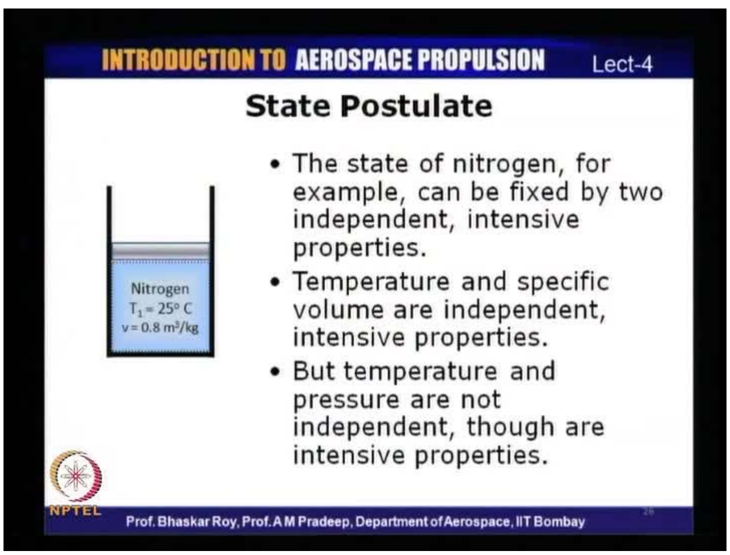

The example that is shown in the slide is that of nitrogen, which is again host with in a piston-cylinder assembly. We can see that the state of nitrogen for example, can be fixed by two independent, intensive properties as per the state postulate. Here we have defined the state of nitrogen by defining it by its temperature and specific volume. So, both of these are independent properties and these are also intensive properties, which mean that it is sufficient for us to define the state of nitrogen by these two properties.

However, on the other hand, instead of specific volume you had decided to define it by temperature and pressure. Then, it is not defining the state of nitrogen because temperature and pressure are not independent. That is, you cannot vary the temperature by keeping the pressure constant and so on. So, temperature and pressure depend on each other. Therefore, it is not possible to completely define the state of a system by just defining temperature and pressure. So, you need two properties, which are independent as well as those properties, which are intensive to be able to completely define the state of a system. So, state postulate helps us in identifying number of properties, which will be required to completely define or specify the state of a system.

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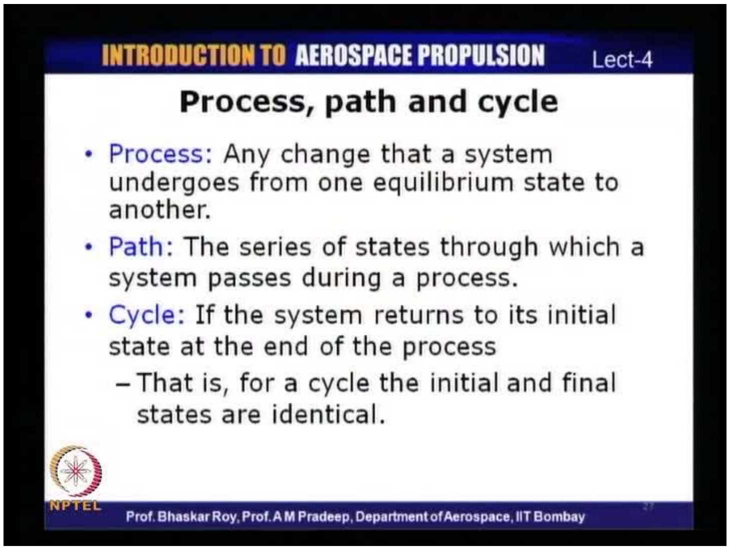

Now, let us proceed further and define or understand a few more terms, which we shall be referring to very often. One such a term is known as process. Now, we have seen that a system, which is in a particular state, can move to another state if one or more of its properties change.

A process refers to any change that a system undergoes from one equilibrium state to another. The series of states through which the system would pass during such a process is referred to as path of this particular process. If the system returns to its initial state at the end of the process, then that is referred to as cycle. A cycle is referring to a process wherein the initial and the final states are identical.

Process refers to change of a system from one equilibrium state to another. As the system progresses from one equilibrium state to another, it could be through a series of different states. These series of states through which the process has taken place is referred to as the path of the process. If the initial state and the final state happen to be identical, it is referred to as a cycle. Let us take some examples, which will help us in understanding what are process, path and cycle.

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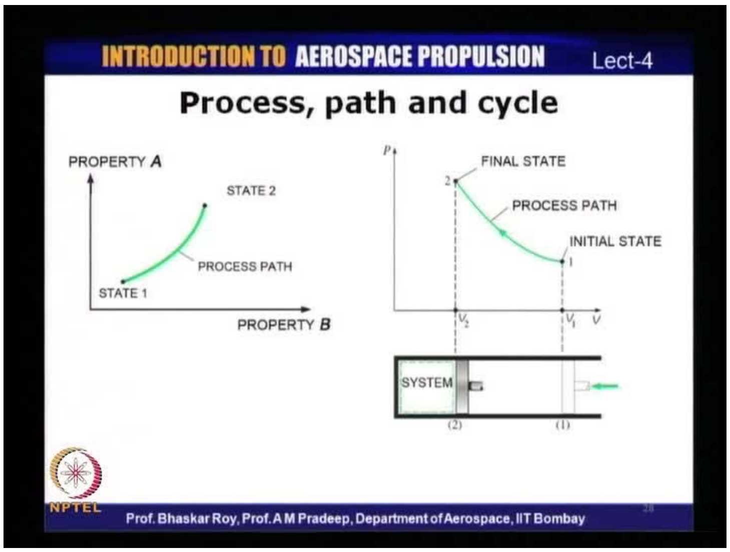

Now, we shall take a look at the classical example of the piston-cylinder assembly, which we have seen throughout this lecture and in future lectures as well. What is shown here is an example of a property change from state 1 to state 2. What is shown here is that a system, which is been plotted from change of state - from state 1 to state 2. This change of state has taken place through this green line which is shown here. You can see that there are so many intermediate states or steps in between state 1 to state 2. So, this is referred to as the process path. To explain this further, let us look at this piston-cylinder assembly example.

Now, the piston was initially at state 1, which is shown by this dotted line here (Refer Slide Time: 49:41). The initial state has a certain specific volume and a certain pressure P 1. As the piston is moving into the cylinder or as the system is compressed. The pressure rises because it is a compression process. The pressure will increase from state 1 to state 2. In the process, the specific volume reduces or changes. The new state, which is referred to here (Refer Slide Time: 50:08) as the final state is marked by 2, has a new specific volume V 2 and a new pressure P 2. So, this is an example of change of state from state 1 to state 2 through a process, which has been indicated by the process path.

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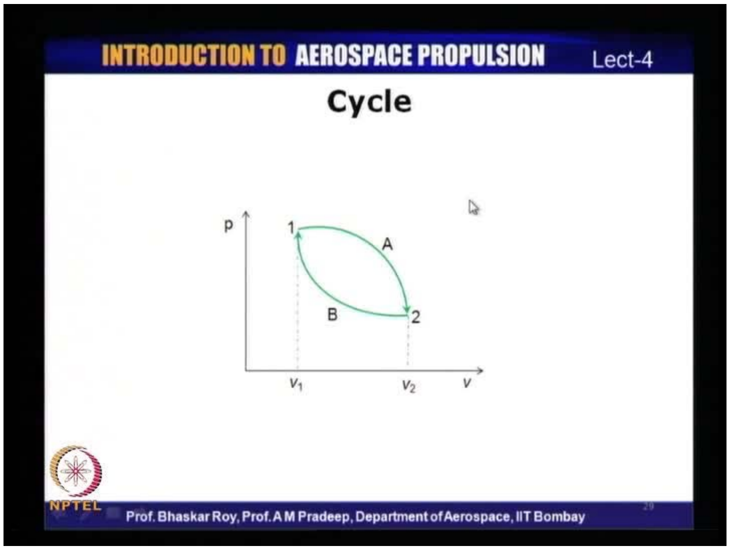

If the same example - we had the process, which is coming back to its initial state, then this is referred to as a cycle. For example, if this piston-cylinder assembly was initially at station 1, after the whole process, it has come back. That is, after an expansion; that is, reduction in volume, increase in volume, and reduction in pressure. Then, further it is compressed back to its initial state. This is referred to as a cycle. That is, the initial state and the final state are identical.

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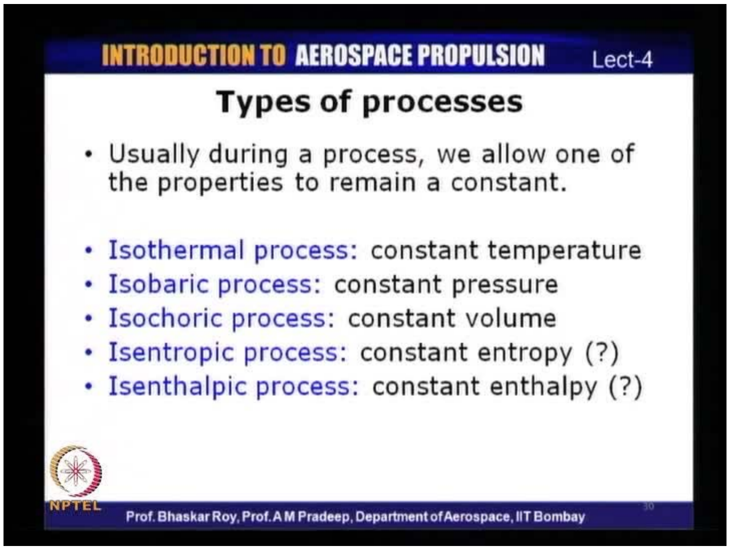

Depending upon the type of process, we can usually classify the processes as different types. As we shall see little later, during a process, we allow one of these properties to remain constant. A process in which the temperature is constant or is held constant is referred as an isothermal process. A process in which the pressure is constant is known as an isobaric process. A process during which the volume is constant is called an isochoric process. A process during which a property known as entropy is constant is called an isentropic process. A process during which yet another property enthalpy, which is constant is called an isenthalpic process.

I have indicated question marks here against entropy and enthalpy because at this moment, you would probably be wondering what entropy and enthalpy are. We shall understand about these terms in very much detail during later lectures. A process during which a particular property is held constant is classified as a different process on its own.

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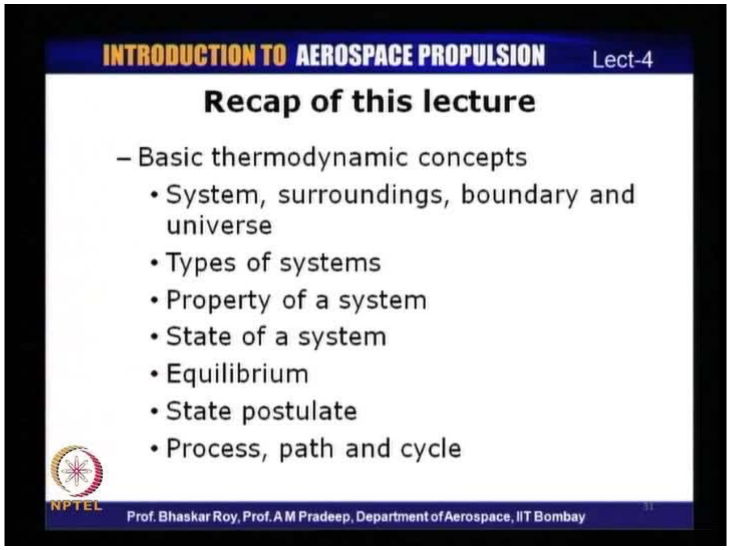

So, that brings us to the end of this lecture. Let us quickly recap what we had gone through during this lecture. We had understood several basic thermodynamic concepts like the systems, surroundings, boundary and the universe. We had also understood the different types of systems that are possible like an open system or a closed system. We had understood what is meant by property of a system; that is, how do you characterize a particular system.

Then, we had also looked at what is meant by state of a system and what are equilibrium states of a particular system. Then, we also understood the minimum number of properties that are needed to define the state of a system that is known as a state postulate. Towards the end of the lecture, we also looked at what is meant by process path and cycle.

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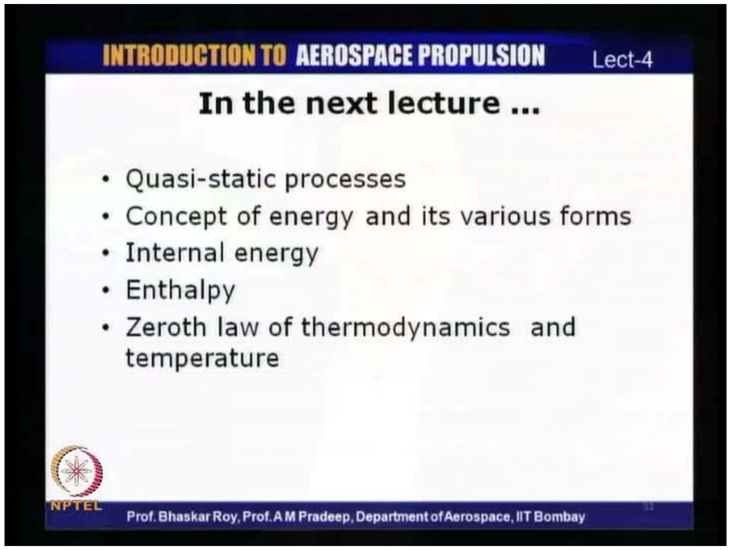

In the next lecture, what we shall look at: we shall understand what are meant by quasi-static processes; we shall understand the concepts of energy and it is different forms; we shall understand what is meant by internal energy and different types of internal energies. Then, we shall also look at a combination property known as enthalpy. Towards the end of the next lecture, we shall also undergo introduction to the zeroth law of thermodynamics and temperature as an outcome of the zeroth law of thermodynamics. So, these are the aspects, which we shall be covering in the next lecture.