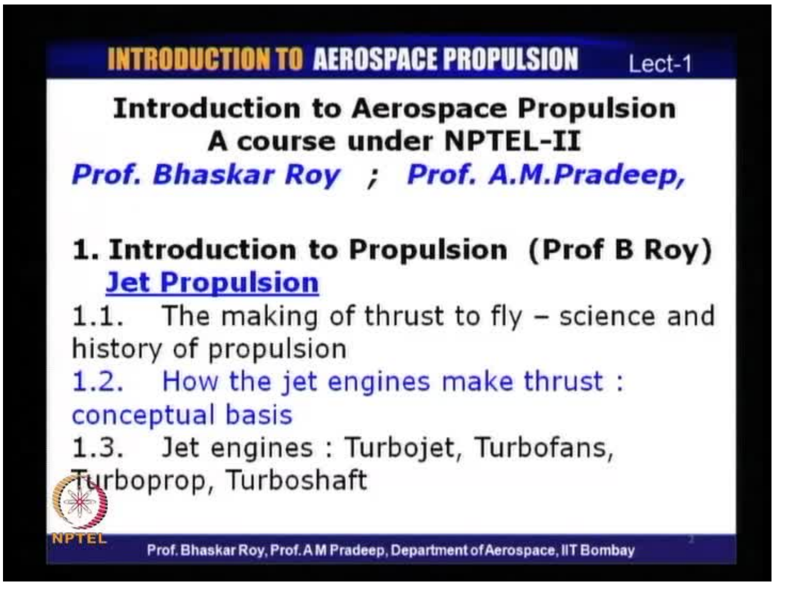
Introduction to Aerospace Propulsion
Prof. Bhaskar Roy
Prof. A. M. Pradeep
Department of Aerospace Engineering
Indian Institute of Technology, Bombay

Module No. # 01
Lecture No. # 01
Course Intro and Historical Development of flights

This is a course on introduction to aerospace propulsion. This course is intended for the students of the junior years of undergraduate program in aerospace engineering. This course introduces the various fundamental issues and fundamental science related to the field of aerospace propulsion.

(Refer Slide Time: 01:21)



The course will be taken by two of us. My name is Bhaskar Roy; I am in aerospace engineering department of IIT Bombay. This course will be taken with me by Professor A M Pradeep and he is also in aerospace engineering department of IIT Bombay. Throughout this course, we will be sharing various lecture modules presented through this program.

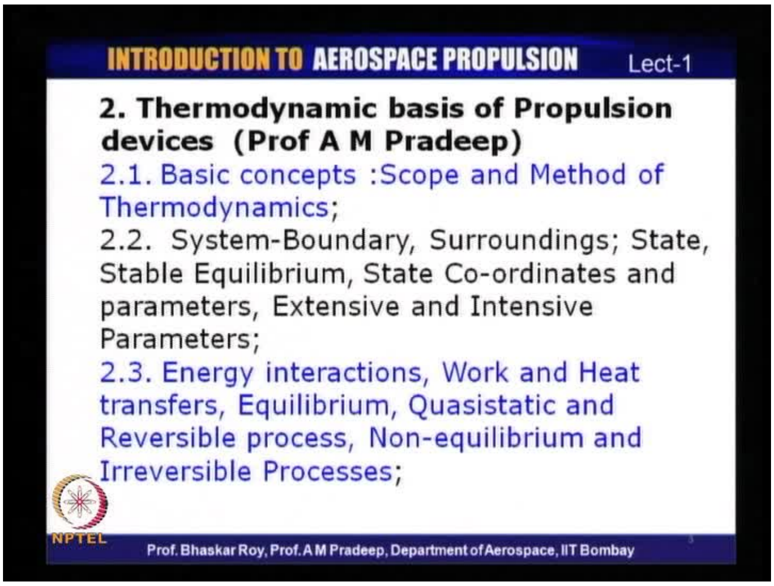
The course actually involves a number of topics and we will be presenting these topics to you in various lecture formats. Let me give you an idea about some of the lecture formats that we will be using through the course of this particular lecture series.

We will start off with introduction to propulsion, which I will be taking. We will start off with a certain amount of history and the development of the science of what can be called today - propulsion. When it started, it was not called propulsion; but today, we call it propulsion.

So, whole science of how to make human beings fly - developed is some of the things. We will first try to look at over the history of this development, then the concept of how the jet engines actually came about and the various formats of the jet engines that we have today.

They were not there when the jet engines first appeared; over a period of nearly 50 years of development some of those things have developed. So, we will have a look at some of those finally developed forms. Later on, we will get back into the science and the technology of some of those developments.

(Refer Slide Time: 03:07)



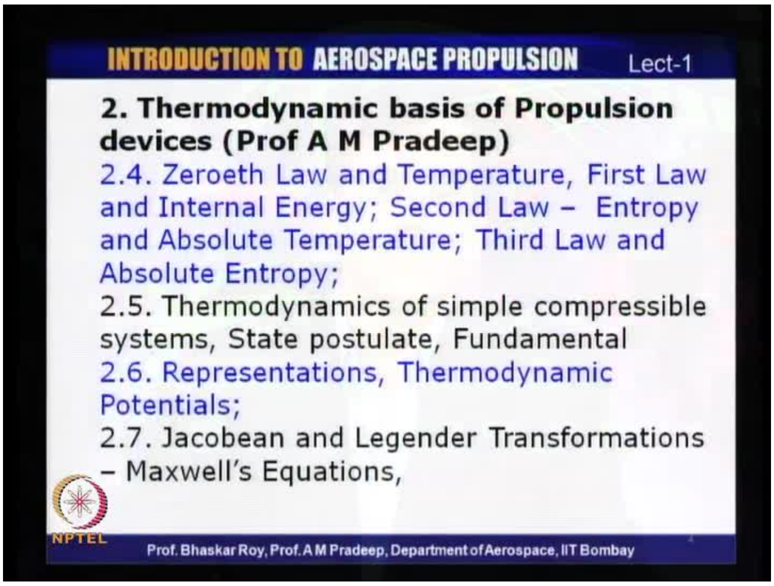
Hello, my name is A M Pradeep and I along with Professor Bhaskar Roy will be taking up this course on introduction to aerospace propulsion. I would be covering some aspects of the propulsion course, which I shall explain in the next few minutes.

We will start with basic concepts of thermodynamics. We will begin with the thermodynamic basic of propulsion devices. We will start with some introduction to basic concepts, which are used in thermodynamics; scope and the method of thermodynamics. We will look at why thermodynamics is used or is an important part of aerospace propulsion in itself.

Then, some of the other important aspects like definition of a system, boundary and surroundings. How do you define a certain system - a thermodynamic system? It is very important for analyzing propulsion systems. We will define different equilibrium states, then the state co-ordinates and its parameters. We will also define what are known as extensive and intensive parameters.

Subsequently, we are going to look at energy interactions, different types of energy interactions. Basically, it is classified as work and heat interactions, as well as, quasi-static and reversible processes. Followed by this, we will look at non-equilibrium and irreversible processes.

(Refer Slide Time: 04:38)



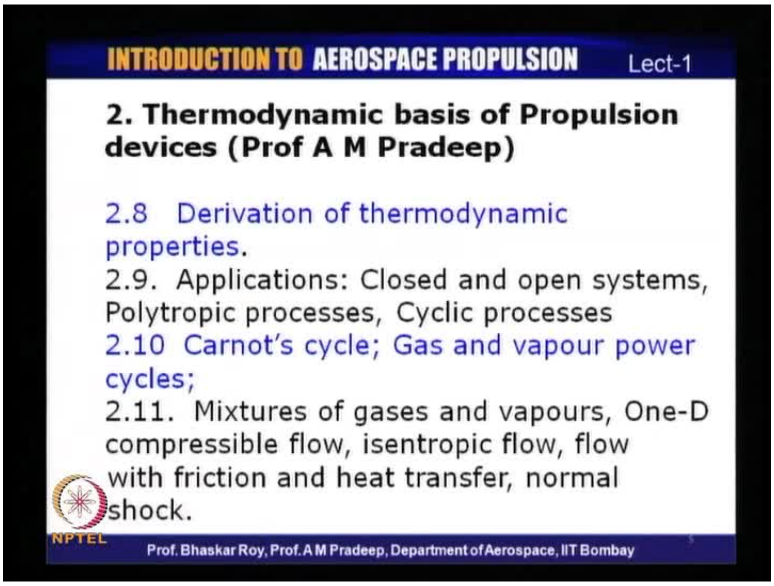
So, this is where we will start with thermodynamic principles. Then, we will continue with defining the laws of thermodynamics, which also play a very important role in analyzing thermodynamic system. We will initially start with zeroth law of thermodynamics, which is the governing principle for defining a temperature scale as we shall see later on.

Subsequently, we will talk about the first law of thermodynamics and its significance. Basically, as we shall see later on, first law of thermodynamics is the conservation of energy principle in some sense. Terminology that we shall come across several times in this course is called internal energy, which is an outcome of the first law of thermodynamics.

After the first law of thermodynamics, we shall take up the second law of thermodynamics. A very important property which we shall come across as an outcome of second law of thermodynamics is the entropy and the absolute temperature scale.

Followed by the second law, we shall look at the third law of thermodynamics and absolute entropy. The thermodynamics of simple equilibrium, simple compressible systems, the state postulates and fundamental principle associated with that will be covered after the first, second and third law of thermodynamics. The thermodynamic potentials, Jacobean and Legender transformations, which lead to the Maxwell's Equations; it will be covered subsequent to the definition of simple thermodynamic systems.

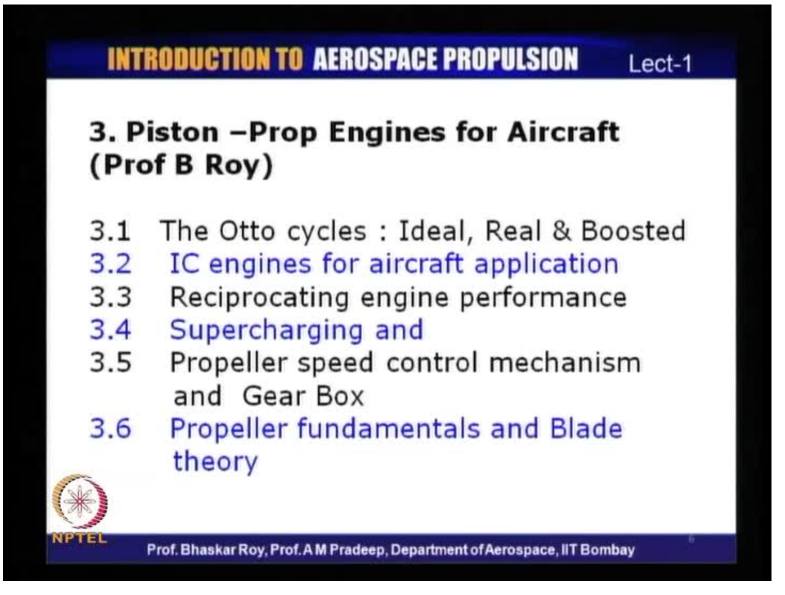
(Refer Slide Time: 06:16)



The derivation of thermodynamic properties, which are followed by which are actually following the Maxwell's properties, it will be taken up subsequent to covering Maxwell's laws. In terms of applications of thermodynamics, we shall be looking at closed and opened systems, then polytrophic processes and cyclic processes. In cyclic processes, we are going to talk about different cycles of thermodynamic systems, basically power cycles, gas and vapor power cycles.

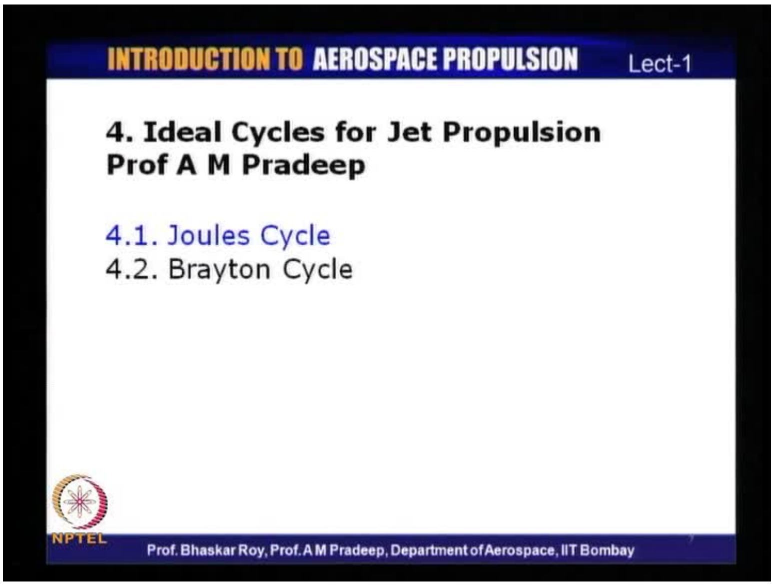
We shall talk about the different type of gas and power cycles, which define very fundamental power cycles, which are used in engineering systems. Subsequent to the gas and power cycles, we shall discuss about mixtures of gases and vapours. A little bit of details about one dimensional compressible flow, isentropic flow, flow with friction and heat transfer, and normal shock flows. So, these are topics which will be covered in little bit detail as they are required for fundamental understanding of different propulsion system.

(Refer Slide Time: 07:55)



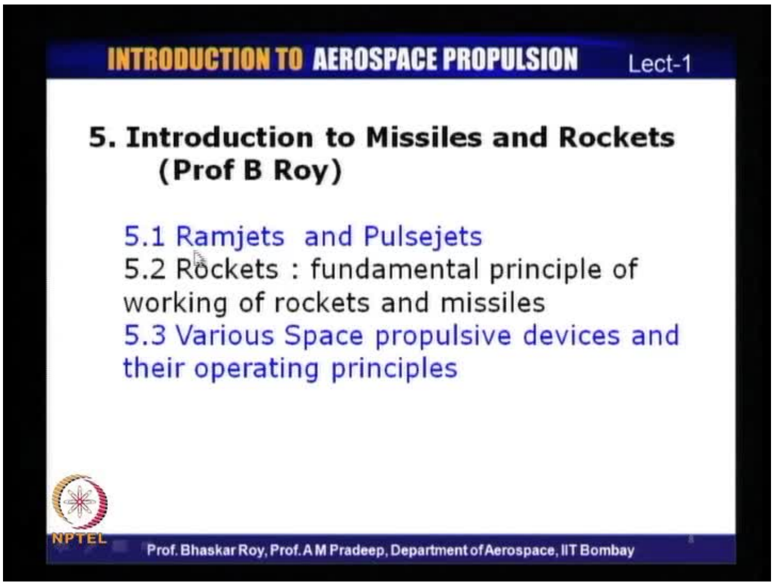
Professor Roy is also going to cover some of the cycles that we had discussed in detailed like the Otto cycle, which is the basic thermodynamic cycle for spark ignition engines. Then, the different IC engines cycles, which are used for aircraft application. Then, we shall also discuss about reciprocating engine performance, supercharging, propeller speed control mechanism and gear box. Propeller fundamentals and blade theory will also be covered in some detail by Professor Roy.

(Refer Slide Time: 08:22)



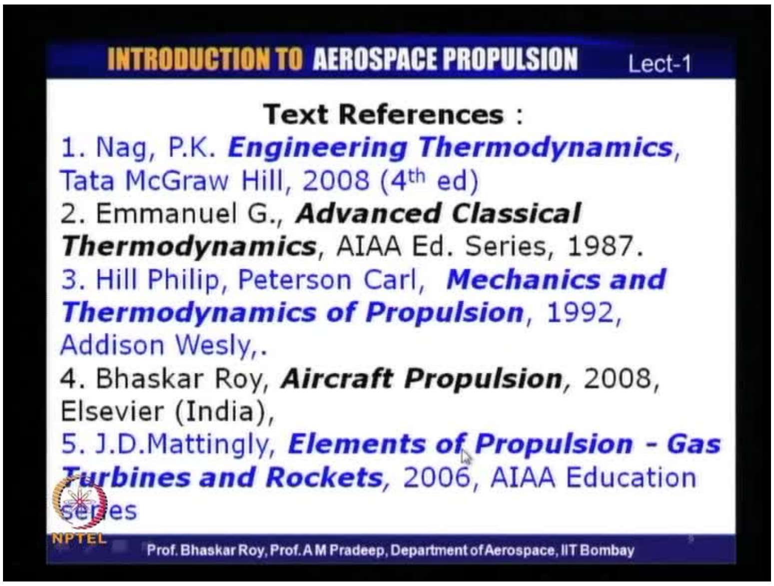
After this, I shall also take up the cycle analysis for propulsion systems - the ideal cycle analysis for propulsion systems. Basically, the Joules Cycle and Brayton Cycle which form the basic principle or the basic cycle for the aircraft air breathing aircraft engines.

(Refer Slide Time: 08:49)



Introduction to missiles and rockets is going to be covered by Professor Roy. He shall be talking about Ramjets and Pulsejets, fundamental principle of working of rockets and missiles, then various space propulsive devices and their operating systems. Now, we shall talk about the text books that would be used during this course, I am just listing a few of them, we shall discuss more about these books in due course.

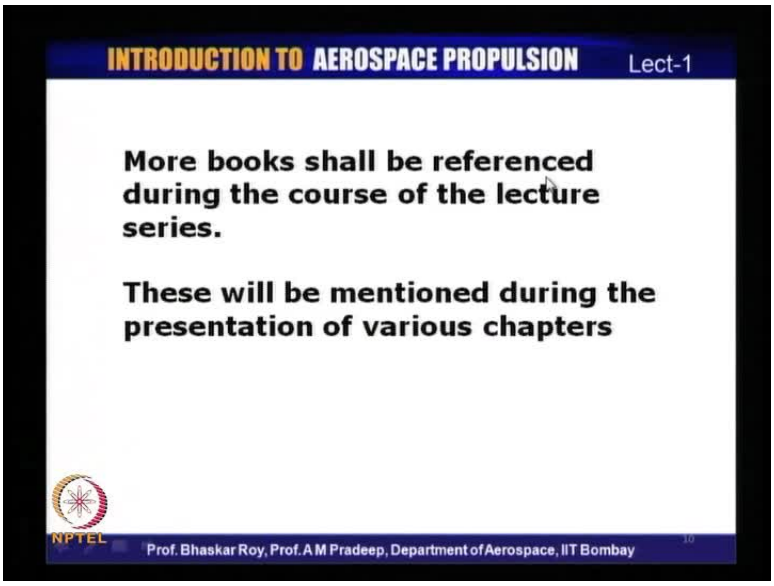
(Refer Slide Time: 09:20)



For Engineering Thermodynamics the book that we would refer to is the one by Professor P.K. Nag, published by Tata McGraw Hill, 2008, 4th edition. For Classical Thermodynamics you can also refer to Emmanuel, which is an AIAA educational series book. For propulsion course, we would be referring to the book by Hill and Peterson, Mechanics and Thermodynamics of Propulsion.

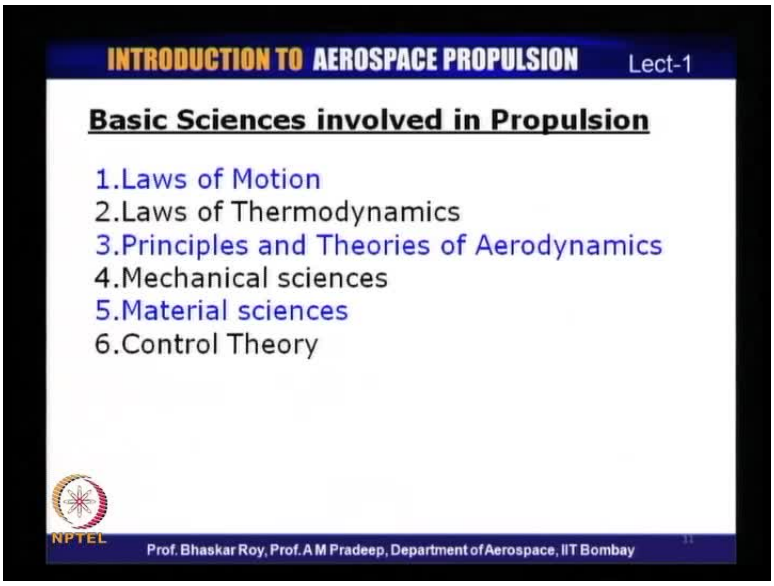
The other book that we should also refer to, the book is by Professor Roy himself on Aircraft Propulsion. There is also a book by Mattingly on Elements of Propulsion-Gas Turbines and Rockets, which is an AIAA education series.

(Refer Slide Time: 10:10)



We shall be mentioning about more reference material during the progress of the lecture series.

(Refer Slide Time: 10:30)



Let us first get ourselves introduced to some of the basic sciences that are involved in the field of propulsion, what we call today as propulsion. Fundamentally, we are talking about motion - motion of aircraft and spacecraft. Hence, the first thing we would need to really be concerned ourselves and knowledgeable about is the laws of motion, because motion is what we are going to really bother about. Over this entire course of propulsion, how to create motion that is our concern in this course as professor Pradeep has introduced to you.

The next thing that we would need to know quite a lot about are the laws of the thermodynamics, because the creation of motion and the field of propulsion is based conceptually on the field of thermodynamics. Thermodynamics forms the backdrop on which the entire field of propulsion has been created. Essentially, thermodynamics is the matrix on which the field of propulsion has been created on. So, we need to know quite a lot about the thermodynamics, which Professor Pradeep will be covering in his lectures, over this lectures series.

Then, he will also cover a little bit of principles and theories of aerodynamics, which we need to know. Much of the propulsion that we will be talking about essentially concerned a lot of aerodynamics. We would need to know many of the aerodynamic laws, the aerodynamic principles and the various aerodynamics mathematics that are required.

In many of the modules, we will see that the various components of propulsion or propulsive devices essentially work on the principles of aerodynamics. Many of them are indeed actually called aerodynamic machines. So, we would need to know thermodynamics, we would need to know aerodynamics. You would see later on that many of the propulsive devices are indeed actually referred to as aero thermodynamic devices; we would need to know both these sciences quite well.

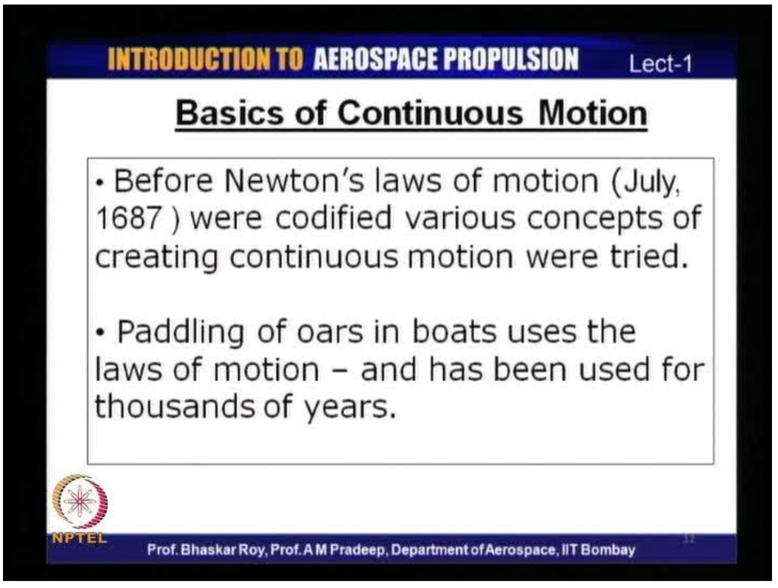
Then, we would need to really be involved our self with the various aspects of the mechanical issues - the mechanical sciences. There is lot of mechanical engineering involved in making propulsive devices engines, which basically are mechanical entities. We would need to know some of the mechanical sciences without going very deep in this course into the mechanical engineering. What we would need to know? We would need to know one or two things that surely have a basic mechanical engineering background.

There are issues involved about the material sciences, the metallurgical sciences, many of which actually are required in building the propulsive devices. The propulsive devices often use the material science and metallurgy of the highest order.

The cutting edge of the material science and metallurgy are often used for the propulsive devices. We would have a look at them time to time without really getting deeply involved in the business of material science or metallurgy, because strictly speaking that is not really our focus here. But, we will mention them as and when, when they are required to be mentioned. Then, there is a question of control. In most of the devices we need to have the engines or the propulsive devices that run an aircraft that fly an aircraft, the propulsive devices that fly a rocket or a spacecraft need to be controlled.

These control theories are extremely involved; they are sciences by themselves. Very deep into them, we would not be able to go. Once in a while, we will mention some of these controls issues just to keep you abreast of the situation that some of the propulsive devices, don't need to be associated and embedded with modern control theories and control systems.

(Refer Slide Time: 14:53)

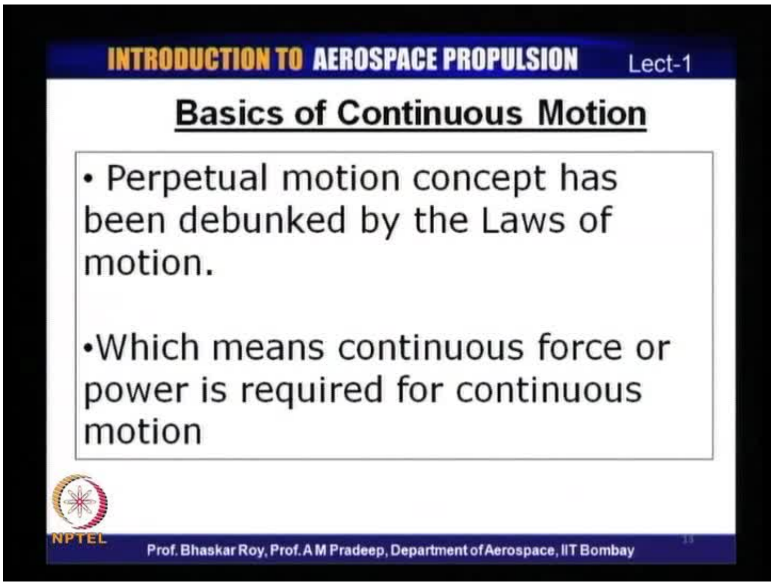


Let us start with what we call motion. What we are trying to create is propulsive devices that will aide an aircraft or a spacecraft going through motion, which we would like to call as continuous motion. It is not just motion for a few seconds or a split second, it is a continuous motion that we are talking about. Hence, there is a requirement that these motion could be subject to certain fundamental sciences, which govern the motion of various bodies.

We know that Newton's law of motion actually codified the various concepts of motion and these motions are what we would certainly be most concerned about in this course. However, even before Newton's laws of motions actually came into being the concept of creating motion through various kinds of instinctive understanding of motion was actually applied.

For example, paddling of oars to make the boats to move in water uses the laws of motion instinctively without quite knowing the loss of motion that has been going on for 1000 of years. So, the question of using the motion has been kind of in the instinct of human beings or in the human civilization for 1000 of years. Really speaking, Newton or Isaac Newton actually codified those laws in the form of physics and mathematics, making it easy for us to create propulsive devices using all the sciences and engineering.

(Refer Slide Time: 16:49)

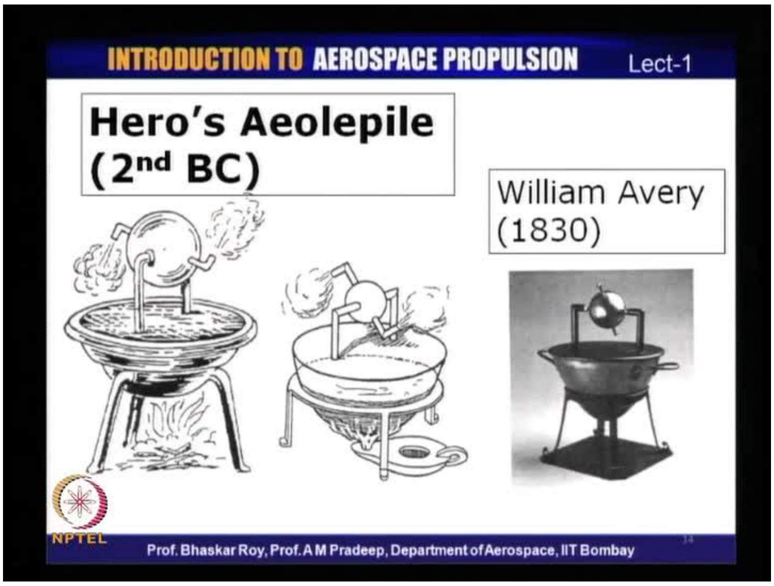


Let us look at a few motions that people have been talking about. One of the things, for example, people mentioned or came up with which we can create perpetual motion. I think it is pretty much now understood that perpetual motion is strictly speaking not physically possible, this is been possible due to the various laws of physics and mathematics that is come into being.

They have clearly proved that it is not really possible to create perpetual motion, which means that we have to have devices that create motion on a continuous basis. You cannot start a motion and sustain it for a long time on a perpetual basis; you have to create a device on a continuous basis aids the process of motion.

In our case, it is a process of flying motion. This continuous application of force or power, this is what finally we need to provide through the propulsive devices. So, our job here in this course is to see whether the continuous application of force and power can be provided for continuous flying motion; that is our concern in this course.

(Refer Slide Time: 18:14)

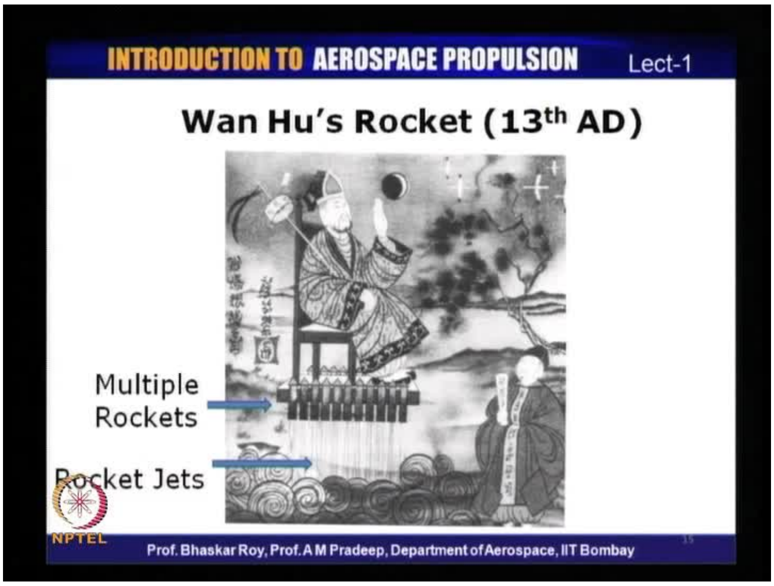


Let us go through a few stories. I will tell you a few stories to begin with how the motion or a flying motion, making power or force to create motion started developing in human civilization.

More than 2000 years back, something called Aeolepile was created by a gentleman called Vogani Hero in second century BC. He demonstrated a particular device, in which if you put a steam and allow the steam to come out through jets in opposite direction you could create continuous motion of a ball. This ball could be held through on two sides, you could have continuous rolling of the ball and at that time it was called Aeolepile in Latin.

After nearly 1800 years or so or nearly 2000 years really, William Avery actually created this ball. The picture that you have on the right side is actually a picture of the Hero's Aeolepile, created by William Avery 2000 years after Hero conceptualized this motion in actual physics. Now, remember those days in the time of Hero, there were no Newton's laws available to him, so he built it on his understanding of motion.

(Refer Slide Time: 19:49)

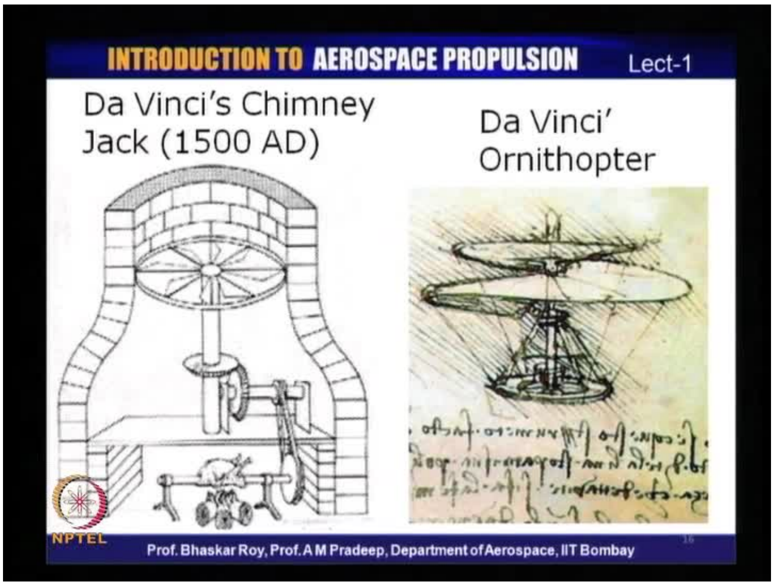


Then, William Avery created that 2000 years after that concept was created. Then, somewhere around 13 century the Chinese scholar Wan Hu decided to try and create a flying motion. Now, we all know that China is very good in creating gun powders and fireworks. So, they had the concept of making small rockets through which more of fireworks and things could be made to fly.

What Wan Hu as a scholar thought could be done is if you put it in a number of rockets and fire them up together, you could make it fly an object. So, what he did? He created a chair and he put a number of rockets under the chair, he went and sat on it by himself and he had his assistants who could light up those rockets.

Simultaneously, one of those rockets were lit up he is supposed to have flown up. We do not have a quite story actually what happened to him, but it seems it was one of the first attempts to make a human being go up in the air. That was in 13 century AD it happened, it reportedly happened in China. It is a story we do not know whether it actually happened, the picture you see is created by an artist.

(Refer Slide Time: 21:24)

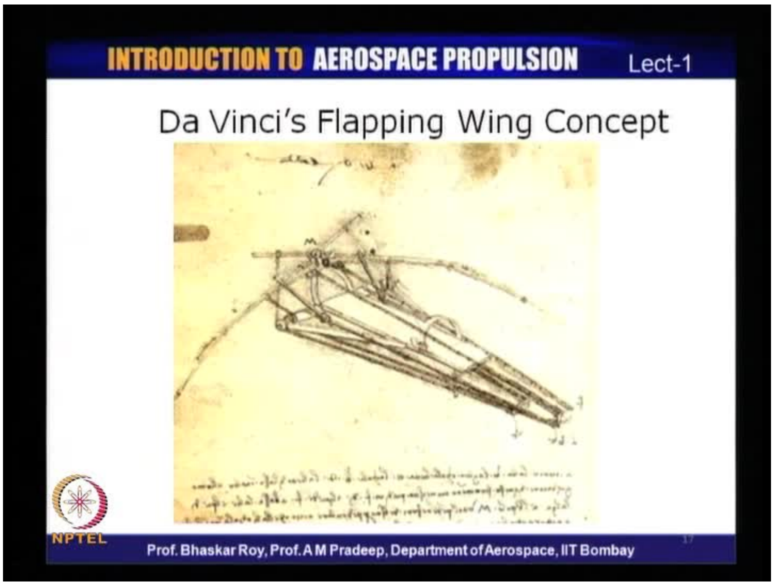


Then we have Leonardo Da Vinci, he is of course the genius of the Millennium and few things that he created we discuss even today. So, in somewhere around 16 century he created what is now known as Chimney Jack. In which the hot air from the chimney, when it is rising up, it creates a motion of a turbine. This rotating turbine, then he used to rotate a number of elements using gear box and belt and pulley drive to finally create motion.

So, he used the hot gas of a chimney to make a turbine. Now, conceptually that was one of the first attempts to create turbine through moving of the hot air or hot gas. Of course, subsequent to that or around that time in many places over the world wind turbines were being created, which uses the natural air or wind available in atmosphere. Da Vinci created a machine using this with in a small space inside a chimney. However, the more abiding contribution of Leonardo Da Vinci is what is known as Ornithopter.

Ornithopter was created by him as a means of actually making human beings fly. His idea was that you can create a small platform, in which human being can sit or lie-down. Then, it would have something like a helicopter, what we call as helicopter today which will have a vertical motion; it has something like a screw motion. The whole device would rise up in the air using kind of a screw motion through the air and it will move up. This was his concept of Ornithopter, which of course he never actually made. He only conceptualized the whole machine; it never was actually made by him.

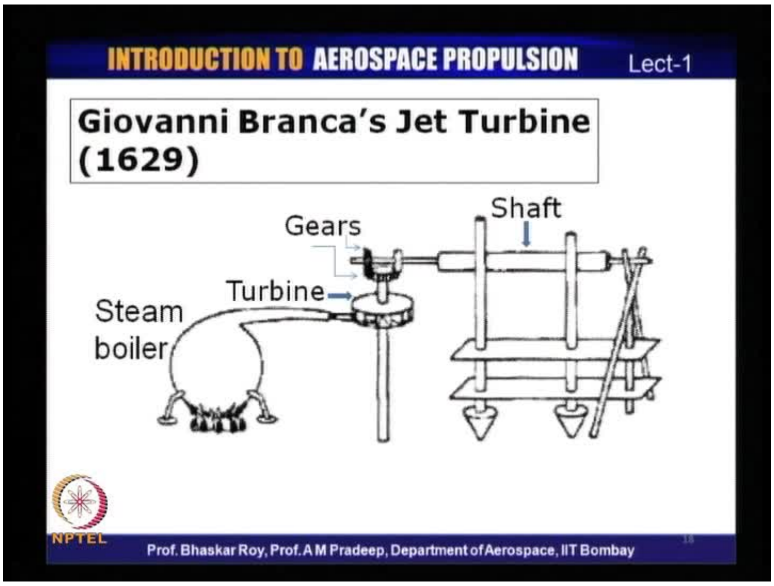
(Refer Slide Time: 23:39)



Da Vinci also created what is known today as the flapping wing concept. Now, flapping wing of course you can well imagine is a copy of the birds flying - motion of the birds flying. This is what Da Vinci thought, if we could imitate the mechanical motion of a flying bird, we should be able to make human beings fly like birds. He noticed as an avid scientist and as an engineer that flapping wing contributes to the flying motion of the birds.

So, he created a small machine - a conceptual machine in which he thought we could have fly flapping wings. If those could be actually flapped during the process of flying it would aid the motion of this particular craft, this is what he had in his design. I am not sure he ever made them actually or whether anybody actually made them, but as a concept there was nothing wrong with it. Today, lot of people are actually talking about flapping wing concept as one of the modern aids of making new aircraft, small aircraft may be with flapping wing concept.

(Refer Slide Time: 25:00)



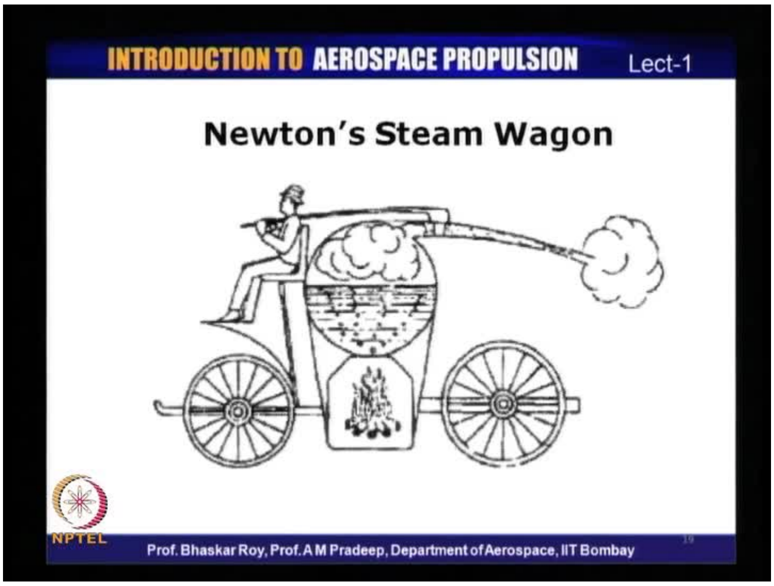
The problem of course was not just making an aircraft, powering the aircraft. To power an aircraft, it is necessary to have engines. When we talk about propulsive devices, we are talking about a devices have an embedded engine inside it. Now, this engine works often on the principle of thermodynamics as we have seen, but the mechanical sciences that do come in the process of propulsive devices involve a number of elements.

Let us look at some of these elements now. Nearly 400 years back, a gentleman called Branca came up with the idea of jet turbine. In those days creating steam was known thing, so if you boil a large beaker and create steam, then allow that steam to come through like a jet and impinge on a turbine, which is rotated, which is held in a shaft, a vertical shaft would create a rotary motion.

This rotary motion could be transferred through the gears to a shaft and then this shaft can be used to run a propeller. So, the entire devices are essentially geared towards creating a rotary motion. This rotary motion would finally be running a propeller and that is this propeller, which would then make an aircraft or a craft to fly through the air that was the concept.

At this particular time, the people were more bothered about creating an engine in which the propeller could be powered, could be supplied with continuous power. So the propeller would create continuous propulsive force, which in turn would aid a craft to fly on a continuous basis. So, this was the idea with which people like Branca started creating devices, in which continuous motion could be generated.

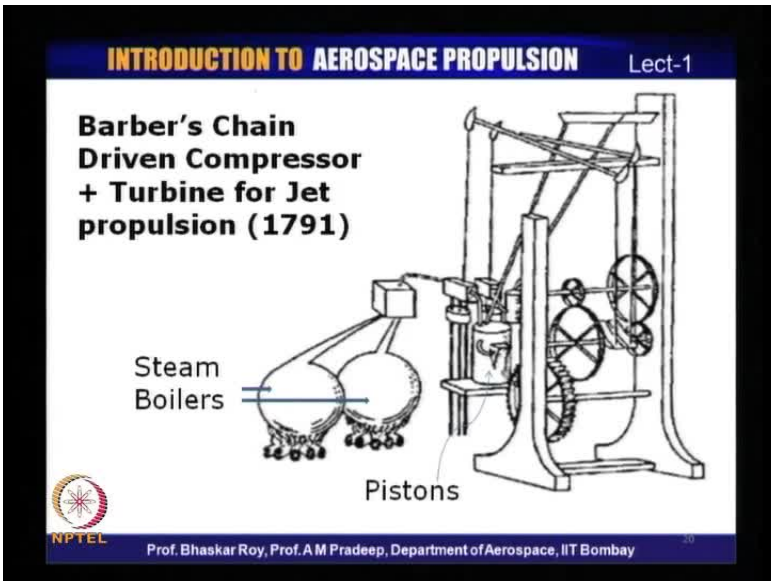
(Refer Slide Time: 27:19)



Then came Isaac Newton's concept of steam wagon, he created this particular sketch in which his concept was that if you just create a steam jet out of a big large beaker or something, you heat it up from the bottom with some heating aide, then the steam that comes out. If it is made to come out through some kind of a nozzle the steam jet would aid the process of movement of a wagon and it was called Newton's steam wagon.

This was just a sketch, this was never made. We are not quite sure this would actually work, because the amount of force required moving a wagon would have probably been impossible to create through some such steam wagon. However, as a sketch and as a concept it provided certain ideas to people who came down the line. We will be talking about the Newton's laws of motions in a few minutes from now.

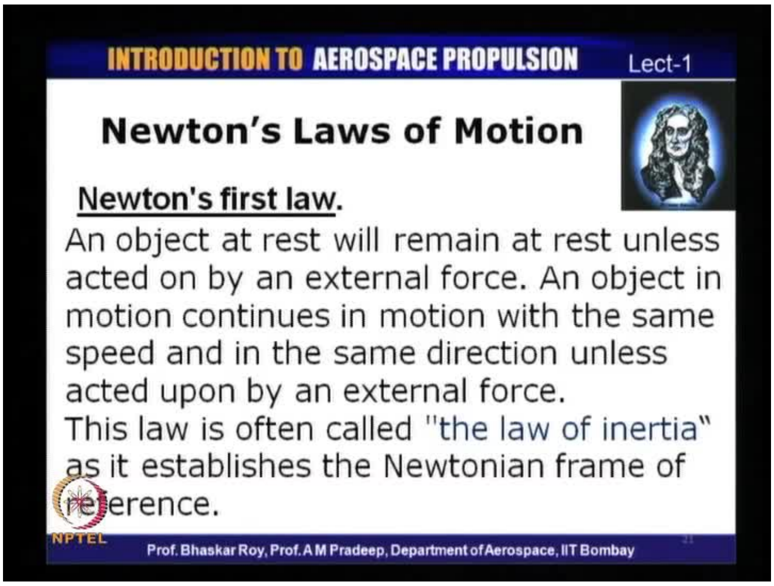
(Refer Slide Time: 28:32)



Then of course the whole idea of creating steam and using the steams to create various kinds of continuous motion was followed up by a gentleman called Barber. He created a steam driven compressor turbine, this is supposed to be a precursor to what we call today jet propulsion; this is nearly 200 years back, little more than 200 years back.

The whole contraption he had created in his own backyard with the help of what was at that time known as chain and pulley system. As a result of which this contraption was probably one of the first, in which a kind of engineering was used along with the concept of steam force to create what can be called as continuous power generating unit.

(Refer Slide Time: 29:35)



Then, of course came with the Newton's laws of motion. Now, many of these laws today form the basis on which various kinds of bodies move, whether it is aircraft or automobile or any other body that moves on earth essentially follows the Newton's laws of motion. In fact, they have to conform to the laws of motion when these crafts are created, it is essential at the time of creation that they are made to conform to the laws of motion.

Let us first quickly try to understand these laws of motion. The first law which states that object at rest will remain at rest unless acted on by an external force. An object in motion continues in motion with the same speed and in the same direction unless acted upon by an external force. This law is often called a law of inertia that means, a body maintains its state of inertia, the state could be the rest or it could be a state of motion.

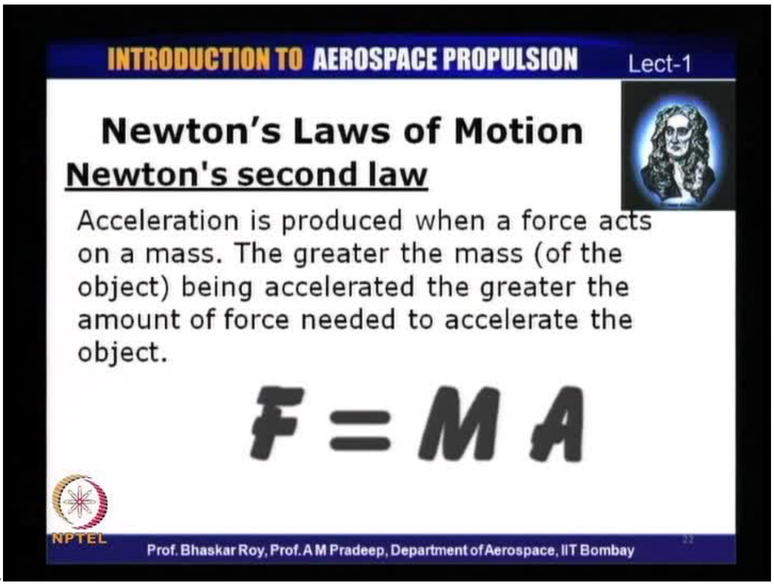
It will continue in the state of rest or motion as per this law of inertia unless and until it is acted upon by an external force. This external force need to be applied. This is essential to understand that to create continuous motion of any craft indeed an aircraft or any spacecraft, you need to create continuous external force. You need to continuously provide force or power to aid the continuous motion, this is important.

First thing that people need to understand is that if you do not have continuous source of power and continuous propulsive force, you cannot have continuous motion, whether in air or anywhere else; this establishes the law of inertia. As we know today, within the

Newtonian frame of reference, which means that the bodies we are talking about are Newtonian bodies, the motion we are talking about are called Newtonian motion. We have to understand this from the point of view that some of the concepts here may not be exactly accurate if you bring in the modern theory of relativity.

In theory of relativity, the state of motion and the state of rest are defined slightly different. So, the Newtonian motion is what we will be bothered about and we will be concerned with. We will not concern ourselves with the theory of relativity at any point of our discourse in this lectures series. Even when we talk about the spacecraft, we will never be talking about the motion of a body in which the relativity as a law of physics comes into the picture. So, we will always be in the Newtonian frame of reference.

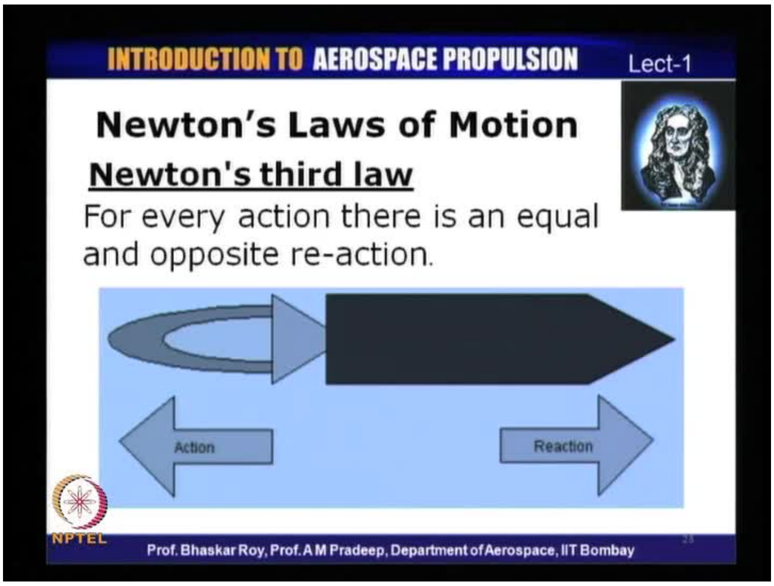
(Refer Slide Time: 32:52)



Let us look at the Newton's second law of motion, which states that acceleration is produced when the force acts on a mass. The greater the mass of the object that is under consideration which needs to be accelerated, the greater the amount of force needed to accelerate or create the motion.

Creation of the motion itself is a kind of acceleration. When you are starting from a state of rest, you need force and that itself is the first acceleration that you need to produce. It is codified simply as F equal to M into A, M being the mass, which we would call the rest mass. As I was stating in theory of relativity, the definition of the rest mass is different from what we would consider in the Newtonian reference. So, this mass to be accelerated requires a force and this is what the second law states. Our business in propulsion is to create this force so that motion can be created.

(Refer Slide Time: 34:05)

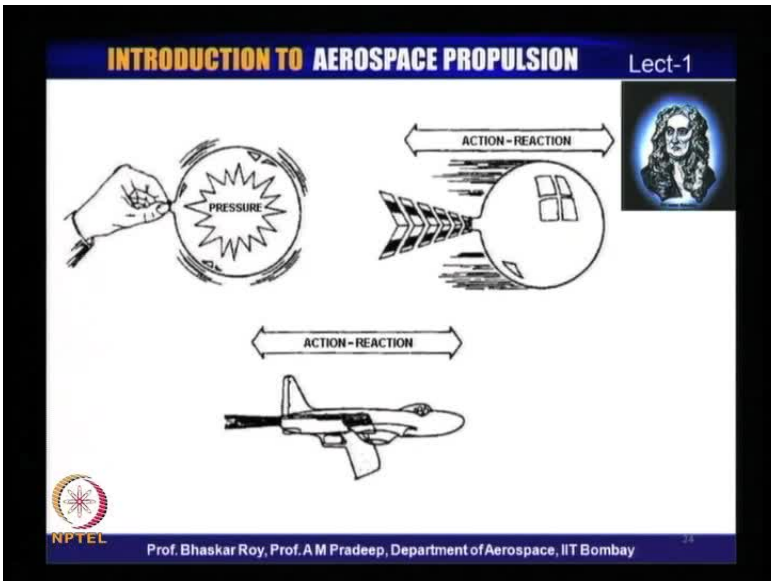


The third law of Newton's motion is codified as, every action has an equal and opposite reaction. Now, this is a probably very well known or one of the most well-known of all the laws. This is the one of the main laws on which the propulsive system that we will be discussing is based on. Actually, the propulsive system that we will be talking about is based on all the laws, not only the third law, but people talk about the third law as the more important one. We shall see that all the laws are really speaking almost as important as the third law in creating the propulsive devices.

Now, this states that if you create an action there is bound to be an equal and opposite reaction. As the diagram illustrates that if an action is created to push a body if a certain amount of material is ejected from a body from the rear. As the diagram illustrates the act of releasing of that amount of material from the rear is the action. The reaction is the force that propels the body forward; this is the concept on which most of the aircraft and spacecraft motion is actually based on.

So, this action of creating a release of certain amount of a material from the rear of a body which we want to move is the first principle on which the propulsive devices are created on. So, Newton's third law does create one of the basis on which a basic propulsive devices have been created.

(Refer Slide Time: 36:09)



This was generated conceptually long back. If you fill up a balloon and hold the balloon in one hand and then if you for example, release take your hand off and allow the pressured air or compressed air stored inside the balloon to suddenly come out through that open a lip, it will create a nozzle as we saw in the illustration of the third law. Now, this nozzle effect immediately, creates a reaction. So, the action created by the release of the air from inside through that open lip creates the force and that has a reaction. That reaction makes the balloon move forward.

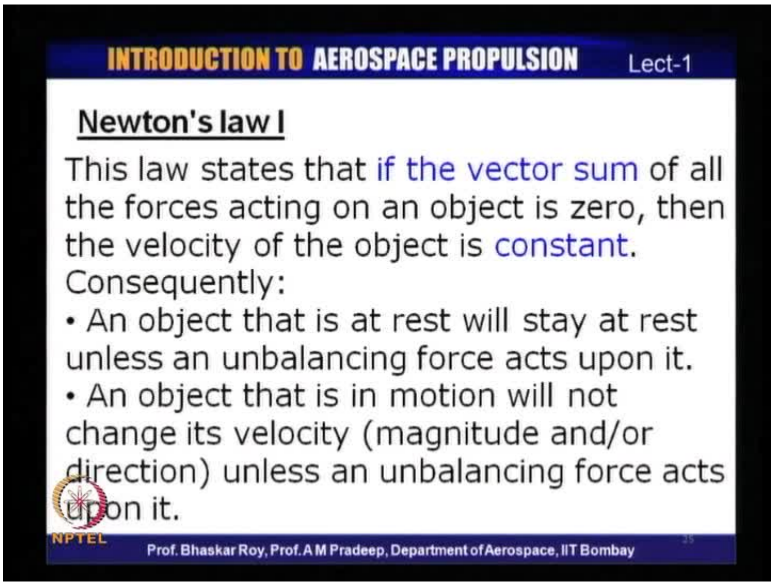
If you do that by yourself in a room, you will probably release the balloon actually you will probably find the balloon moving in a zigzag motion. It is not, because anything has gone wrong with the balloon or anything has gone wrong with your release of the balloon, the point is the balloon is always moving as a reaction to the action instantaneously through that lip. So, the instantaneous reaction of the magnitude and the direction actually creates the instantaneous motion of the balloon.

So, the zigzag motion that you see is the correct motion depending on the instantaneous vector of the action that is created and reaction is nothing but opposite to that particular vector. This is then shown in the lower diagram, which actually tells you that in an aircraft - flying aircraft for example, if you create an action which throws something towards the back, this something we shall see more and more is actually the air in which the aircraft actually is supposed to be flying. If you create this action of throwing the air backwards, then the aircraft actually experience the reaction, which is the motion forward.

Our business in this propulsion is to see how this action can be created through various devices on a continuous basis in a controlled manner, so that in a controlled manner you have the reaction and the motion of the aircraft. We cannot allow the aircraft to move in a zigzag manner as we see in the balloon. We have to have a continuous controlled smooth motion of the aircraft. This smooth motion of the aircraft needs to be done in a controlled manner.

This controlled action and reaction needs to be created through propulsive devices. There is a question of integration of the propulsive device with an aircraft; we shall be talking about some of these issues more and more as we get into the subject matter.

(Refer Slide Time: 39:11)

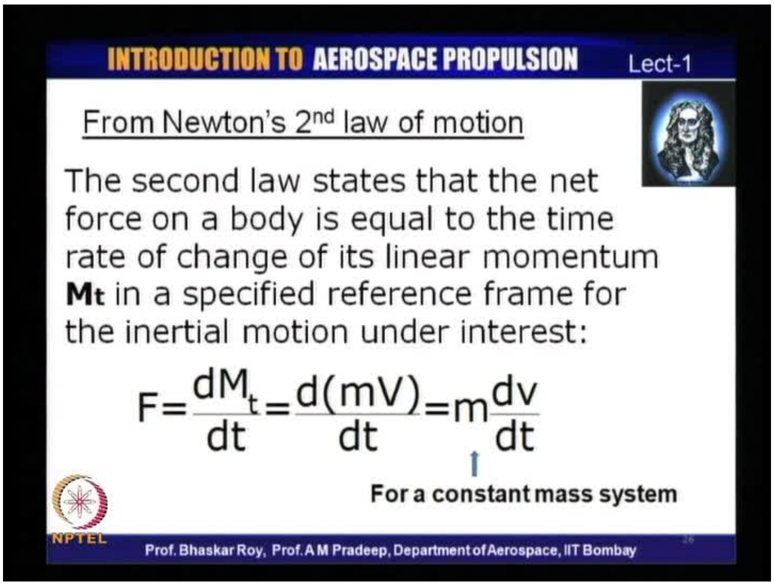


Let us get back into the Newton's first law a little more in detail, because that is what is going to create the bedrock for our subject. This law states that if the vector sum of all the forces acting on an object is 0, then the velocity of the object is constant. It means that if it is in state of rest, it will remain in a state of rest, if it is a state of motion, it will remain in a state of motion without experiencing any change in it is motion.

There will be no acceleration, there will be no change in velocity and there will be no change in direction. If you want any of those three changes of direction and acceleration or a change of velocity you would need to apply force. This force need to be applied as we saw in a certain direction. So, the vector sum of all the forces is what we need to have our eyes on, so that the motion can be created in a particular direction, in a particular giving magnitude.

So, creation of motion as per the Newton's law is the first thing, giving it a direction is the second thing. We need to keep our eyes on both the issues that is creating the motion, the magnitude of the force that need to be applied and the direction in which the force need to be applied, because the reaction will be based on both the magnitude and the direction of the action; that is, created reaction will be opposite to that magnitude and direction.

(Refer Slide Time: 40:58)



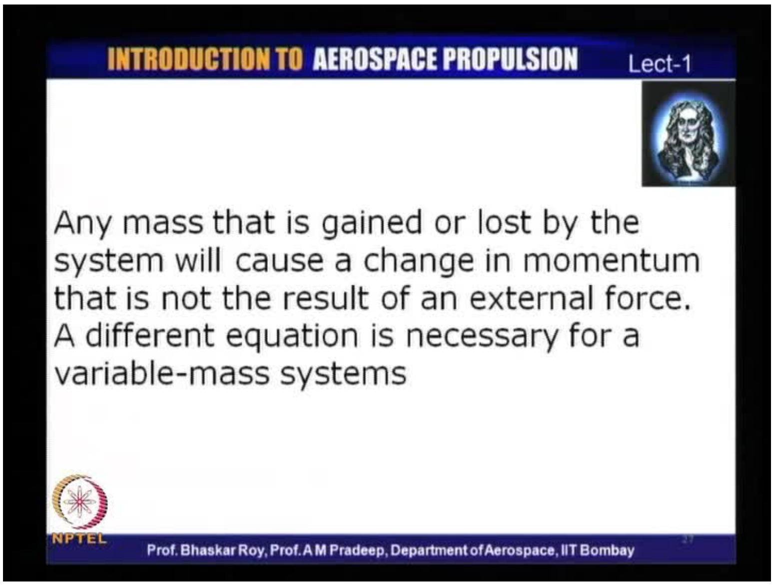
Then we look at the Newton's second law of motion. The second law states that the net force on a body is equal to the time rate of change of its linear momentum. Let us call capital M subscript t in a specified reference frame for the internal inertial motion under our interest. I have stated that you know we are talking about Newton's reference frame. We called the inertial motion that is codified in simple mathematical formulation as F equal to dM t dt. This Mt is the momentum, in our case it is a linear momentum that we are talking about in a particular direction, the direction is important.

This can be now stated as mV, m being the mass, v is the velocity - the instantaneous velocity and we are considering m as the rest mass. This is the change in the momentum, which can also be written down if we consider the rest mass is constant that means the mass that is activated on. If it is considered a constant mass, then if we can take it out and what we have is m into dv dt.

Now, this constitutes what we call the acceleration and mass into acceleration is what we had written down earlier. We will be bothering about considering the fact that we have a certain amount of mass to play around with, to act upon. On that mass, on that given mass, we will have to create a certain amount of acceleration of dv dt, which will then create a change of momentum which creates a force of action and then that will be reacted upon to create the motion of the aircraft.

So, any mass that is gained or lost by the system will cause a change on momentum that is not the result of an external force. A different equation is necessary for a variable mass system. Now, this is the issue that one need to keep in mind that the mass that we are talking about in the earlier equation for example, we considered finally that it is a constant mass system.

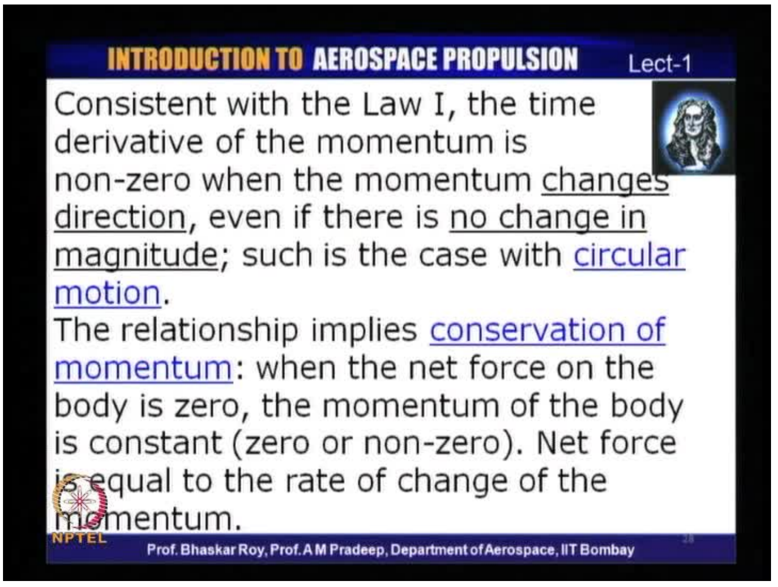
(Refer Slide Time: 43:38)



If we have a variable mass system, which is perfectly possible; for example, in a spacecraft when the mass stored in a spacecraft is used. Over a certain period of time that mass is used up, towards the end, the amount of mass flow that is available could actually be a variable mass. In which case, the equation that we would need to concern ourselves with from the Newton's second law would start looking slightly different.

So, we need to keep an eye on the fact, that for most of the time we will be considering ourselves with a constant mass system, but if we have a variable mass system we would need to come back here and apply necessary correction.

(Refer Slide Time: 44:13)

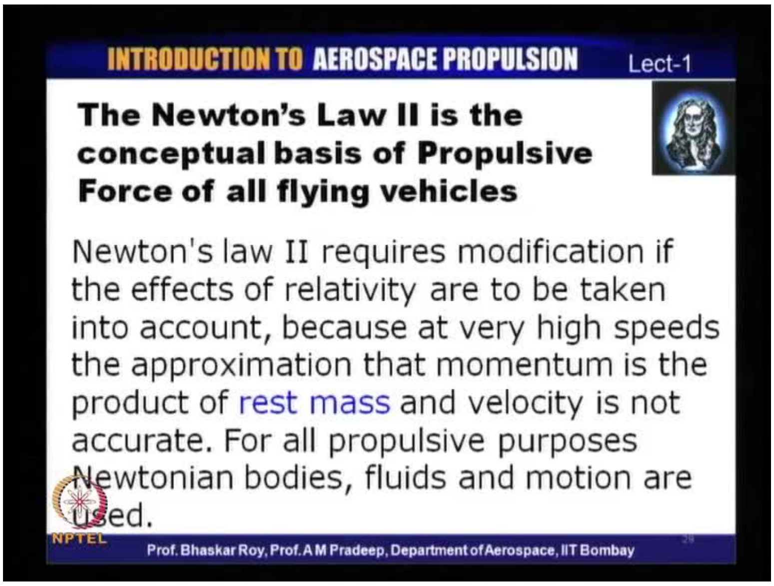


Now, consistent with the law - first law, the time derivative of the momentum is non-zero when the momentum changes direction, even if there is no change in magnitude. This is what happens when you have a circular motion that means, the instantaneous velocity of the motion is always constant, but it is continuously changing its direction. This change of direction also requires an external application of force.

This is what we would need to do. Let us say, when an aircraft is taking a turn or a spacecraft is taking a turn of its flight, which may be circular, which may not be circular, but to effect that change of the direction you need to have applied forces. So, the propulsive devices should be able to create that change in the direction of its action; so that the reaction force which makes a craft move, can also create the necessary change in direction of the craft.

The relationship also implies that we have conservation of momentum. When the net force on the body is zero, the momentum of the body is constant, which could be zero or non-zero. Therefore, the net force is equal to the rate of change of the momentum, assuming there is no loss of energy anywhere. This is the principle - fundamental principle on which the action reaction actually works. So, this is what we will be starting off with when we create the propulsive devices.

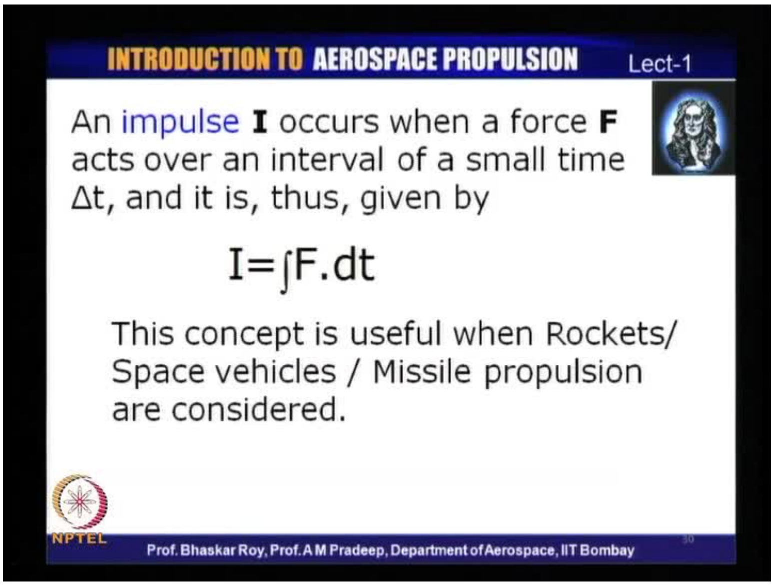
(Refer Slide Time: 45:58)



Newton's second law is the conceptual basis of the propulsive force of all the flying vehicles. We shall see more and more that popularly Newton's third law is mentioned as the law that creates the propulsive action. But, we shall see more and more the Newton's second law. It is what actually is activated or used more inside the propulsive device to create all the motions and all the basic physics that are required in the process of creating the propulsive force.

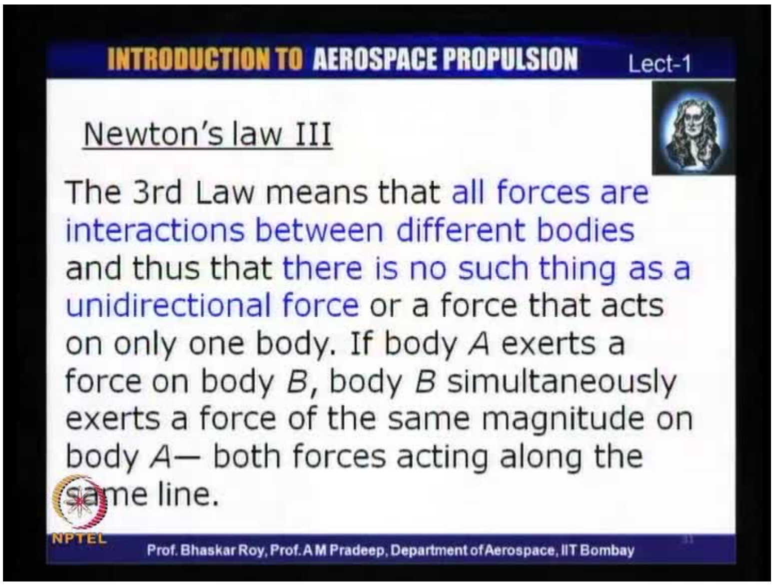
At very high speeds, as I mentioned before, the approximation that momentum is a product of rest mass and velocity is not accurate. Hence, the theory of relativity, in which we are talking about the motion when it near the speed of light, those are the motion we are not going to be concerned with in our various devices; that we will be talking about. We will restrict ourselves to the propulsive purposes that use the Newtonian laws, concerning the Newtonian bodies, the Newtonian fluid and finally the Newton’s motion - the Newtonian motion that we will be restricting ourselves to.

(Refer Slide Time: 47:25)



Impulse is a corollary of the force that we are talking about. The impulse I that is defined here is a force. It acts over a very small interval of time; it is defined as I equal to integral of F into dt. Now, this is the concept which is normally used or often used to define the impulsive force that is required or defined as the force that makes rockets space vehicles and missiles move through the air or in the space. We shall come back to this concept of impulse when we deal with the rockets or space vehicles later on in this course.

(Refer Slide Time: 48:20)



Now, we come to the Newton's third law, which states that all forces are interaction between the different bodies. Then, as a result of which, there is no such thing as a unidirectional force or a force that acts only on one body. The law states that every force has a counter force; every action has a reaction. So, there is nothing like an action and the end of the concept.

Every action has a reaction. The moment action is created we have to consider the fact that the reaction is there. As a result of which, the reaction that we would actually be more concerned with, because the reaction makes the craft actually move.

So, if we put it this way; if a body A exerts a force on body B, the body B simultaneously, exerts a force of the same magnitude on the body A and both the forces are acting along the same direction along the same line. This is the fundamental issue that we have to create an action. That is not the end of the story; we have to bother about what happens to the reaction.

In the next class, we will have a look at some of the devices that people have been trying to create using some of these laws of physics, laws of mathematics and laws of understanding of the engineering, some of the devices that were already in action at that point of time. We will have a look at some of the devices that people have been creating over little more than 100 years. In these devices, many of these devices were patented; many of these devices were actually created and tested in the laboratory.

Where some of them were found to be quite useful, we shall see that some of them actually even though they were great devices to begin with, they had some shortcomings, because of which we may not be using them today. So, we will look at many of these devices, we will look at some of the history of the development of the aircraft and spacecraft.

How the propulsive devices - the engines that make these crafts to move? Actually, it was developed over a period of nearly 150 years. We will start from even before the Wright Brothers; we will look at people who have created the devices; we will look at the Wright Brother’s plane; we will look at many of the engines that Wright Brothers and others actually used in the process of creating flying craft and then we will see what is the state of art as of today in the field of aerospace propulsion.

(Refer Slide Time: 51:17)