Jet Aircraft Propulsion

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

Lecture No. # 01

Intro and Development of Jet Aircraft Propulsion

Hello and welcome to this lecture series on jet aircraft propulsion. This is a new course that is being offered under the NP-TEL phase two initiatives; and this is primarily a course meant for the aerospace engineering students. And there are two of us who are offering this course my name is Pradeep and along with me my collogue Professor Bhaskar Roy both of us from the aerospace engineering department IIT Bombay would be offering this course. So over the next few lectures, our aim, our intension is to educate you with some of the basic aspects of jet aircraft propulsion. We would be primarily focusing on the aircraft propulsion mode that is the air breathing mode of propulsion; we shall not be covering rocket propulsion in this course. And so, this particular course that we are offering is primarily intended for aerospace engineering students with some background and prerequisites that we shall which I shall explain in a few minutes.

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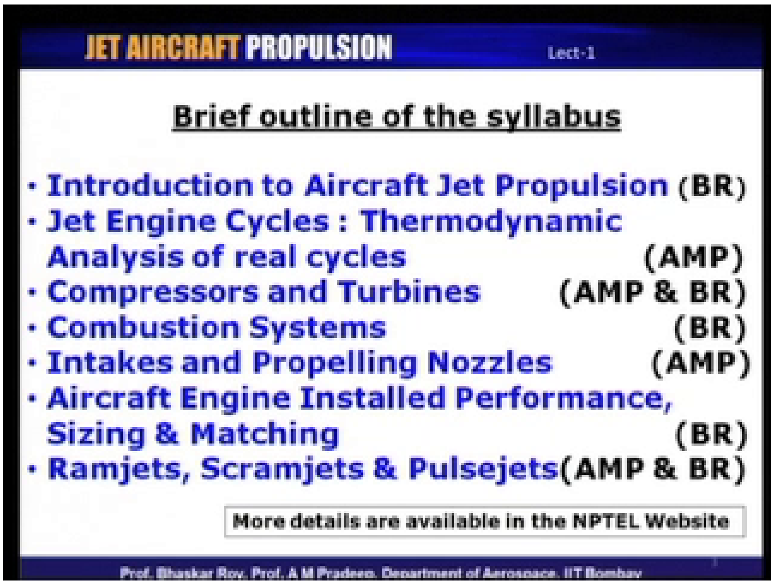

And so before we go into some of those details, let us take a very quick look at what does, what are the contents of this particular course. So, basically these courses consist of these broad areas or topics. And we shall begin this course with a brief introduction to this whole course on aircraft jet propulsion, which will be primarily covered by Professor Bhaskar Roy. Following this, I shall be covering the thermodynamic analysis of real cycles; I shall of course also give some quick review of an ideal cycle of the jet engines followed by the real cycle and its thermodynamic analysis. Subsequently, we shall be discussing about compressors and turbines, basically we will be discussing the various components in which constitute an aircraft engines. And the two main components of the aircraft engine are compressors and turbines. And we also have combustion systems which we shall cover subsequently. And then we shall be taking up intakes and propelling nozzles.

And then Professor Roy will also be covering aircraft engine install performance its sizing and matching in detail. And then towards the end of the course, we will also be discussing in brief about ramjets, scramjets, and pulsejets. And more details of the syllabus and the contents are to be put up on to the NP-TEL website. So, you are requested to take a look at the details of the course and the various topics that will be covered in this course through the NP-TEL website.

So, the basic aim as I was mentioned in earlier of this course is to give you an overview or and also, some in depth analysis of the different components; that constitute an aircraft jet engine and what are different types jet engines that are prevalent and what makes these jet engines different and what is the need for these different types of jet engines; what are that components that are different in each of these engines. So, these are some of the topics that we shall be covering. And we as a mentioned we will also be taking up the aircraft install performance and how it is matched or the various components of the aircraft engine are matched, so that all these individual components operate as a single unit, because though these components are designed separately ultimately all these components have to fit into one single engine and operate as more or less a single unit; so, it is important that there is a matching between these different components.

Now, this course as a mentioned is made for aerospace engineers and as and aerospace engineering students. And so, there are certain prerequisites that are expected from you, regarding some basic courses that you need to have undergone to be able to understand and appreciate various contents of this course.

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So, there are couple of courses that we feel are prerequisites for this course, one is one of our own course that is in on introduction to aerospace propulsion which we had offered under NP-TEL phase two and so that is one of the courses that we strongly recommend that you undergo before taking up this course or if you have undergone a course in engineering thermodynamics as well as a course in basic fluid mechanics; as both these courses will be a helpful in your understanding of the various topics which are to be discussed in this course.

So, we strongly recommend that you have undergone these courses before you start taking up this course. So, that you are able to appreciate and understand the various aspects of a jet aircraft propulsion. And so during the next several lectures we will be having about 42 lectures in total. And so during all these lectures we shall be discussing various topics and what I shall do next is to take you through the contents which shall be discussed in the subsequent lectures.

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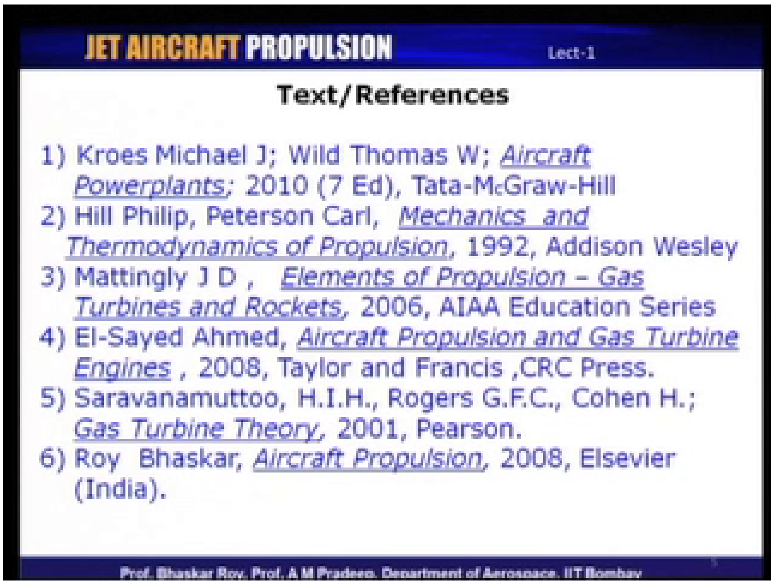

So before that let me also mentioned about the various text books that we recommend for this course. One of the text books that we recommend for this course is by Michael and Thomas on aircraft power plants, which was published the seventh edition of this book published by Tata McGraw hill in 2010. And the second text book which has been there for quite some time and is popularly followed in many colleges is a by hill and Peterson, which is mechanics and thermodynamics of propulsion; there is an earlier version of this available that is published way back in 1992 by Addison Wesley. And the third book that we would recommend is by Mattingly.

So, this text book discusses primarily about the cycle analysis in very much detail so mattingly's text book discusses cycle analysis in good detail and this is published by the AIAA education series and published in 2006. Another text book that you could also refer to is by Ahmed Sayed on aircraft propulsion in gas turbine engines published by Taylor and Francis, CRC press in 2008. And one of the classical text books on gas turbine theory is by Saravanamuttoo, Rogers and Cohen; and this is gas turbine theory 2001 Pearson education series; and this book is primarily meant for land based gas turbine engines but, they do have chapters for aircraft propulsion. There is also a text book which one of the instructors of this course Professor Roy has written on aircraft propulsion published by Elsevier India in 2008; so this also a text that I would strongly recommend that you can take up for this particular course.

So, these are some of the text books and reference material that you should be referring through while undergoing this course; and in addition if we come across some other interesting text books or reading material we shall also discus those during the schedule of this course. And so we shall now look at what are the different contents of the course in little more detail lecture by lecture starting from today's lecture.

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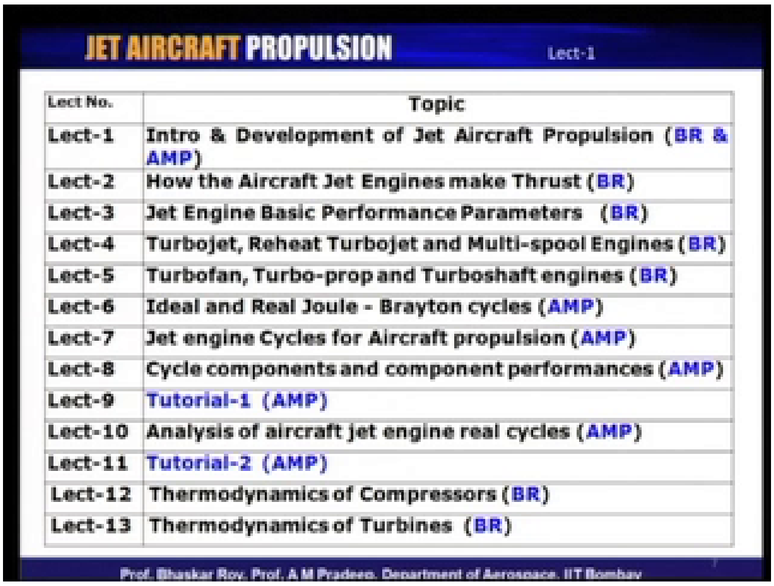

Lect No.	Topic
Lect-1	Intro & Development of Jet Aircraft Propulsion (BR & AMP)
Lect-2	How the Aircraft Jet Engines make Thrust (BR)
Lect-3	Jet Engine Basic Performance Parameters (BR)
Lect-4	Turbojet, Reheat Turbojet and Multi-spool Engines (BR)
Lect-5	Turbofan, Turbo-prop and Turboshaft engines (BR)
Lect-6	Ideal and Real Joule - Brayton cycles (AMP)
Lect-7	Jet engine Cycles for Aircraft propulsion (AMP)
Lect-8	Cycle components and component performances (AMP)
Lect-9	Tutorial-1 (AMP)
Lect-10	Analysis of aircraft jet engine real cycles (AMP)
Lect-11	Tutorial-2 (AMP)
Lect-12	Thermodynamics of Compressors (BR)
Lect-13	Thermodynamics of Turbines (BR)

And so today's lecture is basically an introductory lecture, which both the instructors are going to handle. So part of this course, part of this particular lecture will also be taken up by Professor Roy. It is primarily to do with introduction and development of aircraft jet propulsion with little bit of historical perspective.

The second lecture is to be taken by Professor Roy on how the jet aircraft engines make thrust or how is thrust produced by the jet engines; so, this is a very fundamental concept that you need to understand very well. And so, that will be discussed in detail during the second lecture. The third lecture is on the basic performance parameters of jet engines the second will be covered by Professor Roy. And subsequently, we shall look at the different types of engines in detail starting with the turbo jet engine, the different forms of turbo jet, the turbo jet with reheat, the multi spool engines, etcetera. And the lecture 5 will continue the discussion on turbofans, turbo props and turbo shaft engines. In lecture 6 we shall take up the ideal and real Brayton cycle joule Brayton cycle which I shall be taking on; and then we will also discuss the differences between the ideal and real cycle and how is it that we can carry out a cycle analysis of these cycles.

And then we shall take up the jet engine cycles for aircraft propulsion; the ideal joule bray ton cycle is basically a closed cycle; and so, in aircraft engine as you know dose not really operate in a close cycle mode; and there are certain differences between the ideal bray ton cycle as applied to jet aircraft propulsion so we will discuss that in the seventh lecture. And then we will also be take up the different components of the jet cycle thermodynamically and how do you analyze the performance of these cycle components like the intake, the compressors, combustion chamber, turbine, nozzle, etcetera that will be discussed in lecture-8.

In lecture-9, we will have a tutorial session we will take up cycle analysis and we will solve some problems from cycle analysis the real cycle analysis of some of the engines; and that would give us some idea how we could carry out the cycle analysis given some of the performance parameters. Lecture-10 will be detailed analysis of the real cycles followed by a tutorial during lecture 11. And in lecture-12 onwards we will discuss about the components in much more detail, we will start with the thermodynamics of compressors, which Professor Roy will take up. In lecture-13, we will take up the thermodynamics of turbines.

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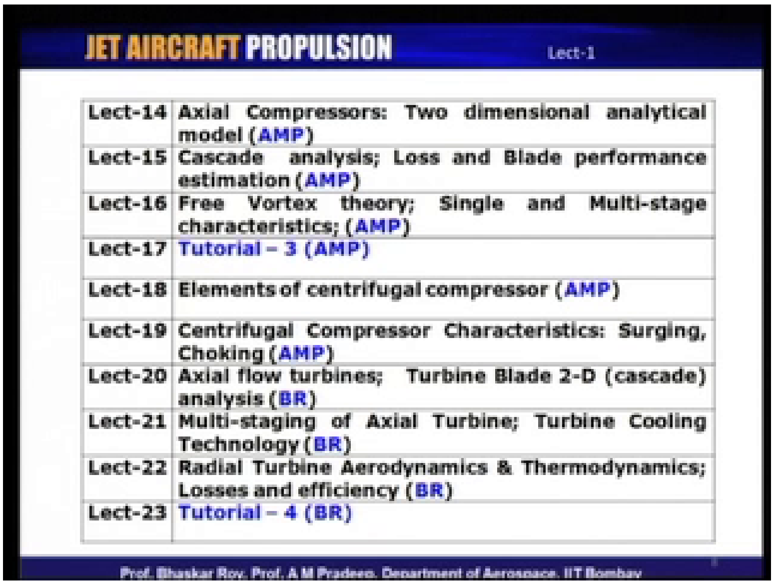
JET AIRCRAFT PROPULSION Lect-1

Lect-14	Axial Compressors: Two dimensional analytical model (AMP)
Lect-15	Cascade analysis; Loss and Blade performance estimation (AMP)
Lect-16	Free Vortex theory; Single and Multi-stage characteristics; (AMP)
Lect-17	Tutorial – 3 (AMP)
Lect-18	Elements of centrifugal compressor (AMP)
Lect-19	Centrifugal Compressor Characteristics: Surging, Choking (AMP)
Lect-20	Axial flow turbines; Turbine Blade 2-D (cascade) analysis (BR)
Lect-21	Multi-staging of Axial Turbine; Turbine Cooling Technology (BR)
Lect-22	Radial Turbine Aerodynamics & Thermodynamics; Losses and efficiency (BR)
Lect-23	Tutorial – 4 (BR)

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Lecture-14 will be the axial compressors we will discuss about two dimensional analytical models for axial compressors. Followed by in lecture-15 we will take up the cascade analysis and how to estimate the loss and blade performance of cascades. Lecture-16, we shall devote to what is known as the free vortex theory, and also about the single and multi stage characteristics of an axial compressor. So, this will be followed by a tutorial on axial compressors in lecture-17. Lecture-18 we shall devote for a centrifugal compressor, what are the elements of centrifugal compressor. And then in lecture-19 we will take up centrifugal analysis, its characteristics like surging, choking, etcetera in detail.

In lecture-20, we will take up the next component that is axial flow turbine and its 2 D analysis, cascade analysis. Lecture-21 is multi staging of axial turbines, turbine cooling, etcetera, which again will be handled by Professor Roy. Lecture-22 is radial turbine aerodynamics and thermodynamics, estimation of losses and efficiency followed by tutorial in lecture-23.

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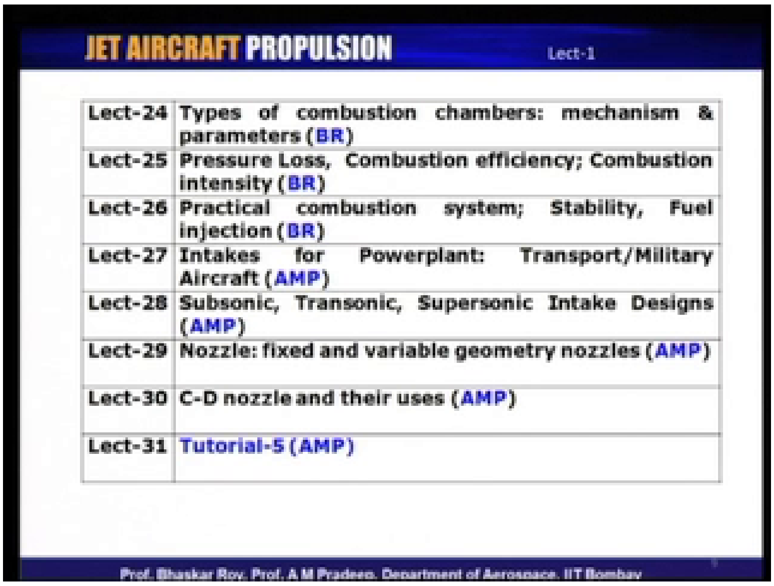

In lecture-24 will start with the combustion chambers, the mechanism of combustion and what are the parameters involved in combustion chamber performance. In lecture-25, we will discuss about pressure loss, combustion efficiency, combustion intensity. And then in lecture-26, we will discuss the particle combustion system which is applied which is about it is in aircraft engines the stability of combustion and fuel injection. In lecture-27 we will take up another component of aircraft engine that is the intake and we will discuss the transport and military aircraft intake separately. We will also discussing about different types of aircraft intakes the subsonic intake, the transonic and the supersonic intake designs that will be in lecture-28. Lecture-29, we will discuss about the nozzle, the different types of nozzle, the fixed and variable geometry nozzles. And then in lecture-30, we will discuss about the convergent divergent nozzle and their applications. Lecture-31 will be basically a tutorial session on intakes and nozzles.

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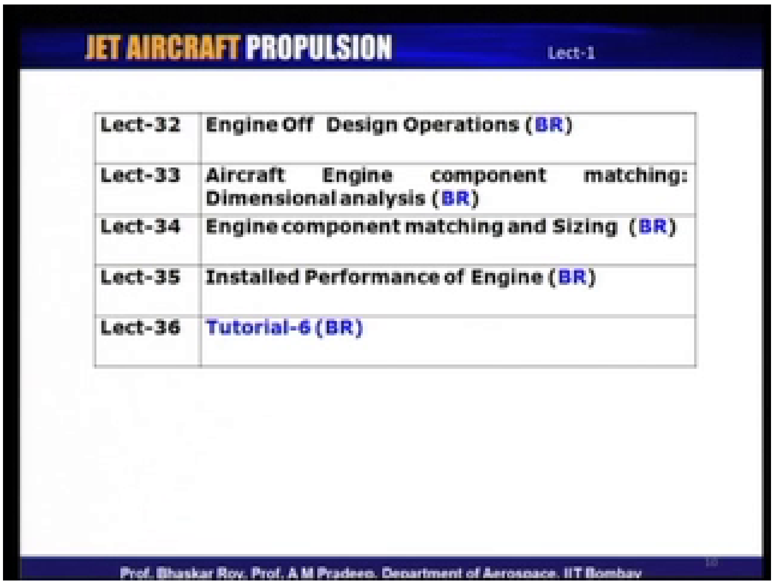

And in lecture 32, we have engine off design parameters and operation which will be discuss by Professor Roy. Lecture 33, we will discuss about engine component matching and dimensional analysis. And in lecture 34, this will be continued and we will discuss that in more detail of component matching and sizing. Lecture 35 will be installed performance of engines. And there will be a tutorial session which will be during lecture 36 on off design performance and matching.

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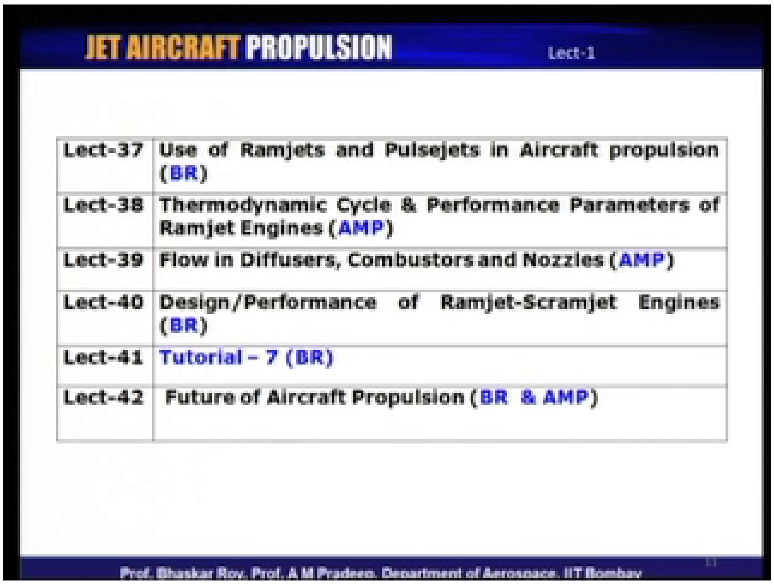

In lecture 37, we will discuss about use of ramjets pulsejets in aircraft propulsion; and you might have already heard about ramjets and pulsejets for we will discuss that in and little detail during that lecture. And take up some analysis thermodynamic analysis of ramjets in lecture 38. And in lecture 39, we will discuss what flow in diffusers, combustors and nozzles, as applied for a ramjet engine. Lecture 40 will be about design performance of ramjet scramjet engines, and followed by a tutorial during lecture 41. And the last lecture that is lecture 42 we shall be discussing about future of aircraft propulsion having discussed the conventional propulsion as well as the propulsion concepts that are being used currently. We will then discuss about where is that the aircraft propulsion is going in the future and what are different concepts that will probably be used in future aircraft propulsion systems.

So, these were the lecture wise schedule and contents that we shall be discussing over this lecture series. And so in today's lecture as we as I mentioned we will discuss about fundamental aspects of jet aircraft propulsion, introduction to jet aircraft propulsion and some amount of historical prospective of that. So, I guess if you have already undergone the basic course of introduction to aerospace propulsion that we have already taken up in NP-TEL; you would have already had some idea about what are the different types of aircraft engines that are jet engines that are currently in use. So, let me give you some overview of what are different types of jet engines that are existing; and also what are the different basically the differences between different types of these jet engines.

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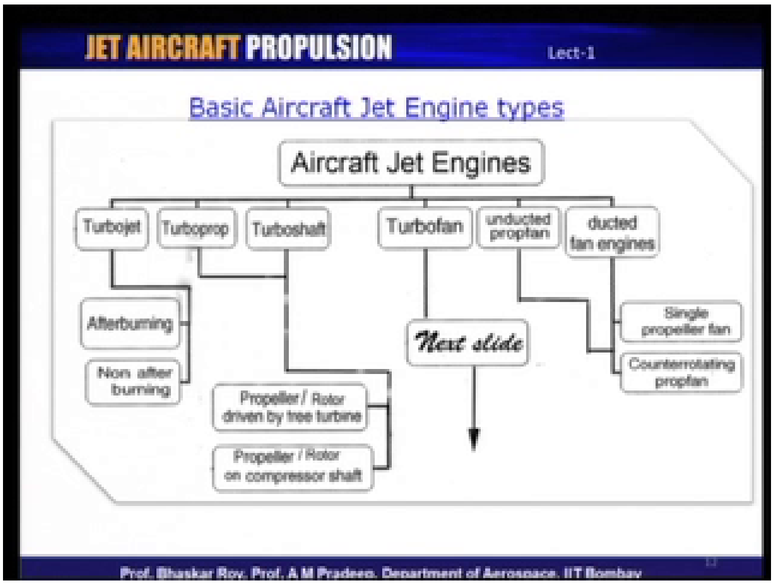

So, aircraft jet engines can be classified into many of these groups which I am sure you would have already heard about. One of basic forms of the aircraft jet engines is the turbojet. The turbojet engine can operate in two modes; it could operate with an afterburner or without an afterburner. And afterburning is basically used to generate additional thrust, when the aircraft has to cruse to super has to accelerate to supersonic Mach numbers and also cruse at the same Mach number. So, it could operate either in the afterburning mode or the non afterburning mode.

The other form of the aircraft jet engine is the turboprop. And turboprop is consists of a jet engine one com one of the turbines of the jet engine drives a propeller and propeller generates a substantial thrust in addition to the nozzle thrust itself. The turboprops are still used in transport aviation, you might have seen some of the smaller jet engines which use turboprops; and so turboprops can again be driven either by propeller it could be turboprops or the turbo shaft; in fact they are also similar because turbo shaft is a engine used in helicopters; And in helicopters as we know there is no jet thrust it is basically the thrust generated by the main rotor blade. And in both these cases the propeller in the case of turboprop or the rotor blade in the case of turbo shaft in driven by free turbine; and it is in some cases mounted on the compressor shaft itself with a gear box.

Now, the other popular type of aircraft engine is the turbofan. We will discuss the classification of turbofan in the next slide because, the many types of turbofans which are prevalent. And then some of the advanced concepts like the unducted propfan and the ducted fan engines; and these both of these could either have a single propeller system or a contra rotating prop fan system. So, some of these will again be discussed in little more detail in later lectures or it has already been discussed in the earlier course on introduction to aerospace propulsion.

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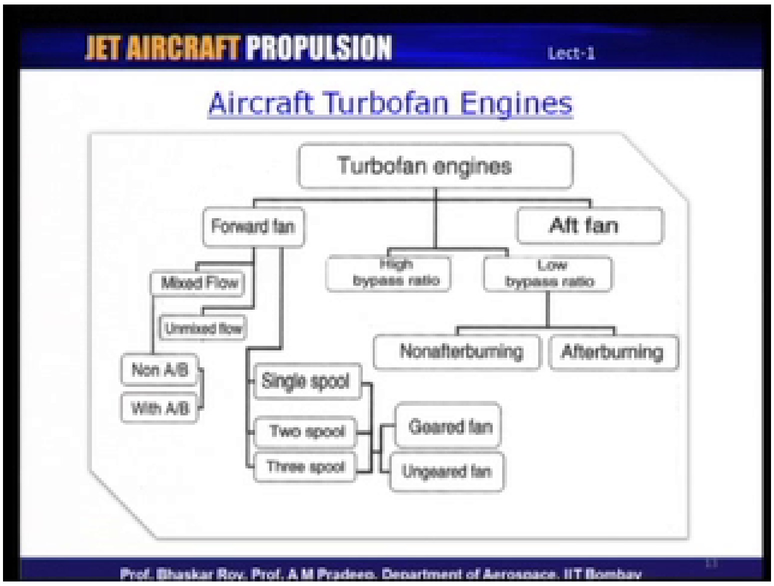

Now, turbofan as you knows is the engine that is used in a most of the transport aircraft and the larger sized transport aircraft. The turbofan engines can as you can see constitute of different types or different classes; it could either be broadly classified as forward fan system and aft fan system or the other classification is the high bypass ratio system and the low bypass ratio system. Now, let us take up the forward fan system which is how most of the engines are in if the turbofan is a forward fan system; the turbofan could either be operating in the mixed flow mode or in the unmixed flow mode; the unmixed flow mode the bypass air does not makes with the core flow within the aircraft within the engine itself; in the mixed engine flow mode, the bypass and the core flow mix within the engine before the exit the nozzle; and therefore, they can operate in both the modes that is non afterburning mode or with an afterburner mode.

And the other type or classification of the forward fan, turbo fan could be based on different spools. These engines could either be a single spool system, two spool or three spool system; and they could be operating with either a geared fan or an ungeared fan; that is with a gear box which will reduce the speed of the fan or not. And depending upon bypass ratio the engines could be classified as high bypass or a low bypass ratio engine. In a low bypass ratio engine, which is a similar to that of a mixed flow engine; the engine could operate in non afterburning or an afterburning mode; and with low bypass ratio the turbo fan approaches that of a turbojet engine because, bypass ratios tend to be very low and they are sometimes use to military engines.

Turbofans could also be operating let us say with a prop fan operating in the where the propeller is or the prop fan is in the rear of the engine. So, it is operating in the aft fan mode, that is the fan is located not in the initial part of the engine but, the later part of the engine, that is the aft fan mode of the engine. So, these are different types of engines and their classification and what are how these different types of engines operate etcetera will be discussed in more detail as we proceed. And so what we shall now do is to discuss about the development of aircraft jet engines so Professor Roy will now take up the development of aircraft jet engines in with some historical perspective in much more detail.

My name is Bhaskar Roy; I am in aerospace engineering department of IIT Bombay along with professor Pradeep; I will be participating in the lecture series on jet aircraft propulsion talking about various aspects of jet propulsion. In today's lecture Professor Pradeep has already introduced to you, the various topics that we will be covering, the various aspects of jet propulsion that we will be covering in the course of this entire lecture series over approximately 42 lectures.

He has also introduced to you the various books, and the various prerequisites that are required for this propulsion course. In today's lecture in the remainder of the today's lecture I will try to introduce to you the various aspects of development of jet engine, with a certain touch of the historical perspective. Jet propulsion has been around for nearly 60 years now or little more than that. Over the period of this 60 or odd years, the jet propulsion has improved and it has become one of the most glamorous field of engineering and technology the world over. It makes the human being fly higher and faster takes them all over the world in a very short space of time, meeting, both personal as well as business requirements of various kinds of people.

However, the development of this jet aircraft propulsion has been going on long before the jet propulsion actually came into being and started flying. Jet propulsion has a concept has been around for quite some time, before they actually got materialized; and various aspects of jet propulsion conceptually and technology have been in development for quite some time at least for a period of 50 years before they actually flew. Today, we will try to take a look at how this jet propulsion development took place, and where we are today, and the various aspects of jet propulsion that make an aircraft engine such a fascinating technological marvel.

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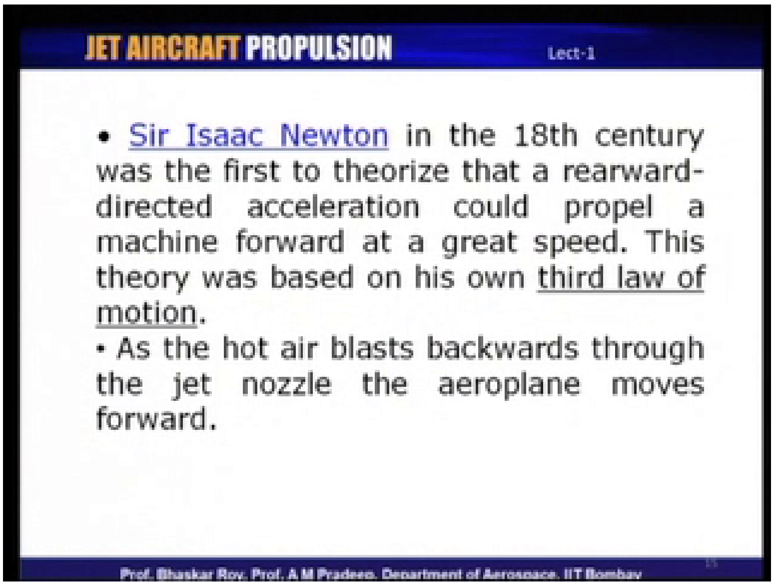

We will see that jet propulsion as a concept has been around for more than 100 years, if we start with how it all started. Sir Isaac Newton, he theorized for the first time based on his own laws of motion; that if you have an acceleration of flow rear-ward this could actually propel a machine forward at a sufficient speed to make a body move. Now, this is the theory that based on his own laws of motion; that started the whole thinking that one could possibly have a jet propulsion.

And if you the working medium that he conceived and people later on have a theorized and materialized, is the use of air. Now, this is an important aspect that you use air, that is bend abundantly available atmosphere and you simply recycle the air to create jet propulsion. This is an important aspect, in the sense that if you have to continuously depend on other kind of material for creating propulsive force, then you are dependence of the other kind of material could limit your propulsive activity.

Now that is exactly what is done in rocket propulsion, that the material that is used for propulsion is completely generated by human beings and stored inside the rocket body. But, in aircraft propulsion the material that is fundamentally used for a propulsive purpose is the air itself. It is taking from the atmosphere and it is giving back to the atmosphere; it comes into the engine and goes out of the engine back into the atmosphere; and this is what Professor Pradeep mentioned as an open cycle that it of it occurs in a cycle, it is taken inside the engine it goes through what we call thermo-dynamically a cycle, and we will discuss that through the course of this lecture series in some detail. And at the end of this operation of creation of propulsive force, the air is ejected out of the cycle into the atmosphere back into the atmosphere.

Now this is an important concept and because of the success of this concept, the jet aircraft propulsion has became such an all pervading technological use in our life. Now, let us look at various aspects of how the propulsive devices are developed.

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Surprisingly, in the 1920s immediately after the world war one in US, under the high powered committee working under NACA, which was the National Administrative Council for Aspects, various aspects of Aeronautical developments, and they actually concluded that a jet engine was not a feasible proposition at that point of time after going through various aspects of science and technology that is required to make a jet engine work.

And because of this high powered committee's recommendation, very little work was done in US on jet engine development. Now, we all of course know, that most of the jet engine development have been going on for last 50 years a big chunk of it is actually in US, but quite surprisingly prior to that prior to world war two, very little work was going on in US because, this particular committee had decided that jet engine was not a feasible proposition. However, Frank Whittle had later on Sir Frank Whittle, he went ahead quietly and patented his concept of jet engine and we will have a look at his jet engine in few minutes from now and he did that in England in 1930.

And this patent is what is normally considered the first patent of a jet engine or first patent granted to jet engine in the whole world. Later on after the world war two, Sir Frank Whittle actually migrated to US; and he spent most of his developments, developing years in US, developing various forms of jet engine, starting of course from his own concept of jet engine.

Doctor Hans Von Ohain working independently in Germany, along the same time as Frank Whittle also went ahead, and patented in Germany, his concept of jet engine in 1936. Now, these two are independent development they had no connection with each other and those days remember, the communication channels were not very easily established. So, they did their work independently, developed the concept independently and went ahead and patented them independently, in their own countries. And this engine developed by Doctor Hans Von Ohain actually flew with the Heinkel aircraft in 1939; and this was indeed the first jet engine to fly. So, the jet engine developed in Germany by Doctor Von Ohain was indeed the first jet engine to fly before Sir Frank Whittle's engine.

Now after the world war two we know that the world was in term all, and after the world two Doctor Von Ohain also migrated to US, and he also developed many of his later developments in USA. So, both the further figures of the jet engine development the mode in jet engine development later on did most of their work in US; and that also explains why after the world war two many of the jet engine were indeed developed in US. Of course, we have seen lot of development also going in England and Germany and many other countries in Europe.

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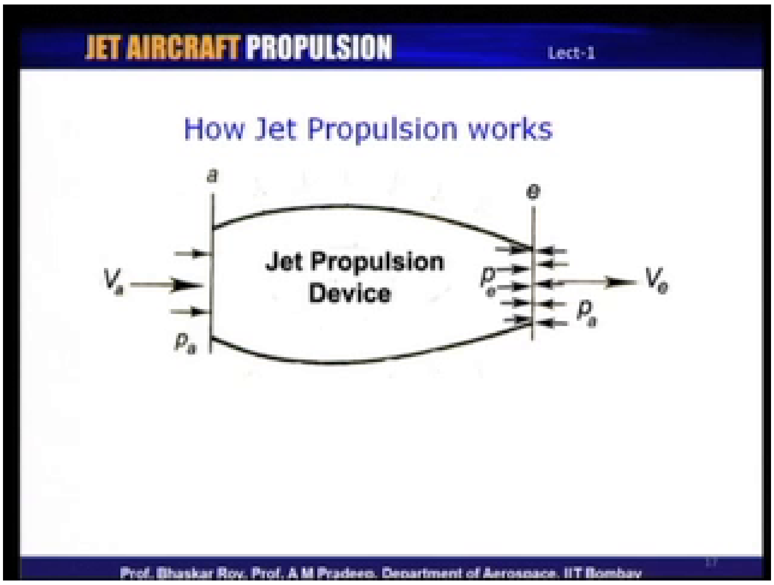

Let us take a quick look at the fundamental concept of how a jet propulsion device indeed creates a propulsive force. Now, as I mention the typical aircraft actually uses air, now what we see in this simple hand sketch is that air comes into the to propulsive device from the front; and this air comes in with a certain velocity let us say Va; and this is the scenario you would have when the aircraft is indeed flying; so, when the aircraft is flying it is coming in with a certain velocity which is matching with the flight speed of the aircraft; so, the flight speed of the aircraft makes a certain amount of air come inside the jet propulsion device; and then the propulsive device does its propulsive work on this air; and then lets it out through the rear with another velocity which is V e. And the Newton's laws quite clearly tell us that if you are to get a positive amount of force created out of this device, it is necessary that V e should be substantially higher than V a; and then the amount of mass that is activated; so, the product of the mass that is activated; and the acceleration or the change of velocity that takes place over this propulsive device indeed creates the propulsive force.

Now this is the simple concept based on which the propulsive devices have been created; so, all jet aircraft engines that we will be talking about over the period of this lecture series will indeed be operative based on this fundamental concept. Now, let us see how the whole concept have indeed developed.

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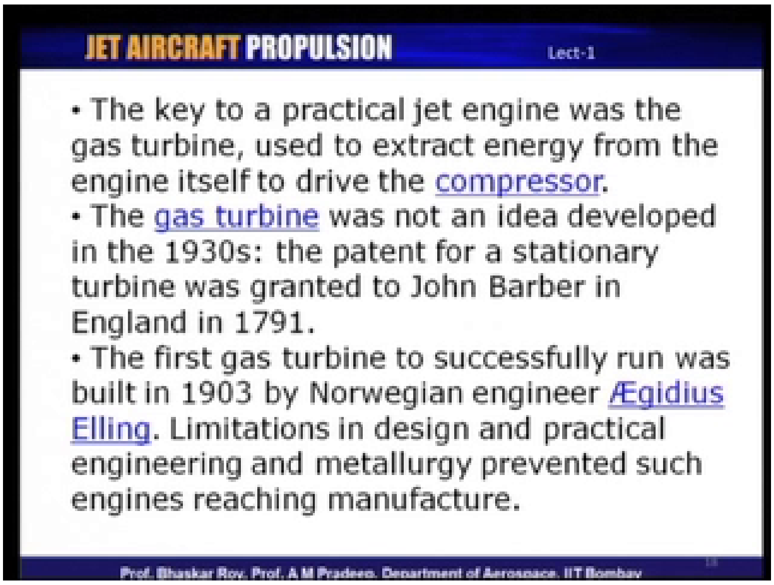

You see the key to a practical jet engine was the gas turbine from which it indeed derives its name. The basic jet engine is technically also referred to as a gas turbine engine; and the key to this is actually the operation of a turbine or gas turbine, which is used to extract energy from the engine itself; and you will need this gas turbine to drive a compressor.

So you have a coupling of a turbine and a compressor, which is an absolute necessity for working of this kind of an engine. And you need a combination of turbine and compressor, which then creates a loop energy loop inside the engine and this energy loop, is the key to the development of practical jet engine. Now, gas turbine is an old concept; it is been around for a very long time. The development actually practical development started in 1930s; compressor development started actually a little later, but the patent for a stationary turbine was granted to John Barber in England way back in 1791; that is a little more than 200 years back.

So turbine as a concept or gas turbine as a concept has been around for little more than actually 200 years. Now, turbines have been around turbines have been around as a wind turbines; they have been around as water turbines literally for hundreds of years; people have been using the concept of using either water or air to rotate a turbine like rotor to develop energy, to develop shaft power and to develop work; and this is how the wind turbines have been developed; they have been around for centuries now; the water turbines have been around for also centuries.

So the concept of using flowing fluid whether its water or air to run a turbine in a rotating mode and to create shaft power and to get work out of it as a concept has been around for literally centuries. Gas turbine as a concept has been around for now little more than 200 years. The first gas turbine was successfully run technologically proven was built in 1903 according to the documents that are available by a Norwegian engineer Egidius Elling; now this is little more than 100 years back. The point is making a gas turbine work you need gas, you need turbine material, that can with stand the gas temperature and pressure, and hence there are certain technological requirements for making a gas turbine work.

So, in design and practical engineering and certain aspects of material requirement of metallurgy quite often prevented actual manufacturing of these engines on large scale. So, large scale use of gas turbine came off a little later even though it was proven way back in 1903; mark the date 1903 is also the year in which Wright brothers flew their first aircraft.

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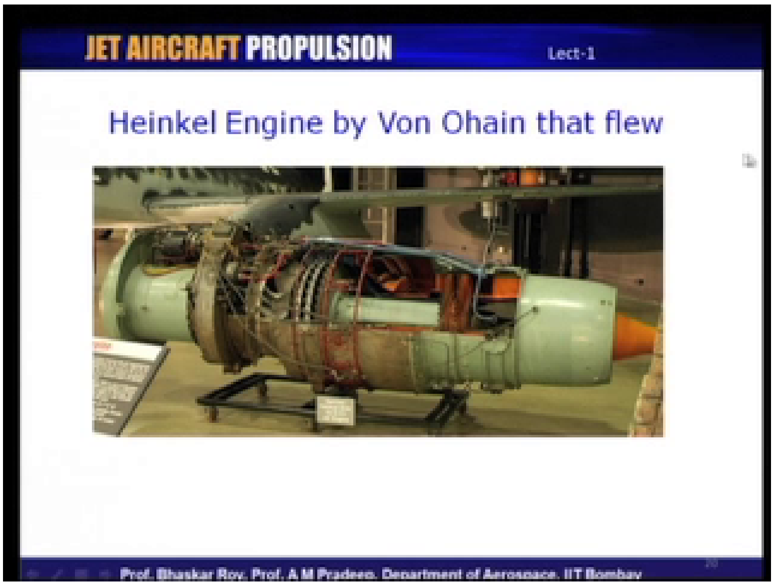

Now this is the engine, which was created by Sir Frank Whittle, and this particular engine you are looking at is indeed the engine that flew. So the first patent he created was way back in 1930, this it jet engine flew about 7 or 8 years after that, a little after Doctor Von Ohain's engine flew in Heinkel aircraft, now this engine is conceptually and in detail somewhat different form Doctor Von Ohain's engine. Now this consists of for example, a centrifugal compressor a number of these cylinders that you see around that look like gas cylinders, they are indeed the combustion chambers and on the side you can see a centrifugal compressor, we will have a look at what a centrifugal compressor is later on in this course in some detail.

And on this one what you can see here is the back of the engine the jet nozzle; the nozzle through which, the jet comes out a hot jet which is been gone through which is gone through a process of compression in the centrifugal compressor or process of combustion in these combustion chambers, which are wrapped around the engine they supply the hot gas, which is been compressed; so, it goes into a turbine, which one is not able to see here very clearly, and then it comes out through this jet for creation of jet thrust so, this is what Sir Frank Whittle's jet engine was that flew for the first time around 1938.

If on the other hand if you look at the Heinkel engine that was created by Doctor Von Ohain that looks little a more like various kinds of jet engines that we see today. Now this is the engine this is of course, a picture taken in a museum, and you can see the various modern components of the jet engine, you can see the compressors over here, and then you have the combustion chamber, and then you have the turbine, and it looks more like a modern jet engine and the jet nozzle through which the jet hot jet finally, comes out. Now, this is Von Ohain's concept of jet engine and this is the kind of engine that indeed flew as Heinkel engine. Heinkel was a business man who supported the work of Doctor Von Ohain who was indeed a proper academician and a researcher, and this engine was as we now the first jet engine that flew.

Now this is the kind concept that you would see you see what happens is if you look at Sir Von Ohain's engine it is a sleek long engine that takes in air from the front and lets out air from the rear creating jet propulsion force.

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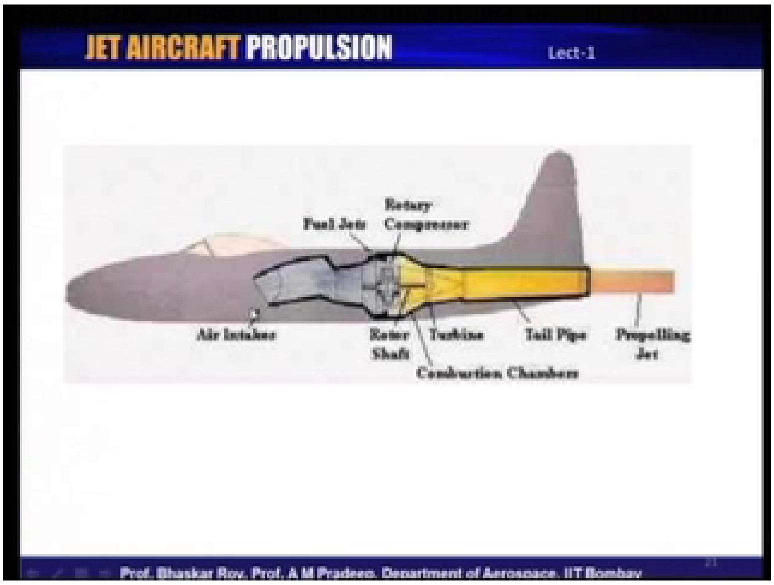

If for example, if you put such a engine inside the body of the aircraft this is the scenario, you would probably have with you the engine is good in proper buried inside the body of an aircraft; and air has to be ingested into this engine; so, you would need rather long air intake system; we will be talking about the intake system later on in this course.

And this intake system delivers the air into it takes from the atmosphere delivers it inside the engine; the engine does it is various kinds of technological work on the air, and then the hot air or gas is finally, let out through a long tail pipe creating a propelling jet. Now this is how the jet thrust would indeed be created, if you have an engine that is buried inside an aircraft and this is how the whole business indeed started that you have one engine buried inside aircraft; in those days, in the early days, the aircraft were indeed small and one engine was considered quite often sufficient to make the aircraft fly.

The typical components of the jet engine are for example, shown here and we will be looking at them more and more as we go along in this lecture series you have you would indeed have a rotary compressor, which we shall see is quite different from the piston compressor which you would normally do in other courses and we have done a little bit of that in the introduction jet propulsion course, this rotary compressor then actually moves in a rotary shaft which is indeed to run by the turbine.

So what just now I was saying is that you need a turbine to run the compressor so if turbine compressor is a kind of a combination, which is buried inside this jet engine device, and this is essential or key to the development of the jet engines, in the sense the turbine compressor combination creates the high pressure air or working medium, which is then ingested with a fuel and raise to high temperature, so that one finally creates high temperature and pressure gas, which is used to create the propelling jet. So, quick key to the development of jet engine was indeed development of turbine and immediately there after development of rotary compressor and we shall see various kinds of compressors as we go along in this lecture series.

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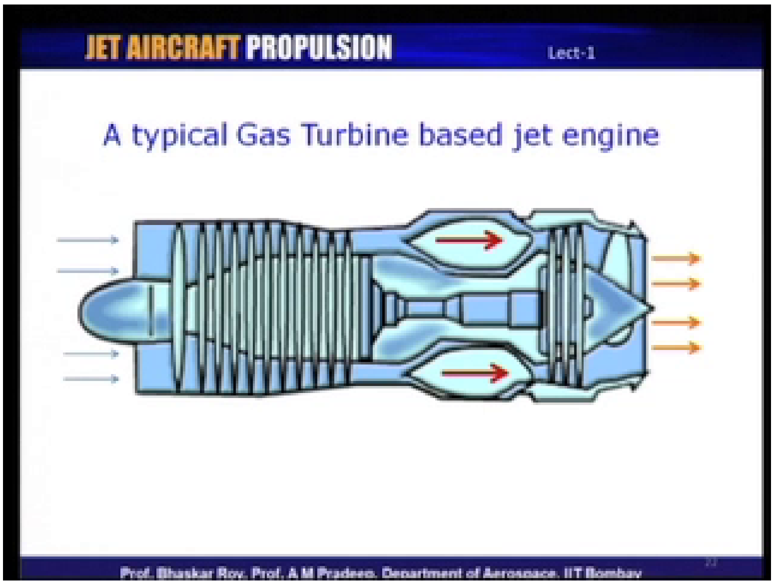

Here, we look at a very simple schematic of a modern gas turbine based jet engine. Typically, you would have the air coming in from the front ingested into this jet engine through this opening that is available, and these are to be properly geometrically designed, and the air has it comes in goes through a rotary compressor has we just saw, the rotary compressor or the process of compression may be done in stages. The typically compression process we would be studying in this course, effectively refers to what is also known as aerodynamic compressor, as oppose to positive displacement compressor, which we you do in piston engines.

Now this kind of compression, which is a rotary compressor uses rotary compressor uses various laws of aerodynamics to create the compression of air. This compressed air is then delivered into this combustion chamber in which fuel is indeed burned very small amount of fuel is burnt and that is sufficient to raise the temperature of the air to very high temperatures;

so, what we have is air infused with a small amount of fuel and one may call it then gas; fundamentally it is air; and then this hot highly compressed and high temperature gas is then released on to the turbine, which is indeed also a rotary turbine and this rotary turbine extracts work out of it as is required of a turbine all kinds of turbine, and this turbine then through the shaft runs the compressor.

So, this what I was saying that you need a mechanical coupling of the turbine compressor, and this turbine compressor coupling creates the high pressure gas inside of which is the stomach of the engine and that is where the fuel is burnt, and the combination of turbine compressor combustion chamber often referred to as a co engine creates the high pressure high temperature gas, and this is then let out through the nozzle which creates the jet propulsion thrust.

So, this the development that is taken place so, all the aircraft engine that we will be talking about over the course of this lecture series will have some form of rotary compressor, it will have some form of combustion chamber and some form of rotary turbine and we will be also talking about various aspects of the intakes shapes and their geometries and various kinds of nozzles that create the that help create the final thrust and their geometries. These are the various things that we will be talking about over the course of this lecture series. We will take a look at a very modern aircraft jet engine. You see if you just go back very quickly to the earlier one discriminate schematic actually shows the line drawing or just a cutout lets us say 2D cut out of the rotary compressor combustion chamber turbine. It looks at this movement reasonably a simple device.

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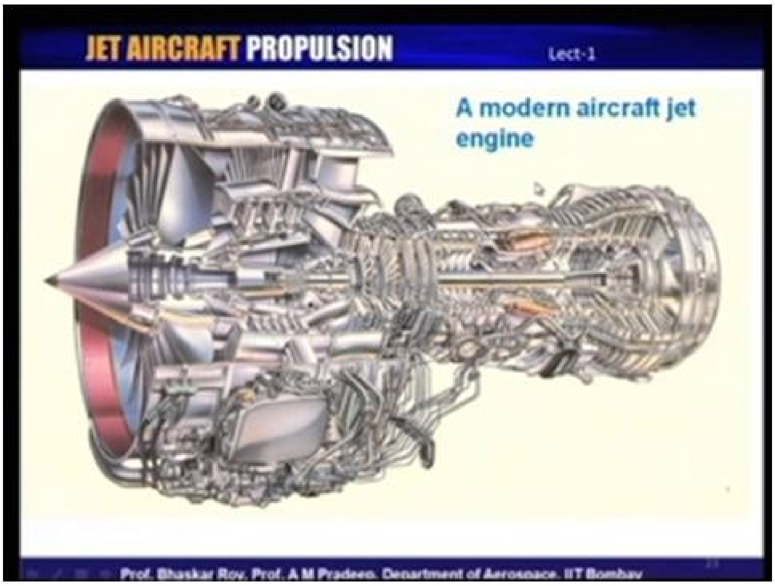

The moment you look at a three-dimensional picture of a modern aircraft jet engine, and this particular picture is indeed a picture of a actual modern jet engine. You can actually see inside of this literally hundreds probably thousands of parts. This is the mechanical engineering that goes into creation of a modern jet engine; the front parts or the parts that we referred to as the rotary compressor, and then you have the combustion chamber here, and then you have the rotary turbines over here; all these and then you have the shaft system along shaft system which as you can in this engine and most of the engine that we will see later on are actually hallow shafts.

And of course, they need to be hallow these parts need to be devised very carefully, because they are going on an aircraft. In an aircraft one of the most important parameters that we will see a later on in this course is the thrust to weight ratio; so, weight of these engine is a crucial point in the development and design of these kind of jet engine. Every part will have to be literally weighed in and should qualify to be on an aircraft engine so, these hundreds of parts that go to it are very carefully designed and weighed in and their utility have to be completely justified to be inside an aircraft engine.

Hence, you can see here that an aircraft engine indeed consists of literally hundreds and thousands of parts, which actually finally make an aircraft engine that is worthy of putting on an aircraft and flying on an aircraft various kinds of aircraft; whether it is large aircraft or small aircraft; some of the basic requirements of aircraft are very similar; We shall have a look at various kinds of engines that go into various kinds of aircraft, and over the course of this lecture series we will have a look at all these parts that you are looking at, and how these parts have been put in place to make up a whole aircraft jet propulsion system.