Introduction to Airbreathing Propulsion
Prof. Ashoke De
Department of Aerospace Engineering
Indian Institute of Technology - Kanpur

Lecture – 01
Introduction

Okay, so welcome to the particular course on air breathing propulsion and I will be the instructor for this course, my name is Ashoke De, I am currently working in the Department of Aerospace engineering of IIT, Kanpur. Now, just to give you an idea about this course what we are going to discuss in this particular course and what about or what not, so as you see the very fundamental principle of propulsion, any propulsion just to create a force to propel any device or move any device or move anything.

So that is what in a pedagogical sense once can think about the meaning of propulsion, now coming back to this particular course here this is more focused for the targeting students of aerospace or aeronautical engineering and mechanical engineering, who would be interested in gas turbine propulsion or gas turbine engines or aircraft propulsion something like that of similar nature.

Now, what we are so fascinating about aircraft propulsion or air breathing propulsion, if you recall the brief history, it is 1903, when the first human flight was flown by Wright brothers and their flight lasted for few seconds. Now, since then so that particular flight that or the rather the aircraft it was operated with single piston engine, it did not have landing gear, it did not have any fuselage or any of these fancy stuffs that you can see in today modern aircraft or engine, so that is the invention towards what we have right now.

And then followed by the 1930s, I mean obviously, in between there are other development and that we will see through in the detailed discussion during the lecture of the introduction lecture but just to give you an idea in 1930s, first turbojet engine came which was sort of an real advancement and then later on 1950 onwards, we had all these turbofan engines and what we see today mostly in civilian and military applications, these are mostly by and large are turbofan engines.

And there is a different generation of engines which are available today and that is the technological development which has taken place, just have been said that so that means, when you see these advancement in technology, obviously propulsion or aircraft propulsion or air breathing propulsion become an inherent fundamental understanding for this technological development.

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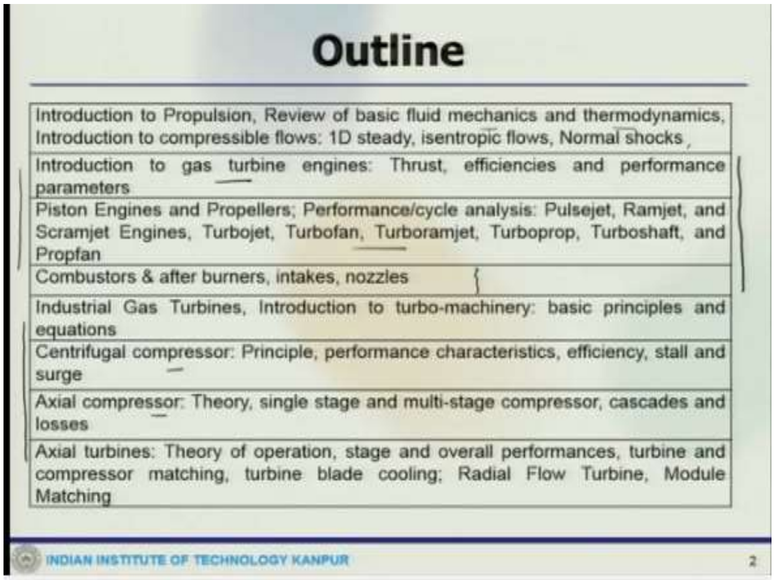

And this particular course is going to be more emphasising on this aero-thermodynamic principle of this air breathing engine and that is what we are going to talk about and more details what is going to be the content of this particular course, this is a brief outline that you can see and what is there is that first we will start with some of the introduction that give you a brief history of these propulsion and aircraft propulsion or aircraft.

So, that give you an overall good idea about what aircraft propulsion is all about and then we will do quick review on the basic fluid mechanics and thermodynamics which would be followed by some discussion on compressible flow and maybe we can do some oblique shocks also here, then that point onwards will move to the all these gas turbine engine discussion like, what are the performance parameter that would be first thing to give you an idea or rather get introduced to this performance parameters as such all these things.

Then we will follow by these different kind of engines or their performance analysis or aero thermodynamical analysis or then we will talk about some of these parts like combustor, intakes, nozzle and then once we have this; this is pretty much the first part of the discussion and that would be followed by the later half of the discussion which contains all the turbo machinery, that means any aircraft engine as we see over the discussion that it has 2 components.

One of the important components are the turbo machinery part which are the rotating components, so there we will do lot of discussion on centrifugal compressor, axial compressor, axial turbine and finally, we will finish the discussion with the mapping of these things, so that is pretty much give you an idea about the whole lecture.

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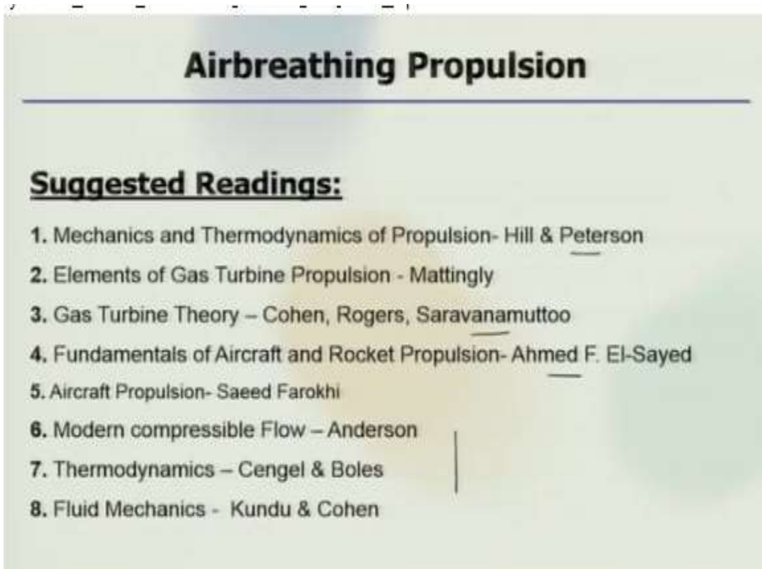

And these are the books which can be followed pretty much these books are all good books, then some of the basic compressible and fluid mechanics books, so these are going to take the whole informations out of different books and then that would talk about all these thing, so that is what you expect.

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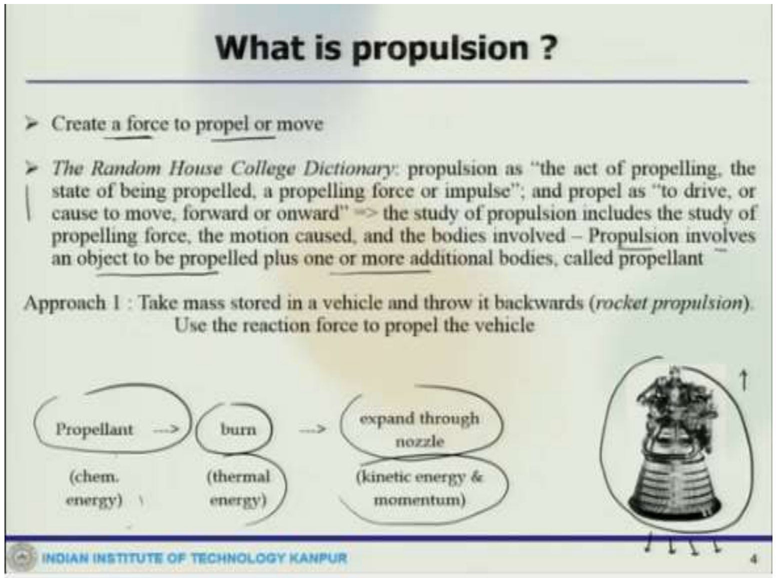

Now, move with the; let us move with the propulsion or the rather the introduction of the propulsion, so as I said the fundamental principle of propulsion to create a force and to propel or move anything, so this could include your bicycle riding, this could be driving a 2 wheeler, this could be driving an automobile or it could be aircraft engine or any other stuff. So, essentially this is the; now, if you go by the English dictionary meaning, this is the act of propelling or the stage of being propelled or these are the different meaning that you can see in the literature or the typical translation of the English and all sort of thing.

So, how we are going to discuss about these things or rather there are different approaches, so another important things to note here, obviously any propulsion which involves an object to be propelled that is the fundamental idea about the propulsion that means, we would like to propel something or rather drive something, rather move forward something and with one or additional bodies like propellant and something like that.

So, there could be 2 ways one can do that, one is that you can store the whole mass inside the vehicle and then try to push backwards like what we do in the sort of rocket propulsion, so that what you do and then this guy actually moves forwards so which means, you have a propellant, so then this is burnt and then finally it expand through the nozzle. So, there are 3 macroscopic steps where it happens.

So, the propellant means, these are some sort of an having the chemical energy, when it burns, its get actually converts to thermal energy and then finally when it pass through these the you obtain the desired kinetic energy and the momentum which will actually give you that thrust force to move forward. Now, when you say that, that means you see these why we are going to do some basic, so they are kind of required the understanding of fluid mechanics and thermodynamics.

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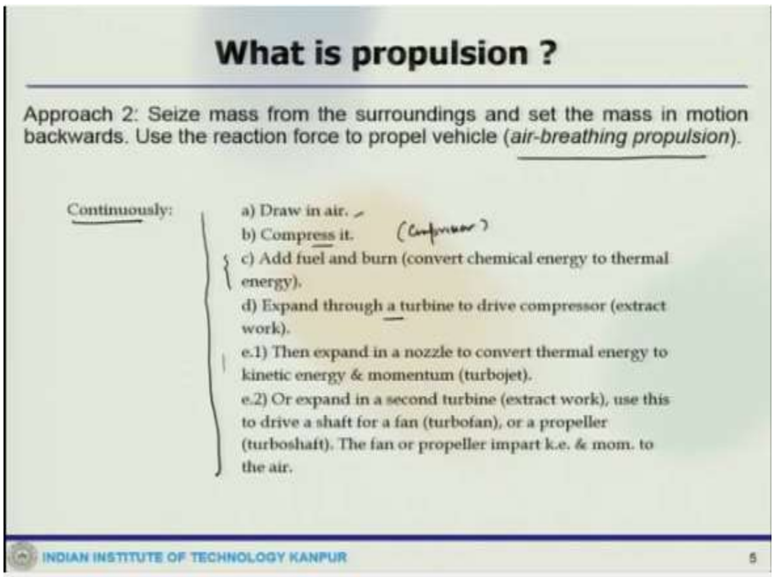

Or the other approach what one can do that you can seize a mass from the surroundings and set the mass in motion backwards and then the reaction force you get that was going to propel the device, so this is what exactly we are going to do air breathing propulsion, okay. So, what it does; it draws the air that means, if you think about any aircraft engine, that is how it works, it draws the air inside the system, then it compress it, so that is where you require the unit of compressor.

We will talk about that more detail as we move along with the lecture, then you add fuel and burn, that mean this is where the combustion takes place in the combustor, then it expands through the turbine that means this is where you extract the work output and then when it pass through the nozzle, you actually get the desired thrust of the momentum to push it forward or sometimes, there could be second turbine and then use the nozzle to pass through the finally to the atmosphere.

So, this is how this whole engine operates and you need so many different component to perform each of these task, so that is what the whole air breathing propulsion is all about, that is what we are going to do it and we are going to look at individual component, we are going to look at the overall system analysis, so initially we look at the overall system analysis and then we will go to the individual component to look at their performance and how they are design and what are the advantage, disadvantage, operational limit everything in total.

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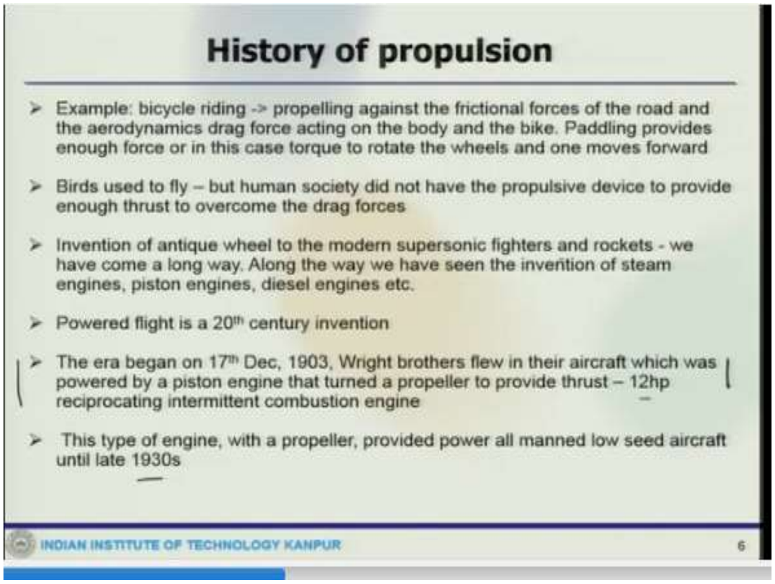

Now, just to again refresh your memory as I said the bicycle riding is also a something you are trying to propel, when the birds fly they are also trying to control their motion whether through manoeuvring moving forward, hovering, so these are also some sort of an propulsion activities one can think about, then you have full modern supersonic fighter and reactors which come all along the way right now what we are in.

And as I said in 1903 that is what the first flight was made and then this is exactly what is written here that this was a single piston engine and that turned the propeller to provide the thrust and which was it 12 horsepower reciprocating intermittent combustion engine, so this is first human flight that occurred by the great scientist of Wright brothers, so this type of engine with propeller provided power all manned low speed aircraft until 1930s, when actually you have the development of turbojet engine.

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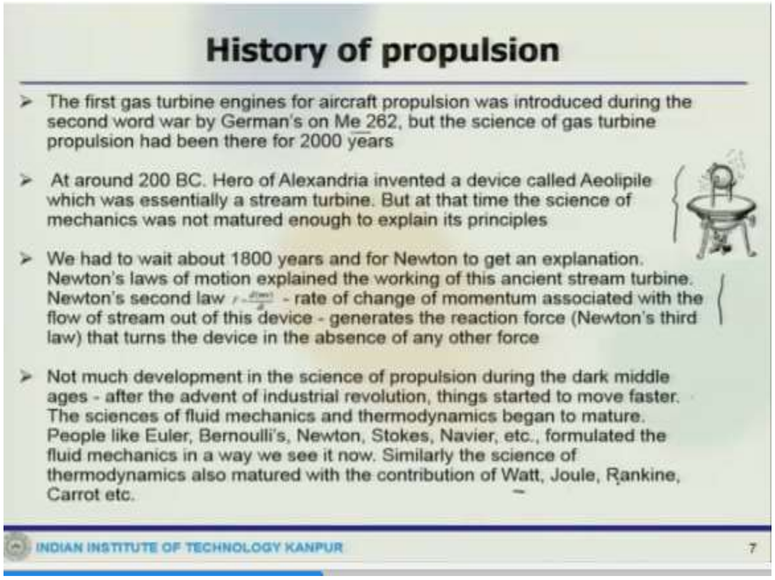

And then the first gas turbine engine, if you talk about for aircraft propulsion was introduced during the Second World War by the Germans which is Me 262 but the science of gas turbine propulsion had been there for 2000 years, around 200 BC is a Alexandria who invented a device called Aeolipile like this, this is the device which was essentially a steam turbine but at the time, the science of mechanics was not matured enough to explain the principle.

Now, we had to wait about 1800 years for Newton to get an explanation, when he propose this laws of motion and that help the world scientific community like in a big way, now then during the dark middle ages, there was not much of development which took place and then after the advent of Industrial Revolution things started to move faster. The sciences of fluid mechanics, thermodynamics begin to mature.

People like Euler, Bernoulli's, Newton, Stokes, Navier as you name them, these are the great scientist who formulated all the fluid mechanics in a way we see it now, similarly the science of the thermodynamics also got mature with through the contribution of Watt, Joule, Rankine, Carrot, all these great people who were behind this.

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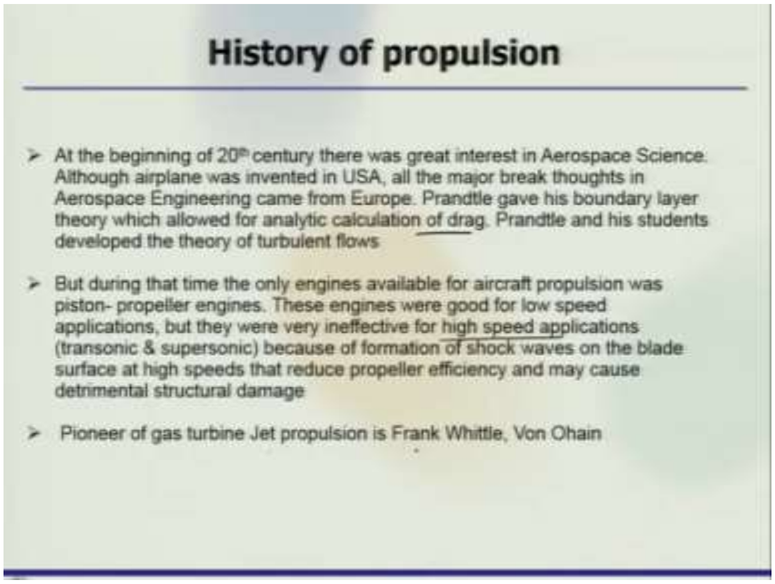

Now, around beginning of 20th century, there was a great interest in aerospace science, although the airplane was invented in USA, all the parts in aerospace engineering came from Europe. Prandtle gave his boundary layer theory which allowed for analytical calculation of drag, because this is an important component when you talk about aircraft engine or any object which is flying in against some force.

And they also talked about turbulent flows but during the time, only engines available for aircraft propulsion was piston propeller engine, so these engines were good for low speed application but they are very, very ineffective for high speed application, okay like if you move from subsonic to transonic or supersonic, so that because there would be formation of shock waves on the blade and there could be losses and all these.

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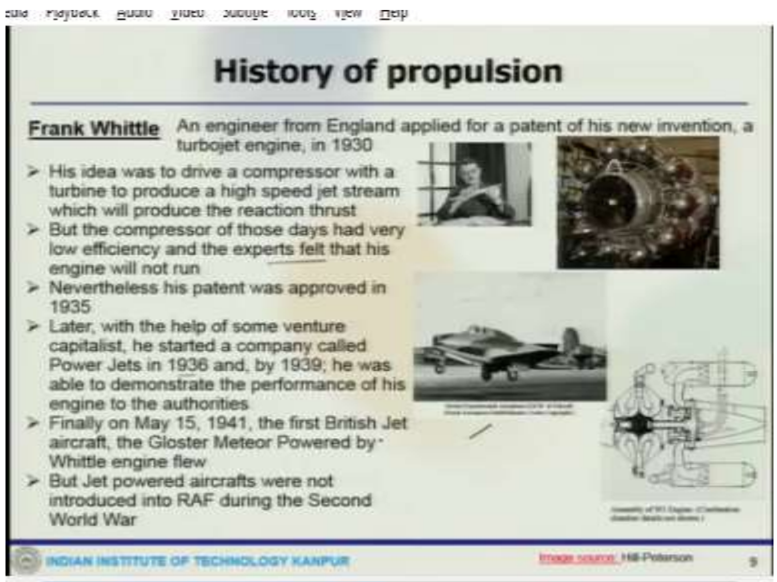

So, the pioneer of gas turbine jet propulsion is Frank Whittle and Von Ohain, so they actually an engineer from England, so they apply for a patent of his new invention, a turbojet engine in 1930 and these are the some of the pictures you can see which are they invented that time, so the idea was to drive a compressor with the turbine to produce high speed jet stream which will produce the reaction thrust.

But the compressor of those days had very low efficiency and felt that this engine will not run but nevertheless his patent got approved and later on the help of some venture capitalists, they started a company called Power Jets in 1936 and by 1939, they are able to demonstrate the performance of engine authorities, finally in 1941, the first British jet aircraft, the Gloster Meteor powered by the Whittle engine flew.

So, this is the engine, so some of the I mean, the old engine where you can see they have now landing here, everything was there, so since 1903 to 1941, it took so much of time and then but jet power aircrafts were not introduced during the Second World War.

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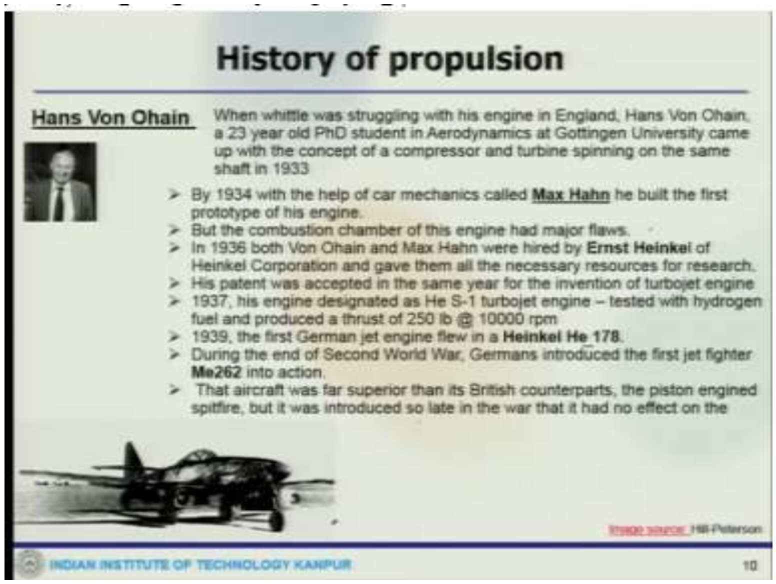

Then, there is another scientist Van Ohain, when Whittle was struggling with his engine in England, this scientist, a 23 year old PhD student in aerodynamics at Gottingen University came up with the concept of compressor and turbine spinning on the same shaft, so this is around 1933. So, 1934 the with the help of car mechanics called Max Hahn, he built the first prototype of the engine.

But the combustion chamber of this engine had major flaws, now in 1936 both Von Ohain and Max Hahn were hired by Ernst Heinkel of Heinkel Corporation gave them all the necessary resources for their research and that patent was approved for invention of turbojet engine and 1937, this engine designed at He S-1 turbojet engine tested with hydrogen fuel and produced the thrust of 250 pounds at 10K rpm.

And in 1939 the first German engine flew is called He 178 which is this is the engine, now during the end of Second World War, Germans introduced the first jet fighter Me 262 into action and that aircraft was the far superior than the British counterpart, the piston engine was spit fire but it was introduced so late in the war that it had no effect on the sale, so these are good to know this history of the jet engine propulsion and all these. Because this is how you can see sequentially things and more as we move along, we will be able to see how the development took place and what we have today.

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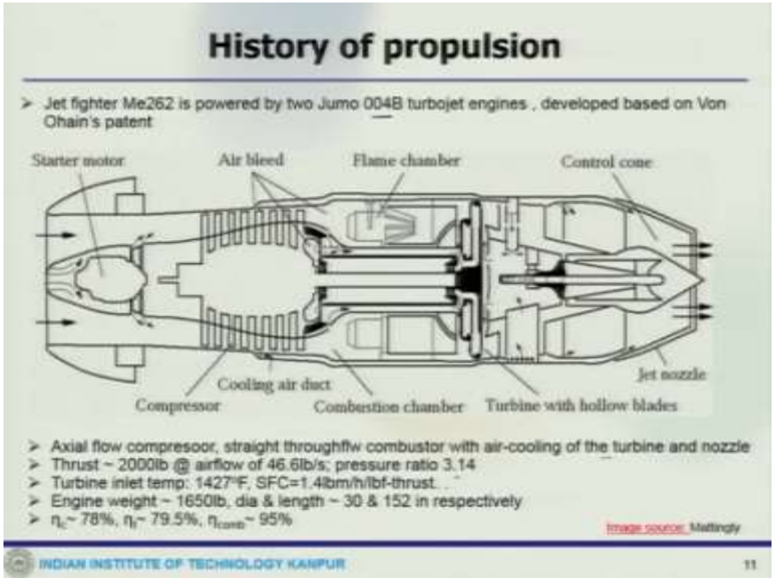

Now, just to bit more on this, the jet fighter Me 262 is powered by 2 jumbo 004B turbojet engines which was developed based on Von Ohain pattern and this is how the schematic was looking like, you had some compressor, then the combustion chamber here, turbine, then the nozzle which passed through this, so you could see that it has an axial flow compressor, then the combustor with straight through flow combustor with air cooling of the turbine and nozzle.

So, this was the thrust which is produced for this particular mass flow rate, there is the pressure ratio around 3.14 that means, this is across the compressor that much pressure rise was done, then these are the some of the specifications for turbine and that was some of the efficiency, that is what the first.

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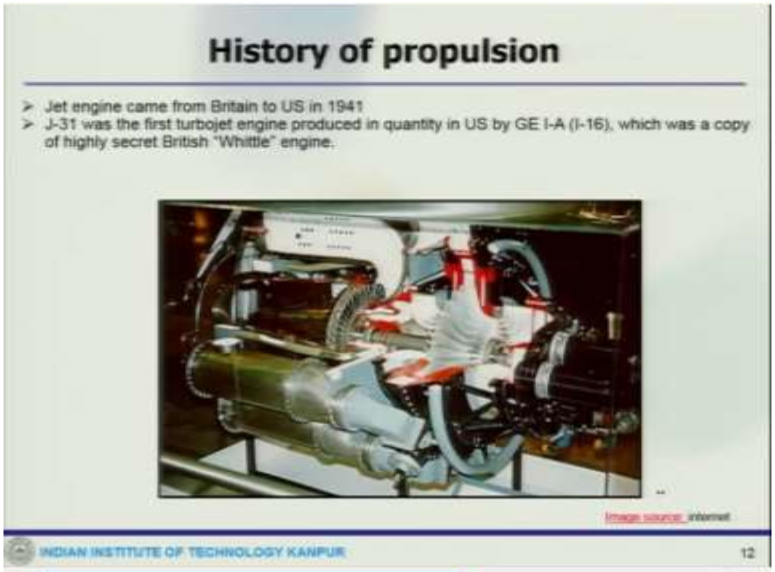

And then in 1941 engine came to Britain to US and J- 31 was the first turbo jet engine produced by US company GE I-A which was a copy of highly secret British Whittle engine, so that is how the first jet engine in US came up.

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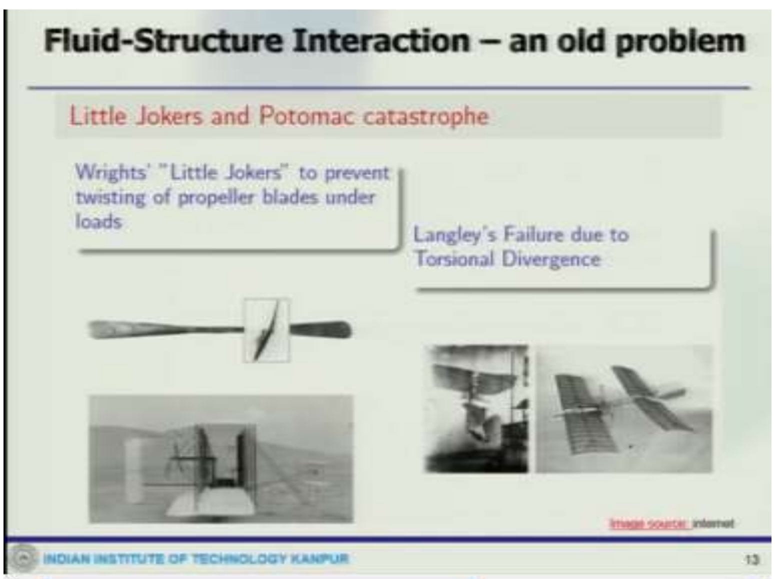

Now, just to talk about something funny here, so these are some of the problems even today in an aircraft like there is a little jokes that Wrights little jokes to prevent twisting of the propeller blades under load that means, the blades were twisted and there was theory, Langley's failure due to torsional divergence, so the thing is that when the early days, these things were made and that is what the great scientist they came up with the new development and all these like these things failed and they were trying to find out the thing.

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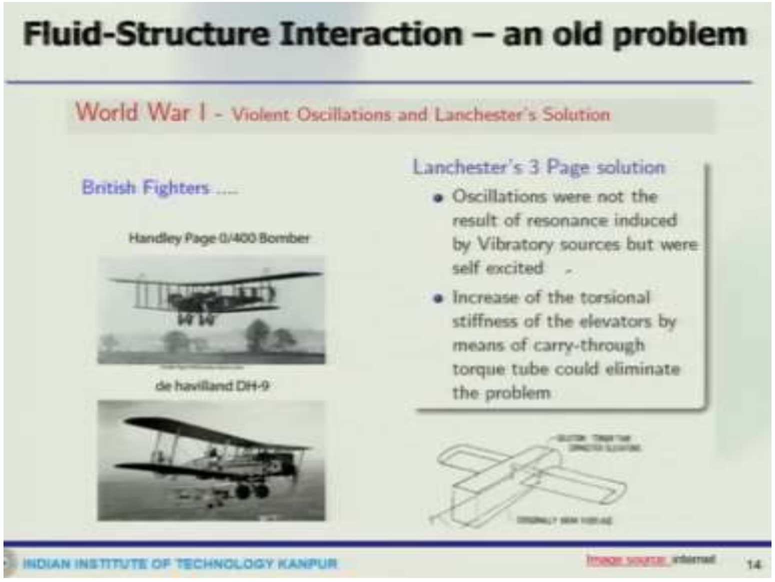

Now, during World War I, this is the British fighters that used and you can see this model and all these and there was a violent oscillations for this blades and all these and obviously, there was some damage or the failure of wing and then the scientist Lanchester gave the 3 page solution. He proposed that oscillations were not result of resonance induced by vibratory sources but were self-excited. In case of the torsional stiffness of the elevator by means of carry through torque tube could eliminate this problem, so then he proposed some solution just to improve that.

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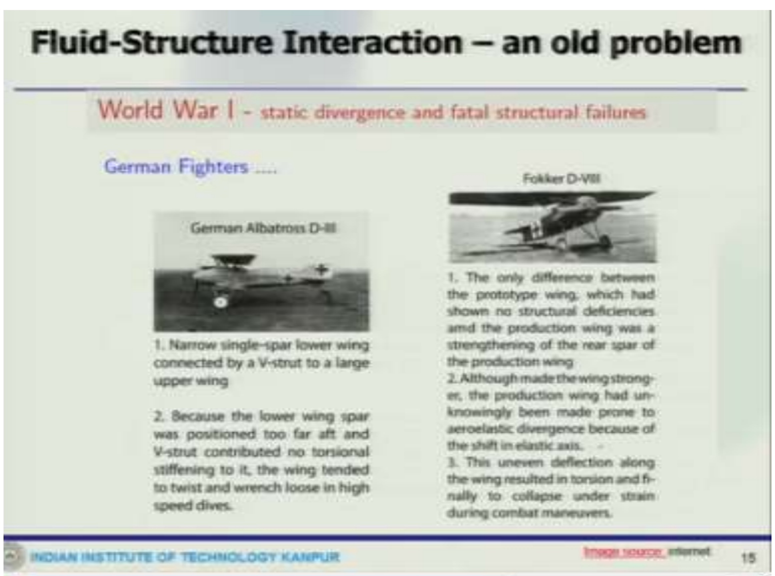

And then at the same time, there was a German Fighter D-III and that also had some sort of an failure of those wings and all these, so one hand we have engine and then other hand we have the total aircraft, so that has lot of other things to be considered and one of these problem is this wing failure or sometimes the fuselage of the body and there is also certain structural failure and if you see that one is the German D-III and the Fokker D-VII or rather 8.

The only difference between the prototype wing, it has shown no structural deficiencies and the production wing was a strengthening of the rear spar of the production wing, although made the wing stronger, the production wing had unknowingly been made prone to aero elastic divergence because of the shift in elastic axis. So, this uneven deflection along the wing resulted in the torsional and finally to collapse of strain, under strain due to combat manoeuvring so, there are some failures.

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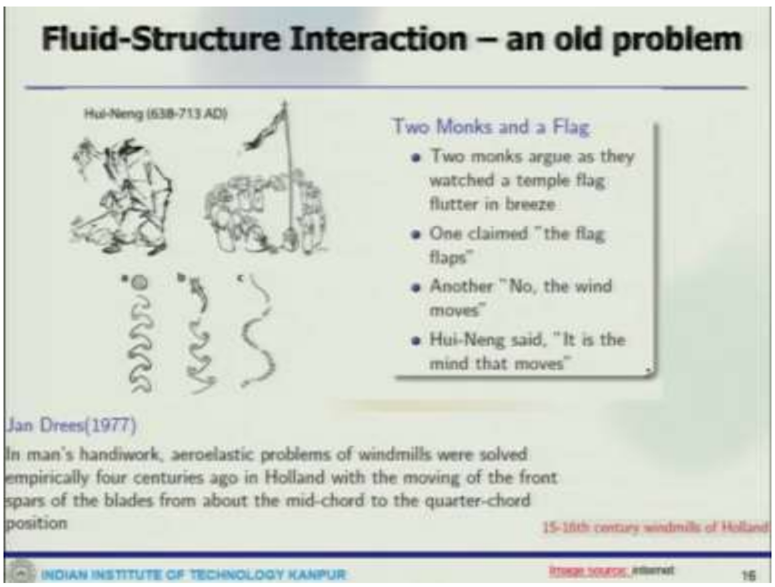

So, there is a nice story where two monks and a flag, they said 2 monks argue as they watched the temple flag flutter in breeze, one claim the flag flaps, the another said no, the wind moves and Hui-Neng said it is the mind that moves, so that is a very nice thing, so in man's handiwork, aero elastic problem of windmills were solved empirically in Holland around 1977 with the moving of the front spar blades about the mid-chord.

But these are problems for wing bodies when it makes more and more large or it is produced such a way that it reduce the drag or get high lift, so more you go towards the high lifting devices, these things would also become problem, so these are the some of the good old problem and still today it perceives.

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Now, when you move to the innovations in aircraft gas turbine engines, when you started in 1903 to 1930, the turbo jet and then 1950 onwards today, we have pretty much very good development like it is a multi-spool configurations that is used, there are variable stator which are used, transonic compressor, low emission combustor, turbine cooling, exhaust nozzles, so modern material and manufacturing.

So, all these happened because of the development in technological front, whether it is the basic fluid mechanics thermodynamics or aero dynamics related development or whether it is material related development, so all these scientific development and innovations has taken us to the state where we have all these sophisticated engine that we are seeing today in flying.

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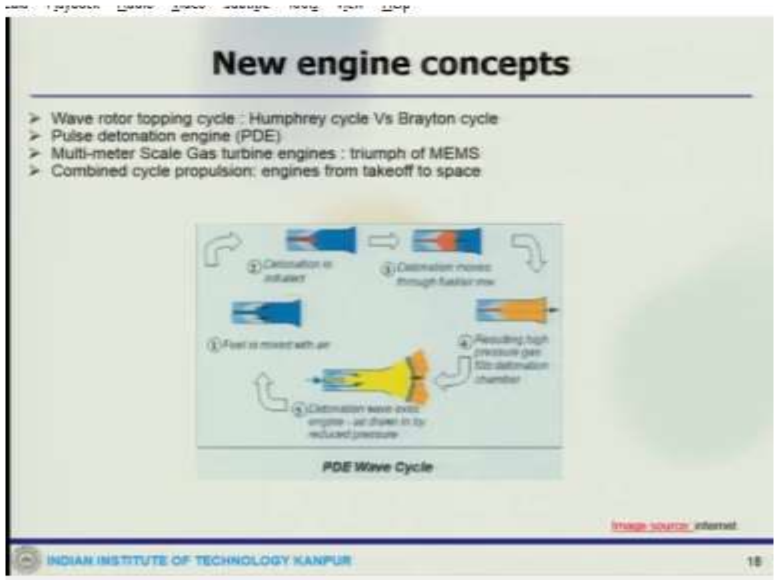

Now, there are other some concepts which are also in place like pulse detonation engine, though it has not been so clear I mean, in the laboratory scale, it has been demonstrated but not in any real life situation they are in place and there are different thermodynamical cycle behind that but we will talk about that slightly late as we move.

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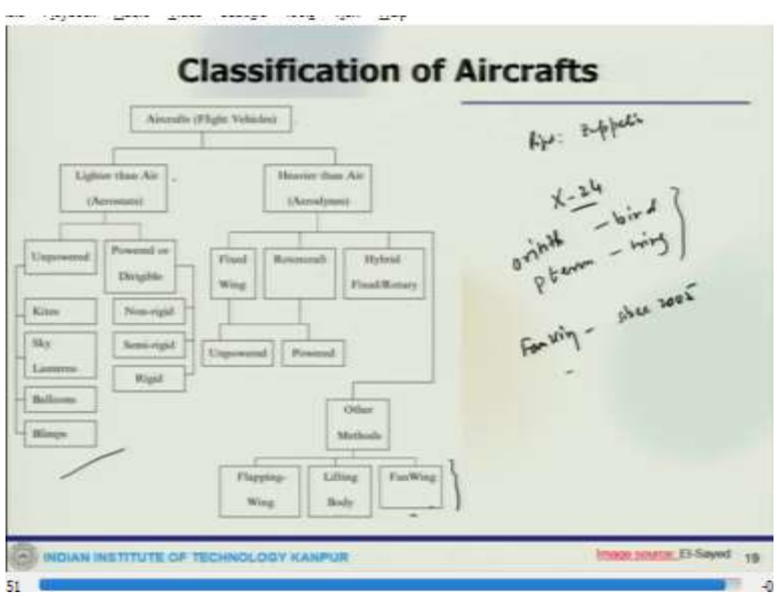

Now that is take us and just to see what is the classification of aircrafts, so now we are talking about this advancement and all these things, so that would be good idea to put these thing together. Now, if you look at the aircraft or the flight vehicles, there could be 2 categories; one is lighter than aircraft, one is heavier than air, which is aerodynes, okay. Now, the aerostats also, if you take this segment, the aerostat segment, so aerostat also could be 2 categories; one is the unpowered, another is the powered.

When you talk about unpowered, it could be kites, sky lanterns, balloons, blimps and all these examples you can think about, they comes under the aerostat, which is lighter than air or powered; it could be non-rigid, it could be semi rigid or it could be rigid, okay. So, when you look at this powered aerostat, so the semi rigid airships are slightly larger and have some form of internal support such as fixed keel.

Non rigid compared to that, sometime these are called blimps also or small airships without internal skeleton and rigid the example one can think about the rigid, example like an zeppelin okay, but these are no longer these airships are used for passenger transport but they are used for some other purposes such as advertising, sight-seeing, surveillance, research, so that kind of things. Now, when you come down to aerodynes, which are heavier than air then you have 3 different category.

One it could be fixed wing, there could be rotorcraft or rotary wing, there could be hybrid or that is fixed and rotary, now for fixed wing, so the aerodynamic lift is generated by the forward movement of the wings, while the rotorcraft, it is as you see there is a spinning of the wing shaft rotors, sometimes called the rotary wings. Then these both rotary; rotorcraft or rotary wing device and the fixed wing they could be further sub divided into 2 broad categories like unpowered and powered, okay.

And the hybrid group which is sometimes mixture of fixed and rotary wing and like these are several types they can have like tilt wing, tilt rotor, mono tilt rotor, coleopter all these and we will see some of these example as we move along and the fourth group which could be basically, some other things which one can be clubbed together like flapping wing or ornithopter fan wing, lifting body.

So, the lifting body has an aircraft body shape to produce lift like for example, one can think about an example for lifting body is that Martin Marietta X-24, this is one of the example of that and then you have ornithopter, so this came from the Greek word, orinthos, which is orinthos; so that means the bird and pteron is wing, so in combination this was called ornithopter and fan wing is a very recent innovation, it was started in 2005, in UK and it represents a completely new class of aircrafts.

So, this is fan wing we are talking about since 2005 and it uses a fixed wing, so it has a fixed wing with a cylindrical fan mounted span wise just above the wing and it would be more clear when you see a picture about that and see that, so as the fan spins it creates air flow backwards over the upper surface of the wing which creating the lift. So, now in the further sub section what we are going to talk about more is now, instead of all these aerostat and all these, we are more focussed and trying to look at some of the example and details of aerodynes which are heavier than air and then see different example of aerodynes and then taking it further, so we will stop here and continue this introduction discussion in the next lecture.