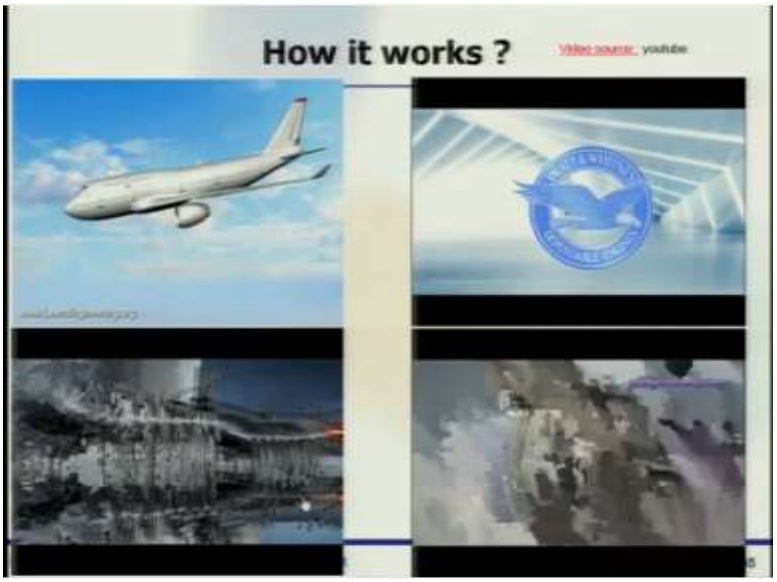
Introduction to Airbreathing Propulsion
Prof. Ashoke De
Department of Aerospace Engineering
Indian Institute of Technology - Kanpur

Lecture – 03
Introduction (Contd.,)

Okay, so let us continue the introductory lecture and what we are doing that we have seen the different classification of aircraft and their application, different purposes and then where we stopped maybe we will continue from there, how this jet engines actually works.

(Refer Slide Time: 00:41)



And this is what you can see and this is the one which we have been looking at, so this video will give you some idea about other aspect,

(Video Start Time: 00:48)

Bird its fly by pushing air, mankind has made many things that push air, one of the great machines that push air is the challenge, challenge is some air in the front, it push out of air outer back, that works is called thrust that builds the aeroplane drew the sky but see how it works.

Now, big fan in the front of the engine force air around the engine, it sucks air into the core for now let us follow the air in the core, it goes into a compressor something like many household fans joined together, each fan gets smaller and smaller as the blades squeeze the air into a tighter and tighter space compressing the air like you squeeze a balloon until that squeeze the air around.

A kind of super gasoline in a combustor that air if you miss you meets a flame and shoots out the back of the engine, they rush a higher spins, its took up energy from the heat in air, its spins the shaft connected to the fan and the front of the engine, the excess hot air from the combustor blows out the back of the engine producing thrust, rather than air rushing outside the engine core together, the turbine and fan push a larger mass of air than the core ever can for much more thrust.

When the extra air pass around the engine door works more efficiently, it moves more slowly then the high air flushing out the combustor and the back of the engine. One of the first engine makers Pratt and Whitney recently designed the new jet engine that lets the fan push air more slowly than the turbine by putting an amazing gear between, Pratt and Whitney calls this the pure power engine because it uses less fuel and makes more thrust and at the same time, less fuel saves money and save the oceans and environment and all living things.

And when they move slow, the noise drive so much to compare the hear ear in the sky, it is a new design for jet engines and the new era for jet aeroplanes that we all can enjoy.
(Video End Time: 03:57).
Now, you can see this is a new engine of the Pratt and Whitney but the interesting to note here is that if you recall there across the world, there are multiple flights were grounded because of some glitches in new engine.

Now, this is another video;
(Video Start Time: 04:17)
Rolls-Royce is one of the most leading engineering companies designed and developing high technology power solutions based on theory of piston engines, recently its applications on lands at sea and in air now, engineering strength is based on 2 technology platforms; the gas turbine and the piston engine. So, how do they work? In the case of the gas turbine on an airliner, the air is sucked in by the large front fan.

The majority of the air is directed around the engine as pure thrust direct into the engine and it squeeze to a compressor consisting of a same…
(Video End Time: 05:00).

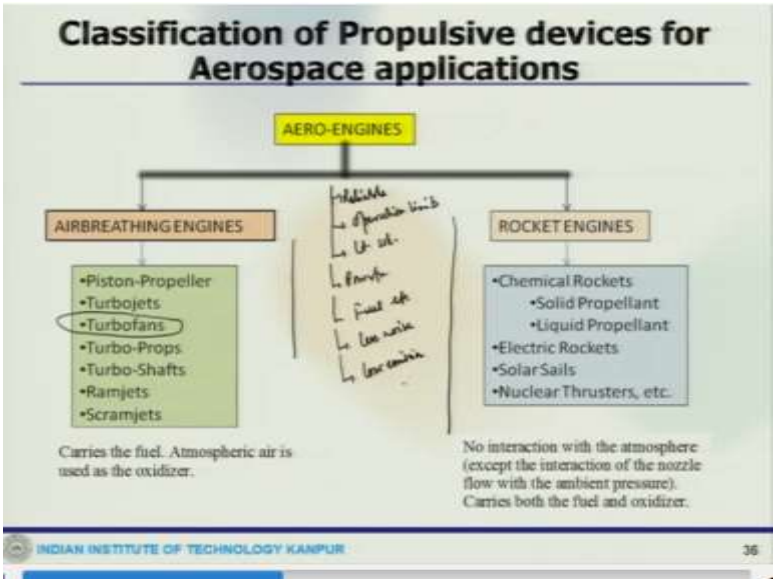
So, this will give you an idea of the similar nature but the another interesting video I would like you to draw your attention is the looking at the different kind of now these are what you have seen so far these are all like civilian applications.

Now, there is another category that we have already talked about is the military application and there the engines are different and there are different manufacturer and you can just go through that video how these different kind of fighter engines are in place, even today how they look like, their operational range and things like that.

(Video Start Time: 05:44)

(Video End Time: 09:15)

(Refer Slide Time: 09:16)



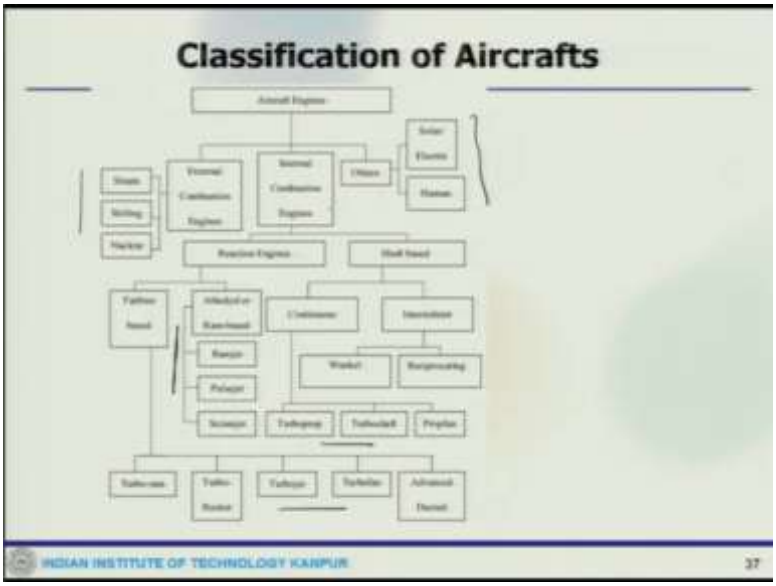
So that gives you an idea how this different and you could see the different fighter aircrafts which are having multi fighting or multiple capabilities, now just to again brief in the thing that you can have aero engines and there could be air breathing and the rocket engines where the whole thing is the in the rocket engine the principle is different, where you use some propellant and the other is the air breathing engines that is what we are going to talk about and that there are multiple different kinds of engine.

But what you have seen the example mostly they belong to the category of turbofans, now any aero engine once if you look at it or the propulsion system, there are certain characteristics it should have, it should be reliable that means it has losing power in an airplane is a substantially a greater problem than in road vehicles, so it should be more reliable that could be one of the feature like reliability.

Then it should operate at extreme temperature, pressure and speed that means, the take-off it should be at the sea level then when it goes to high altitude flying, then it that means operation limits should be high, then the light weight, so the weight has to be as light as possible because heavy engine increases the engine weight and the aircraft weight, so it should be powerful enough to overcome any weight and drag of the aircraft, small and easily streamline to create a drag.

Then the field repairable to keep the cost of replacement, fuel efficient, then capable of operating at sufficient altitude for the aircraft generate as less noise as possible and also the emission, low in emission, so all these are some of the features of the aero engine that one could expect.

(Refer Slide Time: 11:52)



Now, if you say that then this could be again divided into multiple categories like these are starting from external internal combustion engine or other type like solar and human all these, so internal this could be steam, turbine, stirling or nuclear so that is what we are not going to do too much of discussion. Now, the internal combustion engine it could be reaction or shaft base.

Now, when you talk about the reaction engine, it could be turbine based, turbo ram, turbo rocket or ram based ramjet, pulse jet, scramjet this is what we will do discussion or it could be shaft based where you have a shaft in along with the shaft, there are other components which are

sitting there, so this could be continuous or intermittent and then we will talk about turboprop, turbo shaft, turbofan or as a turbo based, we have turbo jet, turbofan.

(Refer Slide Time: 13:06)

So, these are also we are going to talk, now again this was the old engine which was Wankel engine, now the piston engine has different types, so this could be inline, rotary and V type, radial type, so these are known as reciprocating engine, so this was initially or first used this piston engines. So, inline engine has cylinders I mean they are lined up in a row, it typically has an even number of cylinders.

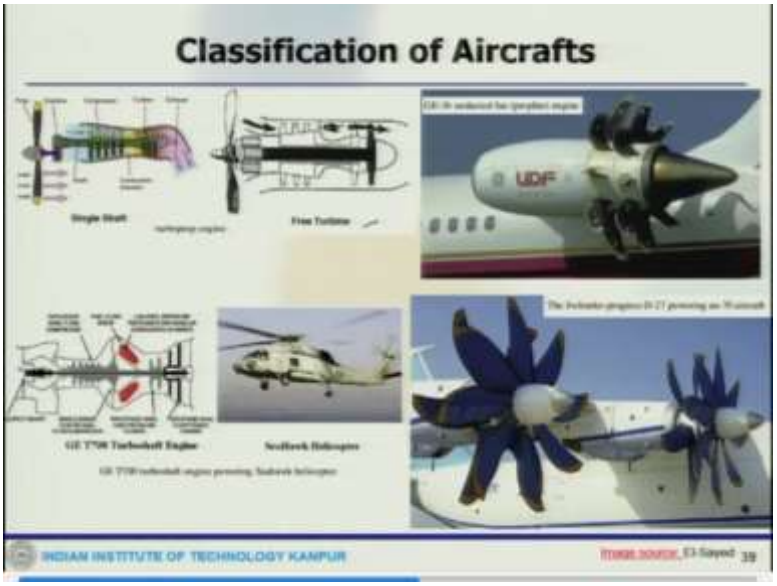
But there are instances where 3 to 5 cylinder engines also very; it were common in early aircraft including the Wright flyer which was the 12 horsepower engine, there are some advantage of an inline engine is that it allows the aircraft to be designed with narrow frontal area for low drag but if the engine crankshaft is located to be mounted up high for ground clearance even with short landing gears.

But there is a disadvantage also, it has a very poor power to weight ratio because the crankcase and the crankshaft are long and thus heavy, so these are pretty much this inline design was abundant and these are hardly or very rarely used in the modern engine. Now, the other could be rotary type which was extensively used in World War I, as it is lightweight, powerful, cheap, easy to manufacture.

So, this has cylinders in circles like this, so but there are also had an advantages and disadvantages with this kind of engines that is why it was sort of out of the operation because

one of the biggest disadvantage of this kind of rotary engine is the gyroscopic effect for the heavy rotating part. Now, there are radial type also and opposed type or this is a combustion type.

(Refer Slide Time: 15:28)



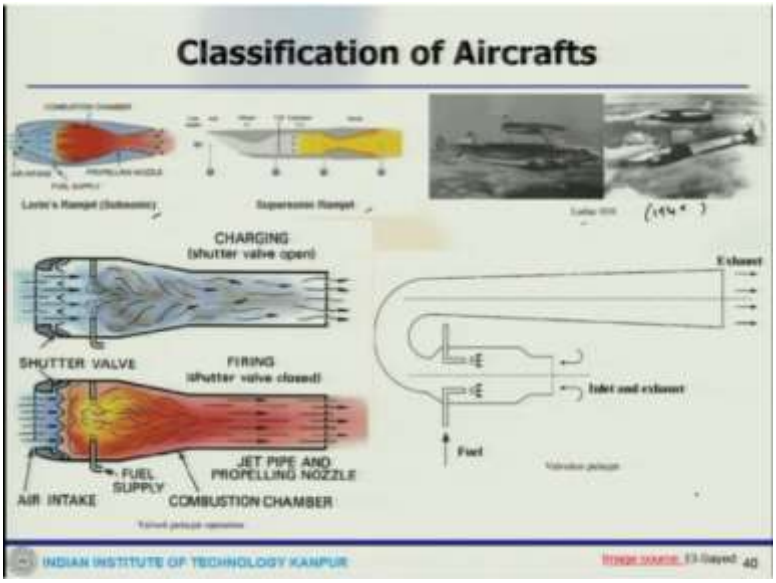
Now, moving ahead we can have turbo continuous combustion type, we have a turboprop engine where it is a single shaft which sucks the air inside, then pass through the compressor and then passes through like this, so there is a free turbine sitting there or this is another engine which would be coming under that category of is the turbo shaft engine, so this was primarily for helicopter an auxiliary power units.

It is a very similar to turboprop but some key differences are there like in a turbo prop, the propeller is supported by the engine and the engine is bolted to the air fan but whereas in the turbo shaft, the engine does not provide any direct physical support to the helicopters rotor. The rotor is connected to a transmission which itself is bolted to the air fan and the turbo shaft engine simply fits the transmission by a rotating shaft.

Now, there are another one is the propeller fan, it is or unducted fan, sometimes this is a modified turbofan engine with the fan placed outside of the engine nozzle and the same axis of the compressor blade, prop fan or propeller fan engines are also known as ultra-high bypass engines most recently open rotor jet engines. The design is indented or intended to offer the speed performance of a turbofan, all the economy of a turboprop.

So, there is an added basically, advantage of turboprop and turbo fan that is what it was used, so this is also bit of fuel efficiency but obviously, when you have these components are sitting outside that will create a lot of noise, so this is another image of that kind of engine which was there.

(Refer Slide Time: 17:59)



Now, when you move to the reaction category; in the reaction category you could have ramjet engine and that could be at the subsonic level or supersonic ramjet which is called scramjet, here there is no rotating component here as you can see, the air comes through this and then passes across the combustion or the; these things and then finally you get the these things done, so this is a ramjet concept.

And this is the flight which used that now, the other is the valve pulse jet, so this Leduc was actually which was the first ramjet flight in 1949 actually, now the other is the valve pulse jet, so pulse jet is a very simple type of jet engine with the combustion occurs in pulses, now these are intermittent combustion while ramjet compared to ramjet but ramjet provides continuous combustion.

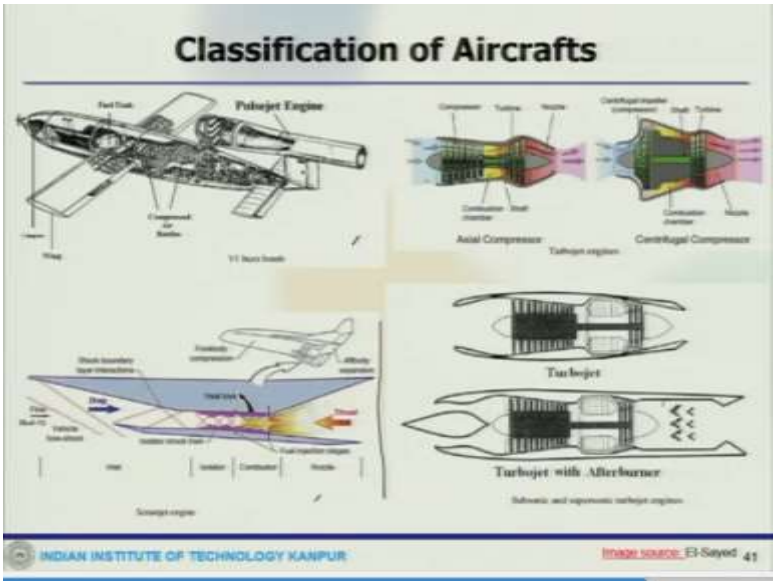
So, these pulse jet engines are very unique in type, for jet engines this is able to operate statically with few or no moving parts, they are simple cheap to construct, so there is an excellent balance between these. There are 2 broad types; one is the valved, one is the valve less. In the valved, there is a mechanical one-way valve which is simple leaf spring type of shutter.

So, if the valve open, so air comes in or the phase charge of air is allowed to come inside, then the air mixes with the fuel and then explosion takes place and which starts the valve and forces the hot gas to go out through the tailpipe and this is how that operates or in the valve less, pulse jet you have no moving parts as such and only there is control is achieved through the geometrically.

So, this expels the exhaust to go out of the long tail pipe for more efficient propulsion and the valve less or the valve less pulse jet engine operates on the same principle as valve type, so the combustion process creates 2 shock fronts, one traveling down and one upper long type and other down the lower tube, now by tilting these or turning these things a resonating combustion process can be achieved which can produce considerable amount of thrust.

So, fuel consumption is very high, noise level is also unacceptable, the French engine manufacturers like SNECMA developed these pulsejets in later 40s to use for drones and all this. Now, there is also history behind that and if somebody is interested you can look through.

(Refer Slide Time: 21:32)



But then you have this other type of things where there is also pulse detonation engine and the this is another pulse jet engine, so this is the scramjet, here where the flow comes here with supersonic and then pass through this inlet section which would be lot of shock interaction, shock boundary layer interaction takes place and then finally it allows through combustion chamber and then finally it produces the thrust.

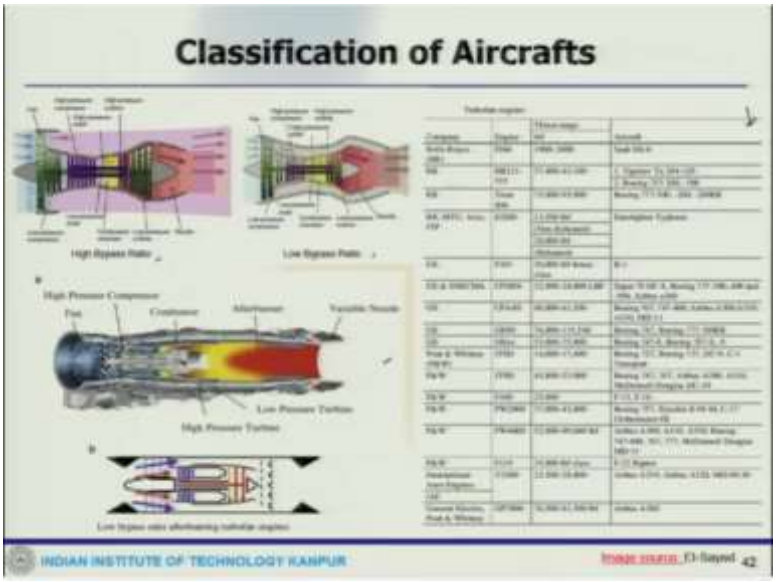
It is an evolution of the ramjet that are able to operate at higher Mach number than ramjet and kind of air within it is an acronym stands for supersonic this combustion of the ramjet, so it is a 1950s and 60s the variety of experimental scam jets engines were built and ground tested and now 81, there are tests made in Australia presently in Brazil, China, France, Germany, India, Italy, Japan, Russia, South Korea there is a they have different, different programs for this scramjet.

But at the same time one has to note that no scramjet powered vehicle as yet been produced outside an experimental program, this finds its application in many recent hypersonic speed vehicle like rocket future commercial transport in the 21st century or at the single stage orbit rocket launchers but still there is nothing like that, so there are hydrocarbon or hydrogen are used for fuels in the scramjet.

Scramjets are quite simple in design but aerodynamically they are more complex than jet engines, so Boeing NASA X-43 is an example of experimental scramjet with a valve speed record of jet powered Mach 9.7 which is roughly 1200 kilometre per hour or X-43 S 8 flight speed record in 16 November 2004. Now, Boeing is also doing another X51which is known as X51 Waverider is an unmanned scramjet demonstration aircraft that completed its first hypersonic flight on May 26, I think 2010 and for around 6 minutes and over Mach 5 in 2013, so these are still at the demonstration level.

Now, moving to that the biggest development of this era is the turbo jet or turbofan engines, so which we have already seen through the video that how these turbojet engines actually work, you have intake diffuser, compressor, then combustor pass through turbine and the nozzle and there are different turbojet engines like subsonic and supersonic. So, when you talk about supersonic, then this has some afterburner that means, after the turbine stages you have another layer or level of combustion which takes place there. So, this allows these things to have some more quick manoeuvring, accelerations and all these things, some examples like GJ 33 flight, GJ 35, these are turbojet engines.

(Refer Slide Time: 25:40)



Then, now the development which took place is the turbofan engine which are added fan sitting there compared to turbojet and advantage associated with turbofan engine is that this is I mean, primarily is the engine which has been in used for this modern days aircraft whether it is a civilian application or it is an military application and there are 2 categories; one is bypass ratio, based on the bypass ratio, one is the low, one is the high.

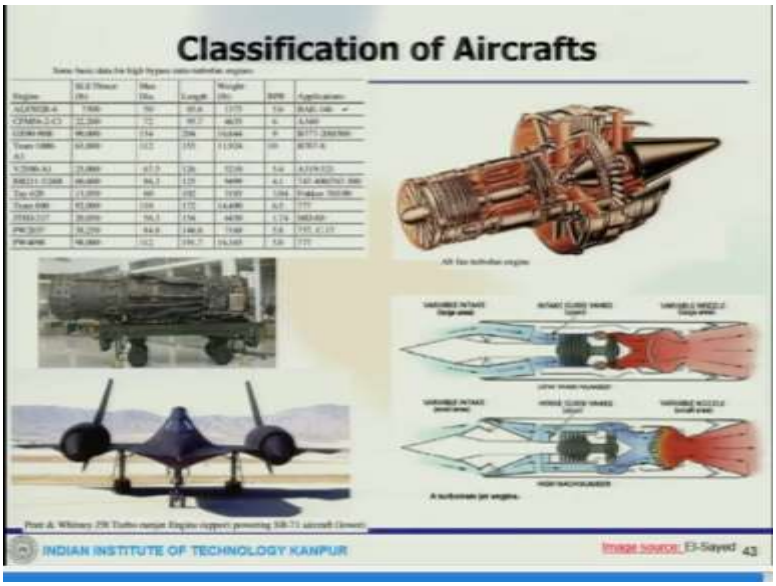
When it is high then the cold air also contribute to the thrust, total thrust quite a bit, low bypass ratio means bulk of the air passed through the core of the engine where it gains energy and all these. So, this is another picture of high pressure compressor and a high pressure turbine and all these, so this is a low bypass ratio afterburning turbofan engines, so the turbofan engines are also equipped with after burning facility and that is why they are quite often used in these military applications.

And there are advantages which are made and this is a huge list of some turbofan engines, there are different manufacturers I mean, primarily there are few engine manufacturers which are there in market, one of the British Rolls-Royce company, then you have GE, which is US based companies, SNECMA is a French company, Pratt and Whitney this is again US company, based company.

And there are also some and they have different, different engine, they have a different thrust range and they are used for different aircraft, so you can see the range is quite high for this turbofan which includes both the application of civilian and military applications and they are

kind of getting improved every day and they pretty much serve the purpose of this aviation industry.

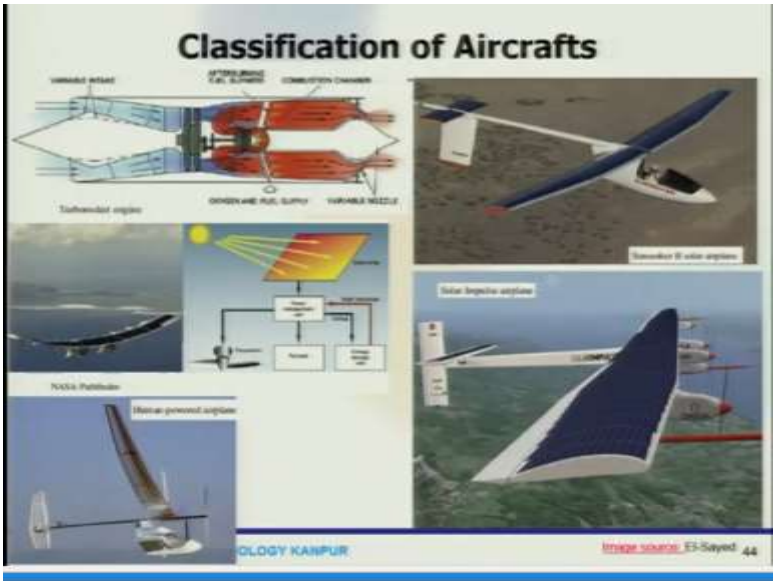
(Refer Slide Time: 28:08)



And but obviously, nothing comes with free of cost even with the engine, there are; now these are some of the high bypass ratio turbofan engines, these are often or primarily used in the civilian aircraft, so that gives you an idea about what kind of thrust it uses but some of them are also used in the like this BA 146 is a fighter aircraft, so this gives you an range bypass ratio, what is the diameter, length.

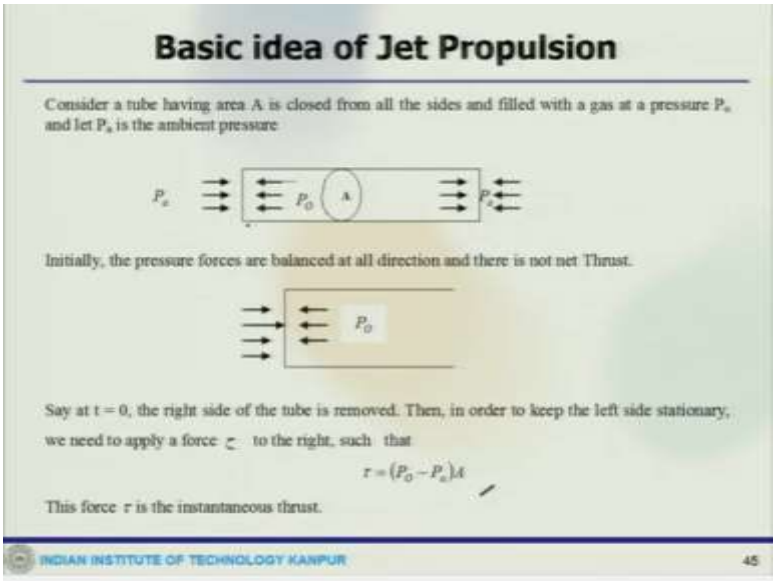
So, these are all sort of an design parameters you may not be able to appreciate at this moment but when you go along with these things, then that time you will see how these things are quite important and then there is another which is called turbo ramjet, now turbo ramjet is a combination of turbojet and ramjet, it is a type of engine that which is designed for high speed flight and its uses both the combination of turbo jet and up to certain Mach number, let us say 2, 3 with the ramjet and beyond that the turbo actually starts operation.

(Refer Slide Time: 29:30)



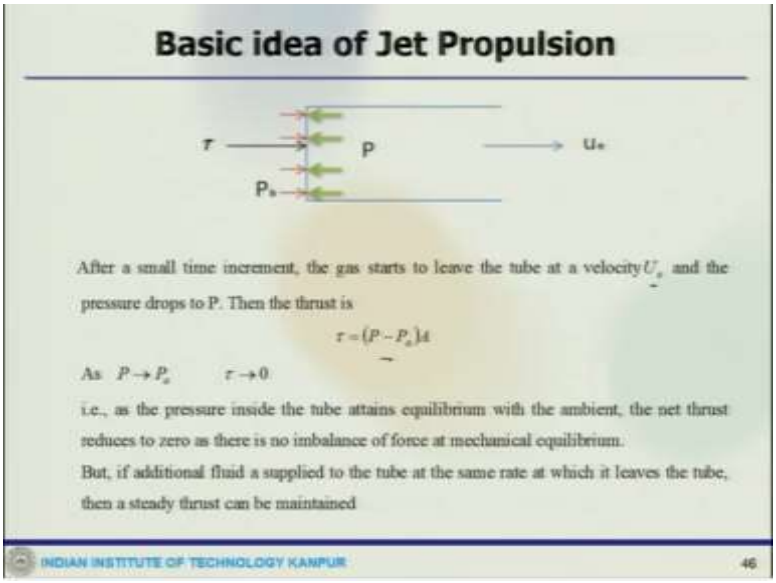
Now, this is turbo rocket engine there and this is another air breathing engine combining the elements of jet engine and the rocket which is known as the acronym it here, so that uses certain informations and all these, now the other power sources are electric powered aircraft, so this is an electric aircraft, this is a solar airplane, so these are the some of these recent developments that took place where these use of these resources which are used to flights.

(Refer Slide Time: 30:33)



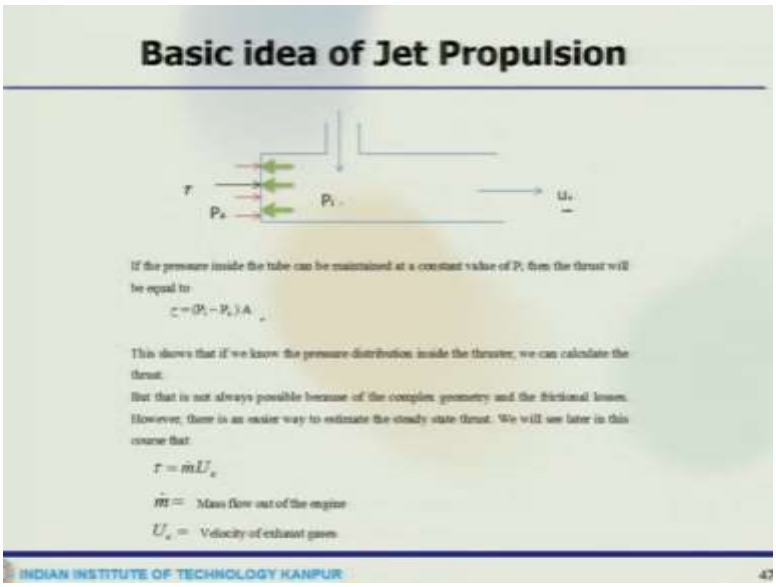
And these developments are taking obviously to the; so this is another human flight that you can see, now just to conclude the whole idea about these basic jet propulsion, you can see that if you have a simple tube and there is an area where the pressure difference across that this is how the force which you can get across this particular surface due to the pressure difference.

(Refer Slide Time: 30:54)



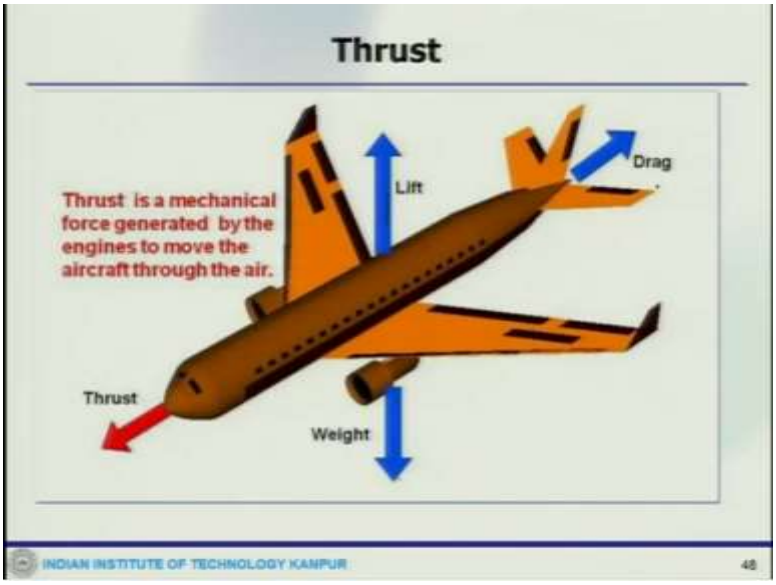
And now, when a small increment the gas starts to leave the tube, so there will be exit velocity and then the pressure drops, so you get this thrust and this pressure would move to the same pressure, if the thrust moves to 0, okay so this pressure inside the tube attains an equilibrium with ambient and the net thrust reduces to 0, okay.

(Refer Slide Time: 31:20)



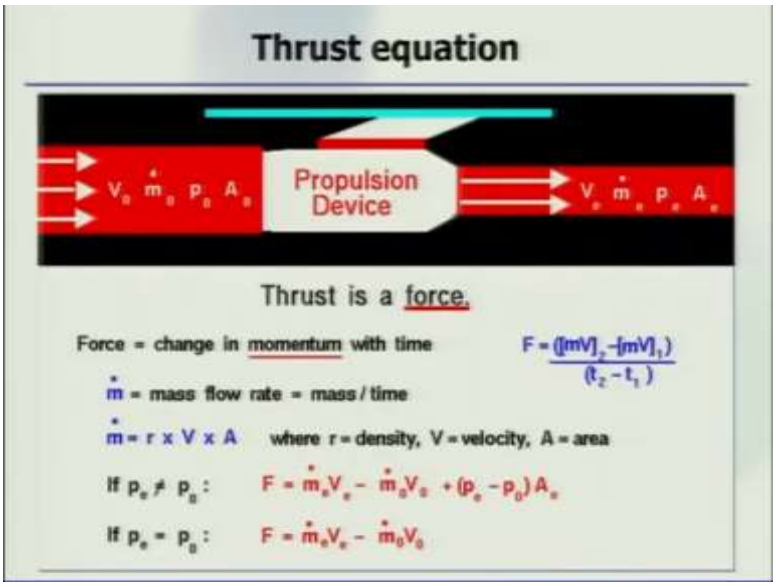
So, now if the tube is maintained at a certain pressure Pi, then the thrust would be calculated like that, so if we avoid any of these losses like frictional, so one can easily estimate that thrust which is simple way like what is the exit velocity and the mass flow rate it handles, so it is $\dot{m}U_e$.

(Refer Slide Time: 31:48)



Now, the simple principle which is just to calculate the force balance and all this if you put it together in an aircraft this is what you have lift acted, weight update, drag and thrust.

(Refer Slide Time: 31:55)



And that is how one can actually estimate the basic thrust for an aircraft engine or this air breathing engine, so that gives you an basic idea how to do these calculations and sort of with a detailed overview of the different kind of aircraft, their engines all these things, so stop these things, now continue the discussion in the next lecture.