Turbulent Combustion: Theory and Modeling

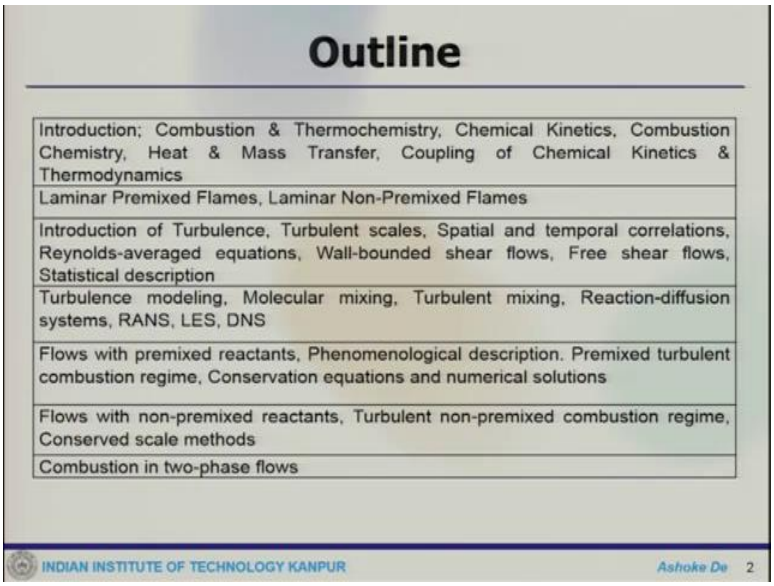
Prof. Ashok De
Department of Aerospace Engineering
Indian Institute of Technology-Kanpur

Lecture-1
Introduction to Combustion

Okay, so welcome to this course on turbulent combustion, which essentially as you can see the title of this course is turbulent combustion or Theory and modeling. So what we are going to talk about in this course essentially starting from the basic combustion and then we will go into the deep of this combustion when it exposed to turbulence and then how is modeled. So, all these things would be taken care of in this particular course.

So, just before we begin with, myself is Ashok De. I am currently working in the department of aerospace engineering at IIT Kanpur and I will be delivering this course on turbulent combustion.

(Refer Slide Time: 01:05)



So, as I tell you that this particular course is all about the turbulent combustion. So, and this two aspect of that will cover here, one is the theoretical aspect and then that would be followed by modeling aspect. So, that will give you a complete idea about how this kind of turbulent combustion modeling done based on the theoretical aspect. So, this is the brief outline of the complete course. So, we will start with some introduction which is quite important because in the

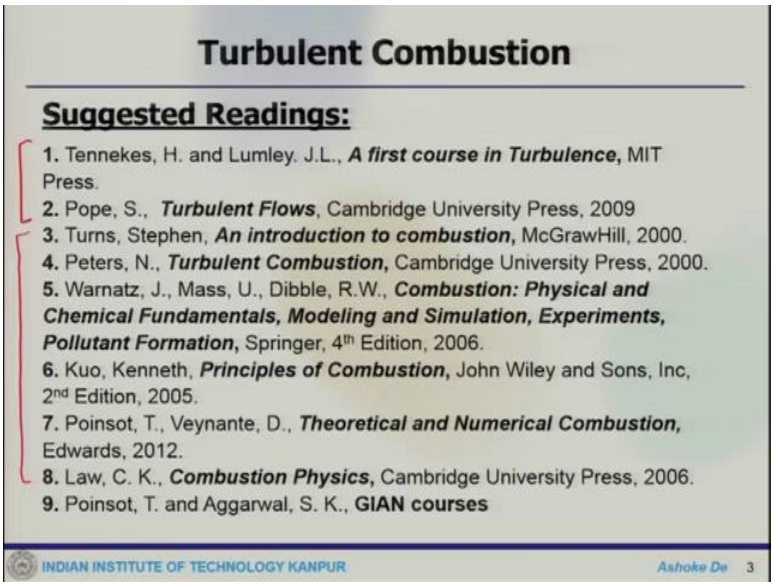
sense that will give you the actual idea about what combustion is, how that is applicable to the real life situation, what are the issues, challenges different aspects complexities everything that will be covered there and then we will go into the fundamentals of some combustion because it may help you to get started with the real aspect of turbulent combustion.

So, talk about certain combustion, which is the basis of combustion Thermo chemistry, chemical kinetics, heat and mass transfer and then finally coupling of context with the thermodynamics. So, that will set the platform for your basic understanding on combustion. Then we will go to the laminar premixed flame where we will talk about the premixed flames and their characteristics how one categorize the flames which will be followed by the non-premixed flame in the similar fashion. So, essentially these two topics rather the broader aspect of the combustion which will get you started. Then we will start with the basis of turbulence, their characteristic scales and everything that would be followed by some modeling aspect then we will look at different kind of turbulent flows like wall bounded flow, free shear flows and their statistical description.

So, that will give you an idea about turbulence. It is not all turbulence, but the turbulence which is essentially required to understand the turbine combustion. Then we will talk about bit of modeling where different kinds of systems and different modeling aspect which is a part of your these. One may are of that these are the common techniques in computational fluid dynamics for turbulent flows. So that will bring to start with our things for that turbulence combustion. And there are some basic aspect of turbine combustion and then we will go to like non pre-mixed flames then premixed flames and we will see how different aspects of premixed non-premixed flames are kind of modeled based on their theoretical basis. And at the end we will touch upon some advanced topics or rather some topics in two phase flows or rather combustion into place flows and they are quite different.

So, up to this point, we are discussing about everything in the gaseous combustion mode. And then when you move to the last topic where we will talk about two phase flows or the combustion in two phase flows like where your sprays atomization and all this would be discussed.

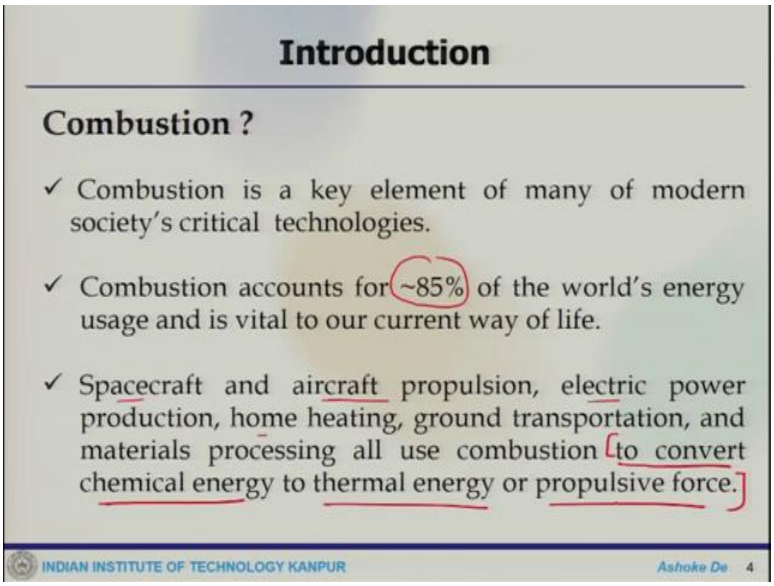
(Refer Slide Time: 04:59)



These are some of the materials that are rather the materials which will be covered in this particular course are taken from different references and wherever it is possible. We are giving the reference where it is taken from. Apart from there one is free to read any other books. So, first two book are essentially on turbulence, then there are books on combustion and turbulent combustion and there are some online lectures, which was also looked at to look at different aspects of this. So, this will actually talk about your complete aspect of this turbulent combustion and at the end of the course, I hope you will have enough idea about this turbulent combustion.

How the basics of the turbulence and the turbulence combustion they are connected with each other and their modeling aspects. Okay. So, now we will start with the basic of combustion.

(Refer Slide Time: 06:10)



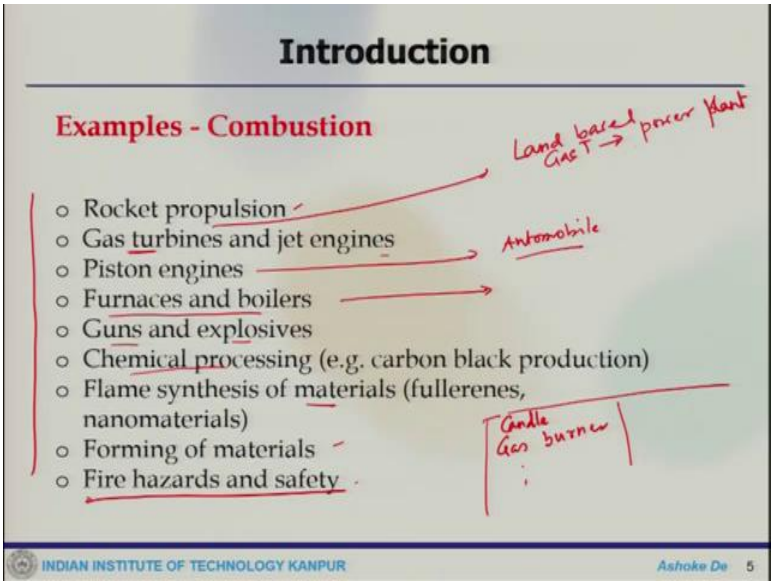
Basic of combustion so, basic of combustion what is combustion? That is the first question one may ask that what combustion is. So combustion essentially one can think about it is a key element of all modern days or modern societies critical technologies. How? Because it is essentially accounts for the almost approximately 85% of the world's energy uses at this moment. So, it is quite important to know what combustion is and how it takes place and what are the different challenges and how it actually impacts our daily life or our current life.

And if you think about the application point of view it starts from our daily life like where we start cooking at our kitchen from those gas burner to our space mission. So it is a wide range of application and that is why it is in key component of our daily life even today. So, you can see the spacecraft and aircraft propulsion. This is where spacecraft means when we talk about the launching vehicle, like rocket other things. I mean the missiles and all these things then aircraft propulson which will actually talk about your both aviation aircraft and all the other.

I mean civilian aircraft and the fighter aircraft. Then you have a power production that means when you go to the power plant. There is a huge application of combustion and we will see as we go along with this different aspect of combustion and we will discuss about all these details, then household application, transportation and different aspect of this. So whole idea is that I mean is the convert of chemical energy to thermal energy or propulsive force. This is the key element of

any combustion. So what happens? So one can in a nutshell think about the process of combustion you actually convert the chemical energy to the thermal energy. Now the thermal energy could be converted to your electric energy, sometimes if the propulsive of the thrust force or some other processes where it is used and it is taken into consideration in that way.

(Refer Slide Time: 08:49)



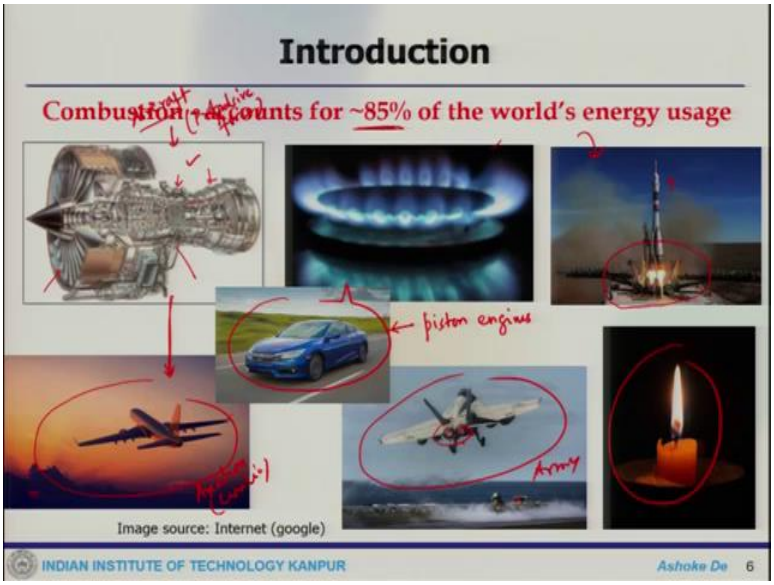
Now, as I mentioned, there are different aspect of combustion or different application start from your rocket propulsion. You have a gas turbine and jet engines. I mean here I mean to say a gas turbine means it could be our land based gas turbine, which is used for basically power production. So, land based gas turbine are used for power production or in the power plant, at the same time the jet engines or the aircraft engines also, they use the gas turbines. But the principle of operation is slightly different from each other and also the kind of fuel they are using. Then you have piston engine. This is another applicable in your automobile sector. So clearly you can see that there is a state, I mean the daily life you are running your two-wheelers, four-wheelers and heavy vehicles. Those are on road, they are operated under piston engines. So the power which you generate for your automobile sector also that comes from combustion.

So, the applicability if you see then you go to furnaces and boilers, this has an application in your material processing industry and were especially in the power plant where the boilers are used and also the furnaces they are used in your steel plant and all these things then slightly different kind

of example for Army applications like guns and explosives, chemical processing industry. Flame synthesis of the materials forming a material fire hazards and safety is how this is another important thing which is off late or even in the recent times that is getting lot of importance for public health safety and security. Because fire is one of the important things and so people are working in that direction. How one can nicely evaluate or estimate the fire or simulate the fire and then how do you suppress that because this is not very, very unimportant area which is getting lot of attentions from the community. So now if you look at it the applications, these are really some applications where you can see the huge impact on the industrial applications.

Now, one can look at some other applications where you have daily life very simple applications like your candle burning, then your gas burner. These are your simple example of daily life, where also these are not having that industrial application. But these are also something come out of the application of combustion.

(Refer Slide Time: 12:06)



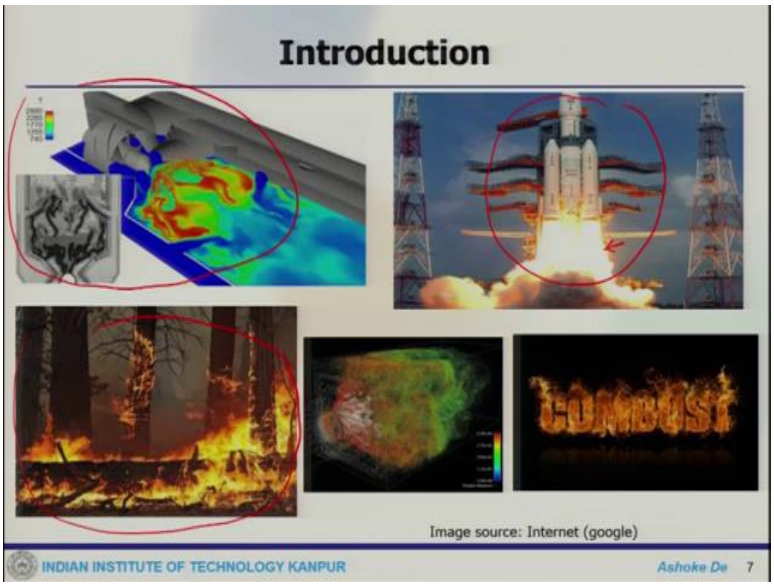
So, one can see why we say that it is now even today the 80% or 85% of the energy it actually. Now, I will take you through some of these nice examples and that will give you an idea of the area of these applications. This is quite I mean range of applications that one can find for combustion. This is starting from your gas turbine engine. So one can see this is your aircraft engine. So, that is the big engine one can see that it has so many components. So there is a starting

component here, which is the fan. Then it comes to the compressor. Then this is the compressor units. Then you get the combustion unit, then turbine and finally nozzle. So there are multiple components which are associated with this particular unit. But the key element is again the combustion which actually generates the power where you get your chemical energy to be transformed to get these propulsive forces or the thrust force.

So, this force is essentially required to propel this particular engine. Then you come to an application where you see it is a nice-looking friend like a gas burner. So it is nice calm and nicely looking system. But at the same time if you come across here where this is again a launching pad open rocket engine, so you see the kind of fume it generates. It is a huge. So it's generates a lot of power which actually sends this satellites and all these things to the orbit. So, that requires a lot of power and that is generated through this reaction mechanism or the combustion which in a nutshell or the basic of a reaction of different reactants or the species and they get you back the force. This is another example where you use this kind of engine your flying vehicle and these days one may think about to travel even a 1000 kilometer in few hours and that because of this kind of engine which operates this vehicle.

And this is your automobile sector where again the powers comes from your propulsive devices; this is the application of your piston engine. This is another example of your gas turbine engine. But this is your aviation or civilian application. This is your army application. So this is a particular example of the picture shows you the fighter aircraft and one may see this kind of different pictures in the Google. These are the images which are also taken from Internet only but the idea here, is that the big vehicle which actually maneuvers and which can move so fast because of these combustion and this is a nice example of your candle burning, which is daily life when your electricity is not there we can use this kind of burning nice calm. It is actually illuminates light. One of another aspect of combustion one can think about that it is also give you some sort of a light. So as I mentioned is accounts for almost the 85% of the world's energy uses.

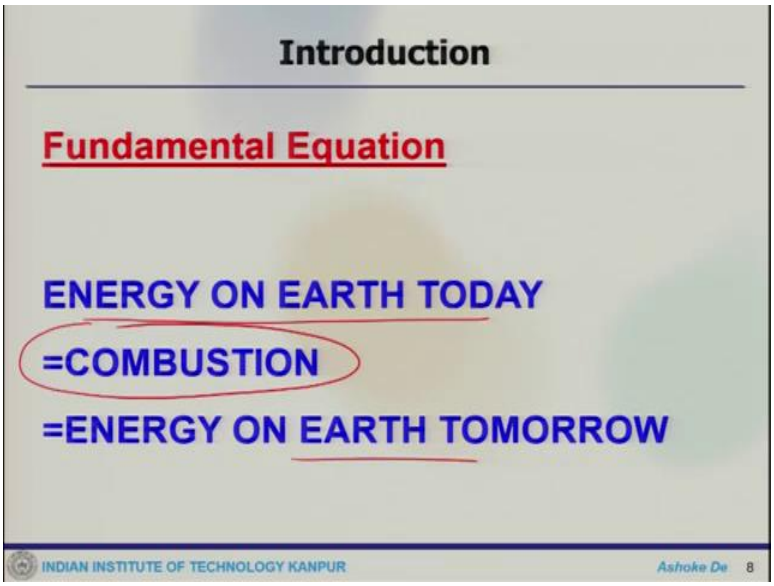
(Refer Slide Time: 15:48)



Now, there are some more example and that one can see. This is another example of your gas turbine combustor. This is a very, very specific unit. I mean, that is and just an example because different gas turbine engine has different kind of combustion. So their geometry would be different. But this one shows you there is a swirling been there. Then the fuel is liquid fuel is injected so this sort of a kind of flame instantaneously that you can see.

This shows you a big satellite, which is launched through the rocket motors and see the amount of fumes that is hitting the deck so it coming out as a product of combustion. There are another thing which takes place in hot days is the fire which spread out over the wide range of forest areas when it is too hot. So this is another area where people are working how to suppress this fire. So essentially you can think about what the area of applications of this combustion. There is wide range of applications. There are huge industrial implications. There are daily life applications.

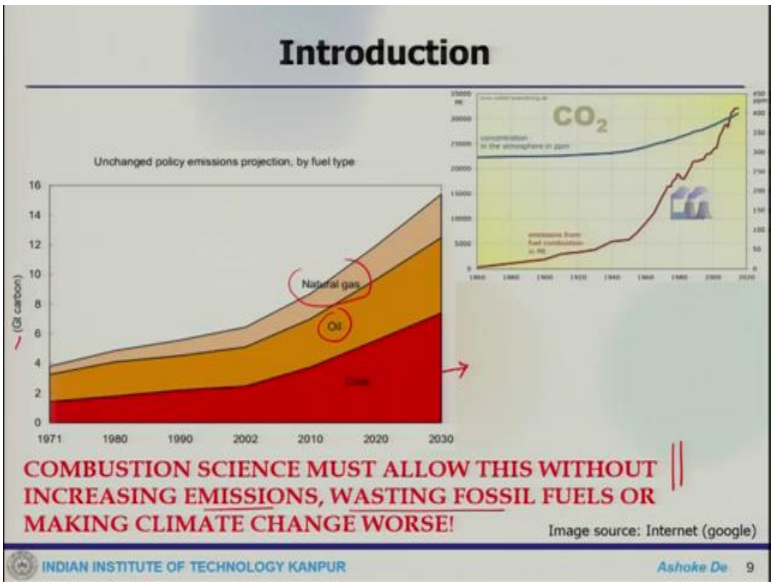
(Refer Slide Time: 17:18)



So, it is everywhere and that is what we keep on so that brings to a very important equation. So this equation is quite important in the sense that what the source of energy on the Earth is today. This comes from the combustion. That is going to be the energy on or tomorrow even so there is a very, very key equation one should keep in mind that even today the primary source of the energy comes due to combustion is any form of combustion. It could be wood fire. It could be burning of your stove.

It could be gas burner or the Industrial level applications or even tomorrow this is going to remain there but what could be the fuel or something else that is one has to look at it because with the growing demand of energy and all these things people start thinking about alternative resources and all these things.

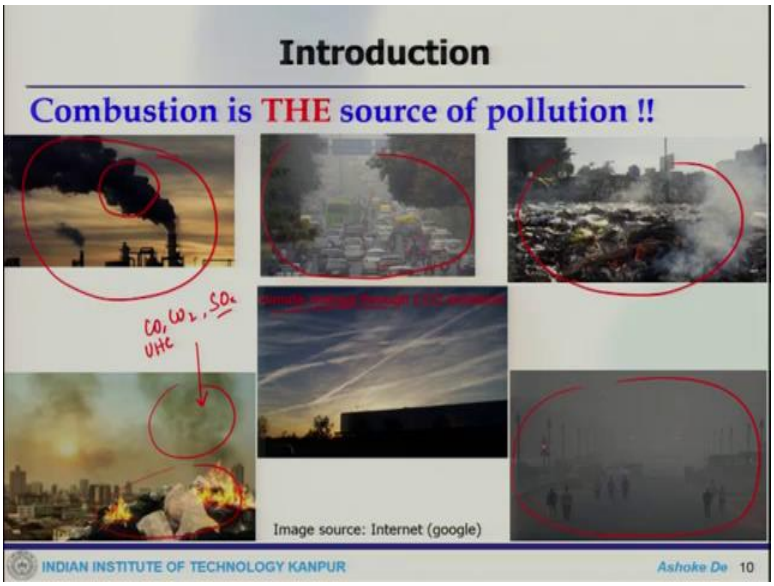
(Refer Slide Time: 18:13)



So one can see this how this previously or the earlier days the primary source used to be the coal where the coal is burned and we used to get the energy then of oil came in, then natural gas, but there is an increasing demand of the energy along with the year. So this shows some sort of a projection and which will produce by the year 2030 how much of the carbon and one of the issue with this element is that this produces lot of CO_2 or CO.

So, that is essentially another problem of combustion though combustion is an essential component of our daily life. But this has also been a huge impact in our emission. So the combustion science it should allow these without increasing the emission. Wasting fossil fuels or making climate change orders. So this one has to also that means; now one can see though the primary source of the energy comes due to combustion, but there are certain issues. Also combustion does not come as a free of cost so combustion it gives you energy but at the same time it also emits lot of hazardous gases or rather the emission then it also is fossil fuels. So, these things also one has to keep it under control. So there lays the challenge that okay. I want to use these things to meet the energy demand.

(Refer Slide Time: 20:06)



But at the same time so in a single sentence one can say combustion is the source of the pollution and these are the gamut of examples one can see where you can see their issues of combustion. The very left hand side here, you can see this is smoke coming out of that industrial chimney. And this is nothing but lot of emission gases along with your carbon particles and these are really-really carcinogenic particles, which has a huge health hazard and safety issues and environmental issues.

So though combustion is essential but this is also a byproduct which terms as an effect of combustion. So, idea is that how we can reduce this kind of situation. Now another example when you in a Metro cities or the outside of the cities where in the garbage or dumb yards you burn this garbage that is also scared smokes. So these also issues lot of CO, CO_2, SO_X and also, Hydrocarbons or unburned hydrocarbons these things are not very healthy for human being.

Now another example in a very traffic loaded road. You can see the kind of smoke it produces from these vehicles. So this is another challenge because that produces is another example of your garbage yard where it is burned and because of the smokes and all these things this is what happens during winter days and the visibility is gone. So that has a lot of impact for the daily life and also due to the CO_2 emission. There is a climate change so CO_2 emissions and one can see these things. So the whole issue here is that though it is an essential element of our daily life. It is very much essential meet our energy demand, but at the same time it also produces lot of gases which are not

very healthy for human health.

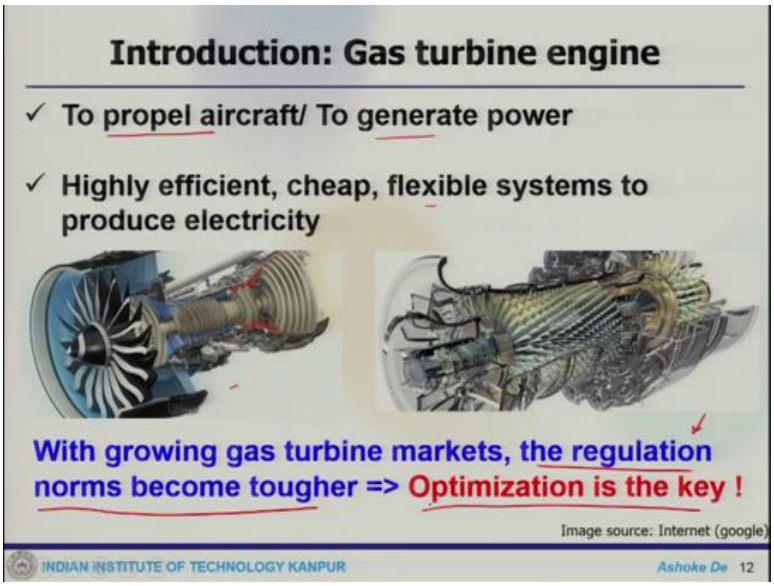
(Refer Slide Time: 22:23)

Now, if you go to a slightly different directions and we can see some of the different kind of examples which will tell you what could be more critical in this regard. You see a fighter aircraft where is actually trying to take off the engine actually got into fire. So that is not something that one is expected to have so we want a smooth ride and move take up. Similarly while flying one of the civilian aircraft also engine got into fire and these will not something that one actually expect or rather anticipate to have it because this has serious impact on public health because there will be lot of damage.

Not only the property damage but also loss of life which nobody wants, so any technology that this is another example of an airlines which was taking off the engine got into fire. So, this another example where it during touching down that got into fire. These are the some of the example of the fire which spreads out in the forest areas. The idea is that we want some technologies always because this is our demand of this Century that we want the technology to be developed, but it is not at the cost of human life. So at the same time, the technology which gives us so much of energy power and everything there is; it is also dangerous, so what is required is the control. So, you see that one hand it actually gives you the possible solution. At the same time, it actually requires lot of control. If the control is there then you can control your emission, you can control not to have

this kind of accidents which will lead to loss of human life. So, that is one of the important area.

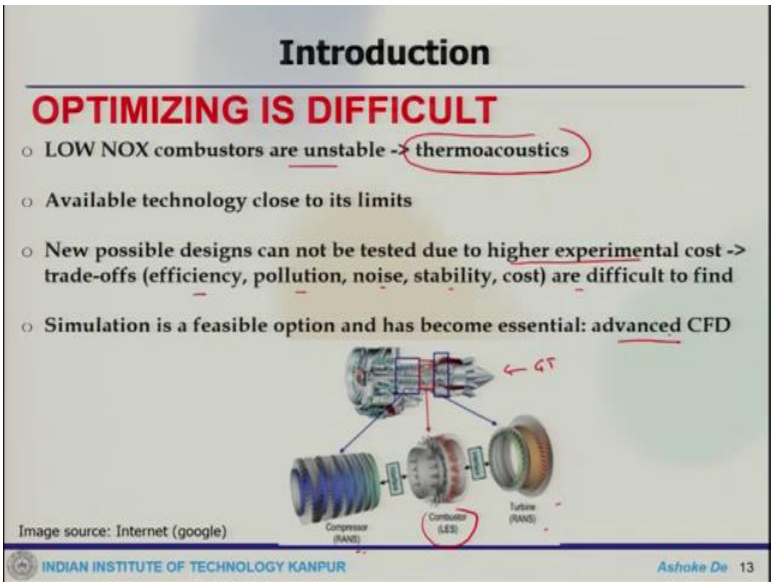
(Refer Slide Time: 24:38)



Now, you take some example of the gas turbine, so which is used in your either land-based unit for power generation or for the aviation system. So, this usually generates the power to propel the aircraft or it generates the power for your land based system. And what is important here for this gas turbine engine. These are highly efficient. It is also flexible systems to produce all this electricity. Now with the growing gas turbine markets the regulation norms become really tougher.

So, the regulation norms in the sense the emission norms so that is getting top and top every day. So what is required, one has to optimize this because see this industry is going to be there and you require this gas turbine units whether it requires for power production or you require for the propelling aircraft engine. So what important is that that you need to maintain the regulation norms and this is becoming really stringent. So, one has to look at the emission and all these things. So, not only the control at the same time you need to have the optimization.

(Refer Slide Time: 26:06)



So optimization if you look at it, it is quite difficult because when you go to optimize the emission so there will be low NO_x combustor, which will also at the same time because unstable that means it will lead to some sort of a thermo-acoustics instability. Then whatever is the available technology as of today they are sort of running close to its limits. Now new possible designs cannot be tested due to high experimental cost. So, because you may have a lot of different kind of designs which could be efficient or optimized but at the same time that cannot be tested because the manufacturing fabrications and the testing cost of quite high. So, there has to be one trade-off now the trade-off in terms of whether efficiency or emission, noise or stability. So these are some of the parameters or rather key parameters one needs look at to make and but that is quite difficult.

So, one of the solution is that one can do simulation where it can be quite handy. So that means essentially doing lot of advanced level CFD and then come up with some sort of optimized solution that given an example this is an unit of a gas turbine unit where you have different components and you see the compression component which are solved using a very simple model like ranch and we will discuss about all these things as we go along with this particular course. When you come to the combustor, you do more computationally expensive or hyper ability simulations like eliate then again, you can go to turbine. So it is and trade-off. So somewhere you get quick solution with a simpler kind of methodology somewhere you use high-end simulations and sometimes so it is in trade off to get and system or get a design through this optimization process.

So, importance of CFD becomes quite important because which will get you an optimized system and that can be handy. It does not require too much of a cost associated with it and you can really optimize the system with low turnaround time. And once if you do that, then you can come with a new design or something like that. So stop here today, and I will take it up in the next lecture. Thank you.