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COMBUSTION

Lecture 49
Combustion Instabilities

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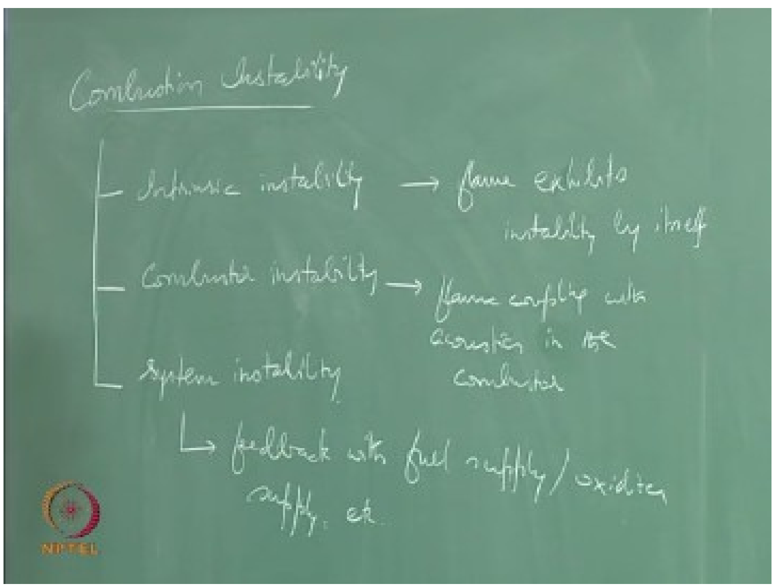

Today we will talk about in just about one lecture this fairly brought brother interdisciplinary topic of combustion instability of course we include this because it is my favorite topic later I wanted to cover this as part of the lectures on combustion again the goal here is to show that whatever we have learnt in the lamina framework can be used to understand more complicated problems, and one of them being combustion instability early on I think Williams had actually identified that there are there are three aspects.

The combustion instability one on one of them is intrinsic instability the second one is combustor instability the 3rd is system instability, so we will first briefly look at what these individually mean and then we will start looking at the details of each of these, but before that we should also first of all look at the word instability regardless of combustion the idea of instability is not specific to combustion it is a something that comes from what we call as perturbation theory so essentially it is an idea of course much more than that I think.

It is a much more common sensical idea there are lots of things around us which are which show in current characteristics of instability some extremely social examples would be like for example if I do not exercise I grow way heavier and then that makes me de more makes it more difficult for me to do exercise and then I keep growing heavier and, so that is an instability right or the other possible is if people stop using public transport public transport run in losses therefore they run less buses and therefore we still are going away from using public transport.

The buses now stop running and so on so lots of such social situations or you know human situations you can go through what is called as instability, so the basic idea is if you now have a system which we think is in equilibrium and then we now try to make a lot of small perturbation question us is a system coming back to the original position or is it goes away from the original position, so here there are a few different things that are kind of important you could actually have a dynamic system.

Which is in equilibrium locally that means at a particular set of parameters, so for example in a flow system you could have a the parameters could be Reynolds number and a combustion system the parameter could be equivalence ratio, so you could now be running an engine at a set of conditions like air flow rate and an equivalence ratio pressure and initial temperature of reactants and so on and then for these set of conditions you now have some equilibrium and what we are talking about is perturbing.

About an equilibrium for this given set of conditions if you now move your set of conditions you now reach a new equilibrium and that need not necessarily be stable as the previous set of conditions for which you are in equilibrium, so equilibrium does not necessarily mean stability you could have a unstable equilibrium or a stable equilibrium so for example the best example is for example before you now have like a rod that is hanging from a pivot, so and then if it is like this and then you do not tap.

It is supposed to go through a sinusoidal oscillator e-motion like a pendulum and the what courts call it a set point that is the equilibrium is very exactly hanging down because of gravity, but then, if you know can also hold this rod up here then that is also actually in equilibrium the weight of the rod is actually being balanced by the support but now you try the tab it now starts going forward and further away from these equilibrium, so the top position is an equilibrium as well but it is an unstable equilibrium and compared to the bottom position.

So the examples that we talked about where we are talking about the physical weight of a person versus the exercise is a situation where we were talking about something that was unstable, so that is what is instability and converting there that means you have a situation and then any small perturbation keeps you going away from that position, so that is what we really mean by instability to begin with intrinsic instability then is actually a instability where you do not have anything else coupled.

To the combustion it is only the combustion itself that is unstable right, so the flame exhibits instability by itself a combustor instability on the other hand is a system of flame coupling with a coustics in the combustor, so this is this is a flame a acoustic system where you have a feedback loop between the flame and the acoustics in the combustor we will talk in greater detail about this but essentially here it is not a standalone combustion alone combustion that is going unstable its combustion coupled with acoustics in the combustion chamber.

That that is going unstable so that is the combustor instability the system instability is feedback with let us say fuel supply air supply or oxidizer supply etc. That means it now is a bit poor specific to how the system actually is configured which is going to cause this instability again we will talk in greater detail about it, so let us first talk about the intrinsic instability here.

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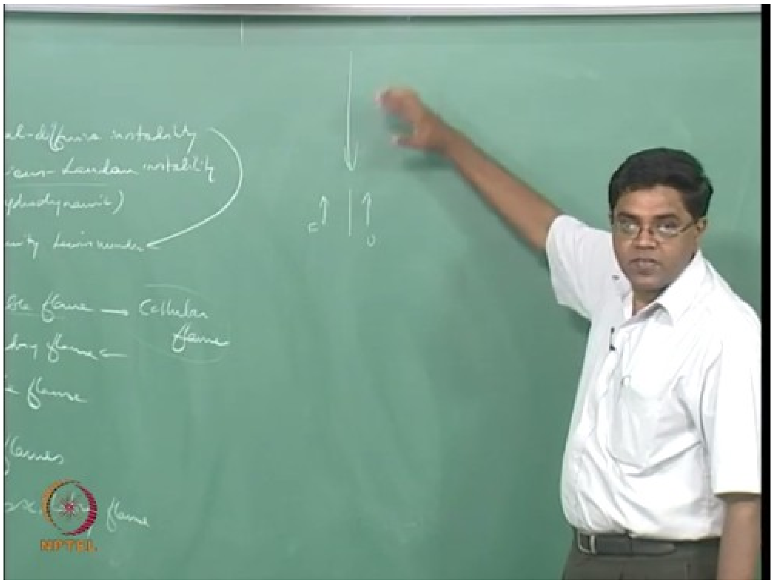

We shall talk about a premix flames plane prep or should say prime exclaims I should not same plane prime explains because that is the point of contention as far as the and instability is concerned let us look at prime exclaims we have talked about the issues involved in here we could talk about our two things one is the thermal diffusive instability and the other one is the dirtiest Lando instability and we have actually discussed this previously when we were talking about corrections to the laminar flame speed okay.

And there we were basically talking about these effects of the flame curvature and the flow divergence effects right so what we were basically saying is if you now have a plane of flame and then let us suppose that you, now put up this right then we have the situation where the heat is actually going radially outward in a flame that is curved concave relative to the upstream reactants course the flow is going from left to right and in this case the heat is actually converging.

While the heat is diverging here and converging here the reactant flow or the reactant diffusion into the flame is happening the opposite direction that means here all the reactants are actually converging towards the flame and all the reactants here are actually diverging, so you have a lesser concentration of reactants in this flame but they get heated up more, but you have a greater concentration of reactants but they are getting heated up less because the D heat is getting distributed right.

So now the question comes what is the effect of lowest number so the thermal diffuse of instability is directly a consequence of non unit using this number, so when you have a non unity lowest number then the heat conduction upstream to the reactants and the reactant diffusion downstream to the flame they do not happen exactly over the same length scale right, so when we were and we have gone through this we said when we have a larger lowest number that means your conductive effects are actually more.

When compared to diffusive effects whereas river assets opposite so depending upon this what you will find is there are ranges of lowest numbers for which you will have something that is unstable right, so this leads to unstable flame or oscillatory or stable flame right, what is meant by that is I mean again going back to the idea of instability in general if you now have a equilibrium point and then you now give it a perturbation and then you are now trying to track what happens the amplitude of the perturbation.

With time right if it comes down like this that is that stable if it now goes like that is unstable the amplitude keeps on exponentially growing that is unstable the other possibility is it looks like it is actually coming closer to the equilibrium point but it begins to oscillate right for clarity let us also look at a couple of other situations where you could you could do it could look like it is coming back, but then it also lets and then its amplitude keeps growing right so this is a this is also literally unstable and the third situation.

The other situation of course is when you now have something that that comes back in an oscillatory manner right, so then they do this becomes table that means the amplitudes are dying down but in an oscillatory manner, so there are many such possibilities what we are talking about here is a possibility where the amplitudes remain constant in fact this refers to like the way the pendulum behaves so when you now give it a tap it looks like it comes back but it kind of misses the equilibrium point.

Because of inertia and then oops again to the other side then it goes back a little it looks like okay it is going to be stable, but hopes event or other side and so on so since you now look at a displacement and then added a small perturbation it looks like it is coming back you will tend to think that it is stable but that is what is called a only static stability but dynamically it now actually attains a nickel a neutral equilibrium of a oscillator state okay and then of course in nonlinear dynamics.

They would refer to it as a Hop bifurcation and so on we will not get into all that Jordan here we will just say that for example you could lead to an unstable flame that means when you now have a plane pre-mixed flame that is perturbed it could now get a become increasingly non-planar right, so if it now starts getting curved and curved more and more and more that that is an unstable flame a stable flame on the other hand is where you now have a perturbation and then it gets back to being cleaner.

The oscillatory flame is it now starts actually oscillating so with a certain constant amplitude right, so there are there are many such in fact the oscillatory flame is something that I will talk about more in the context of partially premix flames, but right now you could say that for different lowest numbers we can find that you can say the flame becomes unstable or the flame and typically the lowest numbers of course lowest number is actually a function of the reactant casing because it involves the diffusivity of the reactant.

So usually we are talking about non unity lowest numbers of the deficient reactant because the deficient reactant is the one that is that there is a flame is more sensitive to the other kind of instability that we are talking about is what is called the Darius Lando instability or simply hydrodynamic instability and this is also something that, we talked about in the context of corrections to the laminar flame speed in some sort of a steady-state framework but not necessarily in a instability framework.

Where what we are talking about is a pre-mixed flame can be taught thought of as a line of discontinuity between two different regions of different density right, so you have the cold reactants that are denser you have the hot products that are lighter right so because of which you now have a flow what we talked about at that time was because of which you now have a flow divergence or a flow convergence behind the flame which could in turn accentuate the curvature so the basic idea about the Darius land of instabilities.

If you now have any interface between two fluids of different densities it is inherently unstable intrinsically unstable or unconditionally unstable right, so that is the kind of mechanism that you will see prevailing in flames as well, so that is like a similar examples are for example you can look at like the surface of water a surface of water with air being the other side, so you now have two fluids of different densities separated by the interface now this interface now is susceptible to perturbation and when this perturbation happens it now starts forming waves right.

So similarly flames also how actually interfaces between fluids of two different densities code recorder then reactants and hotter lighter products, so you would face hydrodynamic instability as well in practice you have a combination of both and therefore it is not very unrealistic to expect plain premix flames in the laboratory that is not because they do they are actually both thermal diffusive least able and Darius Lando stable they could be unstable but those instabilities are cancelling each other all right.

So we are one of the instabilities is actually causing it to go away from the original position the other one is training to actually get it back to the original position and so on, so one of them could be destabilizing the other one could be stabilizing the stabilizing force is destabilizing mechanism could over whelm the instable unstable mechanism or if even if both of them are trying to be unstable they counteract in such a way that you now get a stable flame so this is possible.

Now in the extreme case where actually you have a unseen step unstable flame and you now have this curvature keep on growing then you get into a regime called cellular flames, so this effectively leads to cellular flames where the they play the premix flame is no longer planar, but actually breaks down into many different cells and it now reaches a new equilibrium and a new stable equilibrium where it exists as these cells and therefore that kind of a flame structure is what is called as a cellular flame.

A cellular flame is also a kind of structure also observed for diffusion flames this diffusion flame instability, so if you are now begin to talk about diffusion flames under, so you can also expect cellular flames under some conditions in fact you could you could expect that the thermal diffusive instability is predominant in diffusion flames because you are expecting diffusion effects to be important the dirtiest Lando the instability is not as common because you do not really see like the density jump happening as much.

As in a in a premix flame so premix flames are more susceptible to that, but in reality when you have a non unity lowest number and you have varying density with temperature you can expect both mechanisms to prevail to different extents then finally we have the situation of partially premix flames and here there are some regimes of lowest number greater than 1 where you get oscillatory stability flames that means you are looking at something like a triple flame or something that is more compact essentially like an edge flame.

So if you now look at a triple flame like this with a split up late and then you have fuel on this side oxidizer on that side you have a trailing diffusion flame and you have the fuel rich branch and the field lean branch there are some lowest numbers for which this entire structure actually begins to oscillate back and forth at a constant amplitude okay and of course, if you now change your lowest number or change your damkohler number in fact the damkohler number dictates how much should be the standoff distance.

If you have damkohler number is effectively a indicator of the finiteness of the chemical reaction rates and so the more finite the chemical reaction rates are the or less close to infinite chemistry the damkohler number is more finite and correspondingly the standoff distances increase and of course you even under stable conditions, you will not get equilibrium flame established less than a certain damkohler number and the flame blows off that is a steady state there is a steady state solution does not exist okay.

Now for a steady state solution that exists this is susceptible to small perturbations for some great some lowest numbers greater than one where it actually undergoes oscillatory instability also, so that is the case where we were talking about constant amplitude and of course the amplitude and the frequency or functions of lowest number and damkohler number and they change continuously, so that is something that and of course you can also think about the fuel oxidizer ratio concentration gradients.

That is that the flame is subjected to and so on so these are the parameters over which the oscillatory instability will manifest, so that sets about intrinsic flame instabilities now let us look at the combustor instabilities.

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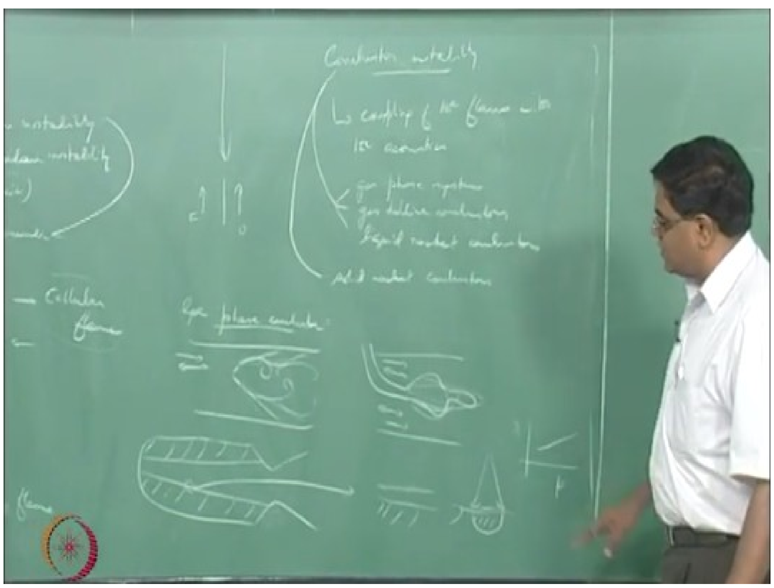

Here basically what is happening is if you now have a flame that is being perturbed the basic thing that we are looking at is what is happening to its properties and these properties mainly in this context could be the heat release rate the temperature downstream of the flame the density downstream of the flame of course all these things are related okay, so the temperature rise is related to how much is the heat release and the density fall is different is related to the temperature rise right.

So if you now perturb the flame and the flame moves around then the heat release rate undergoes a fluctuation and therefore the temperature goes undergoes a fluctuation and the density and there goes a fluctuation, so when you now have these fluctuations they set out a acoustic waves away from the flame and these acoustic waves will now go and get reflected at the ends of the combustor and then get reflected back and set up a standing wave and the standing wave is now going to actually fluctuate.

This flame further and when the flame fluctuates further then it gives sets out a stronger acoustic wave and so that the prevailing acoustics now begins to get amplified and this amplified acoustic wave sets up a stronger standing wave which, now oscillates the flame even further and soon so now you begin to understand that the amplitude of the acoustic oscillations will keep on rising in fact the amplitudes of every oscillation that is there keeps on rising right, so this is essentially the coupling of the flame video questions.

Of course before I before I proceed further what I should say is this is the situation that I just described is something that is very simple to think about for a gas phase combustion alright that means you now have like a gaseous reactant there is gaseous fuel mixing, but mix oxidizer may be a premix frame may be a diffusion flame right, but essentially some gas phase flame there is there is undergoing this and then causing this situation but before we proceed I also should point out that there are there are two ways of thinking about this depending upon.

What we are dealing with on the one hand you could now deal with a gas phase systems gas turbine combustor gas turbines combustors could be gas phase systems or liquid phase system there are land-based gas turbines which use like natural gas for powering the more there are things like aviation gas turbines which use liquid fuels for powering them, so you could have the liquid fuel as well in these and then you can also talk about liquid rocket engines.

I could rocket combustors and soon but on the other hand you now also have solid rocket combustors and the way things happen in the solid rocket are slightly different from the way it happens in these, so we will we will first discuss what happens over here and then we will go back and look at what happens here, so let us look at look at the gas phase combustion for example gas phase combustors could have a course many times we are interested in gas phase combustors.

Being premier having premix flames so you could think about a combustor in which let us say atypical typical geometry for us could be who what is a very simple geometry a simple geometry for us as far as a premix flames is concerned letter supposed to be now take away Gator okay, so if you now take a V cutter we would like to think that you can you can have a flame that is established like that so it is anchored at the edge of the bluff body and then it actually extends out we talk about this when we were dealing with flame shapes with what we said was the flame is trying to trying to travel with a propagate with a turbulent velocity and then.

So it actually Orient's itself in such a way that the local normal velocity component matches the turbulent flame speed and so on, but then the question is what happens when the flow velocity begins to oscillate right, so in the flow bill the flow velocity begins to oscillate on top of a mean flow right so you have a mean flow but it is now going to go back and forth so why does the flow velocity oscillate to start your thinking on the loop let us suppose that there is a perturbation and then what we want to point out that this is going.

To actually give rise to more flow fluctuation okay so what we are saying is when you now have a flow velocity fluctuation you have a faster flow sometime and then a slower flow some time so when you have a faster flow the flame is going to actually get more inclined and when you have a slower flow the flame tries to propagate still further in and, so it is going to go like that so essentially now we think that the flame is going to flap back and forth like this right so when the flame tries to flap back and forth like this.

Look at what is happening to the flame area so the flame area keeps fluctuating and since the flame area is along which the heat release is happening the total heat release in this region is known go now going to fluctuate because you had a larger area over which the heat was released versus a smaller area over which the heat was released and therefore you know going to get heat release fluctuations because of the velocity fluctuations the heat release fluctuations, now try to send out acoustic waves that amplify this oscillation.

And in the amplify and when the oscillation gets amplified further this oscillation is going to become blog wilder right, so that same stability that we were talking about but unfortunately life is not as simple as this, so what happens in reality is when you are now trying to actually send this fluctuation the flame simply does not move back and forth like this instead it actually moves more like that there is a perturbation that happens in bulk for the flow where the flame tries to match.

But there is also the perturbation that is being sent along the flame so there are two ways in which this perturbation is propagating one from the boundary along the flame and one in the flow field itself, so depending upon how long the flame is locally the wave that is propagating along the along the flame starting from the boundary and the flow fluctuation that is happening anywhere in the anywhere at any part locally on the flame they are going to interfere constructively or destructively.

And depending upon that you are now going to get a wavy pattern this now adds further to the flame area fluctuations and on top of it we have to consider, now that you have a non-planar flame then we will have to consider the flame curvature effects and the flow divergence effects on the flame propagation speed okay, so there are there are all these other things and in reality the other problem that happens is the frame anchor point where the it is actually being held at the flame holder.

That itself fluctuates because at the anchor point we went through this dynamics you now have a entrainment of non reacting gases on the one hand and a heat loss to this and this heat loss begins to fluctuate the entrainment begins to fluctuate, so where exactly the flame stops away from the burner that fluctuates and that is where that is where the perturbation is being sent along the flame, so if the flame itself were to move away and then you now send a fluctuation along the flame to constructively or destructively.

Interfere with the bulk flow fluctuation then the flame shape gets altered correspondingly right so these things actually complicate this matter this is purely what we call as a kinematic effect the moment we are talking about the flame speed and a flame sheet and the flame is trying to balance the flow that kind of idea all the dynamics is considered within the flame we have long gone we have long passed we have long gone past the point, where we have to worry about the dynamics of the energy balance.

And the species balance and so on that happens within the structure of the flame we only worry about how the shape changes now, so this is not driven dynamics it is purely kinematical effects right so these are some of the things that happen in the case of let us say premix flames similar things also happen in diffusion flames except that we do not really talk too much about it, so let us suppose that you now had a simplified gas turbine construct where you are now trying to have a flame that goes like this and then you know adopt a Berk Schumann approach to strictly get a diffusion flame because if you do not hurt dropped a book Schumann approach.

Where you had a flame sheet assumption where the flame is flame shield is coincident with the stoichiometric surface, and so on all the old ladies that we that we had then we will have a flame standoff you will have partially premix flame you will have flames that look like more like this that is what happens in reality, but for the sake of thinking about diffusion flames let us think about like a combustion flame and suppose that you know how I overwinter Schumann flame and now, let us suppose that we now oscillate the flow on top of a mean flow the mean flow was the one that gave rise to this flame shape alright.

But the moment you now oscillate this flow you are now begin to actually have well what would you expect the first-order effect of course is the first-order effect as we saw earlier is if you now temper temporarily have a flow that is going faster than it should actually prolong the flame right and for the for the other half of the cycle, where the flow goes slower it should now shot in the flame, so the flame shape should now begin to change like this and therefore the flame area fluctuates again.

And the heat release is happening along the frame sheet very similar ideas to what we had just talked about for the premix flame exists, so we could we could think like that but that is say more simplistic idea what in reality happens is like what we talked about that means you also have like a wavy structure that that goes on for this flame depending upon the frequency and the length scale of this flame and therefore you have to factor that induct and so typically what we are interested in is what is the heat release fluctuation.

As a ratio of the mean heat release for a given velocity fluctuation as a ratio of the mean velocity so you have now two things known as heat release fluctuation over the mean flux mean heat release divided by the velocity fluctuation over the mean velocity right, so this is this is a quantity that is typically referred to as the flame transfer function or something like that and there is a lot of work that is been going on in these things essentially.

We are looking at what is the flame response to the oscillations and what we can understand in the gas phase plane context is these oscillations are essentially happening because of the velocity fluctuations, so you do not expect a big effect for pressure fluctuations that are associated with the acoustic waves it is a velocity fluctuations that are causing the havoc right, so a quick fix for you would be if you find that there are huge oscillations that are happening is it possible for me to locate.

Where the flame exists this the block body here or the flame the fuel injection point herein a place where I have what is called as a velocity node in the standing wave mode, so you have a standing wave and you have velocity nodes then try to locate the flames there so that the flames are more silent right, so they are not really subjected to huge velocity fluctuations no matter what the amplitude is because regardless of what the amplitude of the perturbation is the node is going to always have a zero velocity amplitude right.

So if you now try to locate your flames closer to the known of course the point is the presence of the flame itself changes to a changes the mode the acoustic mode shape okay, so you have to actually sort of dynamically chase the know the velocity node and then look locate it so it is also it's a little bit more involved just saying that and similarly there are other problems like many times in fact one of the things that I have not talked about here is, if you now have a block body you now have a what x shilling that is associated with it.

And the what x now begins to curl the flame and that increases or decreases the flame area and these water sees our shed, so when the what is either shed they take away a part of the flame and burn them somewhere there and then a new flame is established and so on, so you now have heat release oscillations that are associated with water shedding and now you have a new time scale in the problem relative to the water related to the vortex shedding frequency and how is this vortex shedding frequency going to relate with the natural acoustic mode of the ducked.

That is satisfying them acoustic boundary conditions will now also begin to pay play a huge role in trying to dictate what the acoustic amplitudes are and the other the amplitudes of the other fluctuations, so this is now getting to be quite complicated in the solid rockets on the other hand you have a very different situation what you have is now, if you think about a solid rocket obviously we are talking about combustion chambers so combustor instability, so we have to look at a solid rocket motor.

In which if you now have a propellant that is shaped like this then everything that is happening that that matters to us is within a very short distance from the from the surface of from the burning surface of the propellant and this and within this very short distance effectively, if you know for example think about this region and then of course we talked about a homogeneous propellant which has like a pre-mixed flame or a heterogeneous.

Propellant where you have let us say something like oxidizer particles and then you had some diffusion flame maybe some edge flame here and then a monopropellant flame there and so on the question is what is the effect of the acoustic oscillations in this chamber on this flame and here typically the way the solid propellant rocket design is done is to look for how is the burning rate of the propellant dependent on pressure okay, so and usually you get a picture that looks like the R goes as P like that.

This is actually a log plot okay and what we are talking about now is if I increase my pressure then I expect that the reaction rates should increase therefore the flames will now get attached closer to the surface and therefore they will send in more heat to the burning surface and then give rise to more gases that are coming out right, so as the pressure locally increases we expect that the rate of rate at which gases are coming out should increase or the burning rate should increase that the instantaneous burning rate should increase.

And therefore it now puts in more gas into the chamber and that pressurizes the system more and if the pressure and when you now have a less pressure because of the acoustic perturbation then the burnings kind of slows down, and it puts less gas into the into the chamber so that relieves this and then the pressure the pressure decrease further decreases, so when you now have an oscillatory a pressure then the way the propellant burns could or most of the time does actually a help the pressure to increase and decrease more and more so here instead of looking at a velocity fluctuation based flame response as we did in the gas phase combustor.

We look at a pressure based propellant combustion response alright and here again we can now think about a response function where this is actually not in terms of heat release fluctuations and velocity fluctuations this is in terms of mass fluctuations there are relative to pressure fluctuations, so does the characteristic that you are using here to look at how the propellant response to the acoustics is slightly different from how we deal with in this class of problems finally let us now look at system instability.

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This again is not directly related to combustion but it affects combustion so this is mainly seen in gas turbines and liquid rockets particularly gas based gas turbines liquid rocket you can save fuel here you can say propellant here both of them together you are looking at the feed system, so the best or the simplest example that we can think of is when you now have a situation actually it is not hard to be fueled at okay that is fine, so let us suppose that we have air coming in or oxidizer coming in and then you now inject your fuel on the side and you are so that means in this region the field and air actually mix with each other and then you now have a pre-mixed flame that is set up there right.

What we are now saying is oh now if you have a perturbation okay this flame now put herbs and then gives rise to heat release fluctuations which now sets up acoustic wave, so you now have a acoustic standing wave from here to there of course taking into account like a step change that is possible right, so in this acoustic mode where the fuel inlet is actually located the pressure here is actually going to fluctuate because of the acoustics and with the pressure fluctuates you now have a δ p fluctuation for the fuel inlet.

And that is going to correspond to actually a few mass flow rate fluctuation so when your fuel mass flow rate fluctuates for a given constant mass flow rate of air then you have what is called as equivalence ratio fluctuations, so this leads to something called Ø prime we are not even talking about the effect of U prime with the velocity fluctuations, we are talking about the effect of the equivalence ratio fluctuations, so what basically happens you now have for one half of the cycle where the pressure is actually increasing here.

Then you have less fuel coming in so this is slightly linear than design point okay so when it is leaner the flame now burns slower therefore you get a long it but then you when you go to the next half of the cycle where the pressure decreases you have no fuel that is coming in and then mixes really air, but the crucial thing is it is not an instantaneous mixing everywhere in the in the in the flow field in this in this inlet, so you now have a fuel pocket that now convex down at the flow speed.

So the question is when the flame is trying to come back if you now have a field pocket that arrives there with of course mixed with air and makes it less leaner then the flame will want to come back more that accentuates the instability, so when we say when the fuel pocket comes here that means it is got to do with what is this distance relative to what is the velocity also there is a convective time delay for pockets of field to mix with air and come, so the equivalence ratio now fluctuates because of the convective time delay and that can feed back.

Into how the flame wants to flap back and forth and change its area and get along with the combustion instability because of that similarly in the case of liquid rockets typically what they do as far as design is concerned is in order to avoid something like this they have an injection injector plate which is designed to take a δp across the injector play their pressure in the injection pressure is essentially the pressure upstream of the injector plate relative to the combustion chamber pressure.

It is essentially a pressure differential δp and the way they designed this is they want to have this δp to be at least about 20% of the chamber pressure that means the injection pressure upstream of the injector plate should be 20% more then they come the combustion chamber pressure so much δp, so that any oscillations that are happening in the combustor is not really felt upstream now have a fairly robust high pressure over here which can push the propellants pretty much at the same rate regardless of the small fluctuations.

Say if this were only marginally more for example right then any fluctuations here will propagate upstream significantly and cost fluctuations in the flow rates of the liquid fuel and liquid oxidizer and therefore, now when they mix and burn everything is going to oscillate and then that is good that could actually increase these oscillations even more and more and in fact many times when this is not done right then these fluctuations can actually propagate all the way upstream to the tank that is where.

They get arrested so now your feed line has a certain acoustic characteristics anything that is confined has acoustic characteristics because of possible reflections and standing wave modes and so on right, so the feed line can amplify the acoustics if it resonates with the oscillations that are there in the combustor, so many times like the combustor could have something called radial modes but as the feed line could have a longitudinal mode that the same frequency and so on when these things coupled with each other.

Then these oscillations become significant and then the whole system begins to have oscillations all over the place basically then telling us that system instability is a very big problem right, but of course those are now getting into mechanical details a little bit moving away from combustion but you have to keep in mind that the heat release fluctuations in the combustion is like the primary driver for any perturbations to grow and all other things begin to couple with it.

So as a matter of fact simple similarly when you now look at things like solid rockets where you have let us say what is called a segmented rockets which have inhibitors the inhibitors can now protrude into the flow when the propellant burns and you can you can now produce vortices and these water seas give rise to pressure oscillations but that is not significant many times when compared to what it can do to the propellant combustion response to become significant, so these are like a trigger and then the propellant combustion response.

Now takes over and causes the combustion instability so many times there are a lot of other things in the system that will go together with the combustion event once the combustion event is primarily in currently unstable or susceptible to acoustic instability so the assistant system instability typically is the secondary effect it is a combustion instability that that we should mainly focus on trying to damp as much as we can, so we do not want to get into how to damp these things just wanted to point out.

That I just wanted to point out two things one such problems exist things are not as steady as what we have been going through they are inherently unsteady or they are susceptible to perturbations that is number one second, we can understand many of these things based on whatever we have studied laminar flows laminar combustion and steady state ideas and so on but the problems are locked deeper when compared to what meets I in this lecture thanks a lot.

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