Shown here is a typical schematic of how a mixing layer would look like. Let us say, we have fuel and oxidizer here and this, a splitter plate there in between and there is a you have Kelvin- Helmholtz instabilities. That is, this shear layer will tend to roll up and gets organized and roll up and the flame front also will go with shear layer and it will.
So, this oxidizer will get entrained into this vortex and then roll up and get mixed and burn. So, that is like a idealized situation, but in reality you will have this things happening within walls in a dump combustor, let us say and, so you have unburnt mixture of reactants. Let us say, we have premixed flame and you have hot radicals in this recirculation zone. So, the vortex tries to roll up and you have the unburnt mixture get entrained into vortex this way and your hot products here which are entrained.

There is a inter phase here where strain rates would be high and there will be lot of turbulence. So, once you, so the large scale roll up does not necessarily ensure mixing, but then once you really have molecular mixing and then everything is well mixed then you have certain ignition and you have combustion.
That is what we are looking at and from the basic fluid mechanics of jets we saw that there is some kind of instability waves and they scale as. So, if the frequency is f_i, i denotes initial region, so if they scale with the Strouhal number based on the momentum thickness at the exit and the velocity at the exit. Of course, there will be vortex merger and interaction and so on. Eventually, you will have a lower frequency and bigger vortex and which is scaling like s t j, that is the at the jet exit at the end of the jet core. You have a Strouhal number scaling of in terms of the diameter of the jet and the jet exit velocity and this frequency would be usually lower and its Strouhal number, is of the order of 0.25 to 0.5.

So, this frequency would be called preferred frequency of the jet. So, if you excite at this frequencies. Then, you will get very large response of the jet and this vortex will become much more coherent and the spectra will become more sharp. So, this is where we stop and are there any questions? So development of large scale structures is beneficial for the enhancement of large scale mixing or bulk mixing in the shear layer, but this does not necessarily mean that there will be molecular mixing because you need small scale mixing.

So, in the presence of large scale structures transition to fine scale mixing is initiated by braids of vortices where there are high strain rates or high velocity gradients and that is where the in between the high speed stream and the low speed stream and of course,
initially the turbulence production is restricted only there, but then when the vortex roles up this will increase and also the presence of the walls will also increase this fine scale mixing and turbulence and that leads the fuel air mixture to get entrained to the vortex and then burn suddenly, so we are not having a continuous burning in this kind of situation, but you have this mixture that is going to burn gets entrained into the vortex and then comes in and when they are mixed in a molecular level it burns, it’s this concept here. If you are talking about diffusion flame you have fuel and air mixing from either sides, but if you are having a pre mixed flame you may have reactants on one side and hot products on one side, but the hot products which has the hot radicals they have to mix well with the cold reactants only then the burning will happen.

In either case, this scenario would be working. So, if it is, if it is a diffusion flame you will probably inject some where here many times, they inject at the step or slightly behind the step and if it is a pre mixed flame fuel and air are coming together, but you have hot radicals here in either case some scenario like this would be would be valid.

Student: For controlling this, multiple injections are there or by changing angle of injection?

I think that is possible by changing the angel of injection, you would actually be changing the mixing time and the residence time and the convective times and all that. So, you are affecting the time delay, so yes.

It is possible another possibility is, you can change the what is being injected the distribution of injection and then if you are talking about a annular combustor, you can have each injector have a different differently, having a different injection velocity. So, that you have a time delay but each injector have a different time delay. So, if it is like a distributed time delay everything is not coming bang at one shot, but instead one comes first another comes next another comes next. So, the if everything acts together there is coherence and then you have a very large heat release at one instant instead this tends to get distributed.

So, that will reduce the possibility of instability happening. It is a very good point any other questions? In annular combustors what they typically do is they would have different burners located along the annulus, so there will be a number of burners you can have can burners or you can have just annular thing with swirlers. So, you can have
several swirl burners and not necessarily backward facing step, but often with swirl; they may have a step also, but there will be a swirler to have rapid mixing and so on and that is possible, I mean can is of course there, but the aircraft engines they are annular.

So, these strategies could work. Anything else? So we also looked at several different configuration of dump combustors and with bluff body or without bluff bodies with v gutter with cylinder stabilized flames and so on. We saw that all of them kind of fits into this kind of category where there is possibility of a big vortex or large scale coherent structures coming in. Now the development of large scale coherent structures depends on the relationship between the acoustic velocity and the flow instability frequency. So, if the acoustic, sorry acoustic frequency, the acoustic frequency is very away from the flow instability frequency, then, there would be hardly any interaction.

But if you are exiting at a preferred mode frequency that is the frequency that is here I think, there is a good chance that you can make the jet very coherent and you can have very large amplitude fluctuations, but if you are having a cold flow that is there is no combustion, the vortex itself will produce some sound, but it is not that much to create a feedback, but in the presence of combustion the mixture roles up in this vortex and then you burn and that gives the un steady heat release which connects the feedback.

Then, this plays a very big role in creating, sustaining these instabilities. Of course, there are vortex related instability like for example, flute or something where you are actually having vortices and that is actually producing sound and you are locking on to this frequency of the pipe and so on which is the resonator in the flute. If there is time we can look at that later. So the combustion is initiated at the circumference of the large scale structures where secondary stream wise scale eddies are growing initiating the process of transition to fully turbulent flow.

So, you have this and the vortices are being convected down and the combustion happens somewhere down and the vortex is being convected down and the molecular mixing is taking place. So, just as when the molecular mixing has happened adequately it burns and by then this mixture would have been brought down from distance, so that decides the location of the heat release. Like here in this region. It is a vague term .

So, the acoustics kind of reinforces the shear layer and the structures in the shear layer and the combustion is related to these flow structures that is what that is all I am saying.
It is not like we are often tempted to think that particularly because of the pictures drawn at under graduate text books.

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We would tend to think that there is flame like this and when you have a jet you tend to think that the jet has a core and there is an entrainment region and there is a core and the mixing region. These are, I mean yes in a average sense this may be true, but in reality I mean it is very far from this like this or this is more like the reality. This is how the flame happens and it is never ever that you will have a nice flame standing like a v. I mean yes, it is possible in a simple bunsen burner flame or something like that, but not in a real combustor.

You would have vortex shedding, if it is coming at any serious velocity and you would have a vortex roll up and the combustion would be periodic and if you have a jet, I mean jet will have vortices and it is, this is the if you time average over a large time you would get this picture, but instantaneous picture is highly unsteady. So, we have to worry about this particularly in combustion where once you have periodic heat release rate, it is going to modulate the combustor and any combustor which has been built of this sort has had instability under some condition or the other.

Yes, can you rephrase the question pulse combustor doesn’t mean pulsating behavior. I do not know, what you can you restate your question? I am not quite understanding. You are asking whether hydrodynamic instability or coherent structures are a necessary
conditions for pulsating instability. No, it is not necessary at all. We showed example and I showed movies of Rijke tube and Bunsen burner flame with a pipe around it. You did not quite see any serious, I mean, you saw winkers, but not really any vortex related rollup and so on.

Although, you can setup those experiments to have them also, but there it was not really necessary we still had instability, but this is another mechanism which comes into play not in those simple laboratory combustors, but more like in practical combustors where you have to have a serious flame holder, like in a after burner where you have v cutter or you have this bluff body stabilized flame or bits like industrial burners and so on.

There are, so this is one type of mechanism. So, this is a serious mechanism which can drive combustion stability, but this is not the only mechanism that drives instability, but there is a pretty serious mechanism which is real which is there in practical combustors. Did I answer your question? No, pulsating engine is a kind of pulse combustor. No, it thrives on instability because it’s self aspirating, so you have, it is like that in the laboratory we showed a jelly jar combustor where you have a fuel air mixture, it burned and it again entrained air, mixed and then burned. So, similarly pulsating engine, it entrains, it brings in air when the pressure in combustor is low. It just takes air then it burns sends the thing out and in that process generates the trust then pressure comes down, valve opens, takes in air. So, it will not work it has no compressor right? So it would not work without the pulsating and in fact for people who were trying to make very small engines, micro engines or whatever they think of this kind of a pulse jet as a possible option because to make a compressor at that stage would be quite difficult at that small size.

Student: So, basically it is not the vortices that holds the flame.

No flame is being held by the recirculation zone. So, we have to have a low velocity zone to have the recirculation zone, so that is the purpose, so we are not having the recirculation zone or we do not need a vortex to hold the flame, but we need a low velocity zone, but we also want to be greedy, we want to pump in lot of mass flow rate. So, we want to have a high velocity stream coming in, so moment there is a low velocity and high velocity stream there will be kind the mixing layer or the shear layer between them will be unstable and have this Kelvin–Helmholtz instability and roll up and so on.
So, we are not having the bluff body to shed vortices we are having it there to hold the flame to have a low velocity region where there are radicals that are available which will ignite the coming mixture and so on, but you cannot have this and not have that. If you want this low velocity zone then naturally there will be interface between high velocity and low velocity zone which is the shear layer and it will roll up, it won't stay nice and flat like this.

That is only in under graduate textbooks, it will roll up and then it will cause this vortex shedding and vortices being said that is by definition unsteady phenomenon and then that can carry the pocket of fuel air mixture and then burn in a periodic manner. I hope, it is clear. I think now, I understand the question, anything else? So, in summary as what you said due to fluid dynamics and combustion interaction. This heat release is periodic and pockets of high temperature flow are converted downstream form the burner exit and people have measured this, I mean they have in the experiments with planar laser induced fluorescence experiments, that is a laser diagnostic experiment.

So, you can illuminate the region with some kind of laser like u v laser which is tuned to oh radical and look at the emitted signal from the fluorescence. You can do this with high speed imaging, there are cameras which can image things at several thousand Hertz or Hertz or 10000 Hz so on and even before this ccd cameras came people were doing high speed film cameras and have do this in the 80s. You can also see chemiluminescence although chemiluminescence has a line of sight integration as opposed to planar laser induced fluorescence which is a technique on a plane, but still you can see all of this with chemiluminescence and high speed imaging.

People have done that, so there is a large scale structure and it breaks down into fine scale mixing and, so you have also this interaction between vortices and walls and all that which is quite complex. I can’t write a one dimensional model for these things understandably because you have to solve some 3 d turbulent flow equations. But I am just saying the qualitative features that is the best I can do and I urge you to read some of the references. I urge you to read 2 references that I have given and then the 250 references listed in each of them that will be a good idea.

So, the high strain rates and the concomitant small scale turbulence generated by the merging or process of vortices creates intense turbulence and it will accelerate the
combustion. So, the process may reinforce the periodic heat release of a forced reacting shear layer. In the sense you are rolling up and burning, but that burning does not happen as it rolls up but then as it rolls up at some time everything would have completely mixed because of this fine scale turbulence and bang it burns at that time. So, it is really a sharp intense heat release as supposed to a slow and steady burning and if you do have a continuous kind of burning, then, you do not have problem of instability.

So another cause of sudden heat release rate in which is seen in dump combustor. Sometimes, the dump combustor is of low step height and the step heights depend on various performance considerations as to about the steady state performance consideration, but if you have low step height what happened is the developing vortex downstream of the combustor can get impinged against the lower combustor wall and there can be some kind of flapping mode. So, the Kelvin Helmholtz instability can combine with a sort of flapping mode instability. Try to draw a picture.

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Som, you can have either a pre mixed or a diffusion flame and either way it’s coming this way I mean, so you do have a Kelvin–Helmholtz instability and fluid mechanics people often call it K H instability. Then, you can also have this flapping shear layer and that is another kind of instability and both. So, it can start off with the K H instability, but then you have this step instability when this step size is low. If, it is very big then this won’t happen you just roll up with out interacting with the vortices.
Student: What if the shear layer separating from the boundary layer is directly hitting the wall without any roll up?

No, it is rolling up, I mean it is unstable, but it did not roll in to a big thing, but instead it came down. So, if you have a very big wall then there is a possibility that I mean, see you have this without interacting with the wall, but if this some at some small enough step height this can actually go and impinge on the wall that is a distinct possibility. That can be a interaction between the Kevin-Helmholtz instability and this step mode or flapping mode instability which is very complex.

So, you have the developing vortex go downstream of the dump and impinge against the wall. So, again impinge is a very crude term, it is like one shear interacting with, when it comes closer to the wall there is a boundary layer. Then, it is interacting with that and so on. It is not like something impinge does not mean, it just goes and bang hits. So, since it downward velocity of the vortex is large a vigorous mixing occurs between the remaining unburnt reactants and the combustion product again leading to a sudden heat release as the flame as this mixture approaches the wall and the energy is supplied to the acoustic field because the heat release oscillations are if it is in phase with pressure oscillations and if it is out of phase it won't be adding energy and sometimes, this may be that some part of the flame may be adding heat in phase some other part may be adding heat out of phase, but then what matters is, what is the net energy addition to the acoustic field or some part may add some part may take out.

So, the net energy additions would decide whether you are going to have acoustic driving and instability or not and whether this amount of driving the net driving that is there is actually more than the losses or less than the losses. There is one more possibility you can have combustors which are long and short that depends on the purpose of the combustor. If you are trying to have a very long combustor and you want to take out the heat slowly and all that then we may have long, but that also possibility where you may have short combustors where you do not have a provision for long combustor like in aerospace combustors, they are short.

Student: It is dependent on the flow velocity right?

Yes depending on the flow velocity the purpose of the combustion and it depends whether it is an aircraft combustor or a ground based combustor and why you are
burning and so on. So, if you have relatively short length then the vortex will interact with the exit nozzle. If the combustor is long by the time vortex reach the exit nozzle dispersion would have set in and the vortex would have smeared out and would have lost some of its coherence and it could have spread out, but if the nozzle is close to the inlet, that is the combustor is short, then, the vortex will come, it will still maintain its nice coherence and come and impinge the nozzle. So at that time the strong mixing between cold reactants and the hot products will occur after the vortices impinge on the exhaust nozzle creating small scale vortices. This would be followed again by intense heat release in a short time and if it is in the right phase it can add instability.

Student: Is vortices independent of temperature?

See, when you have high temperature, there are lot of other phenomenon that come in and I cannot give a simple straight answer to this. One is there is expansion of the gas across the flame and the vortices and the flame, they are in some sense coming together, but not exactly and then there is also a further vorticity produced because the pressure gradient may not be aligned with the density gradient. So that is called baroclinic vorticity.

So if they are not aligned there is extra vorticity being produced. So the very simple picture which I drew first is not may not necessarily hold. There are the other factors and which is dominant depend on this specific circumstances, so it is not like vortices cannot exist in high temperature region. It will exist and the calculation gets more complex.

Student: Since the combustion mainly happens on the shear layer boundaries, there can be situations when the boundaries split again during combustion.

Then, it is, if it is completely combustion, it will break down into fine scale terminals and small vortices also. It is possible, so several scenario is possible and like I told you, I mean they have in that other paper by Renard et al, with 215 references. They have given lots and lots of possibilities and experimental studies and numerical calculation explaining all this.

So, I mean, it is a very complex topic and I cannot give a simple one dimensional model about this.
Student: Vortices, when they interact with nozzle, it carried out of the combustor?

You mean out of the nozzle. So it can it depends on the amount of dispersion and what happens when it impinges. One possibility when it impinges this mixing can happen heat can be released, but then you can have this hot spot, they can travel thorough the nozzle, if they are not dispersed.

So, if there is a, so this vortices are not coming in isolation they are coming in a highly complicated flow. So, it may be possible that, so high temperature pockets or fancy name would be an entropy spot and they are coming and it can be dispersed or it can be still stay as it is it depends on the velocity profile. I guess you can imagine that. So if this thing is going to go through a nozzle then what happen is as the hot spot goes through a acceleration, it is possible that it can generate acoustic waves because you are having entropy mode generate acoustic mode because of a non uniform base flow.

So, in entropy mode and acoustic modes and vorticity modes, they are independent only when the base flow is uniform, but when the base flow is not uniform. It is a possible, there is a distinct possibility that mode one mode may create another. So, this is called entropy mode of sound generation. So, when a hot spot which and why hot spot because the mixing happens not continuously, but with this roll up, so if this hot spot comes to the nozzle and then there is a sound wave coming back and then that can again give rise to thermo acoustic instability.

So, if it does not go through then this mechanism does not exist, so the way they want avoid this is to increase the somehow increase the dispersion of the vortex. That is it does not stay as a compact thing and try to get rid of that. It is a very beautiful point that you have asked.

Student: Hot spot is related to vorticity in some way?

Not necessarily it can be bad mixing also, but this I mean this is a fluctuating heat release. But it need not if you have bad mixing you can definitely have that and that can also go through the nozzle and create acoustic waves. But his specific question was if it comes to the nozzle, will it go through? If it goes through what happen?

Student: The instability is basically because of transition from laminar to turbulence.
Can you repeat? You are asking a very deep question. So, I have to pay attention.

Student: The kelvin-helmholtz instability, basically it is during the transition from laminar to turbulence.

No. You can have Kelvin-Helmholtz instability for laminar shear layers also. So shear layer will be unstable and roll up. It will in practical combustion, but you can have it not break down also. It will still be Kelvin Helmholtz instability.

Student: So when you have a Kevin-Helmholtz instability why would there be small scales like small scale mixing. Turbulence only gives small scales.

So, it is in a turbulent flow and turbulence has all the scales. So there is a possibility that when you have turbulent shear like this, you tend to make small scale mixing because in this region strain rates will be very high. So, you have small scale mixing and the chance of the large vortices breaking down to small vortices is extra that can happen.

If you have high velocity gradients or if you have high strain rates, you can have small scales.

Student: So essentially, the vortices have to break down. Once they break down, why is this periodicity maintained?

But it comes periodically then break down. So, it is periodic to begin with, start with the large coherent structure and then it breaks down.

So, you cannot get rid of it. You start with the shear layer here and the vortices and the emerging and all that. There is only bulk mixing there and because it takes some time for this small scale mixing as you said it breaks down after sometime. So, it cannot break this big structure to begin with.

Student: Only when it breaks down and you have smaller structure do we have a flame. So in the larger structure, we don’t have sufficient mixing, so there is no flame in the larger structure.

There is no combustion.
Student: So only after it breaks down and when we have small scale turbulence, we have combustion.

Yea

Student: So if that is sufficiently far from this instability, then it should not be periodic isn’t it?

Because the whole thing is starting with periodic. If you do not have the big scale and if you have small scale turbulence right from the beginning then you will have continuous combustion, but it does not come right from the beginning. If, the fine scale turbulence is happening as the vortices roll up. So this is not a steady picture. It is just it just comes like this then comes rolls up, so and till it starts rolling up the fine scale turbulence will be minimal.

That is, what I understand. So, my knowledge on this subject is kind of second hand in terms of reading papers. I have never done experiments myself on this. I am not authority on this, but this is what I understand. But I understand that still there is lots to be done and it is a very intensely debated research topic, very nice if you are driving at a very important point. Anything else? So we will look at combustions with flame holders like ramjets I think lot of people here are specifically interested in that.

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So, this is a example given in this paper by Gutmark and Schadow. So, you have combustors with flame holders where there will be a multiple shear layer interaction. It is a likely source of fine scale mixing and hence leads in sudden heat release. So, during one cycle of pressure oscillations you have 2 vortices of opposite sign shed symmetrically from both top and bottom surface of the flame holder. As this vortices convect down they distort the flame surface and cause flapping of the flame branches. So this distortion will result in oscillatory increase in the flame surface area and hence results in an oscillatory heat release rate.

So, this surface itself will start flapping and oscillating and you can have a increase and decrease in area. So the flapping of the flame branches may also cause periodic interaction of the flame front with the side wall contributing to periodic heat release rate. So, you will have in any case some kind of unsteady heat release rate. But in such combustors the flame will be somewhat long and there is a possibility that the entire flame may not have the same driving or damping characteristics, some parts may drive and some parts may damp.

So, whether oscillations are exited or not depends on, I mean whether the net driving is more than net damping amount. So, I mean and everything goes by what Rayleigh said. If, the heat release is in phase with the pressure oscillations, you have acoustic driving. If they are out of phase then you have acoustic damping. So you can also have a very high strain rates causing flame extinction that is the another possibility. We also have this baroclinic vorticity production because of the misalignment between the pressure gradients and the density gradients that occur during the roll up of the flame. So these things complicate the analysis quite a bit.

Now, I want to talk about another instability, another example where vortex shedding can cause some kind of instability like aerodynamic instability, but happens in combustors in solid rocket motors.

Student: Is it an external agent that is creating the acoustic field or is it the combustion itself that creates the field?

In these cases the acoustics itself is not strong enough to create a feedback, but you will have sound. You put a micro phone you will measure, but it will not be strong enough to
create a feedback. But in these examples, the vortices modulate the flame and that causes the periodicity.

So, let me change the topic and I will speak about something else. So if you have like something like a whistle, it is like called head stone or something like that. So you are actually producing a coherent structure or vortex and that is coming from somewhere and then it is interacting with another surface and then forming a feedback loop or like a whistle which the referees blow. So, you have vortex shedding, but there is some kind of feedback with a resonator. So may be I should speak about that rockets itself.

I will speak about rockets then talk about aerodynamic instability and try to tie up this with that I think that is the best. So your answer will have to wait a little bit when I speak about aerodynamic generation of sound and I do not know if this bottle the water height is right to generate the sound, but let us try. So here there was no combustion, but I am blowing and I am actually shedding vortexes here.

There is a resonator attached, so the vortex, so aerodynamic sound is produced by vortices when the vortex has a trajectory which is perpendicular to the acoustic streamlines. So, here the Helmholtz resonator at this bulk oscillations which leads to oscillations in the neck, the velocity oscillations in this neck region which is this way and the vortex causes this part, so then it make a sound. So, aero dynamically you can have sound, but there needs to be some resonator associated with it and this coupling has to be strong. Then, you can get it and that is one possibility is you see in whistling or another thing in flute and so on, so in general there is this mechanism called a lock on.
So, we are talking about vortex acoustic or flow acoustic and there is flow acoustic combustion. So all three can lock on or we can have structure and acoustic lock on for example. You have cables in water and then there is flow around them and the cables will vibrate because of the vorticity. So, there is a lock on between the cable vibration and the vortex shredding or the flags fluttering and so on. So, you have or this aeroelasticity where the vortex shedding locks with this structure. So you are having 2 different resonance phenomenon coupled with each other and then that leads to large amplitude that is the general class of problems we are looking at and it is a very big subject I would not be able to do justice to the subject at all, but I just briefly mention the points. So just to speak about this problem.
We look at large solid rocket motors. So large solid rocket motors this specifically I will write this and I want to emphasize this word large because large solid motors are cast segments. Small motors like the once in small missiles, they can be cast in one shot, but if you have a very large rocket motor, let us say, typically of the order of 20 meter or so, it is very difficult to cast in one shot because by the time you pour the propellant, it will take quite some time you can imagine to fill up 20 meters or something with 3 meter diameter with propellant. We are taking about 200 tons of something being poured and it is going to take time and by the time the bottom would have set, you are still pouring in the top.

So, this can lead to stress and the propellant can crack and so on. But they would want to make it as large as possible which they can tolerate, so typically you can have segments which are five meter long 7 meter 8 meter long. I think in the future it’s quite possible that you may have segment less motors which are twenty meter long, but at the moment they do.
So, what they do, is you cast this motor into segments, so if you have the grain this way and this is the propellant. This would be cast in segments, so let us say this is 1 segment and this is another segment. We have put 3 segments. So, if you remember the P S 1 has actually 5 segments. This is the motor which is used in g s l v and p s l v. The new motor ISRO is building called s 200. This is a 3 segment. I think ARIEN’s M P 5 motor has also got 3 segments, I think. So what they do is between the segments you have what is called the inhibitor, so this is some material which will burn slow or inhibits the burning. So, we would otherwise what will happen is you can never fit something which is really perfect.

There will be some gap and then you will you will have the propellant start burning from the side and then there will be a sudden increase in as that start happening there will be a sudden increase in flow rate and then, eventually, you know in a solid propellant the propellant itself is insulating the outer casing structure as we saw in last semester in propulsion class. So we want the propellant there, we do not want the gases to burn and come in contact with the wall. So, we put this inhibitor and then after sometime this rocket will these inhibitors will protrude out. So, this is, let us say at the start and then at some time later inhibitor burns at a almost does not burn or burns at a much lower rate. So now it is almost like some disks or orifices inside a tube and you have vortex shedding.
So, this vortex that is shed will come back and come here and right as it comes. Here, the next one may be shed and as it comes here and impinges here, you send a acoustic wave back and this gets into a feedback whereas, so normally it sheds in some frequency, but when you are under the lock on circumstance, the acoustic wave reinforces the shedding and then you get loud amplitude. So, you can do this at home, you can put 2 washers in a pipe and blow air you will get a nice tone. Another possibility is if you have this inhibitor thick and there is flow the front part will separate, but it will reattach and then again separate and there is some kind of feedback there.

That will also produce sound and yet another possibility is if you have a nozzle which has a bucket like structure because of the gimballing mechanism there will be some space provided here. So, what will happen is this vortex, so this is where the gimballing mechanism. So this vortex will travel over this cavity and then it is like my blowing over the bottle. We have this works like a Helmholtz resonator and then you make the sound.

Then, it creates, it creates the sound here as the vortex goes over this. So there are many different ways in which this vortex sound can be produced and even if you make a small fraction of the mean pressure these things have very high mean pressure like 60 bar and so on. So, even if you have very small fraction of the mean pressure as the fluctuating oscillation or fluctuating pressure, you still have possibility to create enough structural damage. So in this case even if you do not have any combustor just the aerodynamic
instability itself may be sufficient to cause some problem. So, we have to check. I think we can probably tolerate 0.1 percentage of pressure oscillations or 1 percentage of thrust oscillations. So, if they are below that then the motor is ok. But anything more, I think motor would be unsafe. So here is another case where this coherent structure is creating problem, but this is more like a aerodynamic instability. So, the combustion is happening just over the propellant surface.

Now, even if you do not have this inhibitors. If you have radial injection like I mean propellant burning is like a radial injection. So, if you have a situation where you have gases coming out this way, eventually there will be vortices being set up because this flow is a inherently unstable flow radial injection flow and even if you do not have vortices and if you have gimbal nozzle and there is a cavity, there is a possibility of making sound.

So I will give another example which is non aero spatial. We have gas lines I think in all the countries, natural gas is a very big source of energy I think there is a lot of natural gas. Now in Andhra Pradesh I think it has been discovered some years back. But do not really have a good supply system set up, but eventually it will be. I think Bangladesh has lot of natural gas.

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So, you have big lines this way and then and you have branches and so on. These lines are very long and sometimes some branches may take more gas, some may not need gas.
Sometimes, the moment you close some branches many times actually instability develop because you have a vortex shredding. Now, you have like a resonator here and then you have very large amplitude sound and quite strong and the ducts are very long. So, if the vortices are strong they can travel long the sound wave will travel quite long and as any sound wave which travels, we discussed, it will steepen into a shock. So you can have large amplitude shock waves coming and destroying this, rupturing this pipe lines and so on. So, when you have natural gas being distributed this way, any time you close this branch, I mean if there is a flow then I think then this will not be a problem because this vortex will be disrupted, but if not I think you will a resonator here and the vortex is crossing the lines of acoustic streamlines and you have large amplitude oscillations and then you can cause lot of damage to the pipes.

Student: Does this happen with water pipes also?

I am not aware of this. I have heard this problem mostly happens in gas natural gas or air lines, but in water I do not know to be honest. There are some other mechanisms like water hammers something. So I do not know about this kind of mechanisms. I have not seen any one report this. Any questions?

So, the next thing to look at is the possibilities of passively controlling this oscillations. So there are 2 possibilities, 1 is we can disrupt the coupling between the heat release and the pressure oscillations. Oh no I have to get to the other part the lock on sorry. So, here actually the vortex is locking on to the acoustic field. There are 3 situations, I will just draw this graph and we can continue the discussion in the next class. We are going back to the question that Shabris asked. I will take 2 minutes more.
If, you have a class after this, it is ok to go. We will plot dominant frequency versus Reynolds number and amplitude versus Reynolds number and if, so typically the vortex shedding frequency would go like this. It will be like you have a we saw there will be a Strouhal number of 0.25 or 0.5 or something and you have the vortex shedding frequency go on. But the duct acoustic modes will be, you know, they are constant.

I mean there is a first mode second mode third mode they are harmonic. So, when you are in this region, you will have initially the frequency coming up like this and then abruptly it locks to here and then you come to jump to the next branch. Of course, there will be some hysteresis and then you go here and eventually it cannot lock on anymore. So after sometimes, it will continue to grow this way and every time the lock on happens if you look at the amplitude, you will see some pattern like this and where it is locking to the first mode here. Then, it will jump to the second one then it will jump to the third one. So, this is, what is happening in this situation where I drew here. Now, the situation in a combustor will be different I will talk about in the next class.