Acoustic Instabilities in Aerospace Propulsion
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Lecture - 33
Role of Hydrodynamic Instabilities - 1

Good morning everybody. In last class, we will looking at how instability is happening the in premix combustors. And we specifically look at that frequencies of fluctuations cause by the mode list of the flow flowed rate and off flow rate. And we derive have expressions for the heat release fluctuations we could do this either and time determine are and all in ammonic domain. And then we also discuss how we can calculate with the acoustic model is that time remain or and ammonic domain and do all the analysis. Now, lot of questions were rise to us and about what the simplicity of the analysis and what all things we are neglecting and so on. But in any case we need if you do a simple analysis with a see something but a, I do any more complicated with analysis will have to be done.

And I was speak about some specific issues which are there are be the combustors. Now, which demand at to the address because if I start addressing that then I would not show the main point. So, from the model we develop we saw that time like this a very important order parameter. And we saw the time like related to the trumping it was predominantly by the travel will be time of the conductive, conductive travel time plus. Of course, the acquastic travel time was much of shorter completed, but that could also influenced. And so we have a qualitative and this standing and we also have it some sense at quantitative way to calculate the stability and so on which we did not do that yesterday. But based on the acoustic solver we can calculate the stability quantitatively Now, there are many different mechanisms that affect the heat release rate other than what I discussed. So, one as the, a direct influence of the velocity fluctuations and on the turbulence and the turbulence will modify the flames speed.

And the acoustic oscillation may interact with the turbulence fluctuations and all stability things. Then there are cohellent vortices which are set from the burner exit that is you may you can see vortex roller and so on. And the fuel goes in packets and it is the fuel product or the mixture is being modulate by the, this volt vortices that is said. And in

addition we have this equivalent of fluctuations which you have already discussed. But this things would come together so acoustic velocity fluctuations at the flame from we will give rights to cinematic per tabulations in the position of the flame. So, it will lead toper tabulation in flame area and portability. So, this can happen even in this kind of combustion that is we discuss this in a very simple combustion where you have a laminar ducted flame. And we saw the flame was rooter, because the assulate oscillation how that fluctuated will be the heat released rate.

So, there is no reason by the mechanism would in happen in this kind of combustion. So, you can have acoustic oscillation you can have this equalization fluctuations, but on top of that there is wrinkling and the equal lent fluctuations also conducted. And therefore, the mixture is burning at different place and there this two things have can intact so that is the first thing. And therefore, the per tabulation heat release will be a more complicated than what you studied in either of this cases and people have note that this kind of situations in the in the literature. Now, the second thing is acoustic means give rights to changes and terbium burning velocity. And even for laminar flames the turb the burning velocity you can change, because as I mentioned due to curvature the flame velocity will change and in turbulence flow.

Of course, it will definitely affects so, in the reaction rate can have change and therefore, the excel features. And now the third thing is you can have large scale coherence structures which is the vortices they go roll up. And so the they affect the stability in server in different ways one is vortex structures will perturb the flame area, yes you have the flame area and vortex is rolling the flame velocity starts going along with a either. So, there will it will perturb the flame area the second thing is it will contribute to per tabulations. And the terbium burning velocity so one be of turbulence is that turbulence have consists of vortices. And the large vortices interact with the small vortices and so on definitely the lot of studies which have been done on this simple problem where we have showed it.

This vortices can perturb the terbium burning velocity and this necessary to take into account the delay in convections from the origin think of the overtake shedding to the locations of the heat release rate. So, this things can happened together with this equalization of fluctuations and real combustors. And so things are not as simple as what we did I completely agree with that. And we will take a look at the e this mechanisms

especially we look at this role of vortex shedding in the combustion instability. I think that is what do a you can do were kind of eluding to in last class. So, I will give you 2 nice references, we can download them from science direct.

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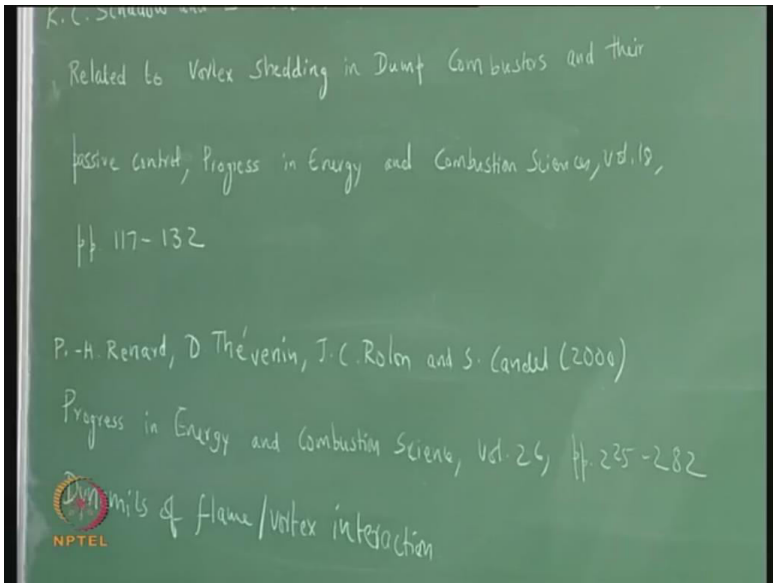

So, this is somewhat old I mean 1932, but it is a very nice reference written by Schadow and Gulmark that will combustion take a little both. And schedule in the combustion and fast control in this general progress in energy and combustion sciences volume 18 page numbers 117 to 132 must say what about this general progress energy and combustor sciences. This is a journalist publishes exclusively review articles and thus know regular papers it only be it took it only review articles. So, each articles gives a over view of the recent development of the subject And last 5 years or 10 years and it gives large number of references. For example, some articles give 50 references some give 100 or 200 references. So, if we are starting out in a new subject the first thing to start of is perhaps look for review article in the topic and combustion. And these are all published in this journal and that is the good way to start.

So, this articles gives a good overview of a subject and give you another reference which has 10 or later approximately again you from the same journal. Then write the title dynamics of flame vortex interaction. So, here the article is focused on how the flame vortex interaction happens. And the other one it emphasizes combustion instability itself so I think please read this articles. So, let us so I am going to discuss qualitatively what

happened, because it is not possible to in this contexts of a class. So, possible to make a very simple mathematical model to capture vortex shedding you know you have to solve with of course, c f d. And I think this beyond this couple with class but I will just give you some highlights of the phenomena. So, I will first draw a cinematic record to how flame with deployed.

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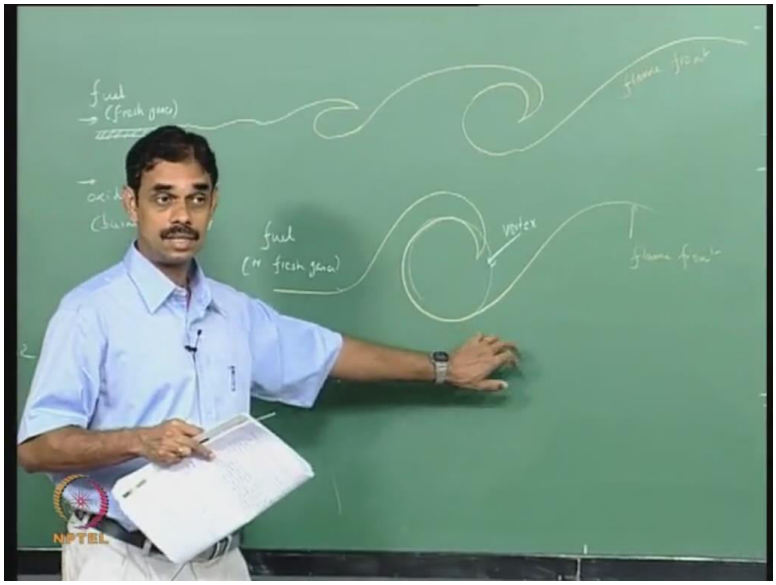

So, let us let say that is a picked a plate here and you have a fuel coming from this side and oxalises here and you would have instability wave like this. So, this would show how will be way the, you work a sheet would look like rolling up and so on. And this would be the flame front and you can also have a situation where we have in the same configuration fresh gases here on products here in the recirculation zone. And you can still have the similar roll up and definitely the role up this periodic phenomena. So, naturally anything periodic would be there is a possibility is that that will give rise to fluctuating heat release oscillations. For fluctuating heat release rate which of course, if it can being phase with the acoustic feel the for oscillation that you can of course, try this oscillation.

So, let us the idea and we draw this cartoon rolling on let us say this region. And so this again is fuel can give fresh gases also I can have oscillating as a here or I can give same picture in here when I have o bar yes. And you have like a vortex here and this would be flame front. So, we can imagine that these kind of situations can arise in a combustion

rate can you. So, the idea is to may I have a discussion of what role these things where on come back instability. Yes this is just a I am I will drawn other things so t just a like a we simple situation where you have a here lights with a plates like a academic configuration and something so where they were show the vortex flow product. Similarly, you can get the flame and this is the showing on this but in reality yes I will talk about few minutes said. Because in reality you cannot have a combustion with this separate here and so what we have to have a combustion to combustion yes. And so there always things will be there anything else.

So, you will a dump combustion or combustion with saw body flame hold us. Vortex is a formed in this here left with the high speed and low speed streams let said the rare what facing step or backward facing step which is called the dump. And the dump combustion or in the wake downstream was a black board black body can used this flame folder. So, the vortex tabulation formation is there and the, it something you which cannot get read of. But either can we get read of this kind of generic combustion configuration like where the flame is being stabilized by some kind of this regulation zone. Because why is this recirculation zone necessary stabilize the flame what happen is high. So, there will be flame typical flame propagation velocity is laminar flame speed is of the order of less then make a pleasure and a even in terminal flow it will be a atmosphere meter proceed. And we want to have a combustion working at much higher I have flow at much have velocity is because then higher the flow rate then you get more heat of order flowed so that is the idea.

So, then we need to somehow make sure that this is region where he have the hot products of his they. So, that you have that hot radicals and high temperature zone is can actually night whatever is coming and this religion should not flow that is why where we have the situation So, in general the high speed stream will consist of un burn mixtures air and fuel and the low speed stream which is there in the re circulations zone. We will concisions of hot combustion products a performing form with it behind this flame holding is a circulations zone behind the dumping combustion. And we can also have a first ablest combustion there out of the previous circulation zone form in this word combustion where do you see where have to know previous situation it were sold stab let us combustions and reality any a gagster of energy there.

So, you have over text break down and there will be a central provided these circulations zone. And that would be what is having the poor of radicals or hot radicals and so which has the radicals and they high temperature to initiated the combustions. So, I will therefore, if you share will be typical combustion configurations so that there equal will be happy that the we are looking as practical situation. So, this is like the typical dump combustion flowed mechanic typical back to would and the combustion down both are the are its like dumping inter a big a reason of that qualities now. So, this would be dump combustion you can also have variations of this you can have a if you have a wall like this that say for example, a you rates this. And I have a over like this then we have this only one side and little break the cemetery, but typically of such combustors are same in laboratory configurations. But the engineering combustions I mean real combustors in the feel they would be cemetery and if it is look like this.

Now, I will show you variants variation of this we can have a block body here. And that can also stabilized flame another other variation which you see are like some kind of wire or cylinder which will whole the flame in its wake. Or you can see of this is word is cold v gutter stabilized flames which are some temperature after burns as act of in genes. You will these are practical combustion of the religions you can also have, we can have multiple flames or being stabilized on so on geometrics like this that is another possibility. And they or of induced in some transferring in seed domestic heaters you can also have ram jet combustion with bond solid if you all solid if you ram that is s of r l g.

So, there also some kind of it is a dump it down so, we can have solid fuel burning and by release here and then we can have this oat is dispend form the over that. So, these or so I am shore you can draw many more configurations in fact this paper shows both the, were paper shows many main more configuration. Then that I have a just talked about some for the configurations I have to give a idea and we can see this papers for I do not speak. Now, about combustion just has to speak the wonders over take shading on block boarding but there also there this interesting instability. Now, let us take a re-look at this picture in the context of these combustions as there equals pointing out.

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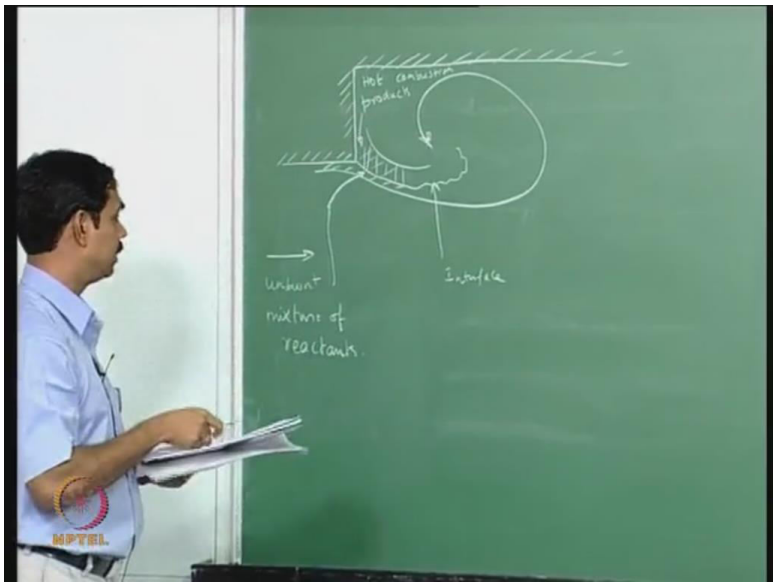

I will draw one side you can draw both side this is diameter from the first reference good marking side of. So, in reality be have walls and the walls we will also in tag with of flame and flow and everything acoustics. So, which is something which we cannot re get read of course, in the laboratory you can set up slitter plate in internal and they have flame and so on. But in real combustion we have to flow walls and there will interact and we have to orient within. So, let say a have a pre mix plain coming so we have un burned mixture of reactions coming here. And we would have some kind of rotate x role up here and so here we have unburned reactions. And then hot combustion products here I around and that is the precise few reason, we have this expunction. So, that this hot combustion products will be there and they will try to get and rain in to this and there will be some kind of inter fascia.

So, this unburned mixture of reaction will try to get in this way and they hot combustion products of trying to coming here. And then there will be inter phase and then you will have a pocket of a poor of mixture which can I live burned in this over takes. So, that is like a carton or semantic and exact details can change depending on how for the walls a what is step heightens and so on. But this some kind of basic schematic the situation that can provided so clearly you can see from this turbulent what a structure can have a significant influence on the combustions. So, in the earlier phase we have un burn mixture on wants side and what the hot combustions products on the other side. And then you we do not have intense mixing and burning, but has the turbulent structures that

development. And the find skill mixing happen into a phase you can have find skill mixing and burning.

So, you have a role up but in reality that is not the only thing you will have interaction between over takes. Because the share lad has in stability that will shed at some frequency those where will some performed mol of excitation and so on. And then what is will be shed up shed and this vortices will actually merge. And then you will probably and the having a lower frequency of the bigger of armature structure And of course, this will be obstructed by the wall sence and similarly, interfiled by the walls. So, that this stationary required from a quite deferent from a flow from a judge it it will have some similarity is it is, but the wall is interfering for show. And large interface between the feeler mixture and hot products with developed and there there will be finds scale turbulence and which cost interment. And so, eventually these thinks and these thinks and adequate number of radicals with defuse or will mix inter this stream and there will be a pole which will suddenly burn.

So, that will be which will be this phenomena will be quite periodic and it happened cycloid after cycloid. And of course, if you study that validated here which says that if heat release rate is in phase with the acoustic pressure then you will have how acoustic driving so here there is a delay. So, from here so from the aquastic mixture coming in here and instead here some burned figures the again this phenomena happened. And all the things that we studied about how the aquastic model with develop, we will again apply here. And this time delay between the fluctuation here and the heat release that clear effect how the react insert going to bond whether than in phase and out of phase is. And therefore, whether than stability or drive stability and people of who as such a, said that this is. And this situation have long for gas face coming combustion, but even if you having spray combustion the spray will be entire into the over takes. And the of course, situational will be must more complex because the spray will not be coming at all though if you speak to if you by spray say it is a average diameter average diameter it not only thing diameter distribution and you have a complex motor draped.

So, it may have a average diameter but small and average complex and the small operates will be non behave go will be the structure. Almost behave like gas the large draped behave heavy amercial so would not flow exactly. Similarly, if there is aquastic oscillation in the combustion this small drops will very well fellow the aqustic oscillation

if you have a time around complain 300 Hertz if you fluctuated 80 percent of the aqustic velocity. But if you have a 50 macron complain with only fluctuate 10 percent of the acquastic velocity. So, both if there in a typical gas will be spray and then therefore, the interactional will be very complicated but now all this spry its role is this there is more difficult to study. And most research have the gaseous phase, but there is some schedule these are on perfect and so on. Now, so, this over take schedule typically comes and this if you talk more velocity and this these own of the large scale. This is large scale cohestant the flow and this problem as will study long in the class problems of. So, here cohestant studies in just ways and mixing lays and so on.

Now, this want give idea of how I can get suggest combustion to word ideally you do not know the combustion to pause, but if you understand how passes then it may be possible those of the possible there to make it pause. So, when it is there design of to terminary combustion make a fast combustion to make a length. So, what can do is if you to, we can move this block body fortain fourth. So, as you come course the velocity will be increase as you push the block backward the power they blocks here will decrease. And typically this things as a they may be move strong on the comes more this means the scroll number will be continues some number. And so if you which means which increase the velocity frequency of schedule will increased. So, if you pull it back the frequency we will rap forward its will come down so if you are frequency they will lock coming to this frequency of the acquastic oscillation will introduce of there. If you have some conduct prefer conduct frequencies is natural more there is coming towards. And then this over take schedule, suddenly lock to aquastic oscillation.

And then this instability can happen but if you should going away. And then chances of these things coming closed you do not have what you have these are modeling and phenomena. So, just have to come close and if you have going away if both the frequencies are going away from each other. Then and actually this way to have some other making you do not have oscillation say this will to happens here you could velocity. But the velocity do not actually frequency come close to the frequency combustion and then then lock to each other. So, that is how in a good sense or in a iniquity sense to understand the you will understand the instability mechanism. So, he if you there want instability the loss to if flow some configuration you can change the elect area and change this field.

And therefore, you will change the frequency of the harden make the instability some you can go there it make some oscillation. So, this is some introduce to how fast combustion this have a combustion this perpus pauses first in 70 s people 60 70s people came up that it model for mechanics how this cohestant applied on a I have to calculation. You calculate for these things you will see if the model for this things which now to couple we can have full combustion solved which factor a you pick if you have a which you have big builders fast computers So, if you do not we can actually solve for suppose you can some assentic equation and then you could leason to the aqustic solve and do a couple solution.

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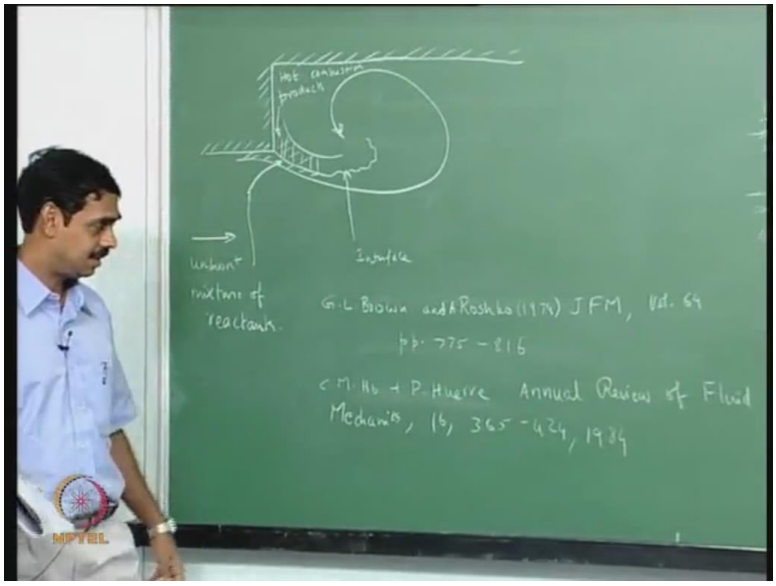

So, people have solvent to be large concept of large scale structures first adventure by Brown and go Raskas for maybe it is 74 JFM of germ of phelomic, germs phelomic mechanic volume 64 page, 7 7 if I 816 they also available in another way it nice article about revive article about this whole concept whole and hole a practical. And we will review of fluid mechanics go on 16 this is also a very prestigious general you cannot just the send articles there they have to invite you. So, if have a big shot where he occurred a claimed person in the area then they we get derivation write a article in the article in annual preview can x I. And this is like the area generalized and this is whole review article this is and normal review articles. And so, one has subject which has f level of naturality a the big shot and subject will be asked to quite review article and this dots. And this is review article centralized about this concept of co and structure features.

So, based on a burn experiments a in a with lower and large numbers this is review of this mechanism. And experiment not really combustion a lower an experiments on turban low it was owned it the shade layer initially development instability view or in the initial region. And then this amply then this ways region and energy level they go up into vortises. And so there will be a initial overtake shade frequency that is called a fire which is also most amplified frequency. And it is often determine by combustion characteristics as said that is velostic proportion to the velostic terminate initial there profile initial shade layer movement and thickness and the get the velocity and.

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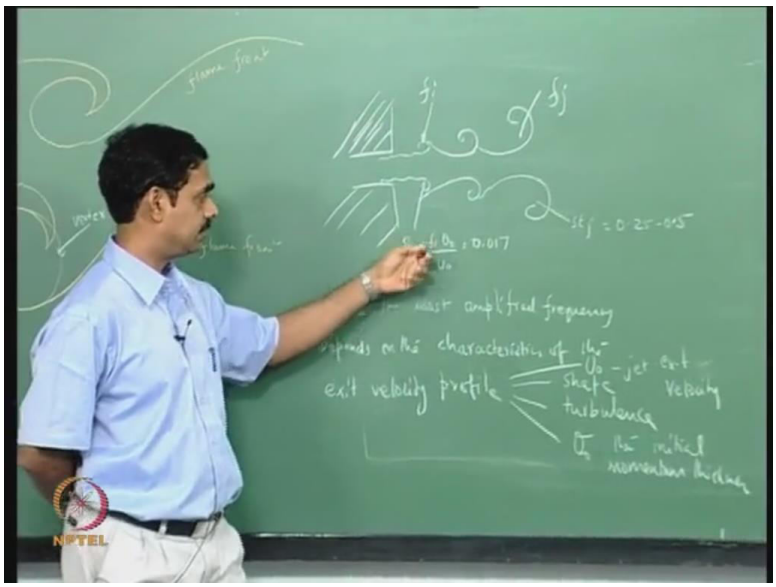

So, let us draw on this concepts you will have this instability ways and they will starts role in here in initially there will be a f i. And so this file will be a not a size initial about exceeding frequency of dimension raiser So, there will be depend on the f i.is the most emphasized frequency. So, its depends on the characteristic so the exit velocity per frequency at this pasted perfect here. And those would be it is a shapes determines Philomena is there theta not the initial of movement of the business also of course, may not the is a except velocity. So, we can always skip scale this like a we have non dimension number like reverse number to look at how this proportion scale. So, similarly, you can also have a so many number which number denoted by s t so s t i equal to s i theta not over you not and typically reply the linier step will be theory.

And form that the linear stability theory s t i equal to 0.13 reference would be michalke JFM v d 23 So, typically j from as per thorough articles which acquired long, we do not see a few article in the particular j or term will be twenty presurity 40 or 50 to the article j which will give comminute with frequency. So, let us indicate this one of picture here so this s t i equal to f i theta not over o not this is obtain 017. Now, the initial vortises many will be shed but the grow and then merge and there converter downstream so this is a merge grow and or conducted downstream. So, we can imagine that when you have voltage merging and the opposite frequencies will come down or will be this the am in issue if you tell voltage. And then merge into through one voltage and then naturally actually whatever happens then merge it will come down to a so the frequency will come down.

So, these are merging and in term and then ratio level losses starts spreading and the, because the when this happens to the entire air from the surroundings. And this would extract is going to the and the voltage will merging that is also make should And the frequency associate with the dominant large voltages decreases. So in the issue level judge some suppose what text interaction can occur before the initial surface is level and the agree judge the potential code so I will write this. So, due to merging and enter in term and the shade level scratch and the frequency of this larger about this what they will decrease. So, this will have careful tractors by stability frequencies associated with the different ices will be voltage and the, is and the, a regional. And end of the potential code by this all would have the merge square and voltage and that is go on by that is called jet column of the instability. And the vortex fluctuation is region they will have another characteristics frequency which will be known as f j.

And this is the end of code so a it is a rare will have so frequency f j We just typically that second or third sub hollmonic of the initial shade level frequency it have certain frequency f i. This would be f j would be f i divided by 3 or something like a typical and this frequency scales with some other variables. So, s t j is the, this frequency with the you will see end of and scares with the diameter of the jet. And you will not the exit velocity with jet and typically you will see in the ratio of 0.25 0.5 that is the s t j in this ratio. Do you start up with f i And end of with f j and f i scares with moment of thickness And the, I mean velocity of the exits f j and there is f i actually scares as s t j equals f j d over u o. So, if you look from a combustion wonder few you want with mixing here

between frequent from the mixing between hot gases and the cold gas that our combustion have.

So, the large scale structure will be a beneficial for the an beneficial for the and happen window large scale mixing or But mixing with this take this flow and mixing the flow. But more less it may not be hence find mixing scale or molecular level of mixing. And only mixing happen in the molecular level you will have combustion otherwise till have the pockets in a 20 pockets and this not in a you have to have pocket in the mixing in the small scale. So, in the presence of large scale structures so you need to transmission find scale mixing. And that is often initially to develop the bright vortices where it is high it is flame rates between the high and low speed themes exist. Let us here in this bright how are the initial find scale terminates in this limited only to this reason for it is conjugate that find scale turbulence approximately. And hence during role of vortices when the vortex is rolling up finalize find scale turbulent marbles increases find scale mixing here increases.

And therefore, so an causes the reactions row called and this is a periodic phenomena they two normal numbers. And if you see a spectrum of a jet at noise many frequency it largest one particular thing you will have a frequency associate with in the initial layer and a frequency develop other way. And you will see a actually kind of Bork and spectrum, but if some proposed frequency you will see a frequency common. And spectrum there from a peak so you will see lot of frequencies, but some frequencies facterful if you are forcing that if you want force with acquastic oscillation. So, if you force this frequency than you are actually you have co- relent factor is coming.

And there is a frequent frequency at this s t j and if you send the acquastic that is corresponding to that you will get this co-relent structure very organized. And if you get the if you look at this specter get the very short peak if you are exiting here you are amplifying the base here so it is about disparity not just mixing. So, once you have it current structure it least is dark mixing and then if the high strength rate available then which having very role up. And you can have this find you can mixing and combustion. So, that is why it does not really start burning why should beginning it just gets in get's in and then covers up. And then will bang part and then again the same happen its happen in a periodic flame people are take can high speed movies and the series so does not answer any question.

So, it is about getting the like this gire was response is the frequency. You will have sudden preferred frequency is exit in those preferred frequency is give response is i is greater than fuel anybody know what is the moment of thickness. So, this is the jet diameter so we should define the way this is a way it is if you do experiment as a several different dio meter jet then it. And then you cause all the frequencies if you all determine flow of the non dimensional like this is a not in other way here this frequency will collapse in different experiment. If you have non dimensional moment of them it is correct here. We use this is f divided by it multiply of theta divided by t over theta. So, f is like all over time scale this is another one over time, any other question? So, I think it is good place to stop.