Acoustic Instabilities in Aerospace Propulsion
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Lecture - 34
Role of Hydrodynamic Instabilities – 2

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Shown here is a typical schematic of how a mixing layer would look like. Let us say, we have fueled an oxidizer here and this, there in between and there is a you have Kelvin-Helmholtz help holes in stabilities. That is, this shear layer will tend to roll up and gets organized and rolled up and the flame front also will go with shear layer and it will.

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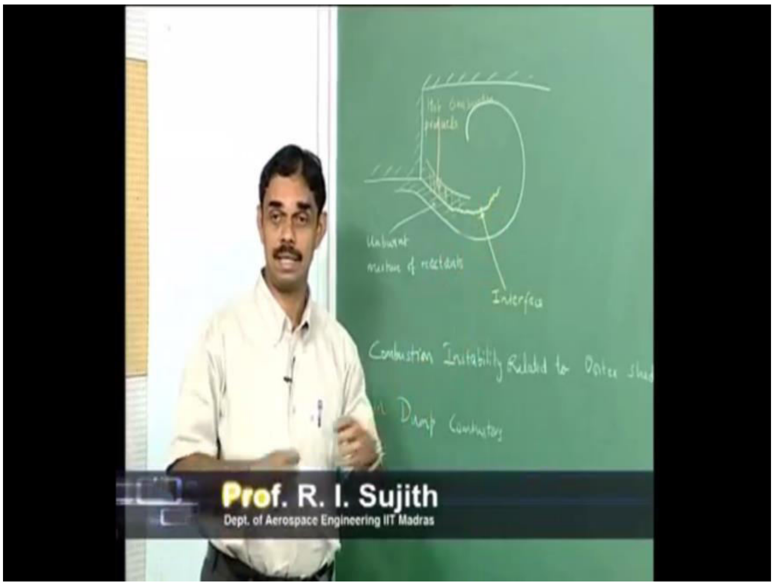

So, this oxidizer will get entrained into this vortex and then rolled up and get mixed and burnt. So, that is like a idealized situation, but in reality you will have this things happening with in walls in a bump combustor. Let us say and, so you have un burnt mixture of reactants. Let us say, we have premixed flame and you have hot radicals in this recirculation zone. So, the vortex tries to roll up and you have the un burnt 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 trouble. So, once you, so the large scale roll up does not necessarily mixing, but then once you really have molecular mixing and then everything is well mixed then you have certain ignition and you have combustion.

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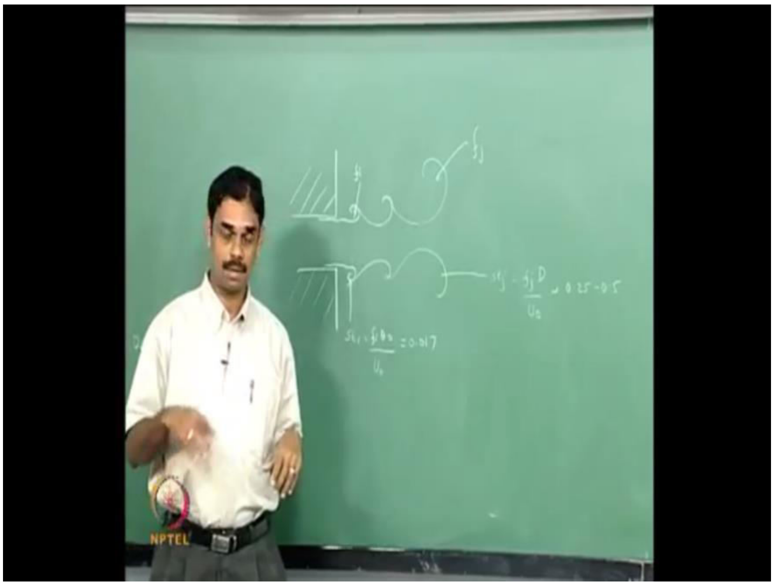

That is what we are looking at and from the basic fluid mechanics of jets we saw that there is some kind of instability waves and they scale as. So, if you are the frequency is f, I denotes initial region, so if the scale with the stovall number based on the momentum thickness at the exit and the velocity at the exit. Of course, there will be vortex merger and interaction and so on. Eventually, you will have a low frequency and bigger vortex and which is scaling like s t j, that is the at the exact exit at the end of the jet core. You have a Stovall number scaling of in terms of the diameter of the jet and the jet exit velocity and this frequency would be usually lower and it is Stovall, is of the order of 0.25 to 0.5.

So, this frequency would be called preferred frequency of the jet. So, if you exit 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, 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 brides of vertices 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 tuberous 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 turbo lines and that leads the fuller mixture to get entrained to the vortex and then burnt 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 is 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 radices they have to mix well with the cold reactants only then the bonding 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 likely behind the step and if the pre mixed flame fuel and they are coming together, but you have hot radicals here in either case some scenario like this would be would be valid. 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, so yes.

It is possible another possibility is, you can change the what is being injected the distribution 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 each reflector 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 means stability happening. It is a very good point any other questions? In angular combustors what they typically do is they would have different burners located along the angular, so there will be a number of burners you can have can burners or you can have just angular thing. So, you can have several slow burners and not necessarily backward facing step, but often with they may have a step also, but there will be a to have rapid mixing and so on and that is possible, I mean can is of course there, but the I mean they are crafted engines they are under them.

So, there strategies could work anything else, so the 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, I mean now to the development of large scale coherent structures depends on the relationship between the acoustic velocity and the flow in stability frequency. So, if the acoustic, sorry acoustic frequency, the acoustic frequency is very away for 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 very coherent and you can have very large amplitude fluctuations, but if you are having a cold flow there is combustion the vortex itself. You 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 a sustaining this in stabilities of course, the vortex related in stability like for example, flute or some thing where you are actually having vertices and that is actually producing sound and you are locking on to this frequency of the pipe and so on. Which is the roughness in the float, 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 trivial flow.

So, you have this and the vertices are being converted down and the combustion happens somewhere down and the vortex is being converted down and the molecular mixing taking place. So, just as when the molecular mixing has happen adequately it burns and by then this mixture would have been brought down from distance, so that decors the location of the heat release like here in this region weight term .

So, the acoustics kind of reinforces the shear layer and the structures in the shear layer and the combustion is related to this 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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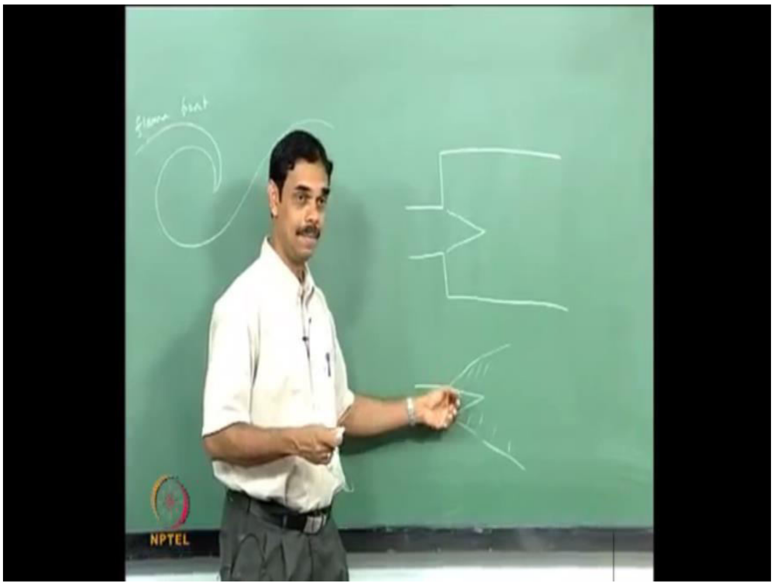

We would tend to think that there is flame like this and when you have a jet you tend to think that that as a core and there is a entrainment region and there is a core and the mixing region. These are, I mean yes in a average sense this may be true, but in reality I mean it is very far from this like 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 bulls and burner flame or something like that, but not in a real combustor.

You would have, if it is coming at any serious velocity and you would have a vortex roll up the combustion would be periodic and if you have a jet, I mean jet will have vertices and it is, this is the if you time average over a large time they 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 model the combustor and any combustor which has been built of this sort has had in stability under conditional color.

Yes, can you replace the question pulse combustion behavior? I do not know, what you can you restate your question? I am not quite understanding. You are asking whether hydro dynamic in stability or coherent structures are a necessary conditions for pulse rating and in stability no. It is not necessary at all we showed example and I showed of wiki tube and also a bulls and burner flame that 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 then also, but there it was not really a necessary we still had in stability, but this is another mechanism which comes into play not in those simple laboratory combustors, but more like in particular combustors where you 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, it is there is a serious mechanism which can drive combustion stability, but this is not the only mechanism drives in stability, but there is a pretty serious mechanism which is real which is there in practical combustions did I answer your question? No, perfect engine is a kind of pulse combustor no, it thrives stability because its self aspirating , so you have, it is like that in the laboratory.

We should a jelly jar combustor where you have a feeler mixture, it burn and it again entrain mixed and then burnt. So, similarly pulse rate engine, it entrains, it brings in air when the pressure in combustor is low. It just takes air then it burn sends the thing out and in that process generates the trust then pressure comes down it valve opens takes in air. So, it with long bark it does not compress it right, but it would not work without the, without the, without the pulse rating and in fact four people were trying to make very small engines, micro engines or whatever they of, this kind of a pulse rate is a possible option because you have to make a compressor at that stage would be quite difficult at that small size.

So, basically it is not the vortexes that are no flame is being held by the recirculation 0. So, we have to have a low velocity zone to have the recirculation zone, so that is the purpose ,so the we are not having the recirculation zone. We do not need a vortex to hold the flame, but we need a low velocity zone, but we also want to be a greedy, we want to pump in lot of mass flow in it. 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 vortexes 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 the there will be interface between high velocity and low velocity zone which is the Sheeler 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 cross this over take shading and vortexes being shut that is by definition unsteady phenomenon and then that can carry the pocket of feeler 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 few dynamic and combustion interaction. This heat release is periodic and pockets of high temperature flow are converted down stream form the burner exit and people have measured this, I mean they have in the experiments with planner lazing experiments with that is the laser diagnostic experiment.

So, you can illuminate the region with some kind of laser like u v laser which is tuned to o h radical and look at the emitted signal from the fluorescents. You can do this with high speed imaging, that cameras can image things at several thousand Hertz or Hertz and 10000 so on and even before this ccd cameras came people where doing high speed film cameras and have do this in the 80. You can also see camera luminescence all the cameo luminescence has a line of certain as suppose to planner laser induced force in sense which is a technique on a plane, but still you can see all of this with cameo luminescence 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 a also this in a interaction between what do you say interaction between vortexes and valves and all that which is quite complex. I can write a one dimensional model for these things understandable because you have to solve some 3 d turbine 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 200 and 50 references listed in each of them that will be a good idea.

So, the high strain rates and the concomitant small terminals generated by the merging or process of vortexes creates intense turbulence and it will accelerate the combustor. So, the process may reinforce the periodic heat release of a forced reacting shield layer. In the sense you are rolling up and burning, but that burning does not happen as it rolls up nut then as it rolls up at some time everything would have completely mixed because of this fine scale turbines and bang it burns at that time. So, it is rally 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 if instability the another cause of sudden heat release rate in which is seen in bump 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 a low step site what happened is the developing vortex down streams. The combustor can get impeached 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 more in stability try to go a picture.

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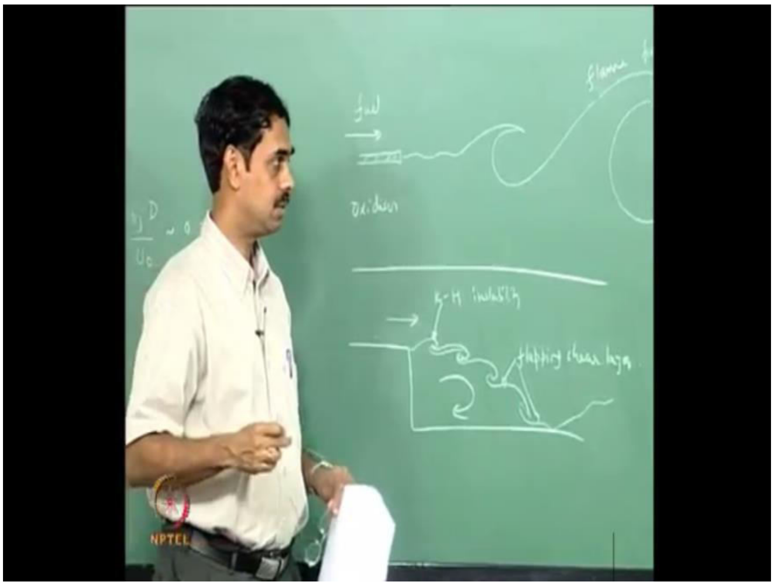

So, you can have either a pre mixed or a diffusion flame and either weights coming this way I mean, so you do have a Kelvin–Helmholtz instability and fluid mechanic people often call it K H instability. Then, you can also have this flapping shear layer and that is another kind of instability and both. So, it can start off with the K H instability, but then you have a 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 vortexes.

So, if this, if I have a no, it is rolling here, I mean it is unstable, but I 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, I mean, see you have this with out interacting with the wall, but if this some at some small enough step height it could have this can actually go and the wall that is a distinct possibility. That can be a interaction between the Kevin-Helmholtz and this step mode or flapping mode itself Kelvin-Helmholtz.

It will be a complex . So, you have the developing vortex go down stream of the dump and imp inch against the wall. So, again imp inch is a very crude term, it is like on 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 imp inch does not mean, it just goes and bang hits. So, since it downward velocity of the vortex id large a vigorous mixing occurs between the remaining un burnt reactions.

The combustion product again leading to a sudden heat release as the flame at this mixture approaches the wall and the energy supplied the acoustic field because the heat release oscillations. 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 by the 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 the 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 any other those space combustors.

They are short, yes depending on the flow velocity the purpose of the combustion and it depends where the air craft 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 the combustor is long by the time vortex reach. The exit nozzle dispersion would have set end 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. It is nice coherence and come and impugn the nozzle, so at that time the strong mixing between core reactor and the hot products will occur after the vortexes impugn on the exhaust nozzle creating small scale vortexes. this would be followed again by intense heat release in a short time and if it is in the right phase it can add in stability.

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 unless there is expansion of the gas across the flame and the vortex and the flame. There are in some sense coming together, but not exactly and then there is also a further more density produced because the pressure gradient may not be aligned with the density gradient.

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

Then, it is, if it is completely combustion, it will break down into fine scale terminals and small vortexes also. It is possible, so several scenario is possible and like I told you, I mean they have in that other paper by the 1 by Reynard it orbits 200 and 15 references. They have given lots and lots of ah possibilities and experiments studies and numerical calculation explaining over there.

So, I mean, it is a very complex topic and I cannot give a simple one dimensional model about this. You mean out of the knowledge, so it can it depends on the amount of dispersion and what happens when it impeaches it. One possibility when it impinches 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 vortexes are not coming in isolation they are coming in a highly complicate floor. So, it may be possible that, so high temperature pockets call fancy name would be and trophy 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 I this thing is going to go through a nozzle then what happen is as the hot spot goes through a acceleration.

It is a possible that it can generate acoustic waves because there is a you are having entropy mode generate acoustic mode because of a non uniform base flow. So, in entropy mode and acoustic 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 possible 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 , not necessarly it can be bad mixing also, but this I mean this is a fluctuating heat release. That is a, but it need not if you have bad mixing you can definitely have that and that can also go through the nozzle and create a acoustic base, but yours is specific question was if it comes to the nozzle, will it go through? If goes through what happen? It is a three dimension, no. Can you repeat? It is a video asking very deep questions. So, I have to pay attention, no.

You can have Kevin-Helmholtz instability for lamina or lamina shear layers also shear layer will be unstable on roll up. It will in practical combustion, but you can have it not break down also still be given Helmholtz himself. You have a Kevin-Helmholtz instability why would there be small scales like small scale mixing.

So, it is in a terminal flow terminals has all the scales, so there is a possibility that when you have terminal. Say 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 vortexes breaking down to small vortexes extra that can happen if you have high velocity gradients or if you have high strain rates. You can have small scales, but it comes periodically then break down. So, it is periodic to being with start with the last coherent structure and then it breaks down.

So, you cannot get rid of it. You start with the shear layer here and the vortexes 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 breaks down after sometimes. So, it cannot break this big structure to begin with. There is no combustion, so only after cooled down and after we have small scale terminals. We have a, we have combustion. So, if that is sufficiently part from this instability. Then, I should not because the whole thing is starting with periodic is not starting with the whole.

Then, if you do not have the big scale and if you have small scale terminals right from the beginning then you will have continuous combustion, but it does not come right from the beginning. If, the fine scale terminals is happening as they over take this roll up as they initially. 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 terminals will be minimal.

That is, what is 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 it is I understand that still there lots to be done and it is a very intense intensely debated research topic, very nice if you are driving at a very important topic 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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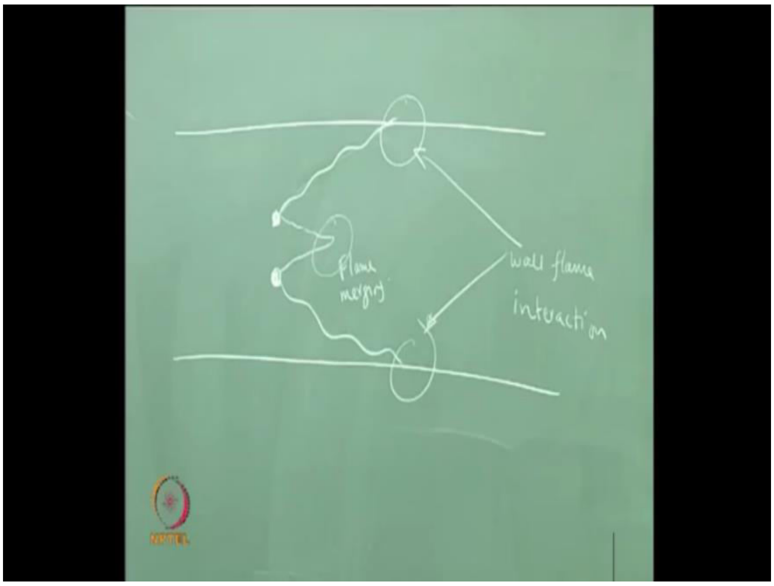

So, this is a example given in this paper by Woodward and Taylor. So, you have combustors flame holders. Where, there will be a multiple shear layer interaction is a likely source of fine scale mixing and hence leads in sudden heat release. So, during on cycle of pressure oscillations you have 2 vortexes of opposite sign shut symmetrically from both top and bottom surface of the flame holder. As this vortexes convert down they disturb the flames surface and cause flapping of the flame branches, so this distortion will result in oscillatory increase in the flames surface area and hence results in a oscillatory heat release rate.

So, this surface itself will start flapping an 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 a in any case some kind of un steady heat release rate, but in such combustors the flame will be some what long and there is a possibility that the entire flame may not have the same driving or dumping 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 really said. If, the heat release is in phase with the oscillations. Here, acoustic driving if they are out of phase they are acoustic damping see you can also have a very high strain rates causing flame extinction that is the another possibility. We also have this barrow clinic, barrow clinic vortexes production because of the miss alignment between the pressure gradients and the density gradients that occur during the roll of flame, so things complicated the analysis quite a bit.

Now, I want to talk about another in stability another example where vortex rating can cause some kind of instability like dynamic instability, but happens in combusted in solid rocket motors, is it an external agent? That is heating an acoustic or it is the combustion where in this cases the acoustic itself is not strong enough to create a feed back, but you will have some sound. You put a micro phone you will measure, but it will not be strong enough to create a feedback, but in these examples. So, the wood is it just modeling the modulate the flame and that causes the periodicity.

So, let me pack the I will 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, if you are actually producing a coherent structure about 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 rough this blow. So, you have vortex rating, but there is some kind of feedback with a rotator, so if you have may I should speak about that rockets itself .

I will speak about rockets then talk about aero dynamic heat stability 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 will speak about aero dynamic generation of sound and I do not have 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 aero dynamic sound is produced by vortexes when the vortex has a trajectory which is perpendicular to acoustic string. So, here the almost resonated at this bulk oscillations which has a 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, but there needs to be some resonated associated whether and this coupling has to be strong. Then, you can get it and that is one possibility is you see in link or another thing in flute and song, so in general there is thi s mechanism called a lock on, lock on.

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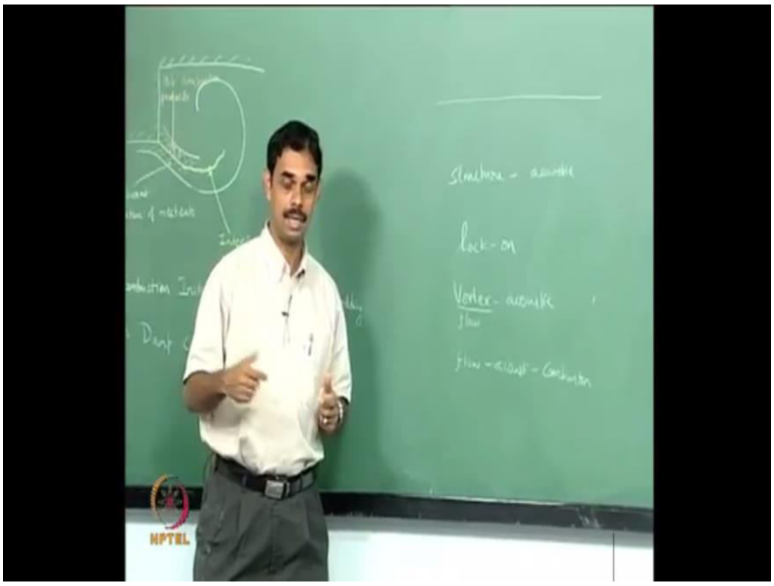

So, we are taking about vortex acoustic or flow acoustic and there is flow acoustic combustion, so all three cam lock on or we can have structure and acoustic lock on for example. You have cables and water and then this 4 on them and then this flow around them and the cables will vibrate because the vortex. 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 aero elasticity where the vortex shredding locks with this structure, so if you are having 2 different resonance for phenomenon couple with each other and then that leads to large amplitude that is the general class of power.

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.

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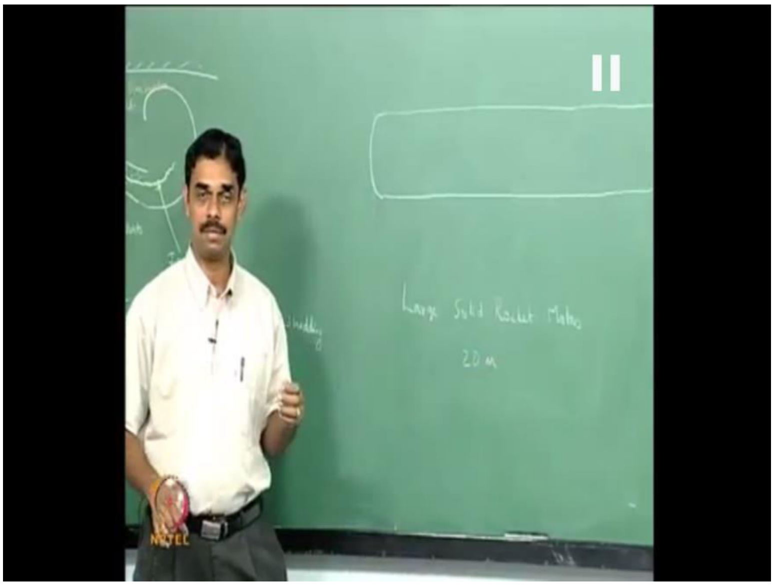

We look at large solid rocket motor, so large solid rocket motors this specifically I will write this and I want to emphasize this word large because large solid motors are casting segments small motors like the once in small missiles. They can be cast in one shot, but if a very large rocket motor.

Let us say, typically 20 meter or, so it is very difficult to cast in one shot because by the time you pour the propylene. It will take quite sometimes, you can imagine to fill up 20 meters or something with 3 meter diameter with proper index. Something like it over 200 tons of something being poured and it is going to take time and by the time you are still the bottom would have said you are still pouring in the top.

So, this can lead to stress and the propylene 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 its quite possible that you may have segment less motors which are twenty meter long, but at the moment they do.

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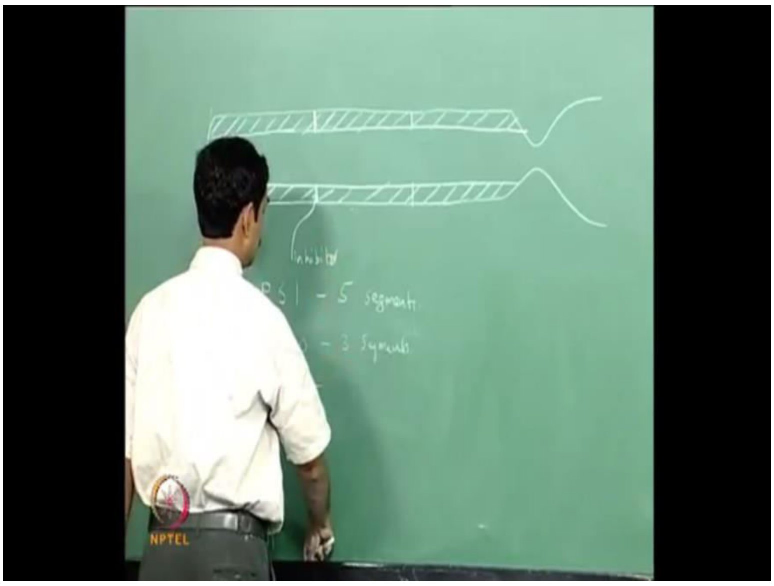

So, what they do, is you cast this motor into segments, so if you have the gradient. This way and this is the propylene this would be cast and segments, so they say this is 1 segment and this is another segment that is it we put 3 segments. So, if you remember the P S 1 has actually segments this is the motor which is used in g s l v and p s l v. The new motor has building called s 200. This is a 3 segment, I think aliens 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 propylene 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 that. Then, eventually the you know in a solid propylene the propylene itself is insulating. The outer casing structure as we saw in last semester in proportion class, so we want the propylene 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 this 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, now it is almost like some dis or odd phases inside a tube and you have vortex shearing.

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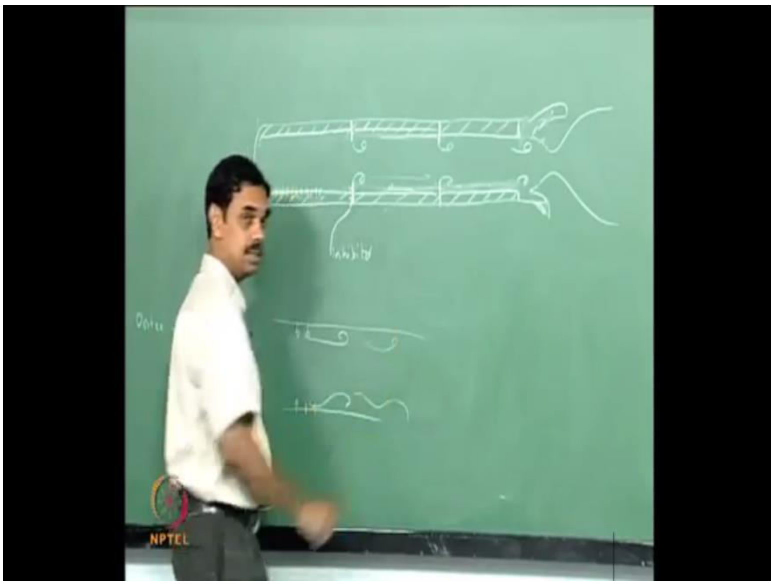

So, this vortex that is shear will come back and come here and right as it comes. Here, the next one may be shear and as it comes here and imp inches. Here, you send a acoustic wave back and this gets into a feedback whereas, so normally it shows some frequency, but when you are under the lock on lock on circumstance. The acoustic wave range forces the shading and then you get loud amplitude. See, you can have if the 2 you can do this at home put 2 washer in a pipe and blow air you will get a nice and another possibility is if you have a 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 Jim Belling mechanism there will be some space provided here. So, what will happen is this vortex, so this is where the Jim Belling mechanism this vortex will travel over this cavity and then it is like my blowing out of the bottle, 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 the 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 possible to create enough damage, so in this case even if you do not have any combustor just the aero dynamic instability itself may be sufficient to cause some problem. So, we have t check, if 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 I mean the motto is, but anything more. I think motto would be unsaved, so here is another case where this coherent structure is creating problem, but this is more like a aero dynamic stretch ability. So, you are not having the combustion is a happening just over the propylene surface.

Now, even if you do not have this inhibitors. If you have radial injection like a I mean propylene burning is like a radial injection. So, if you have a situation where you have gasses coming out this way eventually. There will be vortexes being setup because this flow is a inherently unstable flow radial injection flow and even if you do not have vertices and if you have jim nozzle and there is a cavity.

There is a possibility of making sound, so I will give another example which is down aero spacing we have gas lines I think in all the countries this is I mean natural gas is a very big source of energy I think there lot of natural gas. Now in Andhra Pradesh I think that is being discovered some years back, but we are 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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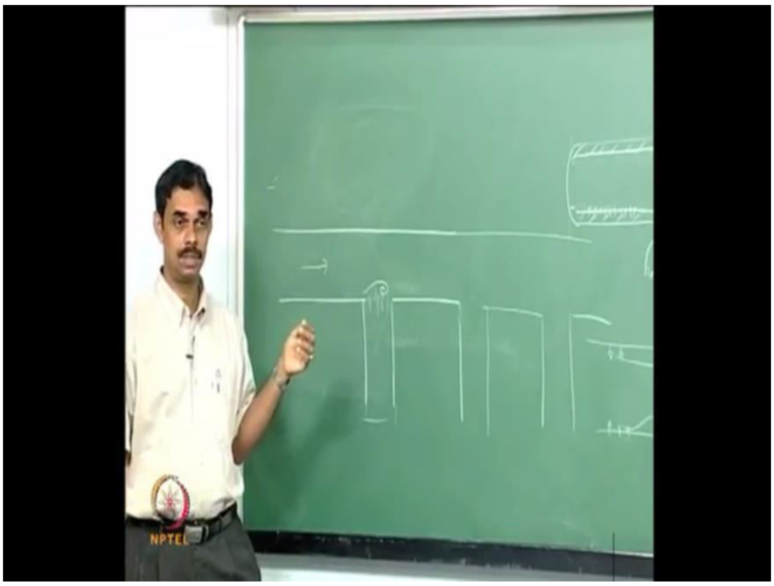

So, you have big lines this way and then and you have branches and so on. This lines are very long and sometimes people some braches may take more gas, some may not need gas ,some may. Sometimes, they if you the moment you close some branches many times actually in stability develop because you have a vortex shredding. Now, you have like a resonator here and then you have very large amplitudes and quite strong and the tubes are the ducts are very long. So, hence the vortexes are strong they can travel long the sound wave will travel quite long and as any sound wave will travel.

We discuss it steepen into a shock, so you can have large amplitude shock waves coming and destroying this structuring this pipe lines and so on. So, when you have natural gas, natural gas being distributed this way in. So, 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 would take will be disrupted, but if not I think you will a resonator here which and the vortex is crossing the lines of acoustic string lines.

You have, you have large oscillations and then you can cross lot of damage to the pipes 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, but 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 the 2 possibilities 1 is to 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, but you can have also. 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 Shabirsh asked. I will take 2 minutes more.

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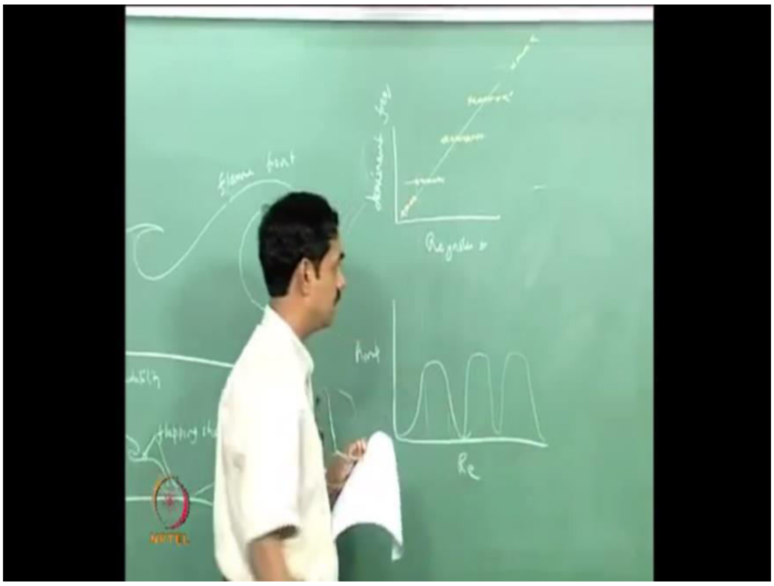

If, you have a class after this, it is ok to go. We will plot dominant frequency versus Reynolds number and amplitude versus Reynolds number and if, so typically the vertex shooting frequency would go like this. It will be like you have a we saw there will be like a number of 0.25 or 0.5 or something and you have, 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, so the you will have initially the frequency coming up like this and then you abruptly it locks to here and then you come to jump to the next branch. Of course, there will be some resistance and then you go here and eventually it cannot block any more, so you continue to 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 withdrew here. Now, the situation in a combustor will be different I will take about next class.