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Acoustic Instabilities in Aerospace Propulsion
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Lecture No - 18
Effect of Heat release on the Acoustic Field

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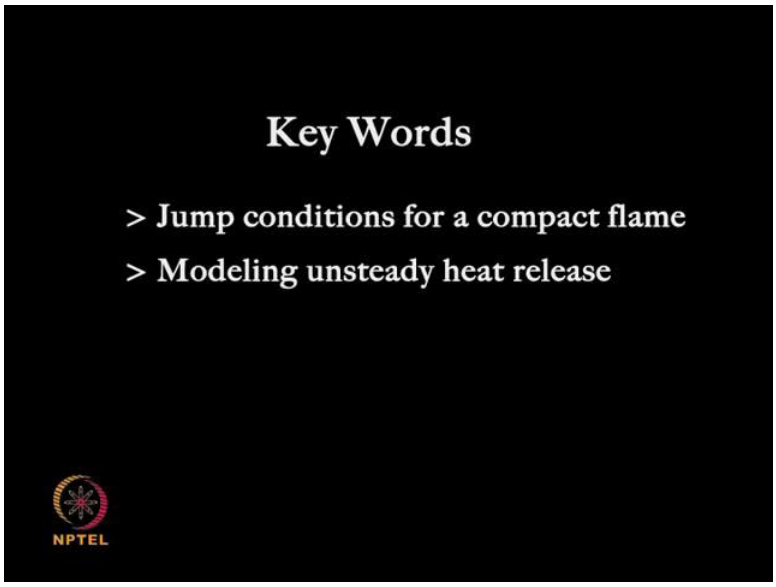

Good morning everybody, we are looking into thermo acoustic instabilities or combustion instabilities. And the earlier work in this topic was perhaps on solid rocket motors and liquid rocket motors and instabilities that occurred in them. Instabilities occurs when your high performance system so, the initial high performance systems were solid rockets and liquid rockets and also after burners of jet engines fighter aircrafts. And of course, later on as you started getting better, performance other devices such as: boilers furnaces and land based gas band engines which came towards 90s. And you started getting instabilities in these devices also, much any confined combustion system as combustion instabilities or some acoustic instabilities.

So, this leads to solids this two instance oscillation and that can be intense heat transfer to the surfaces; which can even lead to sometimes bridge of the combustion wall, in some extreme instances we can have excess vibration and lights come out and nuts and bolts braking up and so on. And, we can also have things like: a change in blow limits

and so on because, the dynamic when the instabilities blow of limit may change. And of course, we saw that we count along with the may be making slide design changes which, will interrupt the coupling between actually heathen is right and the acoustic field.

So, we can have changes in fuel injection distribution pattern if there are bunch of injectors distributed in certain way, we try to redistribute the injectors. We can try to change the injected characteristics itself; so, these just involved change in one part and not really change in the entire geometry. We can also have the change in the flame holder geometry or slight changes in position of the flame holder geometry.

We can of course, implement damping by things like liners and so on, which will absorb the acoustic energy and we can effect changes in of all dimensions of the combustions and we can there by effect the time skates. So, if you alter the length we combusted perhaps we can change acoustic time scale because, the length that the acoustic waves travel will change.

If you change the flow passage dimensions; we can change the flow velocities which will change the hydrodynamic combustion time skates. We can also, perhaps alter the fuels slightly and fuel composition slightly and so on. So these are the different strategies, so people have evidently had success in dealing with instability which is why rockets are flying and engines are working and power plants are making power and so on.

And now here this has come to be very costly and time consuming and we need a ability to predict and eliminate combustion stabilities. If possible a priory but, I think the subject is not at the level where, you can predict everything uploading just like: you make depredation of flow, you can have the prediction of the combustion dynamic characteristics at the difference stages itself and you can alter things during the same stages.

So that, we can have or you can ensure that the combustion stable prepare time to do that but, it is not reached the stage so but, that is where things were going it we may get there in 5 years or 10 years or 20 years I do not know; but, we would probably get there. And, we looked that what is called really acrostic of this says that when the unsteady heat released rate is in face with the acoustic pressure. You create acoustic power and we create we add energy to a system and the amount acoustic energy increases.

So, if this is more than the amount of energy that is arrange to the acoustic field is more than what is lost to the boundaries then, we actually have growth in the oscillation amplitude and we can have onset instability. And we derived a criteria with allow assumptions but, we still showed that this pressure should be in face with heat release where, for the acoustic energy to grow this energy is added to the system. It is more than what is added to more than what is lost. So are there question this is where we stop.

Sir we considered driving because of heat added to the sytem.

Right.

Is there any practical scenario where some other mode driving is there? Yeah, absolutely fantastic question there is one scenery I can think of a you can have a entropy sports entropy sport means, temper hot spots. If they are coming in and going through accelerating through a conversion nozzle or conversion divert nozzle as the entropy sports it does hot spot created in the combustor and then that accelerate to nozzle.

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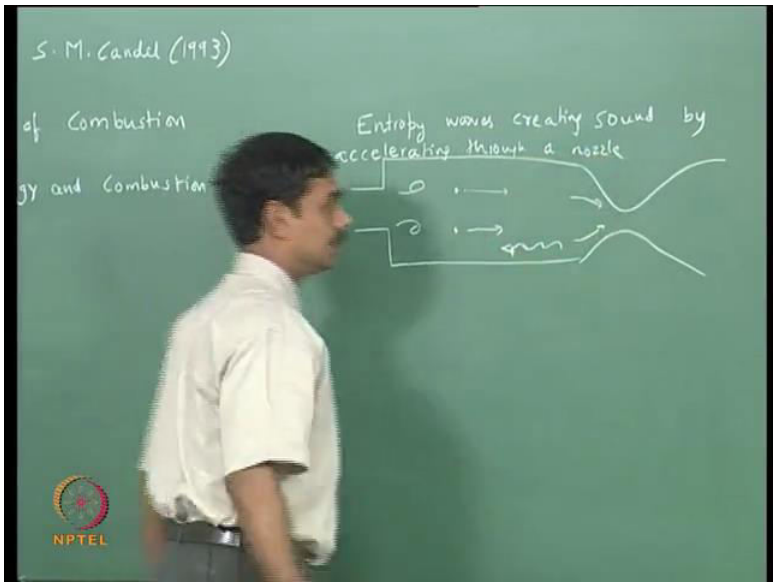

So, let me draw a schematic estimation of let say his is a simple combustor there is a nozzle. So, you have this combustor happening in this and let say the some hot spot here, and they convicted and they convicted in the speed of the base floor an d a mean floor. So, this is a practical example of a this situation where the enter preview is getting couple with the acoustic wave. So you have a enter preview coming because there can be

hot portion you have vertex and burning happens there, the core may be hotter and of course, there will be dissipation, dispersion the uniform. So, it question of the time taken for the aerodynamic dispersion versus the time it takes to get here.

So, if it survives the hot survive and gets to the nozzle then we have a acoustic field and then, this can there can be feedback. So, this is not a pure thermos tic mode this is like a entrapped generate acoustic wave and this can have instability. So this is the one mechanism the other mechanism where, if your oscillatory mass addition like in the case of a: solid propeller and rocket motor, you have like a oscillatory; you have in a solid rocket motor. So this, let me say entropy waves creating sound by nozzle.

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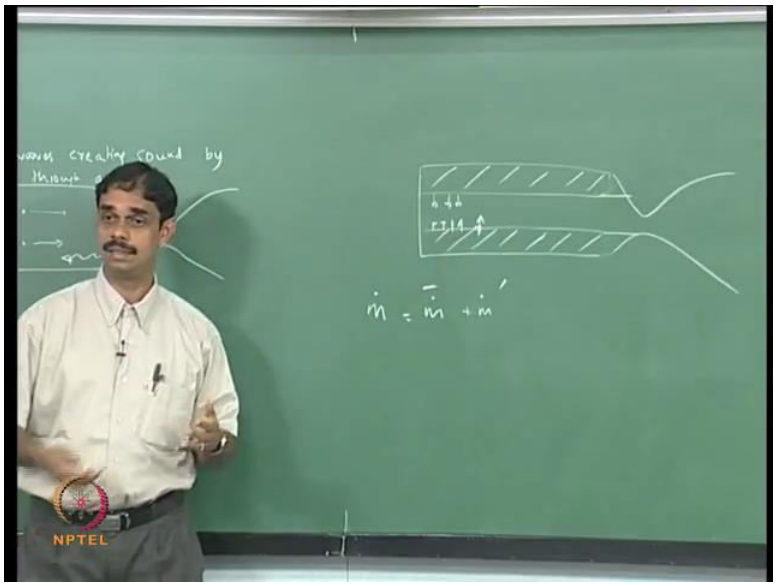

You can have other situation, let say we have a solid rocket motor this drawing is simple schematic, now you when the solid propeller is burns it actually the solid paralysis is combined and then the gas is produced. So, that is like study mass addition in the compensative. But, when the acoustic acceleration this paralysis and the combustion they rates get alter and you actually have oscillatory mass addition that means, there is a study mass low that is: m dot is equal to m dot bar plus m dot prime.

And this can in the produced driving. So this is like energy put in directly from the sites so, this not a while in term but, driving term coming from the boundary. This is just like a loud speaker where it is actually sending in volume of gas or mass of gas and fluctuating volume. So, this is un login situation, so these are two example where, may

could be many examples there. So where it is not daily instead a heat release right but, study mass addition here, (Refer Slide Time: 05:07) here there is enclosing to accelerating to know which is produced or produce nozzle. I hope this answers equation, anything else.

(( )) only when accelerating to a (( ))

When you have a uniform mean floor then entropy and acoustics are completely independent they can be completely decoupled. But, in a presence of a very non uniform base problem it means flow then they get coupled. So needs something to couple a this modes so actually, the presence is a big way of couple in this thing could other way this way of purpose, anything else. So, now we look at other things it associate when it occurs the is a growth an oscillations.

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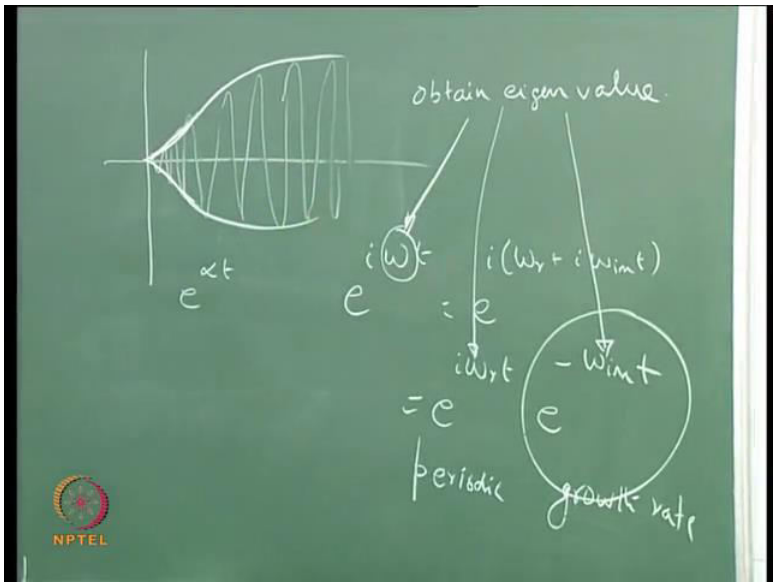

So, if you have if you look if you have plot, let us put a it is a piezoelectric transform in micro for the combustor. And then you see isolation they actually grow and then eventually perhaps level of so, there is a growth wave according to linear thin they can expansion growth. And we saw that we have e power i omega t any conference the you can write i power e trans omega r plus i omega inner t e power i omega t, which is periodic part and e for minus omega minus t.

So, this is the growth rate. So, the idea is we want to simple way do this very simple model and hence if you see obtain a procedure to obtain the i give value of omega for a combustor. And we obtain i will manage to problem to putting bond relation and to solve problem to solve that way become in the periodic part you can have frequency and we will determine in the growth rate. So that is the objective that we having the we will proceed to that ok.

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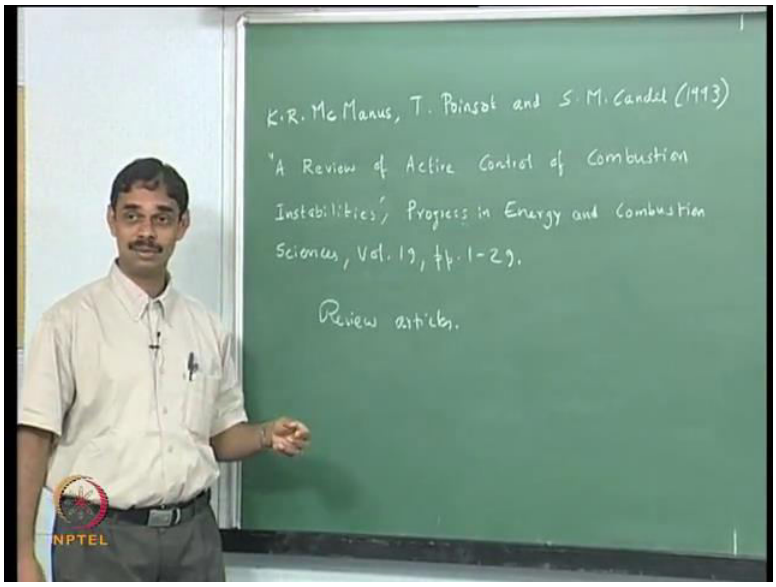

Here is reference of this subject we have review of the Mc Manus, Poinsot and Candel it's a 1993 title paper we review of active control of combustion instabilities in journal progress in energy and combustion sciences volume 19, pages 1 to 29. So, I can give the paper and this journal so, all the journal one of this need by you progress in journal and then, by that is publish journal original articles. But, this journal progress the energy and it is the combustion sciences have volume also get it through science direct; you can download this article you want to issue. And, this is a journal which gives review articles.

So, review article means lot of things and then lot of the subject and then somebody consult and said this is the way we have, this is where I think we should this is the way have and should i solve we should happen. So that's when some development is happen for the book in the inner for non to get development is happen to twenty percent is solving you. So, see you have new student in the subject first is should go combustion

and the combustion science proper look at review articles for the your topic and the study them ok. And your text book is wonderful and your new text book this is the best way and review all.

We did make larges in the associate some other say interesting and what i could say in the most of you predation because, I want to say together that the base answer we want to say fact to this. So, we want to get tractable way problem we can actually tractable will do then for understand. And then once you understand small problem and then you solve big problem make we can complete, we can complete our fancy laser of diagnostic of solve tractable. So tractable problems are you think you see you can deal with so, as I mention if you want if you want I think it is solve reality itself which then you absolute complete.

Because, then you have a big sense complete the even if you have all this sensation in the world distribute form of shows because you have come to study all the state. So we have to construct model which represents and reality for the fantasy where did i tried written to where then it is have a representation of reality. So when I say review of from the broad crop it is actually, it is like on a lot of view about completely I have a bad something good in something. On Monday i have a view good, Tuesday is a very bad, then Friday is a medium i have very impact. Students are very good on Friday is and cause become a Monday and changes also, me may be some may be good in morning did expiry sleep in morning.

But, then we lump everything and say ah it wanting and we say o k this is that obviously it is a nice guy, obviously is a nice guy. So it may be nice sometime or may not be nice so i make a model of or you make a model of omega. Does it properly? Yes or no as a augmenters as it is a too many variable that you cannot describe, so you just distrait what on all thing. So we say that Kerala is rainy Tamilnadu is not rain, it is not that it does not rain somewhere it does rain as that it not rains all the time in Kerala.

But then, we just make a model that Kerala is rainy place is go there umbrella and when you come to Tamilnadu ok you can leave the umbrella hope somebody else can use it, you do not need it. But, it rains so we try to simplify i think so, that we can get on with lives otherwise things are so complex that we just cannot get on with lives. So its

important the model and then you may say if models are so nonsense what is the use so it helps to deal with situation.

for example, when I came to Chennai as a student in 1984, I decided that it was not but, bringing my umbrella I thought it would it is best to leave it there; because I heard from somebody said rain lies two days in a year. So I thought why bring it just leave it home so this helps you do or if you say that so it is particular than you can skip going to class; you can take some other area. So, it just helps you to deal with lives so of course, you can deal with something that may be right or wrong now if it turns out that I am a fantastic prof and you top my class that may be mastered.

But, if you made a model that I have a fantastic prof and you come here and you see that I have spoken total nonsense then, ok you made a wrong. So, all models are wrong all most are need complete but, if you is have wrong is wrong or how right is right or how useful it is in our business. And what is of use may be a different on I it depends on the person it have, so, I was last week saying some combusting civil the data. And this spec table data was jumping up and down seeing this data and to many it is very useful because, you know it enables we to study all these things at that facts.

But, to the person who was designing the rocket and trained to make the this team, for them it is not interesting at all it is disaster for them. So, it depends on what the useful depends on ah what you want to what is your objective what does it do and want to accomplice. So, if your idea is to demonstrate some simple principle or to demonstrate what are the steps involving then a tractable problem good.

If the idea is to make predictions may be tractable this may be bad because you may be throwing the baby with the bathtub some will have many so, you may have a simple solution. We have calculated the answer it may look elegant but, generally elegance solutions that is saying ah all the good solutions have elegant solutions but, all the elegant solutions need not be good many of them are wrong. So you can construct elegant solutions with a wrong and so on.

So we have to be and sounds like a philosophical boring talk but, this is very real because you have see a combustor making sound and you have to predict then, you have gambling and you have to go with and you want on one hand want have the answer. But, on the other hand if you don’t want to have wrong answer but, then do you have a wrong

answer rather than having no answer at all. So these are the issues an engineer has to make up so you have the engineers. So I think it is the important to be able to understand to appreciate this philosophy. So I will make more simplifications so on simplifications you can do is that the heat release happens in a compact zone ok.

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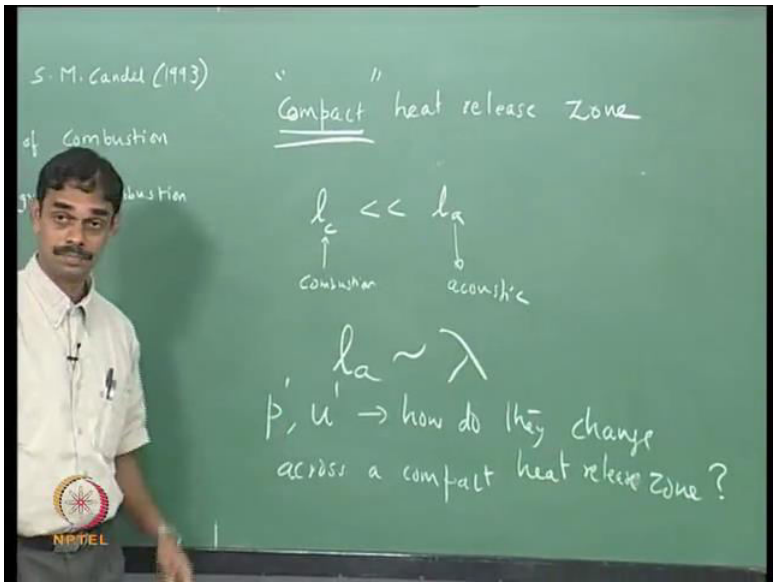

Keyword here is compact, so compact would mean that lets say the combustion zone is would be oh of let us say length b. Let us see l combustion is yes this c stands for combustion and a stands for acoustic and l a is of order of the lambda. It can be lambda by two for lambda by 2 combustor lambda by four for the a co order just viewed tube or 3 lambda by 4 co order. But, it is of that order but, the combustion sound is often may be 1 10th of the unit or much smaller than that, it can happen over a few centimeters like or even millimeters. So, it so this is a good assumptions to make in some combustion it may not be good but, we try to we are looking for some simplifications.

So we will pretend for a moment that we have a compact heat release zone and such things do existed, then if you have this assumptions then lot of things simplify, so this a good simplification. So, let see what simplifies when you have these assumptions. So we want to see what happens to acoustic pressure and acoustic vilest across a compact heat releasing. Ok that is the question, so p prime u prime how is they change across a compact heat release question that I have want to ask any question.

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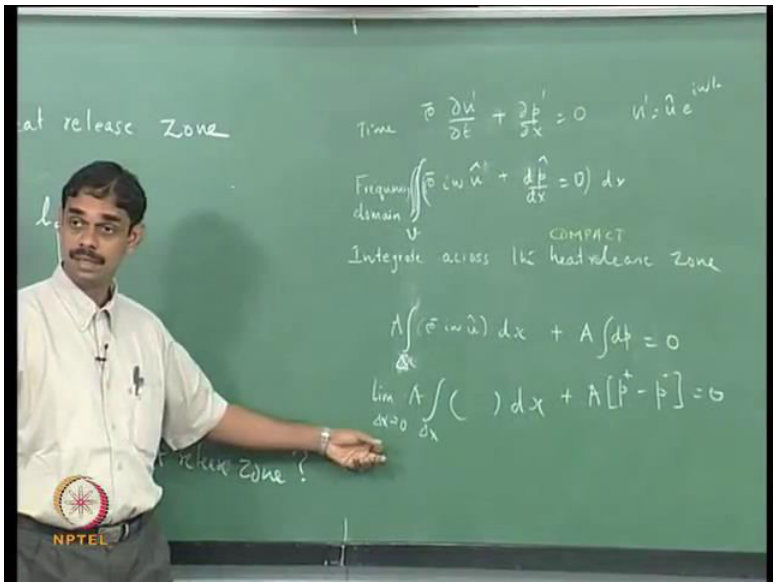

So, let us start with the momentum equations we do momentum is this right, so we can do things and frequency domain we could we simplify things. But, the same analysis can be done for time domain o bar i omega you have plus this is in this is time domain; this is in frequency I have substituted q prime is equal to you have c for in to omega t. So, and what I do is to integrate this equation across the compact heat release zone and I have to remember that I am having a compact it. So, what I do is to it is to a volume intergrowth so you have of go bar i omega you hat d x plus.

So, if you have won devotional compactor this will be integral over existed times area. So I can say I can recast this I can recast this in to integral overrule some links of the compacts the won and up multiply but, its area plus a time intergrowth d p by d x time to d x. This will be intergrowth d p right this term can be return as a time intergrowth d p is equal to zero. The integral d p is a time p 2 minus p 1 of p plus minus p 1. Now we will take over limit of delta extinct in to 0, you say this limit of delta extending 10 into 0 means compact it heat release zone I am.

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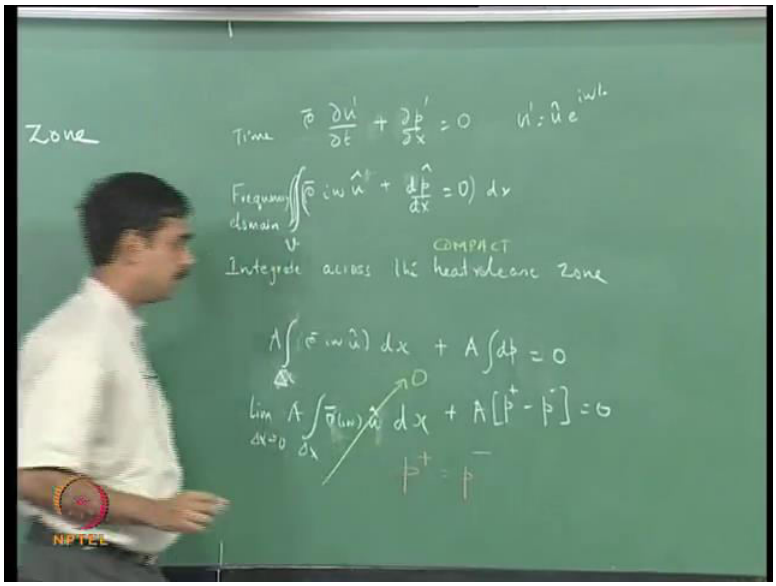

Let us think of let me draw a picture so, this is the acoustics known quadrate and you have delta x and this is the compact heat release zone. And I call this is minus and this is plus I mean integrating across this ok. So this is this is the geometry under consideration so now, you have a find at quantity here if we lock at row i omega and you have there are there all find in thinks, write them here o bar i omega times hat. So if you integrative the find out quantity over a infinity dissemble in distance what happen, it got 0. So, this term can now become p plus equal to p minus that is the condition we get. So p plus p minus which means the acoustic pressure is continuous across a compact heat release zone.

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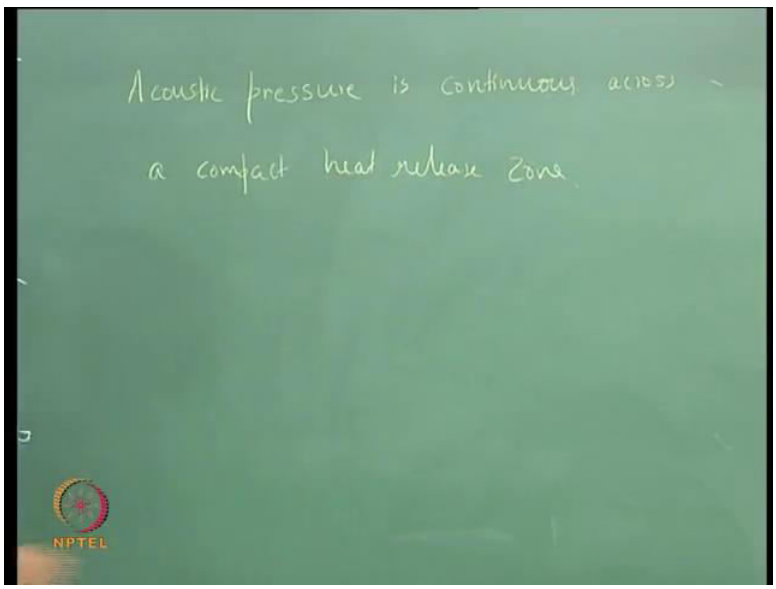

So, this is clear now.

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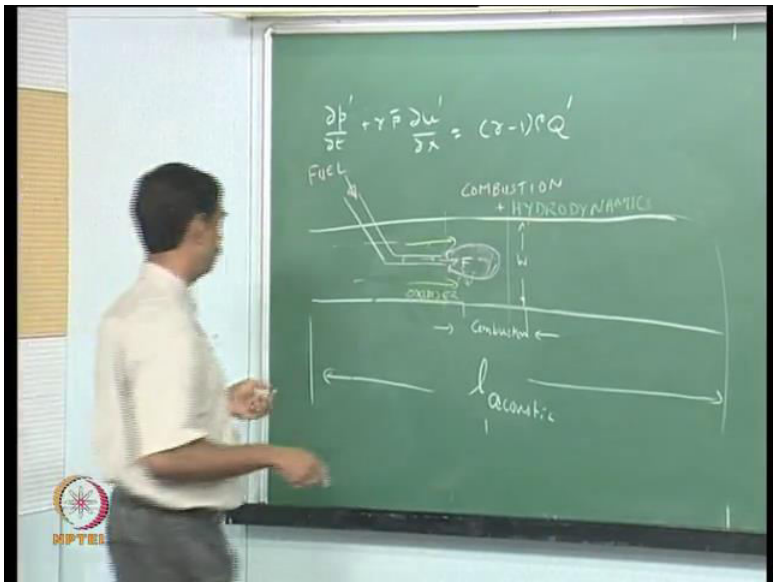

Now let us take a look at the acoustic energy equation. What is the acoustic energy equation?

Here we have (( )) in a high frequency gates (( ))

Then we can to apply this compact of heat release assumptions for example, if you are having bluff body flame, if you are having a bluff body combustor the flame can be quite long. It will be a cons tribute fraction of the combustor language; it will be cons tribute factor of the wave length. So this will be very bad assumption for a sole burner for example, the sole burner the kiddy sound very compact because the sole has intense vigorous mixing and it is very short, the flame is in the so, depends on the situation.

So, there may be so, if you have a like if you have a grits stipulated boner example we take a 2 like this. And I have force here small flame stipulated here thus should be fine but, it may flame is like thus this is like dot and this is the bad. So if have you deliciously, when you have this come back consumption then analysis simplify and there are situation where some valid. So we want examine resumption and I can teach you how to do non compact flame also you seen, this you first do the compact flame and then can be use it construct solution for a distributed heat release. So you have compact heat

release for verses heat leases and he can analysis can that also but, let us go compact and i admit complete that is not always valid account.

So we are not considering the (( )) we are considering the whole (( )).

That all release on reacting yeah, so that is where as the heat release happens.

So this can be, this i c can be (( )).

It can be its very recreation situation because so you have now am go to more detail you have so let us say you have some kinds of way and flame here. Now, ideally if you have ability to calculate entire thing then, we can use comparable equation this contains everything solve it non short and it we get the answer. But, enable to it do that call for simplification and even for if you have compute difficult to do combustible situation.

So, then we try to quite equation for the aquatic round which is of the order of the composter geometry and then we have to write equation for this composter zone. Now, again there is no comparison without hydro dynamics. So in reality here there is, so there is combustion plus hydrodynamics of course, hydrodynamics soon will be out of this. And this reaction may be happening for perhaps the length a flame at wealth in zone otherwise may be the turbulent flame or brush whatever. So with in this zone itself there may be more than own line skill and these are the topics of the color dresses.

So I am kind of the clopping everything into want bag round and so, molecular reaction will be happening but, this link but, then mixing and hide to dynamic both the all these may be happening in this life care. So it is not clear in some problems may be it may be find to have this two scales because you have heat release zone and the fluid mechanism happening over etc like these scale. And definition flame would be example like there, so if you have for example, this is reasonable contribution as a such things exit this skill be idolization for a gas.

So lets you have very nice question thanks fuel coming this way, this is oxidizer here and then there is if kind of mixing happen will be diseases out oxidizer diseases in. And per what idealistic sense you can say this climes stands in this sense. But, even if idealistic you can actually compute the reaction zone and perhaps flame may not stand little bit everywhere and there may be small there be here and we can calculate all this. So in this

problem the hydrodynamic zone would be of the order of the combustion zone because the this is the same reaction zone also here and its mixing happens that the what right determine step its probably slowly and reaction. And then this dimension will be the characteristics all this zone, it will called order of the bit of the bolstered there will be characteristics dimension for the dynamic zone.

But, if you have a premix flame on other hand as a really group you can one line scale for the hydrodynamic another one for the premix flame which may be by small and the may be premix have the for reaction zone and so on. So there term over 3 lines scales so the size nature of the analysis depends of the peruse nature of the power and there is no one short and one solution of everything, that is true for combustible. Whatever analysis do depends specifically particular problem there may be general structure for the analysis. But, the specific analysis like that one thing is there and you can plan different number in analysis the analysis itself may very different. Thank you ask for question anything else.

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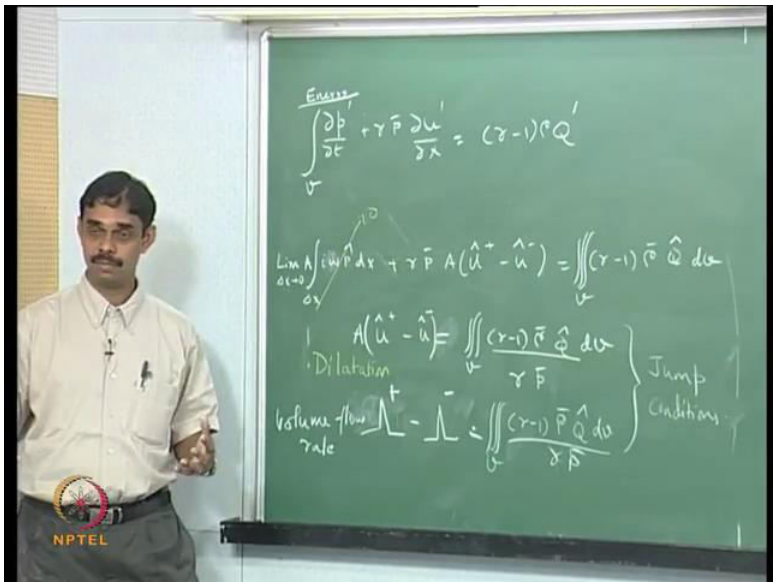

So we go back to our energy equation for, now let us do the same procedure here so integrate over this comparison volume. So this would be so as I mentioned you for a compact zone at extend 0 for this term will go because, your finite thing integrate finite quantity over a in front of us distance would be 0. And then you get to the accurate velocity jump across the compact strict reason here i wrote the fresher and go back here.

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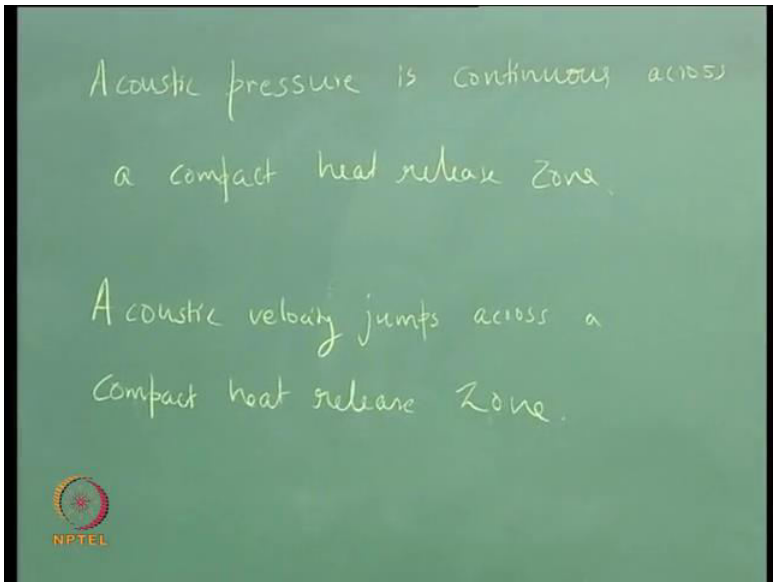

So, costing velocity jumps across the compact heat release zone the jump condition.

So, you have the velocity has jumping and p as plus is equal to p hat minus the pressure jumping a also called linear as ranking linear equation as also called the linear equation we can take the rank. But, can derive but, I derive the many more equity order. one more observation I want to make this define if I multiply I bring the area here. So I will here so that means the volume that volume flours jump across the plane a a u is like volume u times the area is like a volume flour. So velocity times area so this is like a solution we adieus what is the symbols let us call this.

So that means there is dilating the volume is for dilating the dilatation happening and this is what is source. So when this dilatation volume flour this is got a and the increase in the volume flour what happened this is like what kind of source bone of us. So, the plane x as a bone of us that is like a volume fluctuation equation aid lassies volume fluctuation bone of us for so, plane like a bone of us, hope this is clearly. So the next thing is we will as a promise in try to the model problem which is tractable and we will try to makes stability predictions so that is the next.

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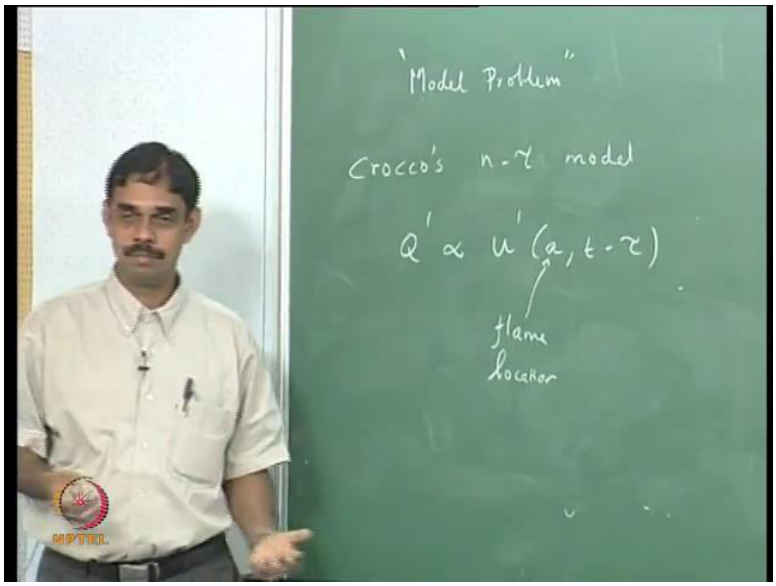

What is the meant by a model problem; you know what model, you know is what problem what is mean by model problems.

Something like the real (( )) not exactly real (( )).

Do you set of some problem a fictitious problems which when you study the problems and you hope that, the reasons you get mimics the some other phenomenon that happens in reality. So you have the thing and the control and it is a problem you setup which has certain resource which are mimics the feature the recourse which are mimicking phenomenon. So that will be a model as suppose to there is a and you try to model so, instability mechanism in real compares are very complex due to coupled reaction because everything in that couple.

And there are also inherent non realities in a studying the flow in a turbulent case thoroughly which is reaction and also the risk acoustic field a and all the mine interacting. So we have to do lots of implication get others as and the validity of the assumptions s depend on the, depend very much on the comparison system and the consideration. So, many cases the assumptions can give live to over simplified problem and that is real danger so for example, if we have a comparison an hydrodynamic instantly.

If you have a critical you have a back would facing step they whether is oat exchanging. And this is critically controlling the combustors the combustor phenomena and let us I have make a model which does not take this over take exchanging is phenomena at all. And then you can still get this is but, it may be wrong so it may not be applicable for making in a use of productions. So there is no universal model as wish no point that some time back everything depends on the.

So in this I might introduce N term model of crocco you might, so crocco was a professor from Italy happens to be the guide of my P. H. D time so moonlight my grandfather. So, what is he said is heat release it its proportional to the velocity fluctuation and this location requirements so that called a vocational climate that a a is to flame and time relate task. At some time which is delay come down at this movement we have lost the heat but, the heat release its movement does not depend on the velocity this movement but, velocity here withdraws some time back.

It is more like give you example you are writing in an examination today you are and the what is being is not effected not only it is not a cricket play but, what you did it yesterday for the quite seriously affects your exam performance. Because you study you do well do you did not study yesterday you are not going to do well in exam. So this is to do like a model you may be very hyper the position may be and you may know everything and you will be able to track the question belongs to study so am not considering such high funda students. But, am looking at personal like be if i was do well in examination am study the previously.

So my performance depends on what happened which some time delay let down like I do not know last night which is come to 12 hours or 15 hours before some like that. So this is something like this, so it is a simplification. What for like my model about examination studying depends upon certain class of people not applicable to hyper but, many for other people. So like than you make a assumptions and you see all models are wrong if I see if you say if you put thing that you are offended and if you do not have this skill if may go down also right and am.

So I did also there so any assumption can fire or back fire right and we in cricket also you see use you send some guy up the order and he swings the bat around and it just get overthrows or get goes like by. Whatever it make some runs and the captain looks like a

big hero or a he puts second slip in place and suddenly a catch comes. But, another time the same guy with the same fonder put the second slip in place and nothing happens all the guys who was who was send up ah he just swings the bat around and peacefully gets over the run in the fast ball itself, so it can go wrong.

So assumptions can fire or misfire or the backfire so it is the same with the theory as well as what is happening in practice and universal model does not exist just like a cricket matches. There is no universal way of winning a game a there is no universe or in exams there is no universal way of this q fire results. So you have to have a case by case basis or I told there is one way, if you solve the full compressible flow equations with everything you can surely succeed so same way if you were studying regularly during the semester abyss our you are studying and doing nothing. But, that other than you will succeed a but, you wont to take chuck converse and take risk minimize the studying time maximize the output that is just like me making a model.

So then you have to gamble and see whether I should study the previous day or may be previous day itself I am forgetting the morning. So I should gets up at four o clock and study if I use to do, so I gets up at 4 a m and study so that then I can go and I knack the exam. So it depends upon what is optimum time delay and all that so and this whole thing may fail also.

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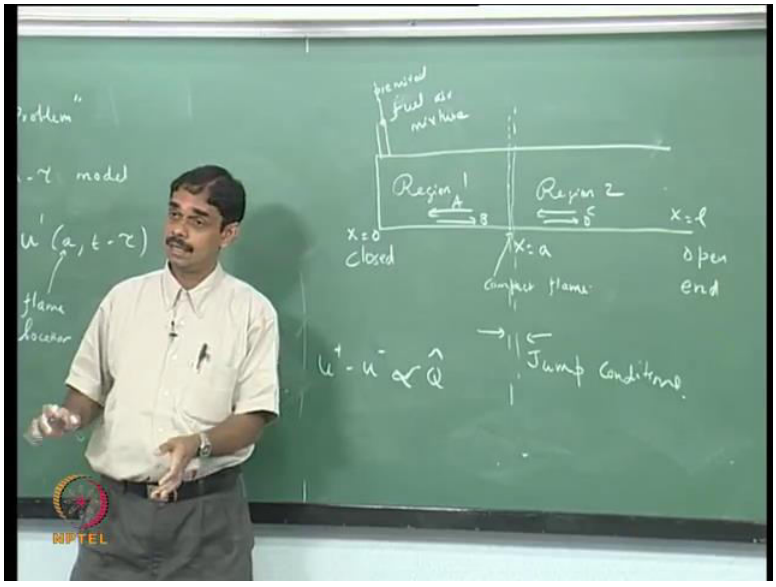

So we look at a very simple problem which will be said up in the flowing with and we know that closed end and open ends are very good. So I want to show that I can deal with both them, so I have one end close and one end open ok. So this is closed and this is open end and let us have a flying border here and you have a compact plane here. This is a realistic assumption some of you came to so see labia experiment and yes very similar to this.

And let say we are siding an and there ways in which you can send it with keeping end thus we close puts simple plate lot of closed them. So we call this x equal 0 this is x equal to l and this is x equal to a. And now, we have the construction solution that will that important eigen value get important growth rate to d k rate. And how do you construction power? So we use this we values crop of assumption so, we have boundary condition here and we can without it hit release rate righting solution a sin k x plus b like a e k minus k x the power becomes only when there is heat release zone.

So let us split into and region 1 where is no hitless and then we will have region 2 here there is also release yes we are very good dealing with classical aquatic. We know did closed then we know did open here solve the problem this here already end condition. So, here we applied the jump condition and jump condition involve heelpost way we say that u plus u minus proportional Q hat. So we need the model for Q hat and now say that we goes like to (Refer Slide Time: 31:38) u prime. So there is new variable now problem is closed, so we applied boundary condition for velocity here, boundary condition pleasure here this is matching condition proportional velocity here and jump condition.

And then, we get system of equation and we can reduce column to 4 equation to 4 are notes in terms of let us we have a and b the way aptitudes and here c and d aptitude. So we can get four are notes and we solve then we can relation between 3 of the between 4 assign. It is a linier power make cannot with the absolute aptitude but, we can relationship between them. And we can get the complex frequencies that is what will we do next class I hope it is clear any question ask me we can go.

Thank you.