Indian Institute of technology Madras

NPTEL
National Programme on Technology Enhanced Learning

COMPUSTION

Lecture 20
One Dimensional Steady Flow

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So we are doing to simplifications here one is first of all we are considering one dimension.

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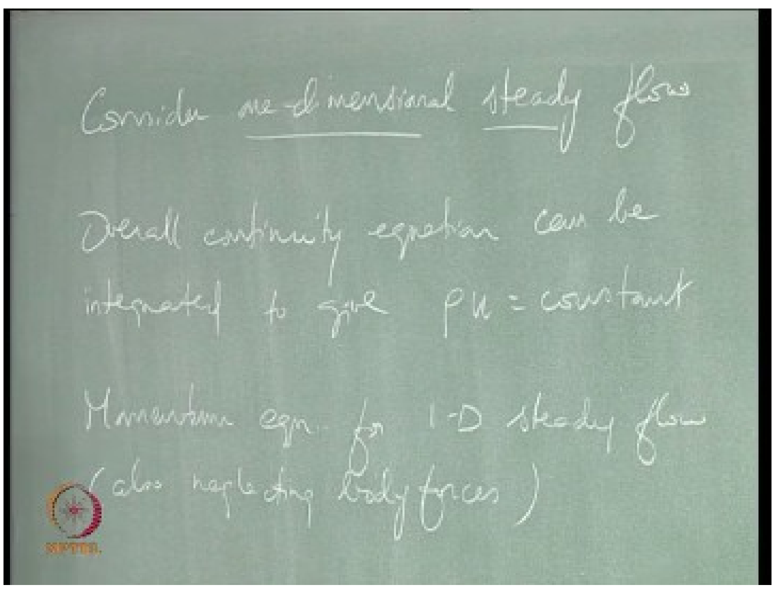

The second thing that you are looking at steady I would like to point out that for what we are trying to do here we do not need to make these assumptions okay one of the words the final result that we are going to get should be valid for a three dimensional unsteady flow as well okay this is just to keep things simple in what we are going to do now, what are we going to do now? Recall in what we did up until now we wrote up the equations of conservation for combustion and found that we had five n plus six equations to solve and n was like 20, 40 whatever and so correspondingly we had like a large number of equations to deal with so the question is it possible for us to a reduce the number of equations and B is it possible for us to decouple some of the equations.

So that it is sufficient for us to solve only one set of equations for doing something another set of equations for doing something else and these are not exactly coupled with each other except that maybe we get solutions from one and plug into the other and that is it, so that means like as far as C second is concerned the first solution is given to it we do not have to solve it coupled with it and as far as the first is concerned we did not have to worry about the second set of equations at all completely and just go ahead and solve for this.

So this is what has been by decoupling sets of equations and we will try to understand what this idea leads to in concrete terms or in other words what decouples from what and so on at the end of what we are trying to do but as I said earlier from now on all we are going to do is to completely go in the direction of simplifying things right and then deal with a few simplified situations from now on.

So one of the way this is not the way of looking at simplify simplification this is the simplification here on one dimension and steady is just make what we are going to do now simple but at the end of it we are going to come up with some simplification that is valid for multi-dimensional that is three-dimensional steady flows unsteady flows as well. So let us now look at the simplify situation if you now have the overall continued equation can be integrated can be integrated to give so what the overall continued equation we had was $\partial \rho / \partial t$ + plus divergence of ρ V vector = zero.

So steady means you do not have a $\partial \rho / \partial t$ 1d means we have a d /DX of ρ u okay, and if that is equal to zero we can integrate that to get ρ u is equal to constant right, so okay the momentum equation the momentum equation for one the steady flow and let us also neglect body forces now neglecting body forces me whenever we are actually making these kinds of assumptions that let us neglect this or assume it to be negligible those kinds of things what did what did we already have a question it is it okay to neglect body forces okay.

So in combustion one of the problems that we will find about this is the body force pretty much is the one that is actually giving rise to the shape of the flame as we know it if you know light up a candle okay like for example you go for a candlelight dinner party with your date and then you are trying to enjoy the moment unfortunately then you start remembering about combustion because you have this flame and then the entire evening is shattered right. So what are you looking there you are now looking for a flame that is kind of elongated vertically okay assuming that your date is happening in a gravitational field and you are not really going in free space.

So if you did if you do it in free space then or a zero gravity environment you now should actually look for like a bulb shape flame whereas if you know or in a gravitational field you have a buoyancy force that is actually trying to push this flame in an elongated fashion, so the question is it okay obviously if you neglected body forces you are not going to get Flame shapes that look like anything that we are used to around here on this planet right well the answer is maybe all that shape is not really important okay for the purpose of burning the candle it is the heat that is actually being released closest to the candle surface that that is really what matters for melting the wax in getting the liquid to go through the capillary pores of the wig and then vaporizing to feed to the flame.

So we do not have to really worry about the shape of the outer shape of the flame far away from the with the back surface the candle surface right so many times what you will find this it is okay to neglect the body force not it not a not a big problem there, so if you now did that then you get your momentum equation which looked pretty ominous previously it is now going to look like UD u / DX = 1 / ρ d / DX of p + 2 / 3 μd / DX – 2 μ du / DX well as we can see from what we have done even the continued equation the there is only one direction that we are looking at X direction and we are only looking at one component of velocity that the assuming it is survived which is the X component of velocity and that is called u okay.

And since you are having looking you are looking at only one direction it is sufficient for us to actually you replace partial derivatives by ordinary derivatives with respect to X.

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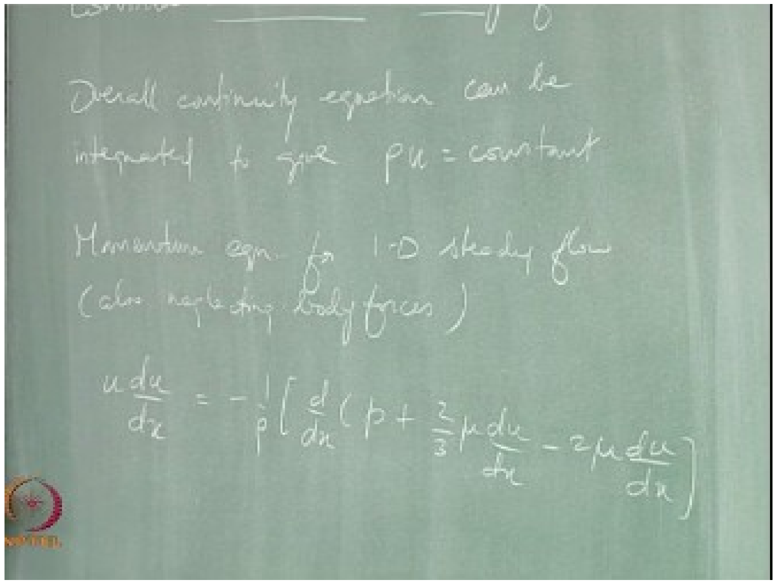

So you have a UD / DX is coming from the convective term is equal to minus 1 / ρ d / DX of p that is the pressure gradient term and then this is the bulk viscosity term and this is the viscous shear stress term okay, so these are these are the terms that survived the unsteady term dropped out because we are looking at a steady flow pretty much all of the terms are around of course the body force has been neglected okay, so this could now be written as if you now write and write this what would I like to do if it is possible for me to write the whole thing as a derivative what did we get over here we had a divergence of ρ b is equal to 0 for the vector form in one day we had a d by DX of ρ u is equal to 0.

So similarly if I can actually get something like a d by DX of something equal to 0 I should not be able to say that something as a constant that is very easy for me to integrate it becomes like a exact integral for me to evaluate therefore so we can now write this as let us say D / DX of a ρ u well do ρu^2 okay = - d / DX of P + 2 /3 μ D / DX - 2 μ D u /r DX how did I get this well first of all I could take this ρ to this side okay and notice that ρ u is equal to constant so if since ρ u is equal to constant I could actually take it inside the derivative all right there is a reason why you got a d / DX of Rho u square okay.

So what that means is I had a d / DX of this equal to -d / DX of that which means I can combine both and have one d / DX right, so if I now put everything together and have a d / DX = 0 then whatever is inside the d / DX should be equal to constant which is now in our case ρu^2 +P – 4 / 3 μ du / dx equal to a constant okay.

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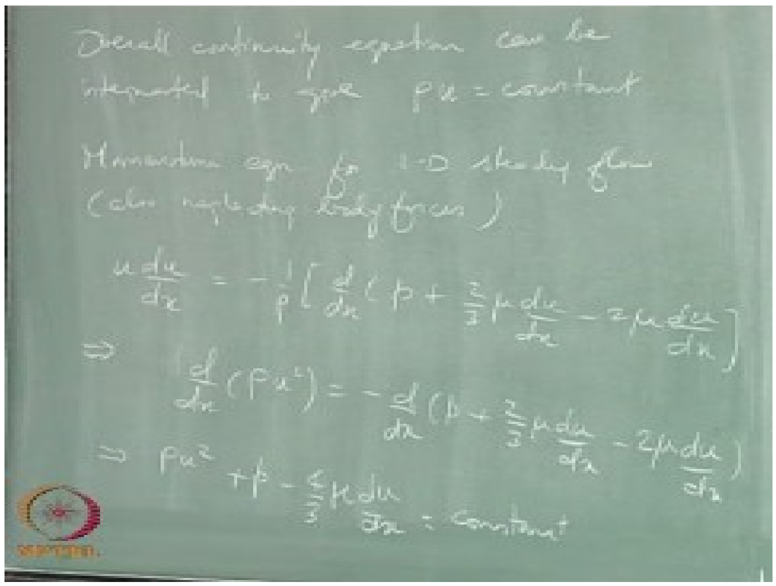

We are now beginning to see things that we are somewhat familiar with from let us say guess dynamics all right previously in gas dynamics you would have done typically in viscid flows where you had a P + $\rho u^{2} =$ a constant for compressible flows okay in fact ρ u is equal to a constant actually comes for compressible flows right. Otherwise you would have had something like a of course in quasi one-dimensional situation you would have a ρ u a is equal to constant this is just one dimensional not even quasi one-dimensional so you do not you do not worry about an area you only worry about a mass flux you do not worry about a mass flow rate okay.

But you have to take an account the variation of ρ with velocity the piece ρ is varying it's a compressible flow okay and there is a reason why you have ρu^2 + p okay but that is not equal to constant like what you had seen for invested flows because we are still considering this quasi T so you have this extra term that comes into picture your viscous effect and that is actually putting the bulk viscosity and the viscous shear stress terms together you get a minus for group 4 / 3 μ ∂ u / DX.

So previously we did not have this term we now have we now have this if you would look at like a incompressible flow you need to have a half ρu^2 + p is equal to a constant for Bernoulli's equation the half did not come because ρ was varying here okay previously if you had only a incompressible flow the ρ would not weary then you would have a u a is equal to a constant for a quasi1d situation that is what you are familiar with for a banal DS equation approach there, so all these things are not very different from what here what we have done with done before maybe with the exception of having this extra term yeah long later when we are trying to do a detonation we will try to revisit the situation and then see how the flow transitions from it conditions to what is called as the Chapman joogay detonation later on through many states that correspond to this okay.

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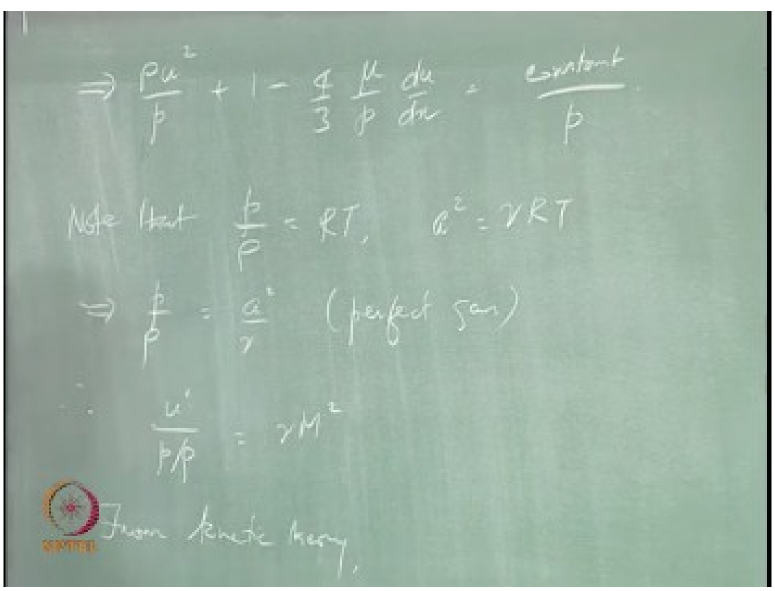

So what you will want to do now is let us say we can write this as ρu^2 / p + 1 - 4 / 3 μ /P D you over DX / sorry equal to constant or p what am I doing this the answer is I want to have a 1 in this, so that I can compare the other terms relative to that okay it is sort of like always looking at making a comparison with one hundred percent. So how many marks are just going to score with respect to a hundred percent how many marks is just going to score with respect to hundred percent okay.

So one essentially is like a benchmark for us, so what did we actually choose pressure to be other one in the denominator and make the pressure term equal to one the answer is we are now going to actually examine how this is going to compare with one and see that under low mach number conditions this is very small and this is also very small all right, so all small with respect to what small in comparison to what with respect to one alright.

So that is what we are trying to look for so a p note that $p / \rho = RT$ $a^2 = \gamma RT$ where a square a is the speed of sound so this implies that p / ρ equals a^2 / γ or you could have said a square $a^2 = \gamma P / \gamma$ right, which is something that we know all this is for perfect gasps of course therefore then if you now try the plug p / ρ $p / p / \rho$ would now be in the denominator in this term right. So $u^2 / P / \rho$ is what we have for this term and that would be simply $u^2 / a^2 / \gamma$ which is sampling some which is basically γM^2 right.

So $u^2 / p / \rho = \gamma m^2$ okay, keep this with you let us look at the third term over there the second type of course is one so let us look at the third term from kinetic theory I told you that we have to have something for μ is a transport property and transport properties can be evaluated only if you go down to a molecular level that means you have to go down to kinetic theory or we cannot get it from a continuum effect within the continuum framework you simply have like a law that states that shear stress is directly proportional to velocity gradient and the constant of proportionality is something called viscosity okay.

That is like a law that we just observe in the continuum world without knowing why, if you want to know why you have to get down to the molecular level and then you will be able to find out what viscosity actually means in terms of molecular level fluid motion all right. So if you want to know how the μ depends on things like pressure and density and temperature and all those things typically you can you can try to relate it to thermodynamic properties and then there is a dependence okay.

So what you are looking for is mainly like a dependence rather than the exact expression because we are looking at an order of magnitude approach okay relative to unity what we are trying to see how this fares relative to unity, so μ can be written as ρ a λ where of course a continues to be the speed of sound now how did you get the speed of sound to come in for the viscosity that is not very surprising because if you want to actually try to find out what is speed of sound you have to get down to the molecular level as well because it is a molecular level phenomenon that is actually propagating sound all right.

So all these things related there λ is a mean free path what is mean free path mean free path is basically the average distance between average distance covered by a molecule between successive collisions alright, so now what we have to look for is d you over DX that means we have to look at an order of magnitude of what that derivative is going to look like.

So if δ U is of the order of you that means that changes in velocity or of the same order as the velocity itself as then this is not to say that the changes are large it is essentially saying that the changes are actually measured as appreciable fractions of this of the velocity so for example if the velocity is let's say 10 meters per second and when you are now looking at d you by DX in fact we should now so also start looking at however what is X going to vary like.

So δ X let us suppose it goes as el L is like a characteristic length a characteristic dimension of the problem, so we come across these kinds of things when you knew things like flow past a sphere or something of the flow through a pipe and so on so where we have characteristic dimensions right like the like the sphere diameter of the cylinder diameter or the pipe diameter all these things these are like characteristic dimensions. So if you know how flow through a pipe and the pipe is about let us say 50 millimeters large then you would try to actually measure the or take divisions like go 1 mm a part or something of the sort right.

So what we are talking about as X is it is going to be a fraction of the characteristic dimension or in other words we are not going to take δ X to be very much smaller when compared to the characteristic dimension it is going to be of the same order so if you now have like 50 mm we are going to go in steps if like 1 mm which is of the order of about point a point not to okay. so there is still or like in terms of what the characteristic dimensions or if for this kind of change in X of course exits in the axial direction in this in this particular case so if you want to now look at what happens in this direction you can even do much larger than a point with 1 mm you could even do things like let us look at what happens everyone every 5 sending me 5 mm okay.

So δ X down simply becomes like point 1which is switches or point 2 so you can take larger steps and if velocity is changing if it is going at 10 meters per second and we are changing by 11 meter per second over a let us say 10 mm difference then these are all the DD / DX is of the order of u / L that is essentially what you are talking about what they are saying okay. So then 4/3 u / P D u / DX.

Now goes ass let us forget about 4 / 3 4 /3 is not very different from one okay, now this is this is some new math yeah so were we kind of cheat on these like when you are in your 4th standard or something like that you really start mugging about these decimal places and all that stuff and then as you grow older and older you become like lot more scrupulous about like a 8 decimal places accuracy and so on and then finally you come to graduate school and we say like 1.33 is the same as would not forget about these two decimal places is this why we studied so hard okay.

That is exactly what is meant by order of magnitude now so let us not worry about the 4/3, so we do now say or if you want to worry about it keep it do not worry do no t worry about keeping it or leaving so then μ goes us ρ a λ and keep it as P here and as I just try to believe at the point δ u / δ X is like you over L right and you should now know how to rearrange this you can get the get a ρ down here, so as P / ρ and then we now notice that p / ρ is a^2 / γ so I can now plug in a^2 / γ over here without the ρ there and then it gets cancelled okay the γ goes to the top and so then you have a we were here at the bottom there is not a at the top anymore but u and a get together to make an M and the λ and L get together to make what when is the last time we thought about the mean free path ah the Knutson number right.

So the mean free path relative to the characteristic dimensions of your problem okay is something that you come across the first time when you do fluid mechanics typically when you are convinced or rather brainwashed into thinking that we will have a continuum approach that can be justified by looking at something called a Knutson number which is very small for typical situations like the kind of flow that we have in this room okay atmospheric pressure room temperature the air is so densely packed when compared to the mean free part let us say you know looking at flow past this table gay that is like billions of mean free path say okay so the little number.

So this together this gives you the Knutson number and as I said you can get a γ m from the other part, so this is actually going to give you a γ M Knutson right if you want me to write what this is that is Knutson number K n right and for typical continuum applications KN is very small k KN is like 100 1 point 0 00 1 whatever it's a very small number 10 to the 10 to the - 3 okay whatever.

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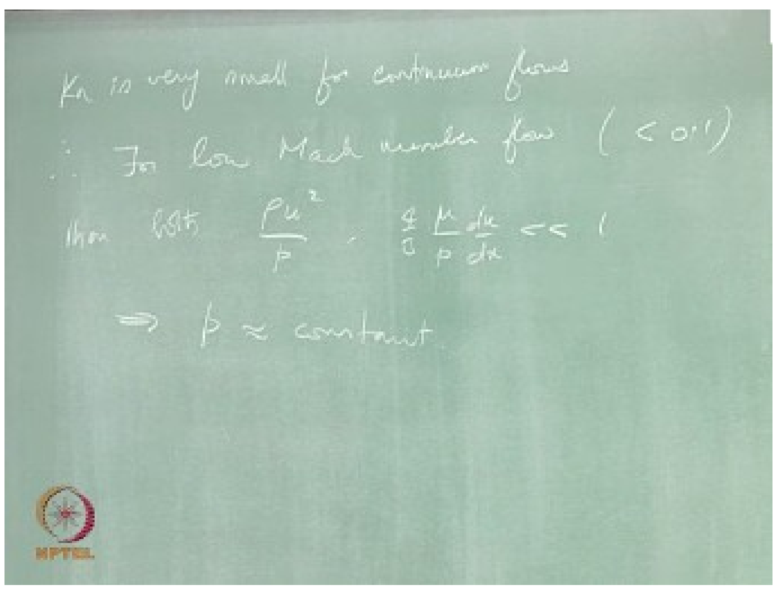

So now k n is very small for continuum flows right then the question that I asked is wait a minute get in combustion is combustion continuum flow it is all vvv duties for talking about like molecules colliding with each other and reacting and then you see even talked about like the molecules need to be exactly oriented, so that you have like effective collisions and then you will have the chemical reactions for some part some atoms are in some parts of the molecule with some other atoms in some other parts of the molecule and all that stuff what if we do not know what all those things at the molecular level we are evolving out suddenly saying continuum yeah I mean continuum does not mean that their own molecules okay.

So the fact that we have to actually use the law of mass action and the Arrhenius law is because we are actually looking for a continuum representation of those chemical reactions the fact that we are able to actually define a concentration of a species at a particular point which actually contains billions of molecules of all the species at the point okay means that we are actually dealing with continuum. So even though the chemical reactions are happening at the molecular level it is happening at a point where you are looking at millions of billions of molecules of lots of species at the point with each of them being able to be represented by a concentration at the point concentration means you not have you need to have excellent mass for the given volume of the little point or certain number of moles of that for a given volume at the particular point okay.

So you are now saying that that point has a low volume and then there is a mosque associated with it in all those things and the point that we are talking about is like a mathematical point in space where your chemical reactions are happening it is not like it is happening in this room or things are happening the size of this room you have to start now imagining like a flame that you are in that you encounter okay, let us say for example if you have a Bunsen burner you know how they flame you are now thinking about aflame that is like a millimeter thick or even smaller okay and then you now should be able to pick a point within that frame and at that particular point you now have all these chemical species with their concentrations and so on all right.

So it is it is a continuum flow that is not a problem at all and therefore so finally what do we have for lower Mach number low flow mach number how low 0.3 is low no point three is like this magical number that we have in our minds about when the flow is incompressible or just becoming I do not worry about all those things right what we are talking about a smock numbers that are even lower right there they are like about 0.1 or less very 0. 1 0 0.1 if you are typically talking about hot flows here the temperature is large then the speed of sound is very large okay.

Therefore or should say the other way that the temperature is very large therefore the speed of sound is large because it goes the square root of temperature, so you have a large speed of sound so even for a moderate velocity k or mach number is a fairly small so if you were to think about a Mach number of about point 1 I think I made this point before if you now think about a Mach number of point one that is happening in like a let us say gas turbine combustor okay and the temperatures there or in the reactions owner of geography like 2500 Kelvin therefore the speed of sound is raw of the order of thousand meters per second then we are still talking about velocities that are about 100meters per second that is like this but if the flow is fast but the mach number is low okay.

So we are not talking about low Mach numbers less than point one and that is not a magic number it is not like a god-given number if it is like 0.11 then do not do it start shooting, huh which is that point 0 9 do not feel concerned like a huge relief or something of that sort of that sort it is very low that is what you are saying is it is quite low when compared to one and then where we have we now say this term which is now beginning to look like this if M we are like point 1 M squared is like point 01 okay, and look on is already like point 01 or less and all miss again point 1.

So this term is going to be much smaller right, so then both ρ u square ρ P , 4/3 U/P du / dx or much smaller when compare to 1 that means in this equation we should now try to get rid of this and this and then we are left with only one okay, we gutted of these because they were actually very small when compared to one so if you now get rid of these we have to keep the one okay so we now keep one and worry of the right-hand side we now say one is equal to one is of the order of constant divided by pressure that is to simply say that pressure is approximately a constant okay.

So this simply means that p is approximately a constant so what have we done we have practically shattered the momentum equation down to a p equal to constant equation we started out with a momentum equation and then just systematically dismantle the momentum Empire if you will okay to get it down to a teeny weenie equation that is like just P is approximately equal to a constant he said okay does it make sense so you light up a Benson flame do you feel like a pressure around okay.

So you go to your kitchen gas stove and then light up the gas stove do you feel like a pressure around you do not really get like a lot of pressure around it is just approximately constant atmospheric pressure around there that is alright what about a gas turbine that is really going at very high speeds and pretty sure there must be a lot of pressure yeah the pressure is high but it is approximately constant right.

So we are talking about fairly low subsonic combustion happening roughly at a constant pressure alright as a matter of fact whenever you are looking at these kinds of things like you know neglecting body forces or when you are now saying let us say continuum and then universe are now looking for low Mach numbers we do not necessarily have a think combustion right if you now had a non reacting single species flow non reacting single species flow okay let ordinary fluid mechanics and we need now say let us not worry about body forces that is okay in fact in combustion that we have to worry about body forces and then neglect it right then it is continuum flow sure.

So next number is quite small and we are thinking about low mach number fluid mechanics there anyway so all these all these assumptions that we are making along the way are satisfied for a normal fluid mechanics flow and then we should now be able to reduce our momentum equation down to p is equal to a constant why are we stuck with a momentum equation that we are not able to solve for 300 years when it should just be said as p is equal to constant are we are we getting in any information here the answer is starting to think about it you just have a piece of pipe let us say a small piece of pipe and then you now go through this pipe okay and then the course again you can play with this and again you can be given and put your hand or other side and then feel the cool air that is coming out because you are blowing and so on of course you do not really get a lot of pressure out there.

So it is all approximately atmospheric pressure that is really the key how much did you blow with right the answer is a little bit more than that repressor therefore you could actually get the flow out to atmospheric pressure, so the δ P that we are talking about there is very small so that this flow field is approximately at a constant pressure where there is a small pressure gradient that was required to drive the flow this is what this is what we are talking about for this kind of low Mach number flows okay.

So this is not to say that the pressure gradient does not exist it's quite small and that is good enough to actually drive a low mach number flow as a matter of fact in a gas turbine with all the complicated machinery like you have these fellers and you have a flower and a sudden expansion in all these things you are expected not to have a pressure drop of not more than five percent if you have a gas turbine that is having a pressure drop of more than five percent it is a bad design okay, you try to try to get it up to 95% a pressure recovery alright.

So you are not looking at a very huge change in the pressure at all therefore all this big flow that we are talking about okay, so this for us does not mean that the momentum equation is gone the momentum equation is still required for you to get the flow field except if the momentum equation now gets decoupled from the species equation and the energy equation this is what it really means okay the means you are starting out to the overall continuity and the momentum together they constitute what is called as the flow problem if you now had the flow solve for that is basically cold flow.

So you are given a very complicated geometry with all this let us say a pre-diffuser I dumped diffuser which is very highly curved and then you have the spoiler and atomizer that is coming through and then you have you have these line or pores and then you have flour and then all the secondary holds and then the dilution holes and then you have this liner flow and then there is a casing around and you have this combustion going on and so at all these complicated things do not worry about all that stuff just take this geometry and then do a cold flow okay work out the flow field in this that means you now take your incompressible equation set for fluid mechanics namely the continued equation and the momentum equation solve for the flow field okay you get your velocities.

These velocities now can be plugged in your species equation and your energy equation that means we now want to worry about the combustion problem as constituting as constituted by only the species equation and the energy equation in other words we now say we want to split the set of equations that we have had into a flow problem that you solve independent of the combustion problem and you solve this flow problem get the flow field plug it into the combustion problem.

So what is the flow problem overall continuity and momentum okay what is the combustion problem species conservation and energy these are now decoupled and there is only one way interaction which is you solve the flow problem independent of the combustion problem get your velocity and plug it in the species where you read this in the convective terms for the species mass fraction convection and the enthalpy convection in the energy equation. So you need the flow the mixture velocity right.

So you now plug this in there right and then this is your combustion problem you just solve this set of equations for a given flow field okay now many times the combustion people do not have time for the fluid mechanics people they get just assume the flow field their lives are okay I mean if you are really strict enough you would probably assume a flow field that satisfies the overall continua t and momentum and many times in simplified problems a assumed flow field that satisfies overall continuity and momentum is simply a uniform flow okay.

So you just assume a uniform flow that naturally satisfies overall continuity and momentum and then plug that in into your species conservation and energy conservation okay and it also simplifies your species in energy conservation because you're now looking at a V dot ∂ Y I and V dot ∂ T kind of terms right and then so if you now look at V dot del if you are only one dimensional velocity the means velocity in only one direction it simply reduces to u d ∂ y / ∂ x and u ∂ t / ∂ X you do not have a v term at all okay.

So the lateral convection term gets absent so you do not have to worry about it okay, so this simply means that we do not solve the overall continuity and momentum equations as part of the combustion problem right but obtained the flow field by solving them and use it as prescribed in the combustion problem right, so what is meant by the flow problem then is overall continuity plus momentum equation right, then we have the combustion problem which is the species conservation and energy equation. So when you now say this arrow that means flow field prescribed.

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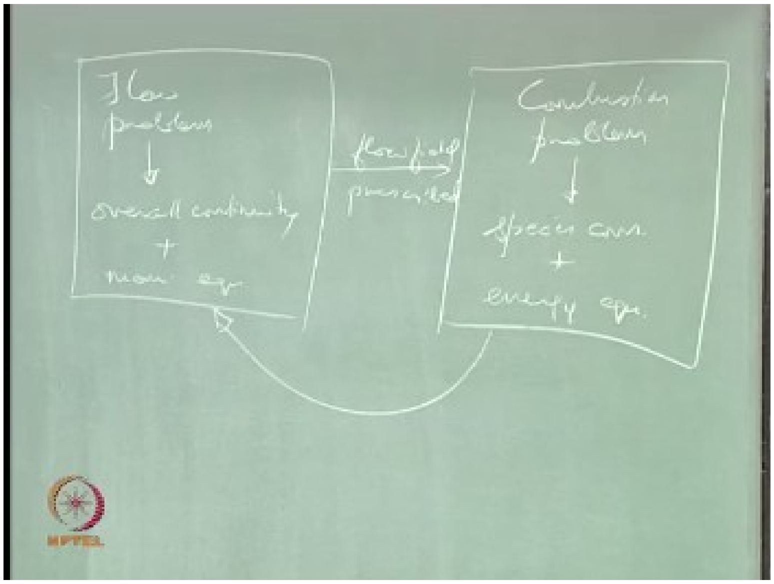

So many times that means we do not even care to solve the momentum equation or the flow problem you just take a flow field that is prescribed as far as the combustion problem is concerned okay now I do not know how many of you are really thinking about this as well as we should what do you mean by saying I prescribe the flow field and then the convection of species in enthalpy is going to happen as prescribed right the question that you are asked is does not this affect the flow field back should we have an error backwards.

Well what I would like to say two things here one if you want to have another backwards still be happy that I could draw these boxes separately and identify a flow problem different from the combustion problem and then have a interaction that is explicitly understood between these two as opposed to putting one big box for all the equations in saying that is it you have to solve all of them all the time okay. I am still thinking about decoupling these problems that means my solution procedure for this may be different from the solution procedure for this is the one that is containing all these bad terms like the chemical reaction terms and all those things.

So I may have to have a solution procedure that is different for this than this right, so it still makes sense for me to think about these with two distinct problems even if they have a two-way interaction but what I have now talked about is only one way interaction okay but should you really have a two-way interaction that being tuned to combustion actually affect the flow field, why would it? Yeah of course it will, if you now think about a candle flame right.

So now let us light up a candle and then assuming that we are thick-skinned which I am okay so I do not take my finger very close to the flame but somewhere near the bottom let us suppose it is that is the flame okay it is a baked potato it is a already called exaggerated view here right to the flame is in so big but I now take my flame somewhere here okay of course I am beginning to feel the heat all right but I do not really sense a draft I do not say any like I do not sense a flow okay but when I now try to take my hand somewhere there do I sense something now see a flow you have a flow of course you might claim how this because of the buoyancy Oh hot gases the rising up all right.

I can claim well if I would actually go into free space or in zero gravity I should now have a flow that is set up radially outward okay instead of going up because we are not in the gravitational field all right but still I am then have a flow which is not the same as having more like still it still are at the bottom okay that is to say if you now have a flow that is going through a flame for the reactants okay, the density is low sorry the temperature is low.

So the density is high okay but then when it now gets past the flame and it becomes products the temperature is now high so the density of this for more or less constant pressure right is now going to be low, so what does it mean for a low density as far as the velocity is concerned if the way u is equal to constant the velocity is now going to go up so sure enough if you know what to think about like a Benson flame right, now have a cold flow that is coming in this is like a blue flame alright but then the floor actually in largest and goes up like that faster than it came in into this flame.

So the density effect on temperature sorry the timber opposite the temperature effect on density has the effect of dilating the flow once the flow goes through the flame which in turn means that obviously the frame affects the flu or the combustion problem affects the flow problem through the density depending upon temperature okay. So you do have a in effect okay this is because ρ goes as 1/ T I say 1 / T because we still assume or suppose that p is approximately a constant right p = ρ RT p is more or less constant therefore ρ should actually decrease just as well as the temperature increases.

So do you give you an idea of what these numbers or if you now think about a reactant that is entering the flames own or combustion zone at let us say 300 k alright and then it gets out there and let us say something that is divisible by 3 to make our life simpler 2400 k it is more like it okay call security if you have taken 20 100 k or 3000 all right but we are now talking about a ratio of about eight anyway between seven to eight to nine something right, so you know looking at a ratio for both eight times jump in temperature for typical hydrocarbons and therefore the density also should actually decrease this was so much so much more and the velocity then increases so much more right.

So but the Mach number does not change a whole lot so the velocity increases but them all because it did the temperature came down, so the temperature got up there for the Mach number came down okay. So that is not a problem you are still going to have like a p approximately equal to a constant but you know how high velocity there, so it is possible for us to actually take this into account and then go back and then alter the flow and then prescribe anew velocity field into the combustion problem.

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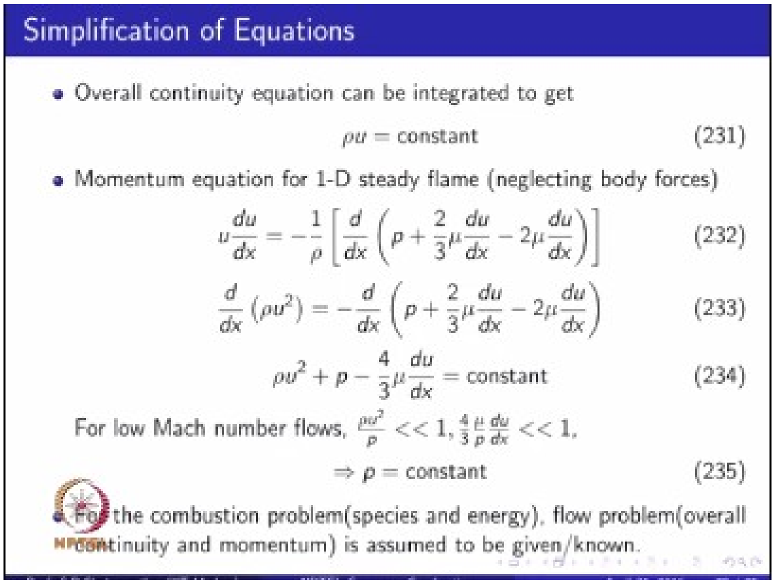

Find out how the combustion changes the temperature field and then therefore the density field and therefore the flow field and so on but still this means we can actually decoupled the two problems and solve them with the different strategies okay but taken account this coupling.

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