Introduction to Explosions and Explosion Safety

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Lecture - 07
Blast Waves

Good morning.

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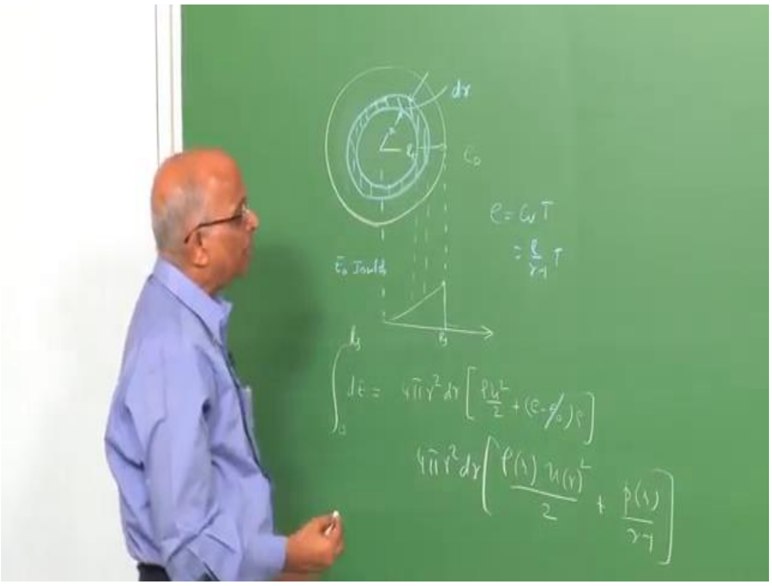

You know in the last class we were looking at the formation of a spherical blast wave from an explosion which realised. Let us say E 0 joules of energy, in other words we are looking at the spherical blast wave which is formed at this spherical blast wave keeps propagating outer. So, we told ourselves that this lead blast wave at time T is at a distance R s from the source of energy release. We looked the energy balance and what did the blast wave do you form a blast wave let us take a look at the blast wave you form a blast wave it keeps propagating.

Now, at different times it keeps moving out and, therefore this energy which is deposited is dispersed within the region of the blast wave as the blast wave propagates out. Therefore, we look at the, we look at the conservation of energy namely e 0 joules of energy which is dissipated in the medium and which creates the spherical blast wave. So, what did we do in the last class let us quickly go through the point because we will continue on the energy release and how the blast wave changes.

Therefore, for that I again look at the energy that means we dissipate some energy the blast wave is the distance R s from the source which is the lead shock wave. We look at the energy which is balanced or we look at the energy which is available at some radius r and of that means I look at this spherical shell of thickness, let us say d r at a distance r. Now, the blast wave is at a distance r, R s from the source, therefore may be this is my distance this is my distance let us say R s over here.

So, the initial pressure jumps up over here and then may be the thing expands out we looked at the expansion in the context of the mass conservation. So, we found that well most of the mass tends to be concentrated different and thereafter there is not much mass left because all the densities over here. Therefore, there is something called as gradient over here we were interested to write the energy which is contained in this small spherical shell over here element of the shell over here.

So, that means the blast wave is here the energy is dissipated I am just interested in the energy here and we got the expression d e is equal to the kinetic energy and what was the kinetic energy. So, the volume of this element is the surface areas four pi r square into d r 4 pi r square into d r which is the volume into the kinetic energy per unit volume is the rho u square divided by 2 plus. So, you have the internal energy and initially let us say the medium outside has a n internal energy e naught we have e minus e naught into row is the change in the internal energy.

Here, we consider that the internal energy change due to the blast wave processing which is very much greater than the initial internal energy. So, this drop out we wrote e is equal to C v T, C v we said C p minus C v is r. Therefore, we could write e, e as equal to C v T, C v could be written as gamma is as equal to r divided that. So, that is the specific gas constant divided by gamma minus 1 into t r is equal to p by row and, therefore this equation became d e is equal to 4 pi r square into d r into I have row.

So, what is this row, let us be very careful it is a distance r from the it is it is the distance r from the source of explosion u at r square divided by 2 plus I have. Now, p at distance r because r t is equal to p by rho p get p gets cancelled divided by gamma minus 1 is the energy which is available in this spherical shell. Now, I integrate the total energy from here to here that means I integrate out from 0 to R s and that will be equal to this energy and, therefore the expression which we got was e 0.

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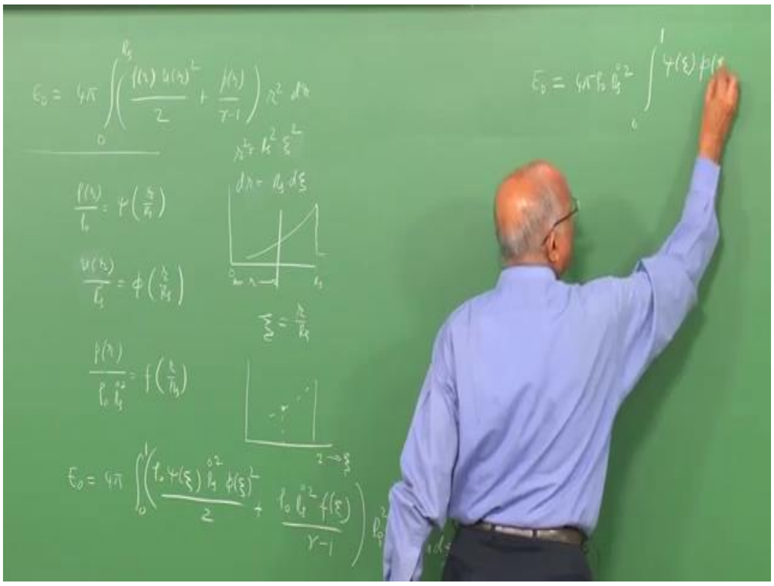

That is the energy in joules which is dissipated to form the blast waves I, now take 4 pi which is constant outside. Now, I take integral 0 to R s of I have row r into the value of u at r square divided by 2 plus I have p r divided by gamma minus 1 into I have r square into d r this is the expression which we got. Now, when we look at the distribution we say from starting from R s it keeps decreases over here or it changes over here.

So, I can as well say that my density at r divided by the initial density I can write it as equal to psi of r by R s because why do I have to write this you know initially, I have the jump. Then it keeps coming down, therefore we wrote this as row r divided by row s into row s by row 0, row s by row 0 is known. Therefore the density distribution as a function of the initial density could be written in this particular form.

Similarly, I could also write the other expressions the other expressions were we could write the value of u dot by R s. So, that means let me, let me put down the value of r as specifically the velocity behind the shock at the radius r divided by R s dot is equal to let us say pi into r by R s. Similarly, I have p at r divided by row 0 into R s dot square is equal to f into r by R s all function of the distance from the shock to maybe I am interested in this particular r, I am looking at the value of r by R s.

Therefore, I would like to solve this equation subject to some distributions like this in the last class when we did the mass conversation we took a power of profile. But, maybe we will, we will consider some of these things again for energy balance, but as of now I would like to substitute the expressions into this particular energy balance equation and try to solve for it. But, while doing so I can also represent this in a slightly different way let me try to tell what I want to do all. So, what we are telling is we have R s over here at R s I have a step change taking place in may be the density may be the particulate velocity may be the pressure.

So, there after it decays down it decays from R s to 0 I am interested in a distance r over here I can as well change the coordinate system such that I am always saying that well. So, the shock is moving I am having always having R s as variable, but I am considering at a particular r as the value of r. Therefore, I can consider let us say zeta is equal to r by R s and I could say well I am considering that case wherein the lead shock is at 1, I am considering the properties let us say.

Now, I am coordinate shifts to zeta I am considering the value of zeta over here which is less than 1, I am looking at the property at this particular value of zeta. Therefore, if zeta is equal to r by R s, well can I change this coordinates automatically r square becomes equal to R s square is equal to d zeta and well d zeta or d r. Let us, let us substitute the value d r over here from this expression becomes equal to equal to R s for a particular value of R s I have R s into r.

So, r square is equal to R s square into zeta I am sorry r, r square is equal to zeta square into R s d r is equal to R s into d zeta. Thus, the limits of integration instead of being R s over here it becomes R s by R s which is 1 and, therefore the above equation for the energy balance will now be given by e 0 is equal to 4 pi into 0 to 1 into our row r.

So, row r can be written as equal to zeta row 0, row r is equal to row 0 into psi of zeta into u r, u r is equal to phi that means R s dot. So, what is it we have u r square, therefore R s dot square into phi zeta square divided by 2 plus I have the value of pressure r pressure r is equal to row 0 R s dot square into phi zeta.

Therefore, I have row 0 into R s dot square into phi f of zeta divide by gamma minus 1 and this value is multiplied by r square r square is equal to R s square into zeta square. So, d r is equal to R s into d zeta and, therefore if I were to simplify this equation, I get e 0 that is the energy released is equal to. Now, take the terms of said well row 0 is the ambient, the shock is moving or the blast wave at that point is moving with the velocity of R s dot square.

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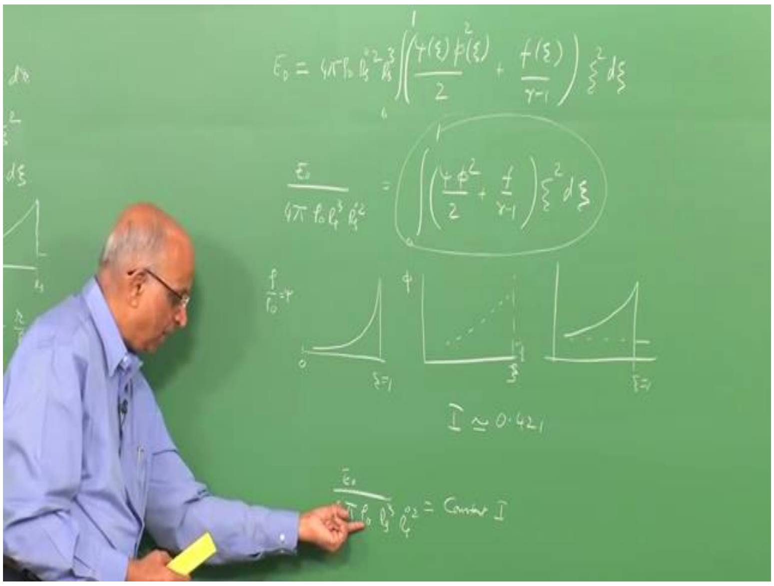

Therefore, I get 4 pi into row 0 into R s dot square this is the expression for this taking out then I get the value 0 to 1 and what is it I get. So, I get the value of psi and zeta divided by the value of velocity that is the velocity at the particular point is phi divided phi square phi. So, phi square divide d by 2 plus I get f of zeta to the power gamma minus 1 into what is left over here I have R s and R s cube well at a particular radius I am interested.

Therefore, R s cube can be taken outside and I have zeta square into d zeta this is the expression I get and therefore, now I take, I bring the terms which are outside the integral sign over here. So, I get e 0 by 4 pi into row 0 R s cube into R s dot square is equal to this particular integral 0 to 1 of let me take, let me recognize. So, that psi is a function of zeta phi is a function of zeta f is a function of zeta and, therefore I can write it as psi phi square divided by 2. Now, keeping in mind these are all functions of zeta such that I do not need to carry these symbols as I am doing plus f over gamma minus 1 into zeta square into the zeta.

Now, you know this expression tells us that the energy deposited in the medium of density row 0 is there this energy. So, if I look at that denominator I have 4 pi R s cube 4 upon 3 pi R s cube is the volume this is the mass this is something like the kinetic energy term. Therefore, this expression is an indication of how much of the energy or how much of this energy deposited gets into their kinetic energy of the medium provided. So, that the entire medium, let us go back to this if the entire shock medium we had to travel at R s dot square that is the net kinetic energy.

Then this expression tells us that what part of the energy travels at the kinetic energy such that the velocity R s dot square. Now, this is what this expression tells and, therefore this integral denotes part of the energy which is getting converted into kinetic energy provided all the particles are travelling. But, at the blast wave speed namely R s dot square you know if I look at this expression little more closely you know yesterday I looked at this point source. So, we said zeta is equal to one at zeta is equal to 1 if I am interested in row by row 0 which is equal to your psi and psi we are plotting between 0 to this.

So, that is zeta equal to 0 that zeta is 1 we found well the slope is like this, similarly if I, if I had to take the value of let us say phi as a function of zeta and you know at zeta s equal to 1 where is there is jump in velocity or there is a change in velocity. So, there is a slope in velocity and, similarly for pressure there is a jump in pressure at zeta is equal to 1 and this jump there is a slope that means between 1 and 0 there is a slope over here. Therefore, we expect there to be something like a power law and this is what we said original used these equations.

Again, we said well William Ray also used these equations to solve for these and you know there are different ways of solve may be could get these things analytically. So, for instance we solve the conservation equations in a blast sort of numerically or we use the perturbation techniques to solve for it or we use the similarity solutions. But, we look at similarity solutions a little later, you know we can always get these slopes and, therefore if we are talking in terms of strong shocks. Well, the jump conditions at is zeta is equal to 1 do not really change with the mark number and, therefore we would expect this particular integral to be near a constant namely if I denote this integral by let us say I.

So, I should be near about a constant intend if you really calculate these things using different numerical methods or as I said may be a perturbation method. Now, let us say the similarity solutions I get I is equal to around 0.421 for the case of this sphere spherical wave which we are considering. Therefore, we tell ourselves well this integral is expected to be a constant and, therefore I can write this value. So, let us write this value I get e 0 by 4 pi into row 0 into R s cube into R s dot square is equal to a constant.

So, this constant is equal to I, which we just now said is equal to this particular integral or this integral which is a constant. So, that tells you what is a fraction of the energy which is deposited gets into their kinetic energy of the medium and this kinetic energy of the medium. Now, we evaluate it at the shock velocity or the blast velocity at that point in time, therefore if this is a constant can I can I use this equation. So, to interpret something well for a given energy release e 0 in a given medium of density row 0 that means let us put down.

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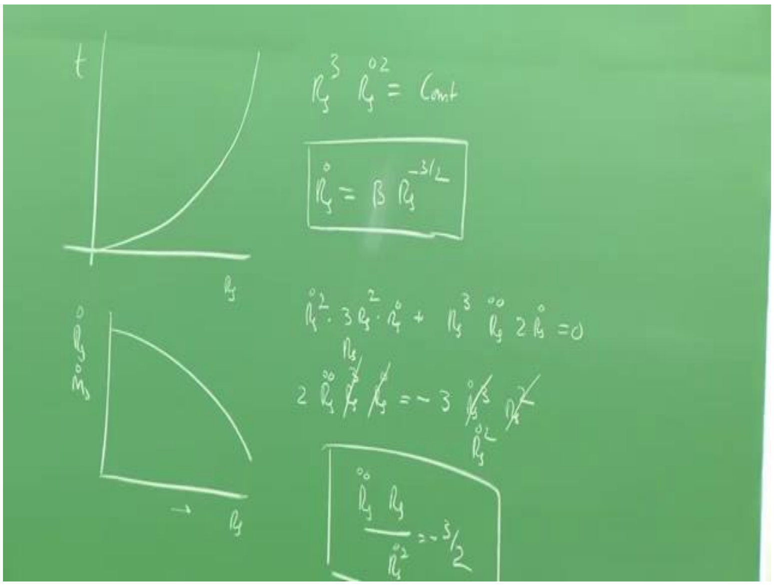

For a given value of e 0 joules in a given medium of density of row 0 kilogram per meter cube what is it I get, you know e 0 I have specified row 0 I have specified. Therefore, it is a constant, therefore immediately I tell myself well according to this equation R s q into R s dot square is equal to a constant. So, what is it I get, I get R s cube into R s square it is a constant or rather from this equation I get R s dot is equal to a constant.

So, let us say this constant is v into R s to the power minus 3 by 2, well if you recall in the second lecture what we had. So, we had used the dimensionless method of deriving the decay of a blast wave, we had got the identical expression let us take a look at this again. So, we have we have to differentiate this, if I differentiate this by parts I get R s dot square into differential that is three R s square into R s dot plus I.

Now, I keep the first value r constant R s cube into I get R s 2 dot into I have 2 into R s dot is equal to 0 constant is equal to 0. So, let me again repeat R s dot square into differential of the first term 3 R s dot square into 3 into R s square into R s dot plus I have over here R s cube which I am, which I am which is the first term. So, differential of the second term is a R s 2 dot into 2 R s dot and what is it I get immediately I tell myself well in this two terms if I had to take one on the left hand side.

So, I have R s 2 dot into R s cube into 2 over here into R s dot is equal to minus 3 on the right hand side. Now, I take it on the right hand side I have R s dot cube into R s square and if I have to take out the common terms over here well r l square cancels here gives me R s. So, I have R s dot over here gives me R s dot square and, therefore I get the value of R s 2 dot into R s divided by R s dot square is equal to minus 3 by 2 which was again the result.

So, which way I had got from the dimensional analysis in other words there is a decay that is the shock is decelerating because of the negative sign. So, we got the shock velocity in terms of this and the same results which we got by dimensionless analysis or dimension analysis we are able to get through the energy conservation. Now, this is 0.1 of the energy equation, this must be clear we have solved the energy equation and we get back the condition 12 in a blast wave.

So, what is it which we are telling ourselves in a blast waves well you have the streak diagram temperature versus R s you form strong waves. So, it keeps decaying or rather in the frame of preference of R s dot versus R s you start with the wave and it steeps as the distance increases the velocity at the front decreases. Well, this is the same signature for m is dot also well this comes from the energy equation let us try to see whether I can use the energy equation to better advantage.

So, to get some more characteristics of these blast waves mind you we must keep something in mind when we did all this we presumed over here. So, that they initial energy of the medium is small, in other words we told ourselves well the blast wave must be strong enough that the value of e 0 can be neglected. Now, second is we also use these profiles which was strictly true only for the case when the mark number of the blast wave was quite high that means we are talking of strong blast wave.

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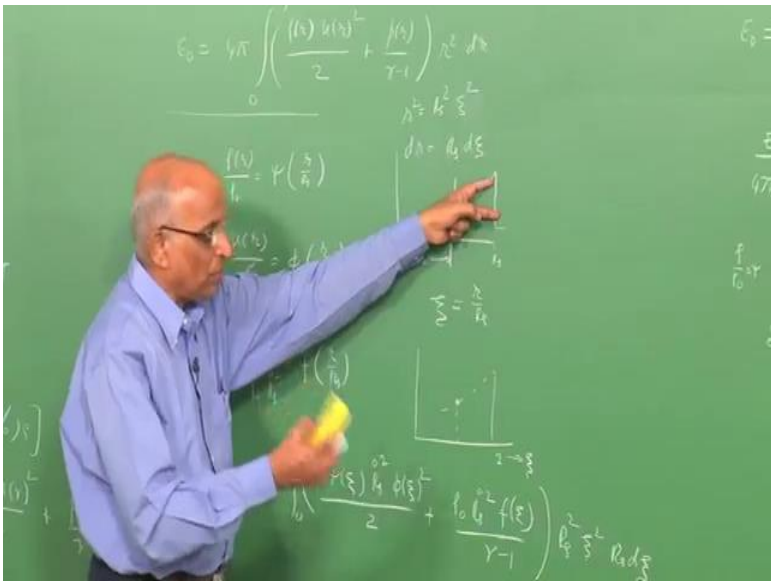

Therefore, the conditions we have derived here are suited only for this initial region or for the initial region over here.

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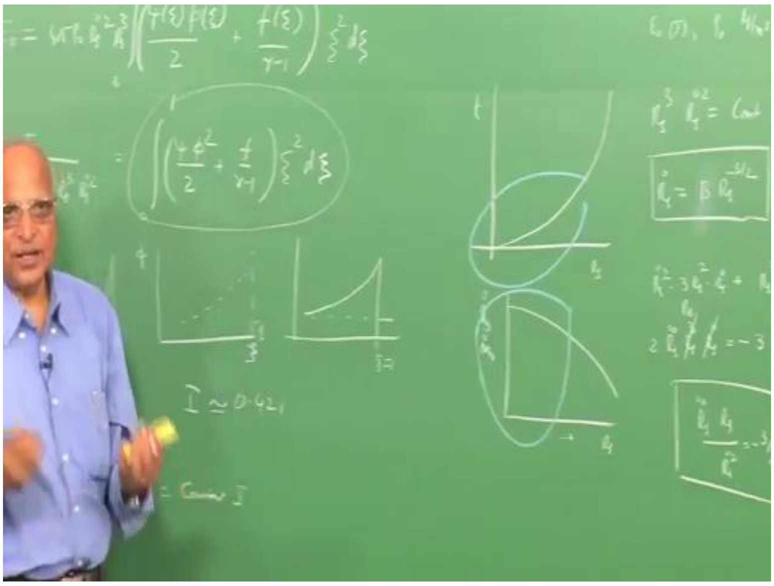

So, having said that let us go into some more details some more characteristics of the blast wave and try to solve some more parameters for some more parameters. So, let us pick up from this equation itself, let us pick up from this equation namely over here e 0 by 4 pi let me write it over here.

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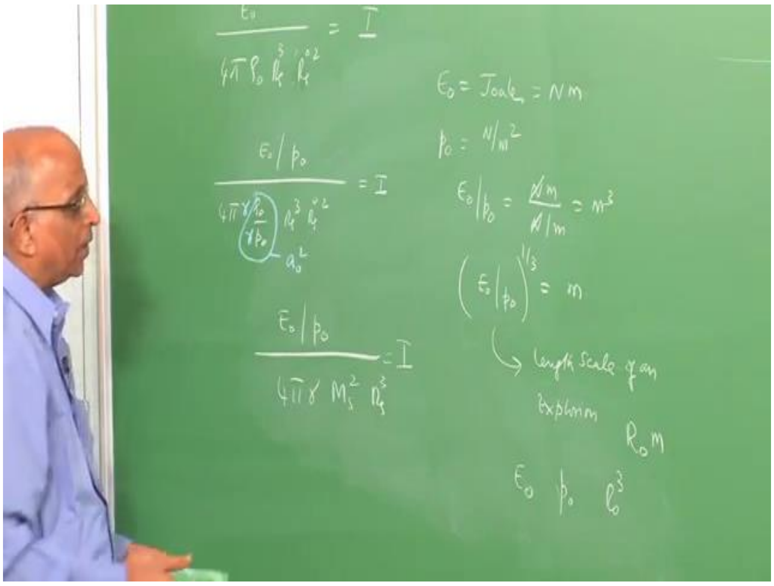

We have e 0, that is the energy released in a medium row 0 is equal to we do not need to construct the integral. So, let me, let me put it in terms of the fraction what we have got we got e 0 divided by 4 pi row 0 R s cube into R s dot square is equal to I. Now, I want to slightly transform this equation into something which is more usable which will help me to scale different types of blast waves. So, let us therefore divide the numerator and denominator by p 0 that is e 0 by p 0 divided by 4 pi row 0 I also divide the denominator by p 0 into I get R s cube into R s dot square is equal to I over here.

So, I have just copied this equation here I have e 0 4 pi row 0 R s cube R s dot square is equal to I, I get this particular expression. Now, let me do something let me multiply the denominator by gamma and also divide by gamma such that I still retain the same. Now, I look at this particular equation I have gamma p 0 by row 0 is equal to a 0 square that is the sound speed in the free stream medium. So, that is ahead of blast wave and I also know well R s dot square divided by a 0 square is equal to the mark number of the shock.

So, Mach number M s is equal to R s by a naught and, therefore substituting this expression in this particular one. Now, what is it we will get we will get the value of e 0 by p 0 divided by 4 phi gamma into M s square is equal to I which is a constant. So, we say it is equal to around when the, for the spherical case which we are right now dealing its equal to something like 0.423. Therefore, now let us take a look at this particular expression whether it will help us to simplify things well in this equation 4 phi gamma into M s square.

But, I think I have still to write the gamma of R s cube is equal to I, now if I were to look at the parameters. Now, I say well e 0, e 0 is equal to energy releasing Joules what is a joule is a Newton meter if I look at the value of pressure is Pascal which is Newton per meter square. So, it is f I look at the dimensions of e 0 by p 0 I find that the dimension is equal to Newton meter by Newton per meter which is equal to meter cube Newton and Newton gets cancelled. So, it becomes meter cube or rather if, now I say I am looking at the value of the e 0 by p 0 to the power one-third I get the unit as equal to meter.

Therefore, now I tell myself well e 0 by p 0 is equal to meter cube or e 0 by p 0 to the power 1 by 3 is a matter. Therefore, I can talk in terms of e 0 by p 0 as a length scale which is associated that is a length scale associated when an energy is impressively released in a medium whose density is p 0. So, that means I say length scale of an explosion I define length scale of an explosion is equal to e 0 by p 0 and it tells me if an energy e 0 joules is deposited in a medium of pressure p 0.

So, I get a length scale and this length scale of an explosion I denote by r 0 so much meters, in other words when I have an energy release e 0 joules in a medium of p 0. So, the ratio of e 0 p 0 is equal to the explosion length square and, therefore I use this explosion length in this particular expression and what is it I get, let us put that down I get the value of…

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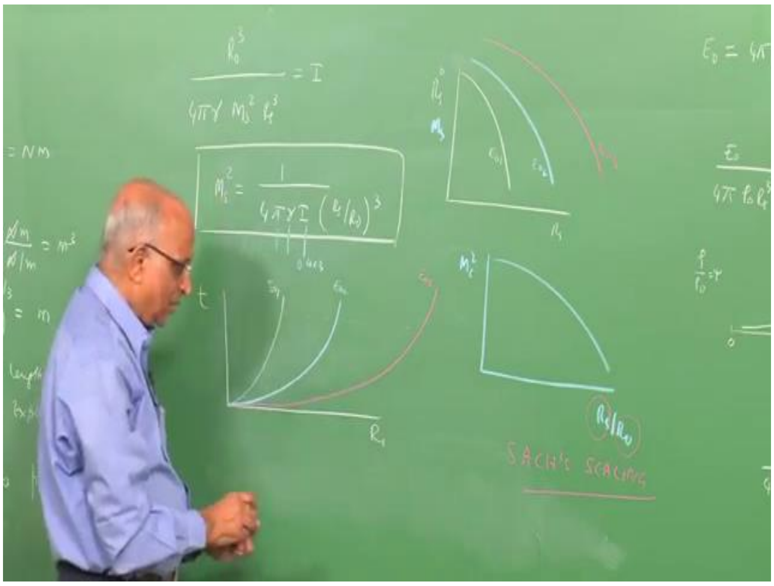

Over here I get r, r 0 explosion length square divided by 4 phi gamma into the value of M s square into R s cube is equal to I or rather from this can I get the value of let us say I. So, I take the value, the r naught I bring it here I get explicitly the value of M s square the mach number of the blast wave what it is it going to come. So, it is going to come is equal to 1 over 4 pi into gamma into I into I get R s by r naught cube this is the value of the mach number of the lead blast wave.

Now, what does this expression tell us all what we had telling is instead of considering the distance if I consider the distance which is divided by the equal and explosion length. So, that means I have the distance which is scaled then I get a value of Mach number square which is given by this if I look at this expression. Well, gamma is 3.14 for if, I am sorry pi is 3.14 to gamma for particular air is 1.4 we said is a constant around 0.423.

Then what we find m square is a function of R s by r naught cube, in other words what does happen when we reduce the energy release in terms of an equal length scale. So, namely the explosion length what is it we have done let us take a look at the figure again and try to interpret this result. So, we tell ourselves, we will go back to the streak diagram with which we are all familiar by, now we say this is the distance followed by the lead blast wave.

So, initially some energy is deposited in a medium I get this to be my blast wave let us say that the energy release is e 0 1 joules from a strong shock wave which decays. Now, I deposit much higher value of energy what is going to happen well if the shock is going to be getting started strongly and it decays after a longer time. Well, this is what the case of e 0 2 joules in which e 0 2 joules is greater than the e 0 1 joules if, now I deposit even a much larger value of energy.

So, what is it I get well, therefore since the energy released is higher it travels a further distance this is e 0 3 Joules. Therefore, may be if I the depending on the energy release I get for this same time may be I get a blast which is which is farther away. So, rather if I there to put this particular figure in terms of let us say the mach number or the R s dot as a function of R s what is it I get you recall s. So, we looked at the decay initially I get a for e 0 1, I get this type of result may be for e 0 2 may be I get some result like this we use the blue colour may be I get e 0 2 like this.

So, may be when I talk in terms of v 0 3, I get a result like this that means I get at this distance when energy release is higher. So, I expect a stronger shock and this is what it tells and, therefore what is it we are telling well R s dot depends on well R s dot divided by a 0 is M s over here it has this dependence. Now, what happens instead of using R s if I use the value of R s by r naught what is it I get, now I am able to convert this figure into a figure which says if I use this scale distance R s by r naught.

So, I am looking at M s square from this particular expression all what it tells is well I have a single curve for the value of e 0 1, e 0 2, e 0 3. But, irrespective of the energy release which gets a portion here I get a single curve and, therefore I am in a better position to solve the equations. So, this ray of characterising that distance travelled by the shock in terms of the explosion length is what is known as Sach’s scaling.

So, that means we are able to scale the mach number of the shock in terms of the scale distance and I do not really to construct the energy gets embedded here. Therefore, I do not need this multiply energy curves to do that I can solve the equations straight forward. So, that means let us, let us think in terms of problem all what we say is the following we deposit some energy in the medium.

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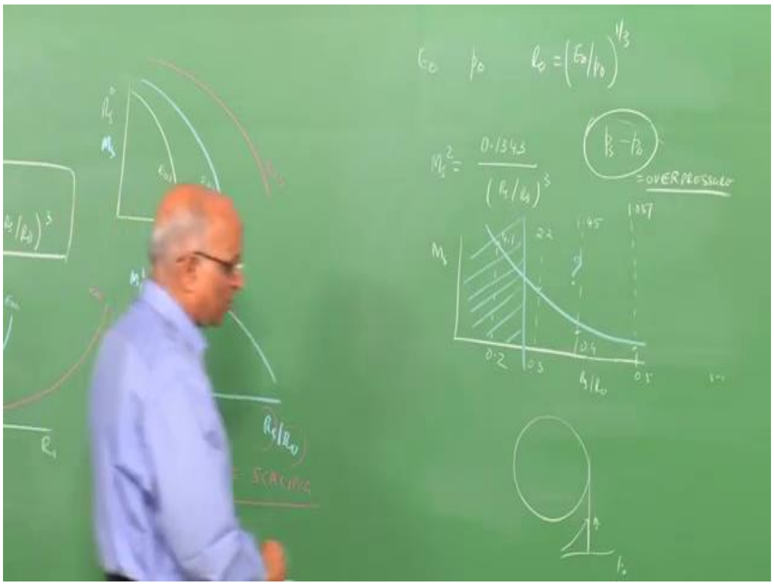

Let us say e 0 joules if the pressure I p 0 I get the explosion length r naught is equal to e 0 by p 0 for the spherical as 1 by 3 and once I know this. Well, I use this particular expression r naught cube by 4 pi r, r M s square is equal to 1 over 4 phi gamma I into R s at the particular distance R s. Since, r naught is known I can calculate the value of my M s square, therefore let us take a look at this expression, again we plot some figures over here I show this on this figure.

But, maybe I look at M s square I substitute the value of these things and what is it I get, I get the value M s square is equal to 0.134, 3 divided by R s by r naught cube. Now, if I have to plot this, what is it I get, I get may be the value of M s square M s lets say I take the under root and I plot it as a function of R s by r 0.

So, what is it I get when R s by r 0 is 0.2 the value of my mach number is 4.1 from the above equation I when the value of R s by r naught is 0.3. So, I get the value as 2.2 when the values are around 0.4 and how do I get it I just substitute the value here I divide this when it is 0.4 the value is 1.47, 1.45, I am sorry. So, then it is 0.5 the Mach number is 1.037, in other words 4.1, 2.2, 1.45, 1.037 and, therefore this is my Mach number distribution.

So, what is it I must infer from this well I made a strong blast assumption, but I keep getting numbers and strong blast is normally we form when we were looking at the density ratios? So, yesterday we found that well it must be maybe getting the constant values of row by row 0 p by row 0 R s dot square. So, u by r is when the mach number is typically greater than 4 and, therefore the validity of these particular results are only in this region.

So, in this region the Mach number influences let us say the initial the jump conditions influences the profile and if we in this case the predictions may not really be that good. Therefore, what is it we have done using energy balance we are able to get the lead shock Mach number and if I get the value of M s square. So, I will be in a position to get my pressure also that means I have when the shock is propagating away at the lead shock. Well, I have the pressure initial pressure is e 0, I have a jump pressure to a value p s and then it decays, further I can find out what is the jump in pressure.

But, if I know the jump in pressure I can always calculate the jump in pressure is p s the initial pressure is p naught and p s minus p naught is the increase in pressure across a lead shock wave. Now, this is something which is known as over pressure let us try to get an expression for the over pressure also we do it its quite simple. So, we have done this already in a in a, since in that we know the value of the shock pressure that means we say p by rho naught into R s dot square.

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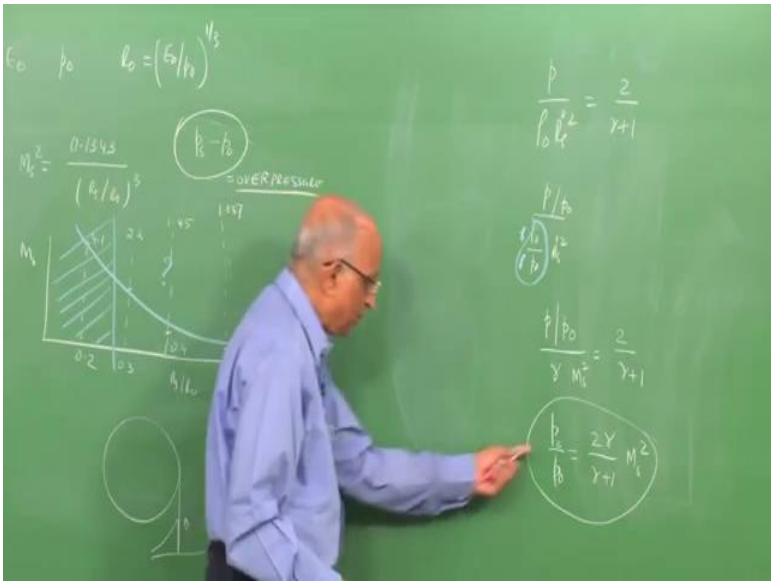

We say it is equal to 2 into gamma plus 1 for a, for the particular case of strong blast wave that means in this particular region. Well, I can simplify this and get it as p by row 0 divide by p 0 in the numerator divide by p 0 the denominator you R s dot square. Well, let me also divide the numerator and denominator of this particular expression in the denominator by gamma again.

Now, I have gamma p 0 by row 0 is equal to M s square and, therefore I can write the value of p by p 0 uses same colour chalk p by p 0 divided by gamma into M s square is equal to 2 over gamma plus 1. So, rather I get the value of p by p 0 is equal to I get 2 into gamma plus 1 into gamma into M s square and, now if you were to look back at the equation what we derived or p divided by p 0 in the third and fourth classes.

So, we have derived the equations p by p 0 is equal to 2 gamma by gamma plus 1 m square minus gamma minus 1 by gamma plus 1, since this is weird we are talking in terms of large mach numbers. Well, gamma minus 1 by gamma plus 1 is negligible and this is the pressure rate, therefore let us calculate the pressure behind the shock. So, to be able to distinguish between p and r I can write this as p s behind the particular lead blast wave I am interested in the value of p s over here. Therefore, let us derive it, we all what we do is we substitute the value of M s square as we got by solving the energy equation either this.

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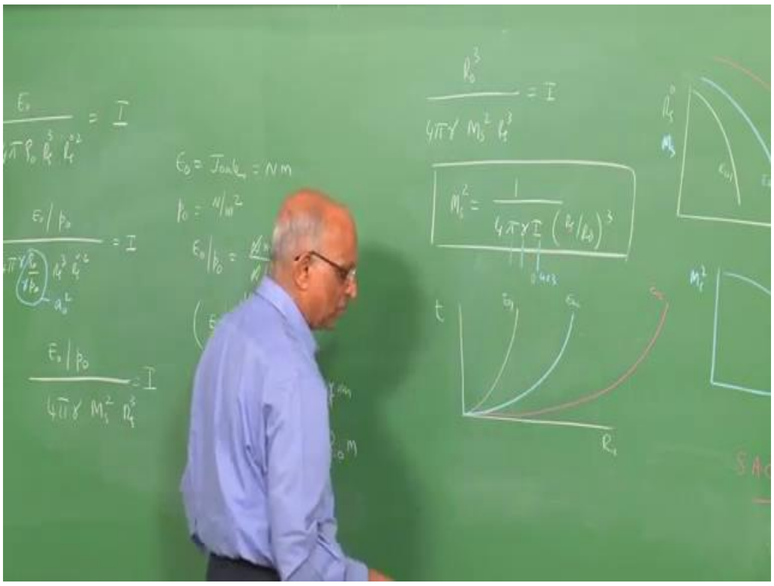

Let us put this M s square, as we got here we got M s square is equal to 1 over 4 phi gamma I into R s by R naught cube, so that we can determine the overpressure with particular distance, let us do that now.

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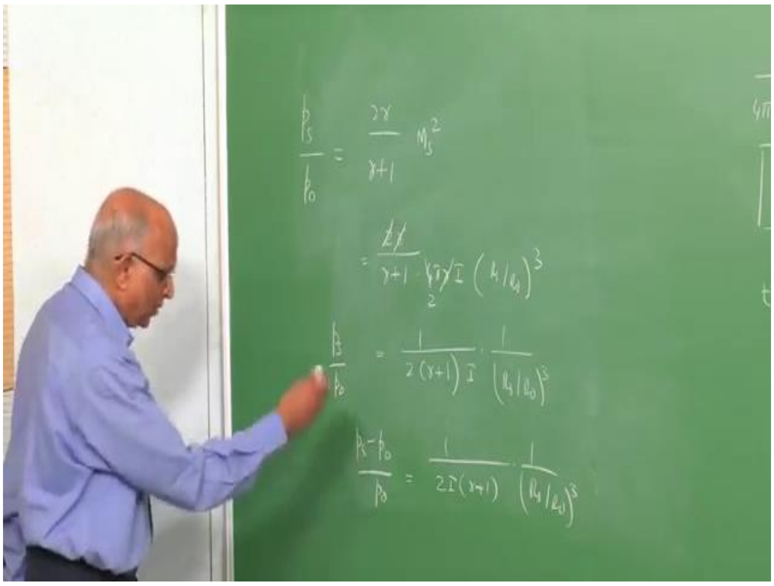

Therefore, write from the expression over there p s by p naught is equal to we get is equal to 2 gamma by gamma plus 1 into M s square. But, M s square is equal to 1 over 4 phi gamma I, therefore this I can write as equal to 2 gamma over gamma plus 1 into I get now 4 phi gamma I 4 phi gamma I into R s by r naught cube. So, rather in this I find gamma and gamma gets cancelled this cancels to giving 2 I get the value as 1 over 2 into gamma plus 1, 2 into gamma plus 1 into I into 1 over R s by r naught cube.

Now, in other words I get the value of p s by p naught and what is the over pressure, over pressure at the shock front is equal to I have a jumping pressure minus the ambient pressure. Therefore, that dimensionless overpressure is equal to p s minus p naught divided by p naught that means you have p s by p naught minus 1. Therefore, the value comes out to be 1 over 2 I into gamma plus 1 into 1 over R s by r naught cube, this is the value of the over pressure and mind you.

Now, we know the value of overpressure or dimensionless over pressure as a function of the stacks distance or the distance divided by the explosion length over here. So, let us take a look at this particular expression and see whether we can interpret this how the over pressure behaves with distance, we will substitute the values and what is it we get, let us, let us get the values.

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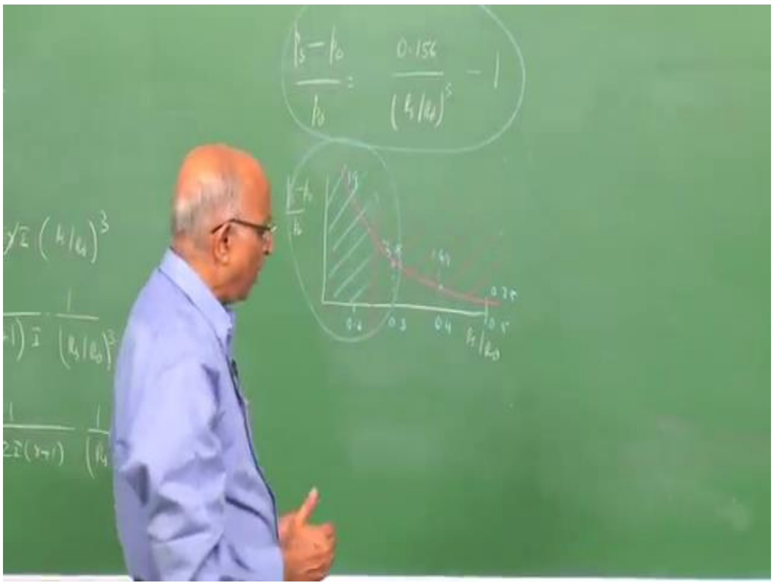

We get p s minus p 0 divided by p 0 I, now have I is equal to 0.423 their gamma plus 1 is 2.4 I substitute the value it gives me 0.156 divided by R s by r naught cube over here. So, this is the value of p s by p naught over here I subtract 1, therefore I should have subtracted 1 over here I get this is the value. Now, if I plot this expression that means I plot the over pressure p s minus p naught divided by p naught as a function of R s by r naught.

So, what is it I get lets again do this similar to what I have done over, therefore the mach number I get at a value of R s by r naught is equal to 0.2 the value of the overpressure. So, that is the dimensionless overpressure gives comes out to b e 19 at the value of 0.3 R s by r naught is equal to 0.3. So, the value comes out to be 3.8 at the value of 0.4 the value comes out to be 1.44 and let us take one last value 0.5 at which the value comes out to be something likes 0.25.

So, in other words if I join the values what I get is well the curve looks something like this and what is it we find well at 0.2 we found out that the mach number was 4.1. Well, strong blast assumption is valid 0.3 the Mach number was 2.2 for which is the over pressure you know.

So, in other words you know when the Mach number has decayed to these types of values well I cannot really expect the over pressures to be correctly predicted because we found. Well, the strong shock wave assumption is not valid I cannot write the density ratio gamma plus 1 or gamma minus or 2 over gamma plus 1 is equal to the shock pressure divided by row 0 R s square and all that. Therefore may be in this region in the region of these strong shock waves that is in the near field to the explosion I would expect this expression to be really valid.

Whereas, in the far field this expression may not be totally valid, in other words I have been able to get, but mind you know in a in a particular region I can predict my over pressures. Therefore, using the energy equation I am able to get the overpressure values well this they have quite a bit. Now, what are the let us quickly summarize what will it will we have understood for the blast wave using the mass balance and energy balance what did we tell ourselves. Well, from mass balance what did we get, we found the following namely when we have strong blast wave that is in the area near to the source of the explosion what is it we got.

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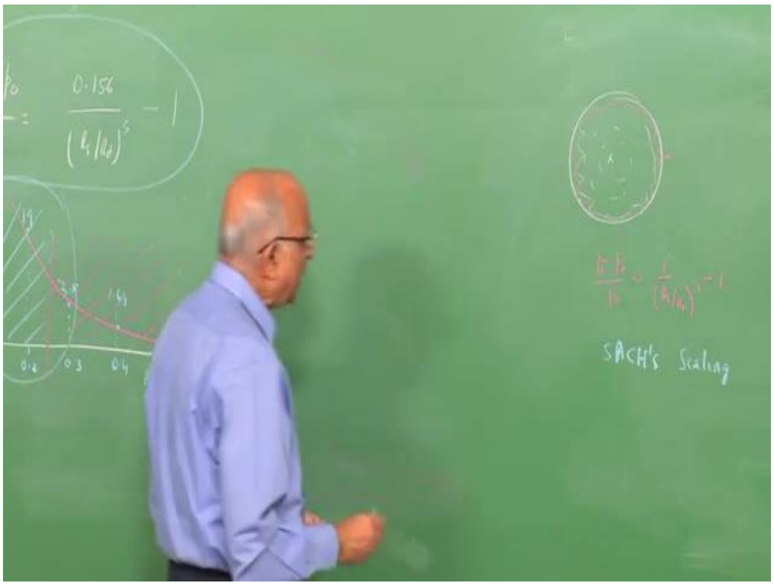

We found that may be I have an explosion over here I form a blast wave over here near to this well most of the blast, the blast wave. So, that is the blast wave as it moves it sweeps collects all the material and locates all the material in the zone of the lead shock wave. So, this is what I have lot of maths here travels with a high velocity and this is what creates my compression or the damage using the energy balance. So, what did we get we have the overpressure shock pressure while as a initial pressure divided by e naught is a function we get of one over R s by r naught cube 1 over r naught cube over here minus 1.

Therefore I am able to predict for a given distance what the type of pressure I have over here is, similarly it is possible for me to predict the velocity. But, let us discuss what we have achieved so far in terms of some scaling that means Sach’s scaling in which I express the distance in terms of r naught has really been useful. Now, I am able to get the overpressure from a blast frame and overpressure is important because that is the one which creates damage for me because the high pressure compresses. So, damage is a building knocks down people and that, therefore we use Sach scaling over here can I think of anything further.

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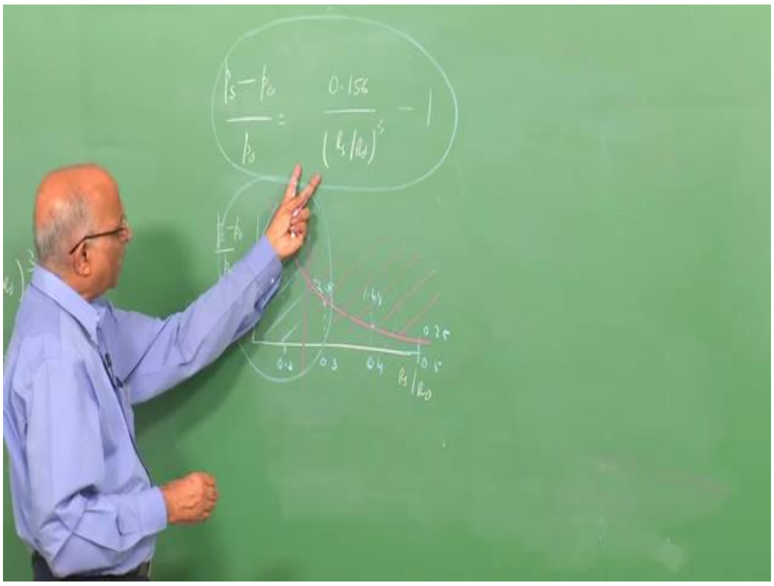

If look at this particular expression what is it I get can I talk in terms of other forms of scaling can I say how does a blast waves came for over pressures. So, in other words let us ask our questions scaling for over pressure can I can I really solve further for this, what do you mean by scaling for over pressure.

So, supposing I have an explosion in which let us say that the explosion length is r 0 that means I deposit some energy e 0. Now, I get the explosion length as r 0 because energy release in a medium p 0 is able to define it I am able to get may be at some distance r is a r away. So, I am able to now predict what is my overpressure namely p s minus p 0 by p 0 minus 1 this is the value of over pressure dimensional over pressure.

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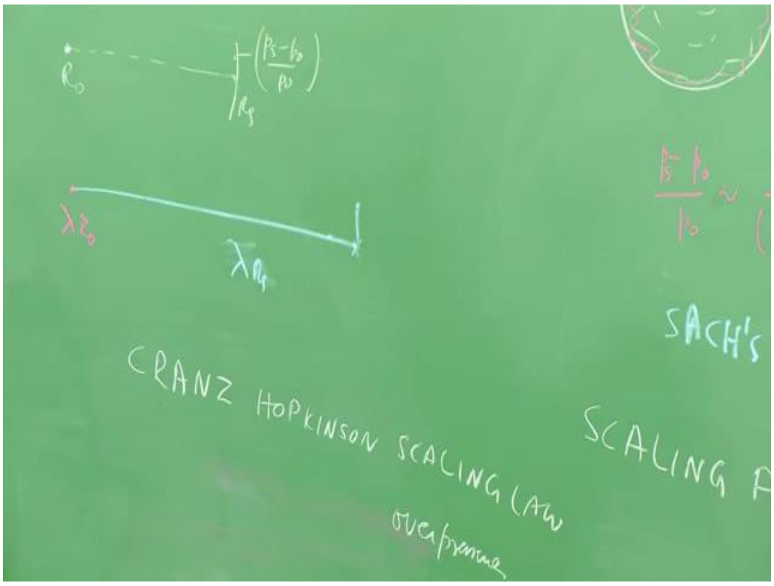

Now, instead of depositing easy row by p 0 which is r 0 cube supposing the energy deposited is such that I now have an energy deposited to lambda times lambda could be multiplication factor. So, that means I deposited a value equal of explosion length e equivalent explosion length to be lambda r naught the same over pressure. So, as per this expression will come out to be at a distance of lambda R s away will give me the same value why is it because lambda R s by lambda r naught comes out to be identical. But, even though the energy released is higher well the scale of over pressure over here and the scale of over pressure are same.

So, this type of scaling laws where in which I change my energy level in terms of r naught to lambda r naught is known as Cranz Hopkinson scaling law for over pressures. So, what is it state it states in for if an observer is situated at a distance lambda R s away from a explosion whose explosion length lambda r 0. So, he will feel the same overpressure as an observer who is stationed at the distance R s away from an explosion whose explosion length is r 0 as simple as that this is Cranz Hopkinson scaling law.

But, it is used left and right in the explosion industry because we would like to find out what is the, what is the energy released from an explosion how it how it affects the pressure at some distance away. So, Cranz Hopkinson's scaling is widely used let straight to slightly different form we draw the last figure which I draw, now is the figure of over pressure.

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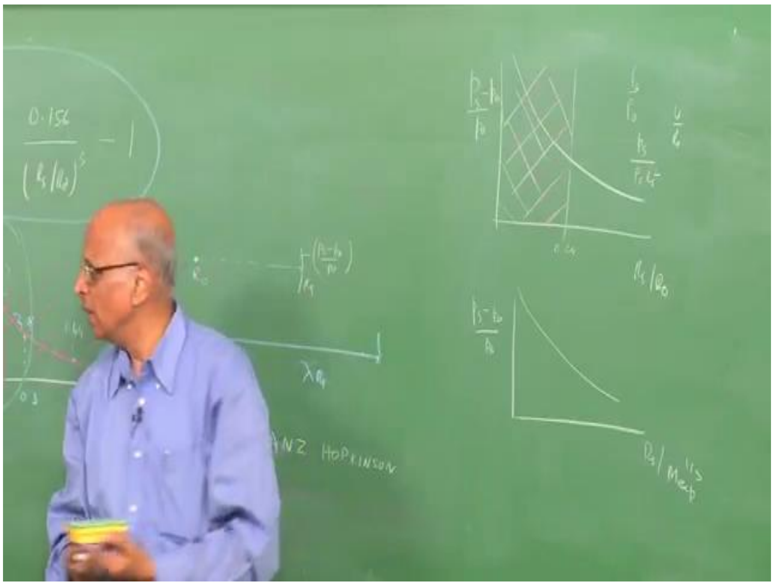

So, I tell myself, well I have p s minus p naught divided by p naught which is the dimensionless overpressure as a function of R s by r naught we got this particular curve. So, we told our curve is valid only in the near region of the blast in which the blast wave is small and, now once I know the energy released from the explosion. So, I know the ambient pressure I can calculate r naught, I want to calculate the overpressure at a given distance, if the distance falls within this let us say around 0.25.

So, I can predict the overpressure and we are able to do some problems, but you know if we look at certain books they do not use the Sach's law. So, in terms of explosion length there are the plot instead of writing r naught they plot this scale as equal to energy release to the power 1 by 3 because r naught is equal to e 0 by p 0 to the power 1 by 3 p 0. So, for most blast in air its around 1 atmosphere pressure that is 10 to the power 5 Pascal and, therefore they express it in this form. So, they get the value of p s minus p 0 by p 0 and therefore they give a curve like this, but instead of looking at energy.

Since, we are looking at energy release from an explosion and this energy release from a explosion is directly proportional to the mass of explosive used very often. Now, why instead of this we even using energy over here they put mass of the explosive use to the power 1 by 3 and this is how many books like Baker's book. So, like in terms of R s by mass of the explosive or mass of the particular explosive used we will take a look at this a little later. Now, this is how figures are drawn well this is Cranz Hopkinson’s scaling laws we are able to get the overpressures.

But, something which we must keep in mind see I keep qualifying each time we can predict in the near field of the explosive where in the blast wave is high. So, why because we showed earlier that the value of row by row 0 at the shock front p s by row 0 R s dot square. But, the value of U divided by R s dot are all above the same in this particular region because the jump conditions did not really depend on the mach number square.

Whereas, in this region it is a function of Mach number square, therefore the integral which we use here in the expression as equal to 0.423 may really not be valid. Therefore, it is only in this region which we can use let us try to get some more information of that and for that let us look at the assumptions what we made. So, with that may be will be will be a little wiser, what is the assumption which we made while deriving this overpressure relation.

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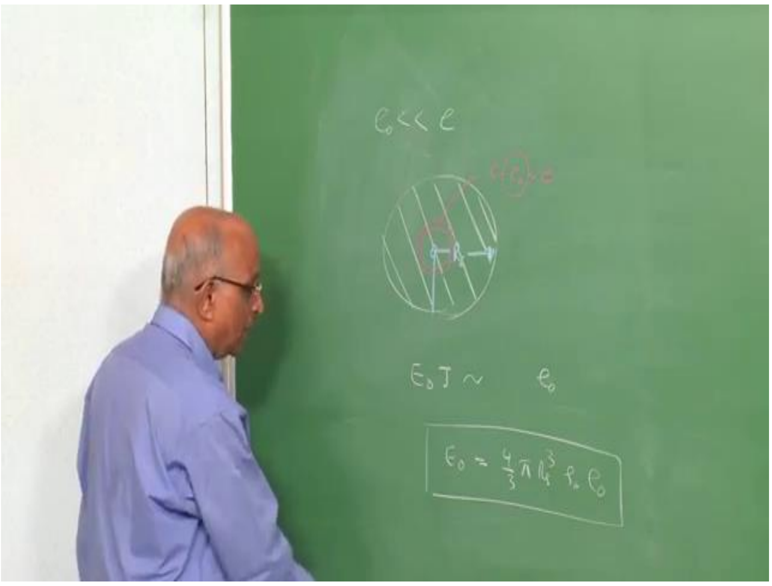

Well, we assumed that the value of the initial internal energy of the medium is very much less than the internal energy of the medium which gets enhanced due to the blast wave. So, rather you will recall the recall that we had a spherical blast wave we talk in terms of a small segment or a small annular area spherical shell over here in which we said it is equal to e minus e 0 is equal to e. So, that means we neglected the value of e 0 that means what is it we have neglected we have neglected the internal energy of the medium.

Here, can we find out under what conditions for what values of R s by r naught does the internal energy of the medium become significant. So, let us say in this particular figure if I find that R s by r naught for this for R s by r naught greater than this e 0 becomes significant.

Well, I can immediately say in this region the internal energy has initial internal energy of the medium has to be considered. Therefore, my predictions are only valid in this particular band or in this particular band of R s or r naught, therefore let us do the problem. Therefore, we tell ourselves well the shock is over here the source is here this is the shock which is R s distance away and what is it we are telling ourselves.

Well, the energy release of the by the source we say is again e 0 joules and if the initial internal energy of the medium has to contribute. But, what is it we are saying e 0 joules must be of the same order as the internal energy e 0 of the medium, but what is the internal energy of the medium is pi unit mass. Therefore, we tell ourselves when e 0 is equal to 4 upon 3 that is the volume occupied by the particular volume within the lead shock wave 4 upon 3 phi into R s cube into the density.

So, that is the mass which is available here is equal to into e 0 that means the internal energy of the medium here is of the same order as energy release. Well, I should be able to get this particular point and beyond this what is happening is the initial internal energy affects my shock or affects my over pressure. But, it also affects my mach number of the shock and, therefore I can look at this particular expression and get a feel for what is the value of R s by r naught. So, from this expression which will decide whether the region in which my predictions are quite reasonable, let us do this to be able to do this I just simplify this expression.

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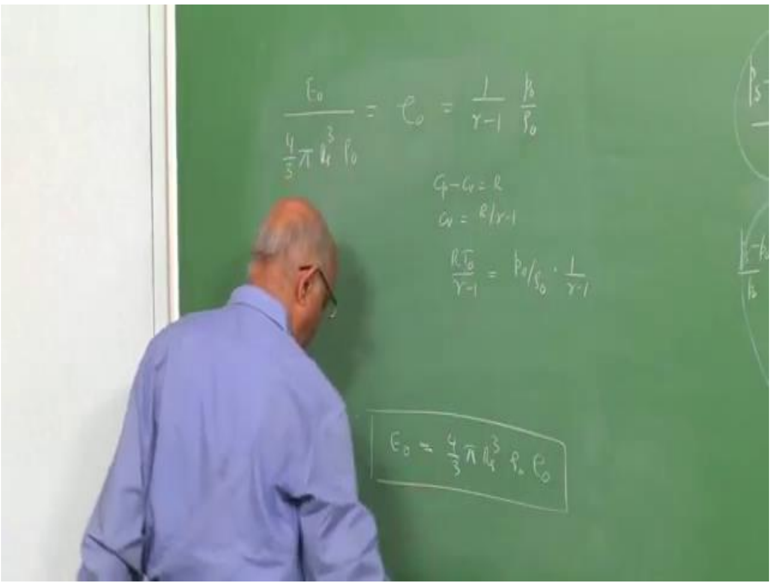

So, I get the value of E 0 divided by 4 upon 3 pi into R s cube divided by row 0 is equal to e 0 and what is e 0 internal energy by unit mass which is equal to C v t. So, that is specific heat at cost and volume into temperature because we know that d e by d e of temperature is equal to C v, C v t is the value and C v. Now, we have seen earlier can be written as again we do that C p minus C v is equal to specific gas constant C v is equal to, therefore r divided by gamma minus 1.

Therefore, I get the value of C v t as equal to r t by gamma minus 1 or this is equal to p 0 and the ambient temperature is t 0. So, this is equal to p 0 by row 0 and, therefore this part C v t I can replace by the value of p 0 by r 0 is r t 0 into 1 over gamma minus 1. Now, I carry this forward here and, therefore C v t can be replaced by or e 0 can be replaced by the expression 1 over gamma minus 1 into p 0 by row 0.

So, if I have to solve this particular expression over here what is it I get, I get e 0 I bring p 0 over here in the numerator divided by what is it I get. Well, row 0, row 0 gets cancelled over here I get 4 upon 3 pi into R s cube is all what is let over here is equal to 1 over gamma minus 1 portion. So, the terms e 0 by p 0 is what we call as cube of the explosion length e 0 by p 0 to the power 1 by 3 energy release in a medium 1 by 3 is equal to r naught and, therefore what is it I get, so I simplify this.

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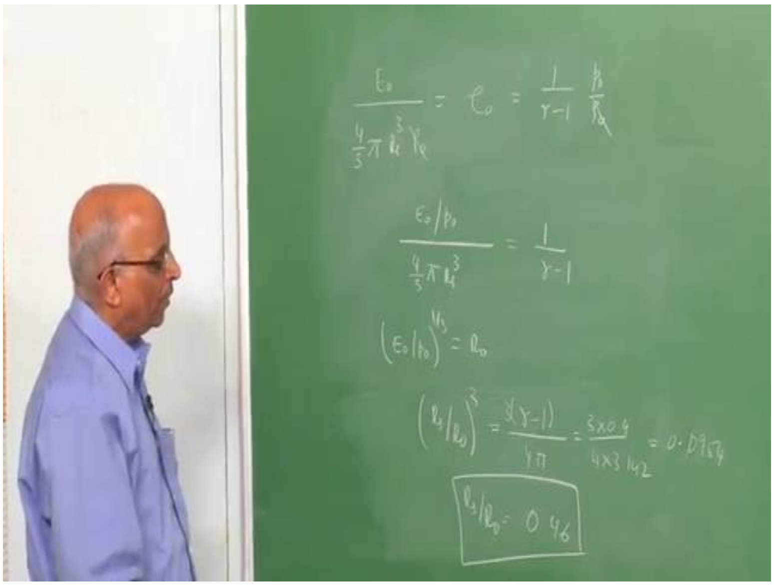

I get the value of R s by r naught cube bring it on the right hand side over here must be equal to I get the value of gamma minus 1 divided by 3 comes on top. So, 3 into gamma minus 1 divided by 4 pi 3 into gamma minus 1 divided by 4 pi is equal to this particular value and what is the value. Now, I am able to find out the value of R s by r naught at which the value is such that if R s by r naught is greater than this value. So, this value let me get the precise number for you the value of R s by r naught is equal to put the value three into 0.4 divided by 4 into 3.142 which is equal to 0.095.

Now, rather the value of R s by r naught taking the cube root comes out to be 0.46 and, therefore what is it we tell ourselves if the value of R s by r naught is greater than this particular value. Well, my predictions are all wrong because the initial internal energy begins to play a role and predictions will be much lower than this. But, in, but we also found when it is 0.4, the mach number of the shock has already decreased to a value around 2 or something.

So, it is still in the weak blast region the predictions what we have done so far are, therefore valid only for values around. Now, let us say less than around 0.25 or 0.3 this is where I conclude today and be able to put things in perspective what is it we have done we have looked at the energy conserved by the lead shock wave. So, we have been able to get an expression for p s that is the over pressure behind the over pressure of the blast wave.

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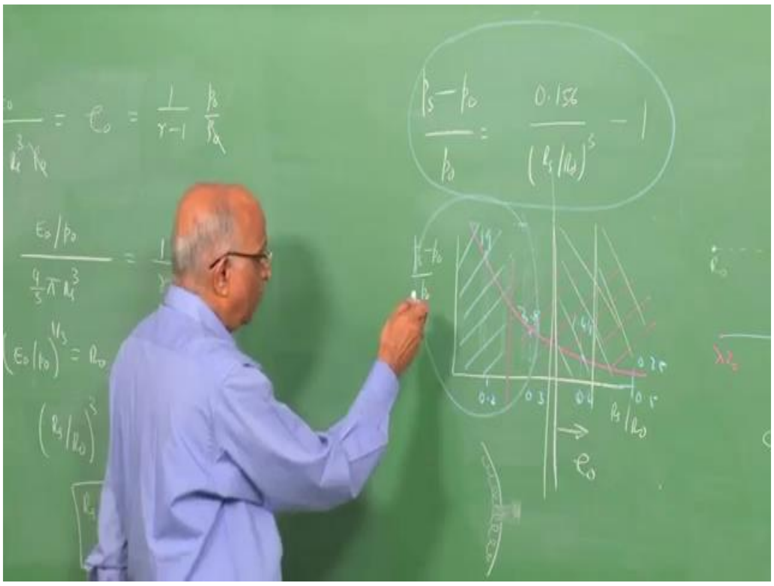

So, in addition to this we talk in terms of Cranz Hopkins scaling law we talked in terms of Sach’s scaling law which is able to give us this expression. So, we also did in the last class the mass balance which told that whenever I have a strong blast region, well the mass gets concentrated at the front. So, this is mass concentration is something like a hammer and something like a concentration which moves my material at high velocity and tells the dimension.

Therefore, in next class what we look at is we have, we are looking at only the strong blast region we would like to take a look at the weak blast region such that we can we can have some expressions for this. But, in weak blast region it is somewhat difficult as we tell ourselves the initial conditions are dependent on Mach number.

Therefore, we look at the weak region and get the overall that means in both the strong blast region and the far field region in which the blast wave has decayed. So, we try to get the overpressure and in addition to this we also take a look at the impulses and with that we would be done with the blast wave.

Thank you then.