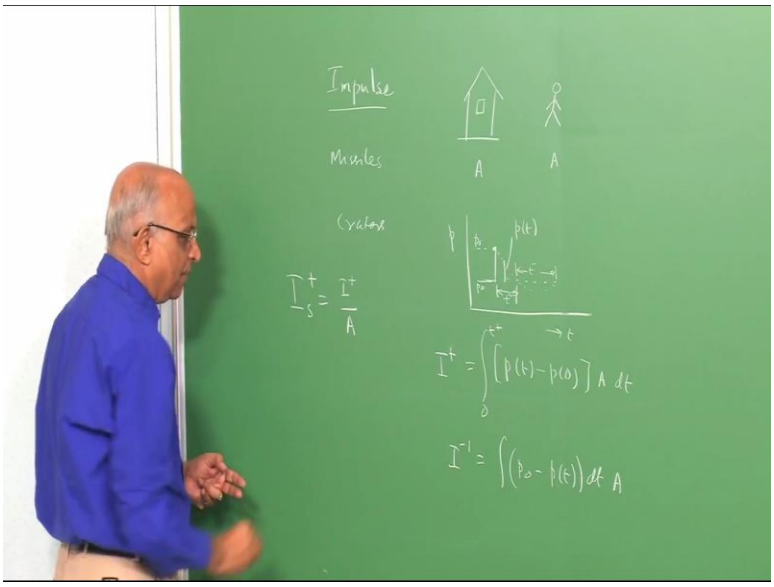
Introduction to Explosion and Explosions Safety
Prof. K. Ramamurthy
Department of Mechanical Engineering
Indian Institute of Technology, Madras

Lecture - 9
Blast Waves: Non-dimensional impulse, Cranz Hopkinson Scaling, Missiles, Fragments and Shrapnel, Craters, Examples

(Refer Slide Time: 00:16)



Good morning, in today's class, we will discuss further on impulsive or impulse generated from a blast wave driven by an explosion point one. After that, we will also try to take a look at something like missiles may be fragments sharpness, which is generated by explosion missiles from explosions. If time permits, we will also take a look at craters which are formed at the sight of the explosion. Let us take a look at impulses we already defined what an impulse is to clarify further, let us take two examples. Let us say I have a house, and let us say a small house over here with a window pane over here or let us take a man who is standing over here.

Let us assume that there is an explosion occurring some distance away from the house in front of the house. Then, you have blast waves which come and hit the house as it is what happens or a blast wave comes and hits the front of the human being. Let us say that the area is A, the frontal area is a at which the blast hits it, therefore, what happens when the blast wave hits the house. That means the ambient pressure let us say is p 0, let

us have a plot of pressure as a function of time, the blast wave comes and hits the house and therefore, I have pressure that is the pressure from p 0. That is the ambient pressure prices to a value of p s when the blast wave hits it.

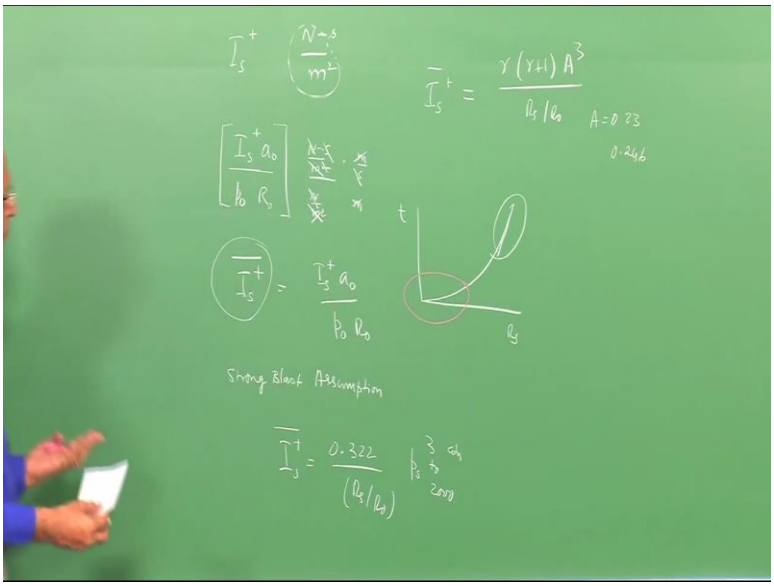
You have something like a pressure could be higher because the blast wave gets reflected. We will take a look at the reflected pressures tomorrow, but if I were to look from the side view that means I have I am looking at the blast wave as it is progressing, I am looking from the side. I take the pressure rise across the blast wave here and what happens the blast wave further propagates the pressure decreases. This is the type of pressure decreases and when the pressure decreases because of the change of pressure, I have a vent may be because of the momentum the pressure could even go to negative values.

Therefore, I have a duration over which the pressure is higher than the ambient may be over duration of t plus I have pressure higher than the ambient value p 0. I have duration; let us say t minus over which the pressure is less than the ambient. Therefore, if I say that the area of the house or are of the person is a then at any time t, let the pressure be p t. Therefore, the pressure difference which the person experiences p t minus p 0 and if I multiply this by the area, I get the force and the value of change of momentum is equal to let us say this is the force which the body experiences at this force is a variable.

I want to find out what is the impulse and what is the impulse is the change of momentum rate of change of momentum is the force. Therefore, I can write the impulse which the body feels as equal to p t minus p 0 into a as it is integrated from 0 over the particular duration. Let us say t plus for the positive impulse because in this case the force is higher the building is sort of dragged in this particular duration because of the change in momentum.

In this case, the building comes towards the front I have negative impulse that is minus is equal to I have the ambient pressure minus p t into sort of d t into area; this also is integrated with respect to d t. Over here, I have the positive impulse, I have the negative impulse and what we defined yesterday we as we said, and well I can talk in terms of specific impulse which is equal to the impulse divided by unit area.

(Refer Slide Time: 04:18)



Therefore, we write the expression for specific impulse which is positive in the positive specific impulse as equal to 0 to t of p t minus p 0, which is the ambient pressure into d t over here. Similarly, I also have the value for the negative specific impulse; therefore specific impulse is different from the impulse in that we are talking of impulse per unit area. This is equal to these two things are equal to I divided it by a I plus divided by a is I s plus and if I talk of I s minus I minus divided by a is I s minus.

I will talk of specific impulse; I think it is also necessary for us to look at the units of the specific impulse. Well, the unit of impulse is equal to change of momentum and what is change of momentum you have mass into velocity is the change of momentum that is kilo gram meter per second. I can also write this as equal to kilo gram meter by second square into second kilo gram meter per second squared is Newton this is second and therefore, impulse could also be written as Newton second.

In fact, this comes directly from this integral, therefore let us take a look at this integral this is force in Newton into time, which is Newton second. Therefore, we can say well the unit of specific impulse should be Newton second. Since I am talking per unit area, the unit should be Newton second which is for impulse divided by area Newton square.

This is the unit for the specific impulse, let us say positive let us say negative, in general most of the blast waves the damages done by the positive impulse because the magnitude of the negative impulse over here is always much lower than this value. Therefore, we

look from for damage point of view looking at the positive impulse alone and most of the literatures gives values for the positive impulse. You must also remember that the negative specific impulse is also important, let us take this example again of the house.

Let us say I have the blast wave coming hitting this over here, let us say this is the window pane of the house which I now show here and what happens because of the impulse and the sudden rise in pressure. Let us say that the window pane gets shattered, therefore initially the impulses acting in this particular action towards the house. Therefore, it takes some time for the window to break and when it breaks the window is subjected to the negative impulse it takes some time for the window to break, then it is subjected to a negative impulse. Therefore, the fragmented part of the window falls towards the explosion side rather than falling along the explosion inward.

That means the effect of the negative impulse supposing I have a window pane like this something get ruptured the blast is travelling in this direction the ailed window or the fragments fall in this particular direction. This is how the negative impulse also influences; we will basically look at the positive values of the specific impulse and thereafter calculate value of the impulse which is just the multiplied by the particular area. Having said that, let us also take one more look you know we are talking in terms may be the pressure distribution. This gives me the value of impulse and the impulse is over a particular time over which it is taking over which the blast wave is moving or over which I have the positive contribution of pressure.

Now, you know there is something which we must not forget, you know when we are talking of these impulsive taking place let us let us take a look at what causes this impulse. You know is it possible to write the value of impulse this is in units of Newton second per meter square. We told ourselves initially there is arise in pressure it comes down with respect to time and what did we say that the rise in pressure that is the pressure behind the blast wave. We write it in non dimensional form as p s minus the ambient pressure divided by the ambient pressure can I also write the value of the impulse instead of carrying a Newton carrying a unit like unit second per by meter square.

It can also be expressed, it in a non dimensional form, therefore, we again take look, yes my value of the specific impulse which let us say positive value is given as Newton

second by meter square. Now, I want to make into something like a non dimensional forma and therefore, I find that I have a value like Newton per meter square and the easiest way of getting rid of this would be to say well I have I s plus if I were to put it in terms of the ambient pressure.

Well, I get Newton second by meter square, now I get Newton per meter square in the denominator. Therefore, this goes, but still I am left with a second and easiest way is if I multiply the numerator by a velocity and denominator by a distance. Well, I have the sound velocity in the free stream medium, I know that the intensity of my pressure spike here depends on the value of the explosion length because that tells me a how strongly it is how strong or how much energy I am driving in. Therefore, if I put take a look at this, I have meter per second I have something like meter here. Now if I cancel, I get meter over here, I get meter over here, meter and meter get cancelled over here, then Newton and Newton get cancel, second and second get cancel.

This becomes a non dimensional unit for the specific impulse and this non dimensional unit is represented by I s, let us say plus non dimensional which is equal to exactly what I have written here. The specific impulse with units divided by this divided by p 0 ambient pressure into the explosion length. We want to derive the expression for this and see how it affects the building may be we will do this when we are assessing the damage, but to be able to get a value for non dimensions specific impulse. All what we do is well we know when we have a strong blast wave the magnitude of this as expressed as p s divided by rho 0 R S dot square.

The changes in density and the changes in velocities associated with this are not highly are not dependent on the mark number. We also note that the gradients behind it will be similar and using, therefore I can write for a strong blast wave that is from blast assumptions. That means Mach number is high I am talking of R S by R naught, which is somewhat near to my center of the explosion. For the strong blast assumption, I can therefore, get it explicitly and the expression if I put the gradients and all down, we can comes out to be I s plus is equal to 0.322 divided by R S over R naught.

This is the way the non dimensional impulse is changing with R S by R naught you know, in fact you know if you do strict analysis, you will find that the velocity behind the blast wave. If I do a self similar analysis or I write the conservation equations in

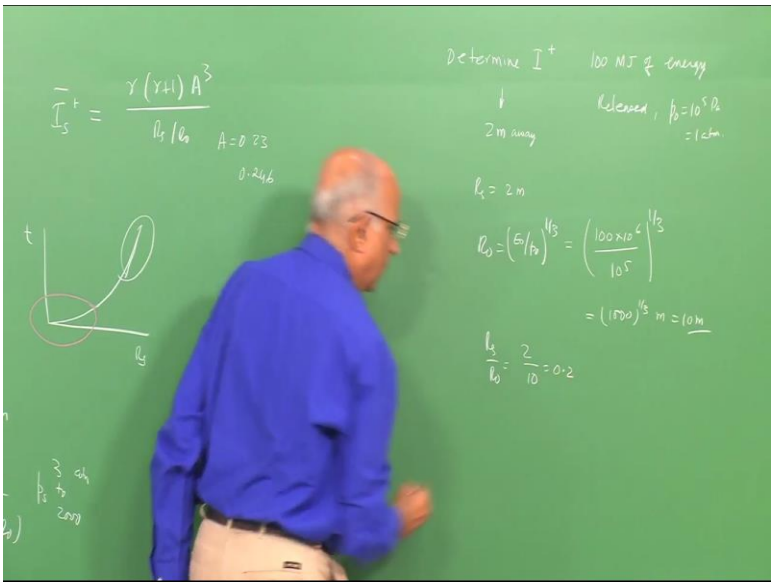
differential form and evaluate the velocity the velocity changes behind a blast wave sort of linear and. Therefore, you get the values of I s plus as equal to 0.322 divided by the scale that is the scaled value of the distance R S divided scales by R naught and this is non dimensional. This in fact is true for strong blasts that means when I talk of the values of p s between let us say 2 to 3 to something like may be 2000 atmospheres or so.

When I talk of rarely high values, I get this particular value you know I have not derived it I just used this values there are lot of correlations available in literature for different types of explosions how the non dimensional specific impulse will behave. This is for a strong blast assumption; similarly, if I have an assumption which is let us say a weak blast that means I have something what let us see what should I say. Now, if I talk in terms of t versus R S, I start with a strong blast assumption that means in the strong blast assumption, I am in the near field wherein R S by R naught is less than around 0.4 to 0.5 or let us say less than around 0.35 for which this expression is valid.

When I am talking of the weakened case, namely when the blast has gone to the far field and it is the mark number is not that high then in that case may be I use in the far field. I use the acoustic approximation and what I get is I s plus is equal to I get gamma, let me get you the exact expression I s plus is equal to gamma into gamma plus 1 into a cube divided by R S over R naught in the far field. You know the value of which is a constant varies between A is equal to 0.23 to something like 0.246.

You know there are as I told earlier there are number of values of the non dimensional valuable for different types of explosion, but I think we will just examine these two for strong blast case and in the far field. Therefore, I think this is all about the impulses and let us do a problem such that we are very clear how to calculate the impulse and I do this simple problem.

(Refer Slide Time: 14:38)



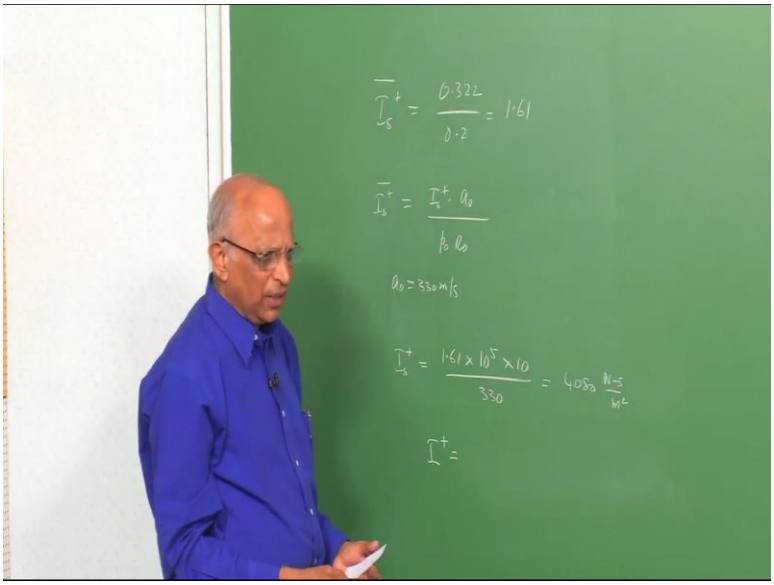
Let us take this problem of let us determine, let us say I say determine the impulse that is the value of the positive impulse when I have an explosion in which let us say 100 mega joules of energy is released. That is an explosion in which 100 mega joules of energy is released at a source in an ambient pressure wherein the ambient pressure p naught is equal to let us say 10 to the power 5 Pascal that is equal to 1 atmosphere. I want to determine the value of impulse at a distance of let us say 2 meter away from the sight of the explosion. Therefore, what I do I have to calculate this value well my R S is equal to two meters away the energy is 100 mega joules, therefore, I know R naught is equal to e naught divided by p naught to the power 1 by 3.

Well, I am still in the frame work of the spherical explosions I assume that the explosion is spherical of spherical geometry. Therefore, this gives some 10, 100 mega joules into 10 to the power 6 divided by p naught which is 10 to the power 5 over here Pascal, be careful about units Newton per meter square, this is Newton per meter cube this is equal to 1 by 3. This is equal to 10 over here, I have 1000 to the power 1 by 3, so much meters which is equal to 10 meters.

Therefore, the explosion length for the energy deposited at 100 mega joules in an ambient pressure of 10 to the power 5 Pascal is 10 meters. I am interested in R S by R naught that is R S is 2 meters 2 divided by 10, which is equal to 0.2, we know from our earlier discussions that this is the near field in which the blast wave is strong. Since blast

wave is strong, I am justified in using this particular expression and therefore, I now split the value of the non dimensional specific impulse, let us calculate that value.

(Refer Slide Time: 17:05)



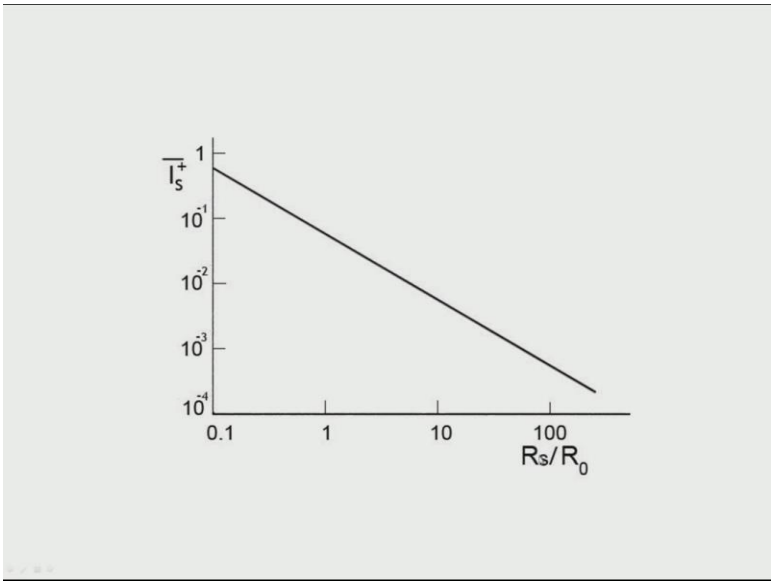
Non dimensional is equal to 0.322 divided by the values 0.2, which is equal to 1.6 that is 3.2 divided by 2 say 1.61 is the value of the non dimensional specific impulse. This is not dimensional waned to calculate the value of specific impulse and specific impulse I s non dimensional is equal to I s plus into let us put down it is equal to the sound speed divided by the value of p 0 into R 0. We have the ambient which is equal to 1 atmosphere, let us say that the temperature is ambient the sound speed in ambient is around 33 meters per second.

This should have been given to you and therefore, I get the value of I s this positive specific impulse as equal to 1.61 into the value of pressure is 10 to the power 5 Pascal the value of R naught. We determined as equal to 10 meters divided by the sound speed which is 33 meters per second and therefore, the value of the specific impulse comes out to be 1.61 into 10 to the power 5 divided by 33 into the value of R naught is 10.

Over here, this is equal to 4080 into second by meter square this is the value and depending on the frontal area the frontal area is let us say 0.5 meter square the value of the impulse is equal to the value multiplied by the frontal area. This is how we calculate the value of the impulse, therefore, you know what is it we have done so far.

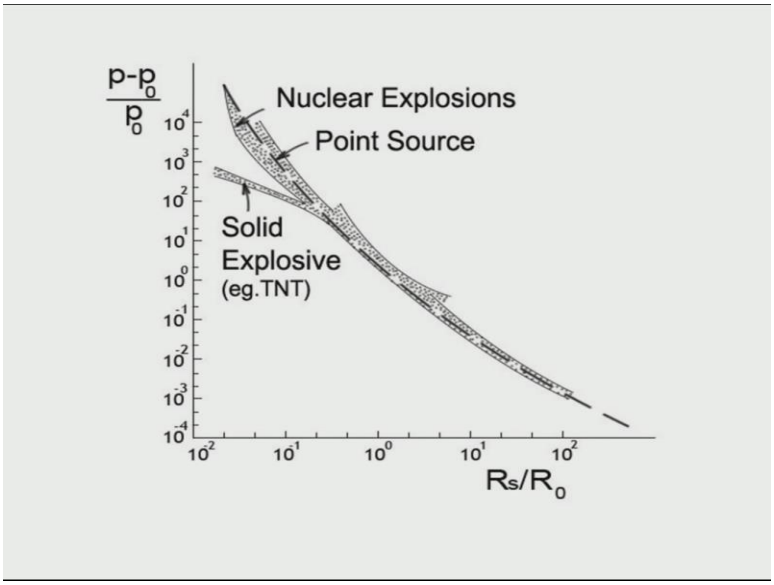
You know we did not get into details of derivations of this because we already know for a strong blast it is like this may be if I am looking at a distance far away. Therefore, I need to first calculate the value in the far field and if I now it is in the far field I use different expressions for I for the value of the non dimensional specific impulse in this case I use this because I know it is in the near field. In fact, you know there are plots for the non dimensional specific impulse like I show in this particular slide.

(Refer Slide Time: 19:28)



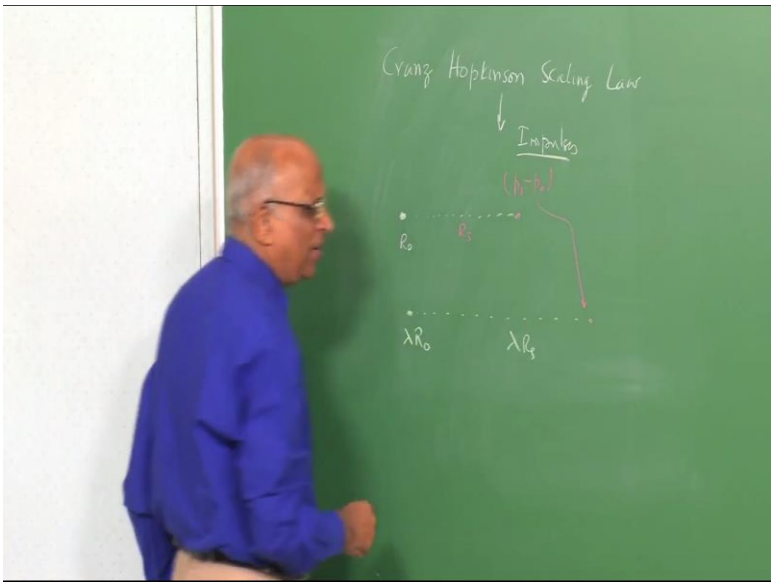
I show the non dimensional positive specific impulse as a function of R S by R naught, it varies over here.

(Refer Slide Time: 19:37)



You know to be able to apply it, first we go back to what we did in the last class, namely the over pressure we find out at the R S by R naught. What is the type of over pressure and find out what is the shock pressure? Find out for this type of pressure what we have whether what type of correlation to use for the impulse and use the particular correlation, but in this case in this case may be I use this correlation. I could use different type of correlations, which are available in literature; this is how we calculate the values of the specific impulse. Now, one last thing I should also qualify for these impulses because you know you will recall we talked in terms of some scaling law; I called that scaling law as Cranz Hopkinsons' scaling law.

(Refer Slide Time: 20:25)

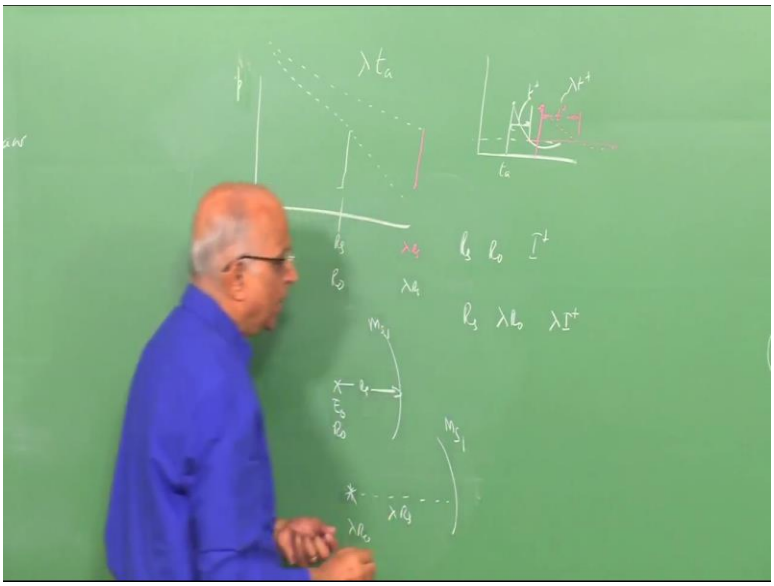


We did this for Cranz, what was this scaling law you now if we say I deposit some energy in some particular medium I say I deposit some energy size that the equivalent explosion length is R 0. At some distance from this explosion side, let us say that the magnitude of the pressure spike is let us say or the pressure over pressure is p s minus p naught at a point let us say R is away, then what was the Cranz Hopkinsons' scaling law for over pressures. We say if I have an explosion, let me use a different color chalk if I have at the at a similar side a similar explosion for which the explosion length is lambda R naught, then at a distance let us say lambda R is away.

That means, the explosion length is increases by a factor lambda and the distance if I increase by the same particular value of R S then at this particular distance R S is away well the magnitude of the over pressure is the same. That means, an observer stationed at a distance lambda R S is away from an explosion of explosion length lambda R naught feels the same over pressure as an observer standing at a distance R S from an equivalent explosion. From a similar explosion of explosion length R naught this was the Cranz Hapkinsons' scaling law for over pressure.

Can I write a similar scaling law for let us say this was or over pressure? Can I write for impulses and if so is it exactly the same or is it different? For this, I have to go back and ask myself how the distance is changed with explosion length; let us do this particular problem.

(Refer Slide Time: 22:34)



Let us say, well I have the explosion taking place let us say over here I have may be at a distance R S away I have may be a value where in the pressure spike is so much the explosion comes over here pressure jumps by this. When the explosion length is let us say R naught, now if my explosion length is increases what is going to happen the same pressure spike I will get R S by R naught is still the same I will get the same value of spike at a distance lambda R S away. In other words, in this case what is going to happen if I am going to take a look at s dot or marked number the or let us say the pressure ratio I started the high value of pressure it decays like this in this particular case. In this case, since I am I have increased the energy or increased the value of lambda R naught.

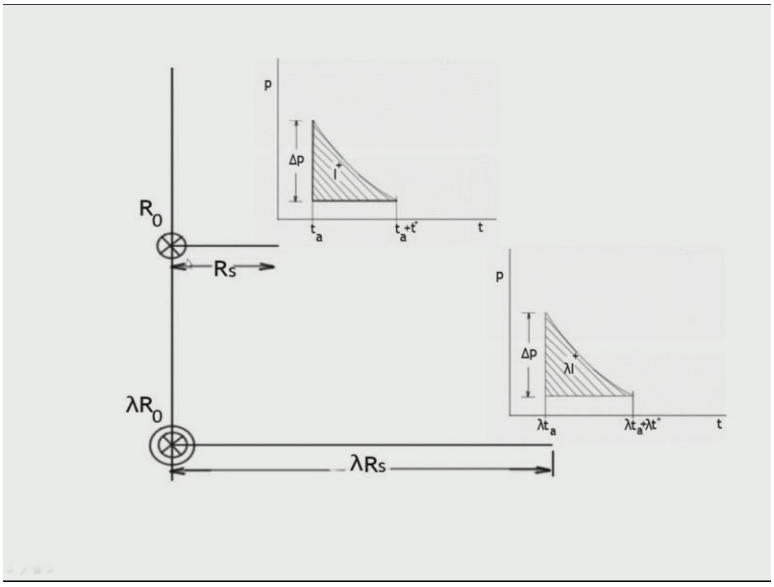
Well, the blast wave will decay a little slowly that means it will take a longer time in other words all what we are saying is supposing I have an energy release e naught I have a marked number. Let us say m s one formed at a distance R S away if I release higher energy let us say I put more energy over here.

The same marked number m s 1 is at a higher at a larger distance from the centre over here and if this value is R naught and if this value is lambda R naught. Well, I have the same m s one at a distance lambda R S away, therefore, the distance from the sight increases if the distance increases. Well, the arrival time increases by the same factor lambda t a from an explosion length of value lambda R naught if the arrival time increase let us let us take a plot at the value of the impulse.

That means, initially I had at the value of pressure going up this is my ambient pressure it case and it came like this now what has happened is the lambda t a that means the pressure spike come came over here. It came over here and therefore, what is going to happen the time scale of the duration of the positive impulse which is over here also scales in the same way this was t plus over here. The distances have increases, therefore, the times because the same value of the velocity is not decreasing by the same amount.

Therefore this time t plus is equal to lambda into t plus if the tie increases well the value of the impulse if the value of impulse at a distance R S from the side of an explosion of explosion length R naught is equal to let us say I plus. If now I consider an explosion of length lambda R naught at a distance R S where value the impulse will go by lambda times. That means, the impulse scales as the explosion length lambda and this I show in the slide and let us take a look at this.

(Refer Slide Time: 25:45)

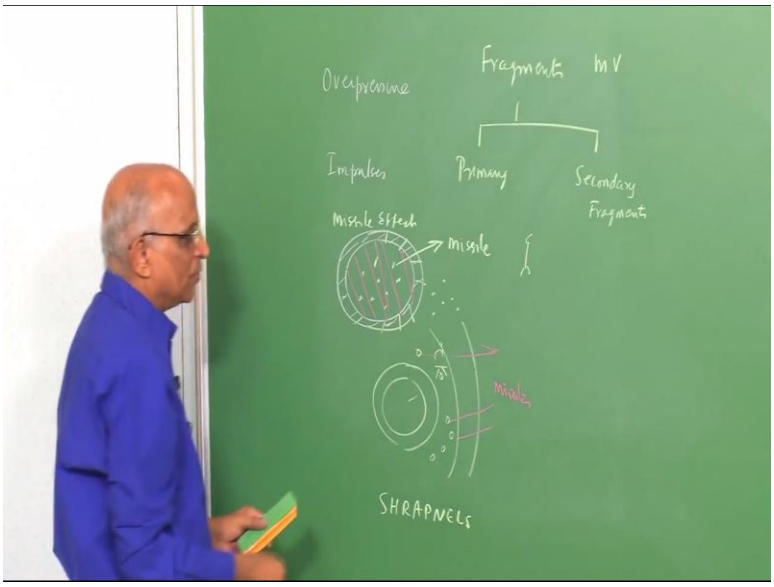


You know this is what I show here if I have an explosion of length explosion length R naught then at a distance R S I get an over pressure delta p and I have an impulse I plus over here the arrival time is lambda a and the impulse acts over at time. Let us say t plus over here t a to t a plus t plus if I have an explosion length whose value is lambda R naught. That means, I increases the value and now I look at the impulse that is lambda R S way such that R S by R naught is same in both the cases well the over pressure by the by the Cranz Hopkinsons' rule is still the same.

Then, the duration my arrival time here is lambda t a the value of the time at which the pressure falls to a value p naught is lambda t a plus lambda t plus this is equal to t a plus t plus. Therefore, the magnitude of this impulse will be lambda times the value over here that means Cranz Hopkinsons' scaling law for over pressures is that at a an observer feels an impulse. This is lambda times the impulse observed by an observer who is standing at a distance R S away when the explosion length is R naught here.

In this case, the explosion length is lambda R naught that is the impulse scales directly as the explosion length for similar scaled distances and this is what the Cranz Hopkinsons' law for impulse is. Well, this is all about impulse which we will look at maybe we will try to solve more problems as we go along. Let us turn our attention are there, any other effects of an explosion taking place what are the two effects which we consider.

(Refer Slide Time: 27:33)



We considered may be over pressure from a blast wave driven by an explosion which literally crushes the object because of the high pressure. We also talked in terms of impulses that mean momentum which really drags the object. Now, in addition to this you know whenever an explosion takes place let us say I have an explosive it is contained in a casing. Let us say this is the casing, which contains some element of the explosive over here the explosive is burnt or it produces high pressure and what happens? The casing ruptures and because of the high pressure and velocity the casing travels, that means the broken casing travels as a missile, it travels at high velocity.

If somebody is standing over here, the object hits him and may be you know when some object like iron or a fragment hits you. Well, you feel the punch of it more than what an air pressure could hit you therefore; in addition to over pressure and impulses you also have the missile effects from the explosion. That is the fragments which are broken off from the casing could come and hit you it is all not only these fragments are pieces from the casing which break and come and hit you as missiles if I have let us say the casing over here.

This explosion takes place and there are some objects that are littered like I say let us say I have some table over here or say I have some chairs over here some other objects may be some pieces of earth or something which is lying over here. What is going to happen when the blast wave travels forward? This blast wave is also going to drag these things and give them some velocity and also these particular things will also act as missiles.

That means, from the casing I form fragments which are held as missiles I also have the neighboring objects which are there which are accelerated by the blast wave and come and attack a person or impinge on a person as missiles. Therefore, we can tell ourselves well the casing I form fragments in the casing and if this casing let us say this fragments have a mass m and they travel with a velocity v the momentum is m v and when this momentum is brought to rest. Well, I get a force and that causes injury to people who are standing in fact fragments sometimes do much more hover than over pressure and impulses.

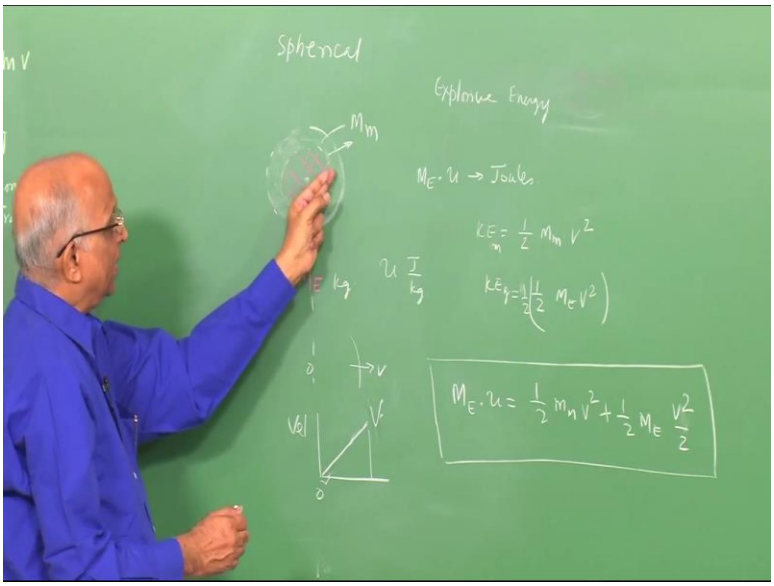
Well, these fragments can be classified into two cases I could call them as primary fragments primary fragments are fragments generated from the casing of the explosion itself when the neighboring masses which are accelerated, I call it a secondary fragments. Well, what do the military people do you know or what do this terrorist do you know in the explosive they put some objects may be some shape objects like let us say nails or let us say some lead shots or some material. It is put in the explosive I have, they put these objects over here which are known as sharp nails. When an explosion takes place, these particular shape objects are the shapes objects over here travel at high speed.

They sort of produce lot of damage not only on buildings on buildings on human beings on living things which are around the place and we talk in terms of fragments missiles and sharp nails in the case of an explosion. Therefore, our aim is let us let us do a small

problem our aim is to find out what is the momentum which something let us s I have this duster in the region round it I call this duster as a secondary fragment. I have the shock or the blast wave which comes this is need to fly off at a high velocity and when this hits some object.

Well, it transfers a lot of force to the object because it is travelling at high sped it is brought to rest, I have a force and this is what causes the damage. Therefore, let us let us try to get the missile effect coming out, let us do this particular problem; I want to calculate the velocity and the momentum. Let us make some assumptions; as usual you have to be able to solve a problem we need to make some assumptions.

(Refer Slide Time: 32:25)



Well, let us assume that the blast wave which is produced form the explosion is spherical that means I have a thing over here I have a casing over here inside the casing. Well, I have the explosion taking place over here, that means let the mass of the explosive is let us say m e over here, the mass of the explosive. Let us assume that the mass of the casing which holds the explosive has a mass let us say M m, that is the mass of missiles which is formed the total mass of missiles, which is formed is equal to M m. Well, mind you this all gets fragments is thrown in different directions over here, therefore, we say well I assume a spherical geometry then I assume that the mass of the casing is M m.

I want to calculate what are the fragments? What is the velocity? They have from this, it holds an explosion M e kg let us say. Let us also assume I want to find out the energy

which is released I say energy release form this particular explosive could be let us say u so much joules per kilo gram is the amount of energy, which is released from this particular explosion.

Let us also assume that since being center and velocity at the casing when the things just bursts is let us say at the casing the velocity of the gases is v at the center. Since its symmetrical the velocity is 0, let us assume that the velocity varies linearly from v to the value 0, that means the value of velocity along this, when the thing explodes at the edge over here the velocity is v. At the center, there is velocity as a function of this particular distance at the center because of symmetry the velocity is 0 over here and with this let us tries to write an expression. The expression we can say is well the energy released from the explosive provides the kinetic energy for both the gases, which are being given out and are also the mass of the casing which is totally the total number.

Total thing which goes out is, goes out with the same velocity, let us assume that the fragment here also leave with the same velocity with which the gases are leaving. Therefore, the kinetic energy of the fragments from the casing and the kinetic energy of the gases is equal to the exclusive energy which is released. Therefore, with this with this type f scenario, let us try to calculate the velocity let us write the expression down the total energy which is released if the energy released is u joule per kilo gram. I have mass of explosive which is m e the total energy which is related is m e into u so much joules of energy is released.

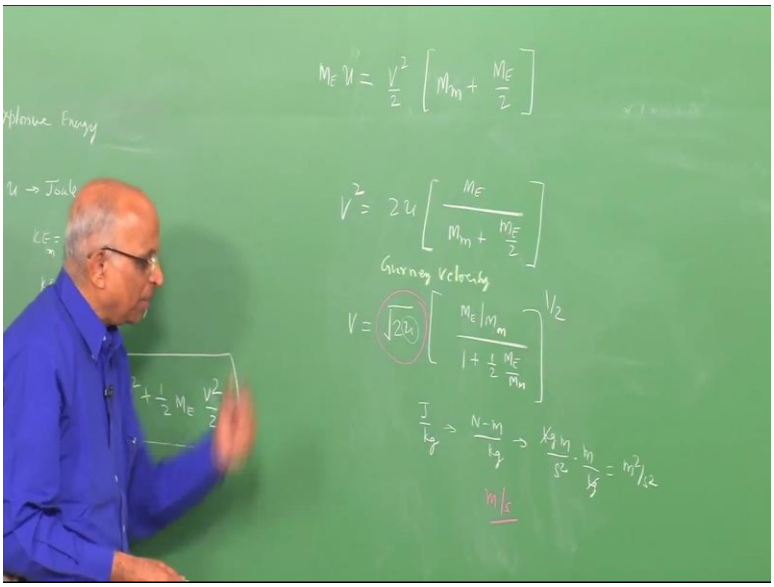
Where does this energy go into? Kinetic energy of the gases and kinetic energy of the of the fragments of the casing and therefore, let us say kinetic energy of the casing that is the total mass is equal to a half M into m into v square. That is the velocity with which the fragment leave the leave the explosion side that s at the time of starting it is v square which is the same as the gas velocity. This is let us say of the mass of the casing as it is or let us say the missiles what are formed kinetic energy of the gases is equal to a half into mass of the explosives which form gases now into v square that is over here at the center.

Well, the velocity is 0, it is 0, and therefore the average kinetic energy is equal to half of half into m e into v square. Therefore, I can now write m e into the value this is the total energy is equal to half mass of the missiles formed from the casing into v square plus

half into mass of the explosive which is generated into half of into v square divided by 2 M e v squared by 2 into half of this. This becomes my general energy balance equation, this is based on the assumption that, well we say at the center the velocity is 0 because of the symmetry the velocity here is v.

The casing travels with a same velocity v and it is broken into fragments over here, this is the total mass of the all the fragments put together. Let us solve this equation let us see whether I can get some number s for it let us calculate the velocity, I solved this, I want to get the velocity of the fragments v.

(Refer Slide Time: 37:25)



Therefore, I tell myself well m e into v square is equal to I get v square M m e into u I am sorry this is equal to the energy per unit mass is equal to v square divided by 2 into I get the mass of the total number of fragments which are formed plus m e divided by 2. Rather, I am interested in the velocity, therefore velocity is equal to 2 u let us calculate v square is equal to 2 u. Now, if I were to put this down, will get m e on top and I get M m Mass of the missiles which are formed into m e divided by 2 or rather I took 2 over here this becomes 2, you I have m e over here and I get I just write this down.

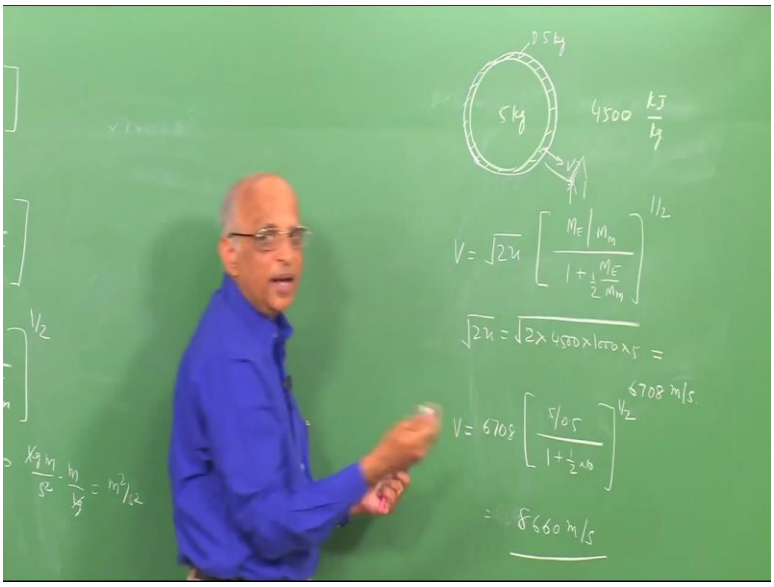
Rather, I get the value of velocity is equal to two into u into I get let us divided it by one way or the other let us divided it by m m. Therefore, I can m e explosive divided by M m into 1 plus that is the mass of the missiles into 1 plus half into m e by M m and this also becomes half that is I take the square root of this.

Now, if I if I look at this particular expression you had nits of let us say energy release per unit mass. Therefore, the value of twp u has units of joules per kilo gram the value of joules per kilo gram I can write joule as Newton meter per kilo gram. Well, I can write Newton as equal to kilo gram meter per second square into I have to compete this meter per kilo gram. Therefore, kilo gram gets cancel this gives me meter square by seconds square or rather the units of this particular factor, which is getting multiplied over here has units of under root this that is meter per second. Since it has units of second, it is given a name it is known as a gurney velocity g u R n e y gurney velocity.

This is indicative of the energy in the explosion and this multiplied by this gives me the velocity of fragments. Mind you this velocities can be very high if the mass I have something like an iron, which is getting accelerated compared to plastic, whose density is much lower than iron, since iron has a heavier mass. You know the mass into the velocity gives me a high value of the momentum and this momentum when it hits an object is capable of piercing and causing misery to people.

This is how we say well these are the missile effects from fragments from sharpness and also from the objects which are flying around that which called as secondary fragments. Let us go further, let us try to do a small problem in this such that we calculate some velocities let us do this particular problem, let us calculate the velocity of fragments for the case of the problem which I consider.

(Refer Slide Time: 41:08)



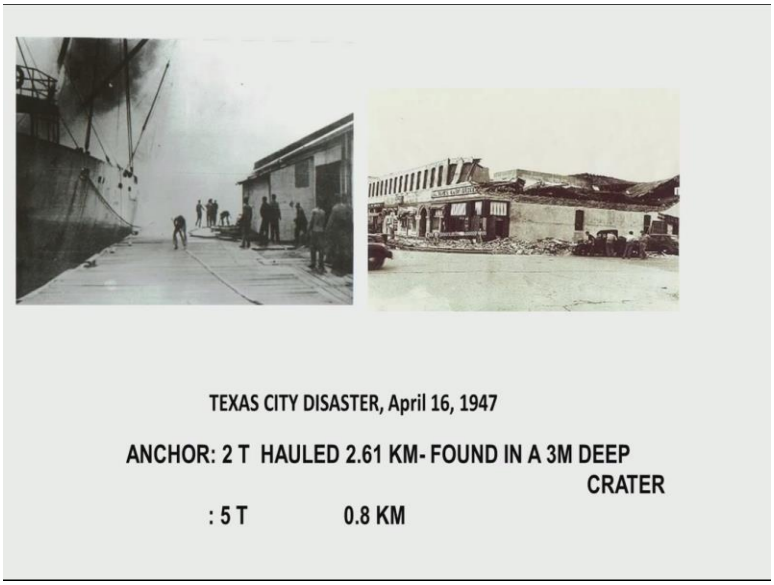
I have an explosive of let us say mass 5 k g whose energy per unit mass is let us say 4 1500 kilo joule per kilo gram is a energy. Therefore, the total energy of this explosive is five into four thousand five hundred kilo joules now this particular mass of explosive is contained in a steel shell. Over here, the mass of this steel shell is let us say 0.5 k g the total mass is 0.5 k g, I want to be able to calculate what is the velocity of the missiles or fragments which are found from the rupture of this case. What is the velocity with which it emerges out of the explosion? I am interested in V, therefore, I day well I have just derived the expression I know that the velocity is equal to the gurney velocity two into small u into the value of m e by M m, mass of the casing.

Whatever flies over here into 1 plus m e by M m into 1 by 2 to the power half this is my velocity? Therefore, if I now put the value of gurney velocity I have 2 into u which is equal to 2 into the energy is 4500 kilo joules mind you is aid to be able to get the velocity back I have to have joule. Therefore, it is 1000 joules into the mass which is 5 k g that is 5 into 4500 is the energy in kilo joules into 1000 is joules this is the value of 2 u and this comes out to be 6708 meters per second. This is the gurney velocity and then I calculate the velocity over here v is equal to 6708 which is equal to the value of under root 2 u into I have mass of the explosive which is 5 k g divided by mass of casing which is 0.5 divided by one half into 5 by 0.5.

This is 10 over here to the power half and this gives me the value as equal to 6708 into 10 divided by 6 to the power half the well the value comes out to be 6708 into the facto which is equal to 8660 per second. You find that the velocities are indeed large and therefore, if an object at this high speed you know we are talking of mark number of this. If I calculate with respect to the condition of the of the sound velocity which is something like 33 meters per second we are talking of mark numbers, which are extremely high divided by 300. What is it, you gets something like mark number 200 that means extremely high speeds and these impacts in somebody may be even at some distance.

These thing will by drag, it will decrease in velocity, but if it hits a human being well it just penetrates into his skim ad c sues misery even if it hits a building well due to the impact the building may get damaged. This is the effect due to the missiles, let me take you through one more example and this example I will show in a in a slide.

(Refer Slide Time: 44:52)

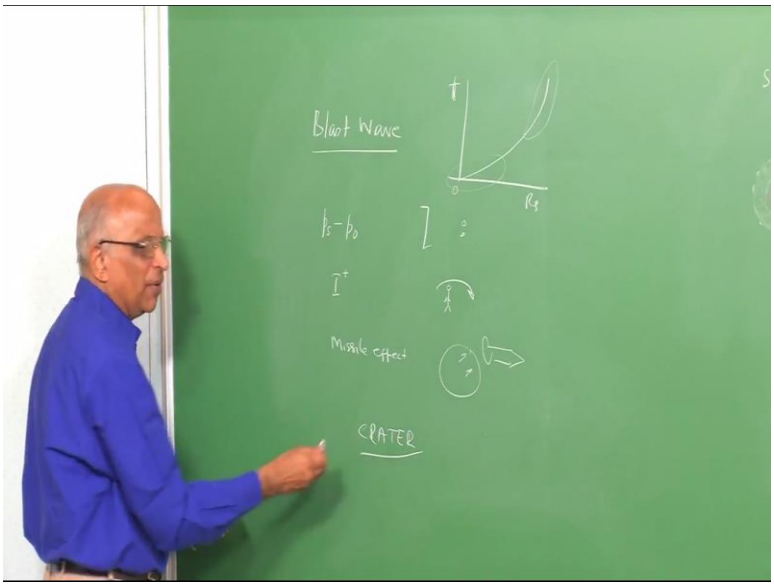


This example we have already done while looking at the different types of explosions we take the example of the Texas City disaster which happed on April 16, 1947. What was this we found that the hull of a ship in this case carries something like 7,700 tones of ammonium nitrate, which was a fertilizer grade?

We called it as f g a m fertilizer grade ammonium nitrate and when it exploded. Well, we said that the type of explosion what we had caused something, the sound could be had could be heard from this explosion over a distance of 450 kilometers away. The window of buildings got broken over a distance of something like 40 kilo meter away and that was the type of explosion what you had.

You know in this case of explosion, I want to bring out the missile effects this particular ship was berthed over here in the sea using a few anchors the one anchor the main anchor was give tones and you know what is an anchor. You now you have a ship let us take a look at what we want to do we are taking a look at the missile effects.

(Refer Slide Time: 46:14)



You have the ship over here well it drops an anchor such that the ship is berthed over here it does not move over here you have an auxiliary anchor, which is in this case is two tones. You have a main anchor which is 5 tones and what is happening what happens to the anchor you know you have an explosion taking place over here because of this. Well, this becomes an object in the vicinity of the explosion that it is something like secondary missiles which could be formed or a secondary fragment and in this particular explosion.

If I were to go back to the slide the anchor, which is two tone was hauled over a distance of 2.61 kilo meters away. That means from the site of an explosion it travelled a distance of 2.6 kilo meters and it formed a crater of three point of three meter deep well we will look at craters later.

The main anchor which was 5 tone was hauled over a distance of nearly 1 kilo meter mind you a huge massive object being pushed over a distance of something like 1 kilo meter away or something like 3 kilometers away this is the type of havoc which can cause. This is I just took this example because it illustrates the type of effects to the missiles, therefore, what is it we have done so far? Let us quickly review before we go into the subject of crater because inadvertently we found one of the missiles formed a crater we will we will look into it, but before we do that, let us therefore take a look.

We are by now, we should be absolutely clear what we mean by a blast wave generated by and explosion what is the thing it starts off at a the site of the explosion travels at high

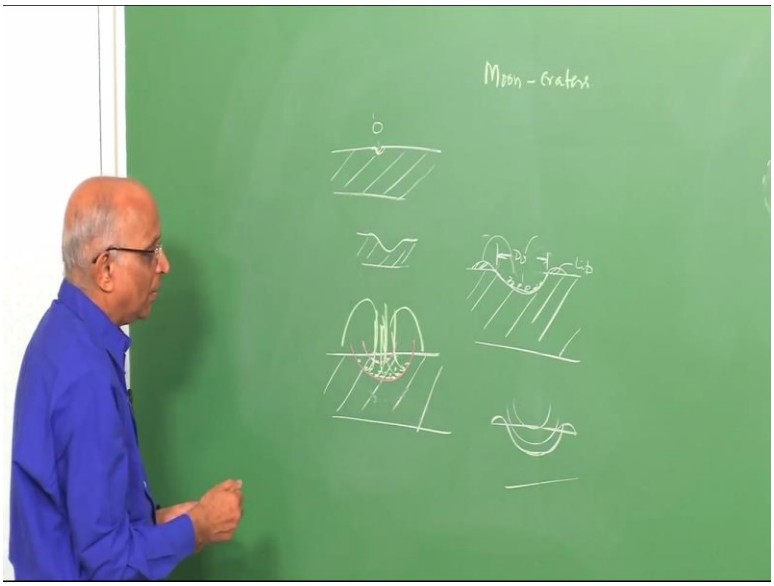
speed and gradually decays. Therefore, time versus distance has this particular characteristic, we talked in terms of different types we talked in terms of constant velocities we were able to get the marked numbers using that we derived in the near filed wherein I have a strong blast wave, I was able to calculate the value of per pressure. I was also able to calculate the impulses, similarly, when it blast wave decayed we said well it decays at the values when the marked numbers are little lower.

I again calculated these values thee were the over pressures which all of a sudden increased in pressure that which has a compression process and this when some something is over here it literally crushes and damages the object. Well, the wind effect is associated with impulse and it and it moves the object may be tilts the object may be toppled. This may be if I have may be somebody riding or somebody walking on the road the impulse topples him down because it drags him and pushes him. Well, these were the two types of destructive influences which we talked of and the third one we say is the missile effect missile effect from fragments and also sharpness which are done.

You know these sharpness you know unfortunately what happened is you know what happens is may be people put some nails which have these you know you have an nail has a point like this which has a head over here. When it hits, you know the nail can again puncher your skin and does damage and these things which unfortunately some people use to infect damage on human beings.

Well, these are the three effects and now let us come back to the last part namely we said well something goes and hits something well a crater is found, what do you mean by crater? What is the effect of crater and how does a blast wave form a crater? This is the last one which we do, let us take a look at this particular example.

(Refer Slide Time: 50:08)



Let us say I have the earth over here it let us say it is wet earth over here loose soil may be a drop let us say a marble or a ball over here I form something like a dent on this, you know if I drop an object, which is spherical I form something like a dent on this. Well, in the case this which is say well a dent which is formed on the earth somewhere on a loose soil when a blast wave hits the earth something I have the earth over here. Let us say, I have an explosion taking place, I have a spherical explosion taking place, I have a spherical blast wave, which travels into the earth.

Now, the when the blast wave travels what it does is it compresses the earth over and you have such a huge compression, that means if the blast wave is strong, I have a huge compression, it strains. It comes and makes it strain such a value such that it gets into the plastic state and then what happens behind the blast wave? Let us again take it one more figure I have a spherical blast wave over here I have t he earth which is being compressed over here it gets into the plastic state. Once the earth behind the blast wave, I have the explosion fan that mans I have the pressure reducing over here these when the earth gets to the plastic sate and crumbles.

That means I have fragments of the earth which are available and because of the pressure decrease all these things now have a velocity because of the low pressure it goes up these are all thrown up. These things fall back over here and therefore what is it I am going t get if a blast wave strikes the earth that means I have the earth over here I form

something like a earth is removed the earth is thrown up. I have lip over here, which is formed, I have something like a crater which is getting formed and this is what we call as a crate that is the crater diameters is let us say d naught because of a blast wave. The earth is thrown up, the low pressure behind it is thrown up it accumulates here to give me something like a lip over here and this is what we all as a crater.

You know we just dealt with it in a simplistic manner all what we are saying is well the surface of the earth is hit by a a blast wave and it for something like a crater over here and the lip of crater is due to the falling o the debris which is thrown up. Some of the debris falls into the crater again; we keep talking in terms of different types of craters, we say on the moon. We have craters, we say well mars has lot of crater, mercury has some craters, well even on earth we have craters.

You know and these are all these are all filled with water today and these are used as lakes we will take a look at examples. What really cause the crater is may be the blast wave, you have a blast wave which is coming and which creates the loose earth which flies up because of the rapid expansion behind blast wave and that is what causes a crater.

(Refer Slide Time: 53:39)

To be able to qualify it, let us take the example of another example which we talked of in our second lecture that is at Chelyabinsk, wherein you know we had the comet entering the earth's atmosphere at high speed and at high speed. It enters blast wave got formed

and this blast wave could it the earth or else the comet itself could come and hit the earth. When something hits the earth at high speed, I have a blast wave which is associated with it just ahead of it and that forms a crater. In fact, this particular case you had a piece which hit a lake known as lake Chebarkul. And in this lake also there was a huge indent which was formed it was mind you it was frozen and you had something like a crater which was formed.

(Refer Slide Time: 54:25)


In asteroid's aftermath, a sigh of relief

Using a mix of data, scientists now have a better picture of the space bullet that grazed Russia

CLOSE ENCOUNTER: *A frame grab of the small asteroid.* — PHOTO: AP

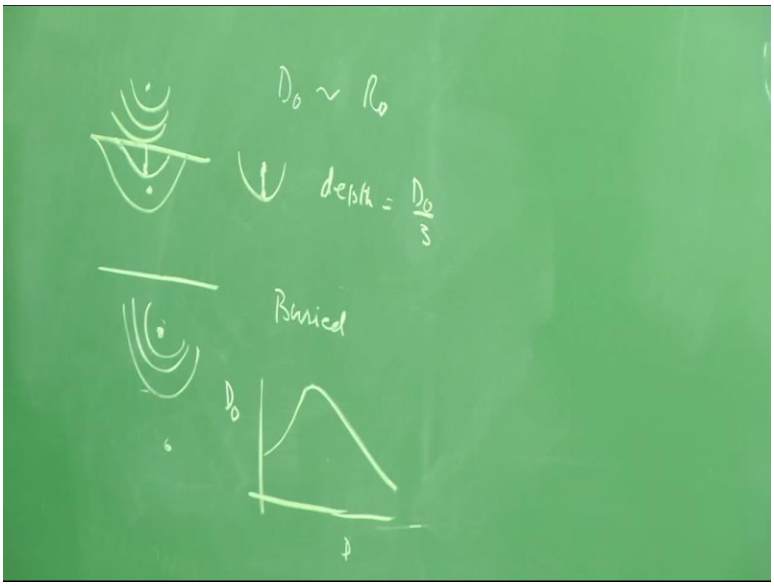
Henry Fountain

Using an eclectic mix of crowd-sourced video, information

calculate the mass of the meteor, about 11,000 metric tons. "It's all about the kinetic energy of that body," which is related to its mass

Well, in the next example, in the same one, I just show this a blast wave being formed it is instructive to calculate what is the energy, which is released what is the type of blast wave which is formed.

(Refer Slide Time: 54:36)

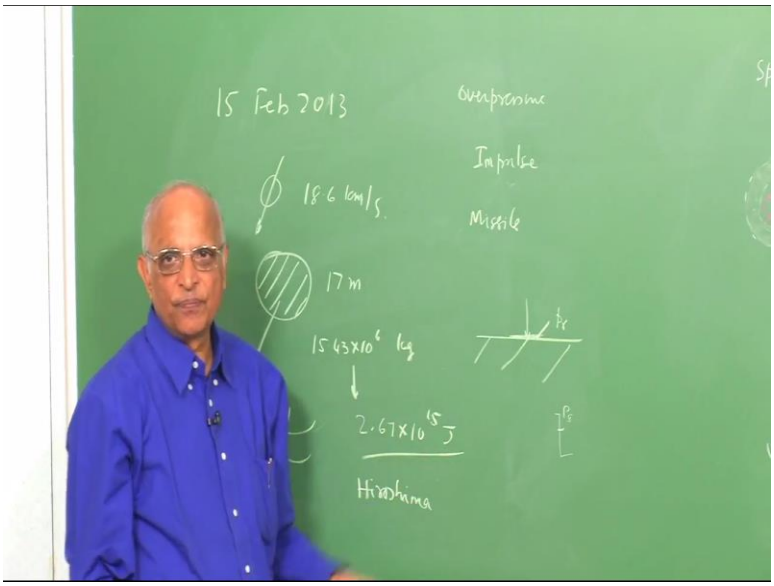


You know when at the surface of the earth, some energy is released, we call it as a surface burns of energy over here or if I have the earth over here and over the air I form a blast wave. This blast wave creates a crater, we say well I have something above the surface above the earth where in the energy is getting released. I could also have something like buried explosive, that means I have an explosive over here, I have something like a buried case in which case may be the explosive forms a crater and it is to be expected that if I have a buried explosive. Maybe, it will create a larger one, but I the depth of burial is such that the explosive is very much deep inside it.

It has to remove the earth from this particular place therefore, the effectiveness or the width of the crater or the depth of the crater which is formed as the depth increase may be I say that the diameter of cater is d 0. Well, the d 0 will increase as the burial depth increases and then maybe it will come down. Well, the diameter of the crater goes as the energy which is released, therefore it is proportional to the explosive explosion length, and second thing is in addition to diameter being dependent on the explosion length directly.

The depth of the crater being somewhat let us say spherical the depth of the crater is always a function of diameters and this depth is approximately round like diameter of the crater to the power divided by 3. Well, this is all about crater; we will quickly do this example of this Chelyabinsk type of an explosion, what happened?

(Refer Slide Time: 56:31)



We considered well this was on as we said this was on fifteenth February 2013, earlier this year you know the velocity with which the comet entered the atmosphere was around 18.6 kilometers per second. The diameter of the particular comet was around seventeen meters we can estimate the mass of this comet assuming that the density is typically of a comet is around 0.6. The mass of this comet is I calculate comes out to be 15.43 into 10 to the power 6 kg, mind you the velocity is high it is traveling with a with a velocity of 18.6.

Therefore, it has a huge kinetic energy and this kinetic energy when it reaches the atmosphere at some height is getting reduced therefore, this dissipated kinetic energy is what drives the blast wave and some reminisce of this comes and hit your particular ground. They form a crater and this is how we calculate let us say that the kinetic energy of this assuming that the entire velocity is available works out to be a huge number something like 2.6 even into 10 to the power 15 joules. That is the huge energy which is something like it is something like 40 times the value of the energy released in the bomb which was released over Hiroshima and Nagasaki.

Therefore, you have huge blast waves which are formed in nature and some of the pieces which come sand strike the earth, they create craters and these craters have a diameter which is directly proportional to the explosion length. Well, these are the different aspects of the blast waves we have considered the over pressure.

We have considered the impulses from blast wave we also talked in terms of the missile effects. Using these three in the next class what we do is we will address ourselves on the problem of how do I assess the damage because even when a blast wave strikes the particular earth over here.

You know there is something like a shock wave hitting the earth, the pressure that is the reflected pressure is going to be higher than the incident pressure that is we are always looking at the side view pressure namely the value of p s. The reflected pressure could be higher and it could cause further damage. Therefore, let us take a look at how to look at damages caused by the blast waves.

Thank you.