Ships, Shocks and Cavitation – The Physics of Underwater Explosions

Key Stage 4 Programme

Pupil Name	
Handbook Designed by	Dr A C Dinham

Timetable and Assignment Submission

Timetable – Tutorials

Tutorial	Date	Time	Location
1			
2			
3			
4			
5			
6 (Feedback)			

Timetable – Homework Assignments

Homework Assignment	Description	Due Date
Tutorial 1	Base line assignment: Gas bubble pressures	
Tutorial 2	Reflection of shock waves	
Tutorial 3	Cavitation and its effects	
Tutorial 4	The physics of shock waves	
Tutorial 5	Damage from an underwater explosion	

Assignment Submission – Lateness and Plagiarism

Lateness	
Submission after due date	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

The Brilliant Club KS4 Programme – Pupil Feedback Report

Grade	Marks	What this means
1st	70+	Performing to an excellent standard at undergraduate level
2:1	60-69	Performing to a good standard at undergraduate level
2:2	50-59	Performing to an excellent standard at A-level
3rd	40-49	Performing to a good standard at A-level
Working towards a pass	0-39	Performing below a good standard at A-level
Did not submit	DNS	No assignment received by The Brilliant Club

Lateness	
Any lateness	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Name of Teacher	Dr A C Dinham		
Title of Assignment	Ships, Shocks and Cavitation – the Physics of Underwater Explosions		
Name of Pupil			
Name of School	The Heathland School		
ORIGINAL MARK / 100		FINAL MARK / 100	
DEDUCTED MARKS		FINAL GRADE	

If marks have been deducted (e.g. late submission, plagiarism) the PhD tutor should give an explanation in this section:

Learning Feedback Comment 1 -	
What you did in relation to this Key Learning Priority	How you could improve in the future
Learning Feedback Comment 2 –	
What you did in relation to this Key Learning Priority	How you could improve in the future
Learning Feedback Comment 3 –	
What you did in relation to this Key Learning Priority	How you could improve in the future
Resilience Comment	
How you showed learning resilience during the course	How you could build learning resilience in the future

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Course Rationale

In this course, we will cover what happens in an underwater explosion and look at how shock waves are formed and travel outwards from a detonation in the ocean. We will also look at what happens when these shock waves hit the surface and the sequence of events which then take place. A critical question is how much damage will be caused to a ship or submarine in the vicinity of an underwater explosion. We will consider design factors which can help to strengthen the hull so that a vessel has a better chance of survival in the vicinity of an underwater explosion.

An important effect which follows in the aftermath of shock waves caused by an underwater explosion is a phenomena called cavitation. Cavitation is the formation of cavities or bubbles in the water and there is conclusive evidence that it occurs near the surface of the ocean in the aftermath of an underwater explosion. The presence of cavitation has a very large effect on what happens in the water and we will discuss this and how it leads to what can be seen at the surface after an explosion has taken place. A similar effect occurs when shock waves hit a ship or submarine and cavitation bubbles form in the water next to the hull. In these circumstances, the presence of the bubbles can have a significant effect on how much damage is done to the ship.

During the course, we will look at high speed film of a shock wave hitting the surface of water and the motion in the water, including the growth of cavitation bubbles. We will also analyse what happens inside the explosion which caused the shock waves by treating this as a very hot ball of expanding gas. Students will use spreadsheets (a tool for carrying out lots of calculations, which will be provided as part of the course) to work out what happens when shock waves hit the hull of a ship or submarine. A final assignment will be set which will use the spreadsheets to analyse the result of an explosion and to design how the resistance of the hull could be improved so that a ship has a better chance of surviving an explosion without sinking.

Mark Scheme Table

	Skills	1st (70-100)	2:1 (60-69)	2:2 (50-59)
Subject knowledge	Knowledge and Understanding	○ All content included is relevant to the general topic and to the specific question/title ○ Good understanding of all the relevant topics. ○ Scientific terms are defined and used accurately throughout ○ Clear justification on how the content included is related to the specific issues that are the focus of the assignment	○ Most of the content included is relevant to the general topic and to the specific question/title ○ Good understanding of most the relevant topics ○ Scientific terms are used accurately but not always clearly defined. ○ Adequate justification on how the content included is related to the specific issues that are the focus of the assignment	○ Some of the content included is relevant to the general topic and to the specific question/title ○ Good understanding on some of the relevant topics but occasional confusion on others. ○ Scientific terms are used mostly accurately with occasional confusion and often not defined. ○ Some justification on how the content included is related to the specific issues that are the focus of the assignment
Critical thinking	Research and Evidence	○ Use evidence/calculations to support claims/assertions /ideas, consistently clearly and convincingly ○ Data is effectively analysed and appropriate assumptions/conclusions are reached	○ Use evidence/calculations to support claims/assertions/ideas, mostly clearly and convincingly ○ Data is analysed and the assumptions/conclusions that are reached are mostly appropriate	○ Use evidence/calculations to support claims/assertions/ideas, at times clearly and convincingly ○ There is an attempt to analyse data is and draw assumptions/conclusions
	Developing an Argument	○ Argument/proof exceptionally well-developed and well-justified ○ Content is analysed effectively to support the argument	○ Argument/proof clear and well-developed and position justified ○ Analysis of content to support the argument	○ Argument/proof clear but not well-developed ○ Some analysis of content to support the argument

	Critical Evaluation	○ Moved beyond description to an assessment of the value or significance of what is described ○ Evaluative points are consistently explicit/systematic/reasoned/justified	○ Mostly description but some assessment of the value or significance of what is described ○ Evaluative points are mostly explicit/systematic/reasoned/justified	○ Only description with minimal assessment of the value or significance of what is described ○ Evaluative points are at times explicit/systematic/reasoned/justified
Written communication	Structure and Presentation	○ Ideas are presented in paragraphs and arranged in a logical structure that is appropriate for the assignment ○ The introduction clearly outlines how the report will deal with the issues ○ The conclusion summarises all the main points clearly and concisely ○ All calculations, formulas and methods are clearly structured, clear to follow and correct ○ Tables and graphs are effectively constructed including appropriate headings, units and scales. ○ All sources are referenced correctly in an agreed format	○ Ideas are presented in paragraphs and arranged in a structure that is mostly appropriate for the assignment ○ The introduction adequately outlines how the report will deal with the issues ○ The conclusion summarises most the main points clearly ○ Calculations, formulas and methods are mostly structured, clear to follow and correct ○ Most tables and graphs are well constructed ○ Most sources are referenced correctly in an agreed format	○ Ideas are presented in paragraphs and arranged in a structure ○ The introduction mentions how the report will deal with the issues ○ The conclusion summarises some of the main points clearly ○ Calculations, formulas and methods are not always structured, clear to follow and correct ○ Some tables and graphs are well constructed but contain errors ○ Some sources are referenced correctly in the agreed format with occasional errors

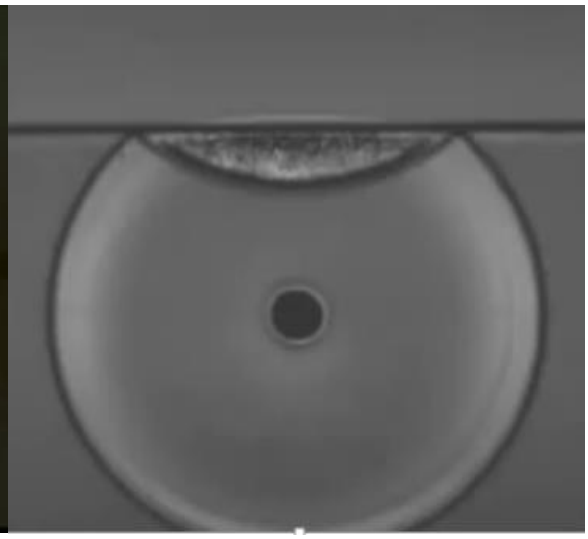
	Language and Style	○ No spelling, grammar or punctuation errors ○ Units and significant figures are presented accurately throughout ○ Writing style consistently clear, appropriate for scientific documents and easy to follow ○ Accurate and consistent use of technical language and vocabulary	○ Minimal spelling, grammar or punctuation errors ○ Units and significant figures are presented accurately throughout ○ Writing style mostly clear, appropriate for scientific documents and easy to follow ○ Some attempts of using technical language and vocab alary, but not always accurate	○ Some spelling, grammar or punctuation errors ○ Units and significant figures are presented accurately throughout with occasional errors ○ Writing style moderately clear, appropriate for scientific documents and easy to follow ○ Use of simple language and vocabulary effectively but struggles to use technical language

Glossary of Keywords

Word	Definition	In a sentence

Tutorial 1 – Shock waves in an Underwater Explosion

The detonation bubble of an underwater explosion



Shock waves spreading out from the detonation and hitting the surface of the water (the detonation bubble is the black sphere at the centre)

What is the Purpose of Tutorial 1?

- Objective 1: To understand how the detonation bubble evolves in time
- Objective 2: To determine how the pressure inside the bubble sends out shock waves
- Objective 3: To determine how shock waves move through the water

- *T1.1: What is the relationship between the pressure and volume inside the detonation bubble?*

When a quantity of high explosive is detonated underwater, the ignited explosive immediately vaporises into a very hot gas, at a temperature of around 3,000 C and a pressure up to 140,000 atmospheres (14,000 MPa).

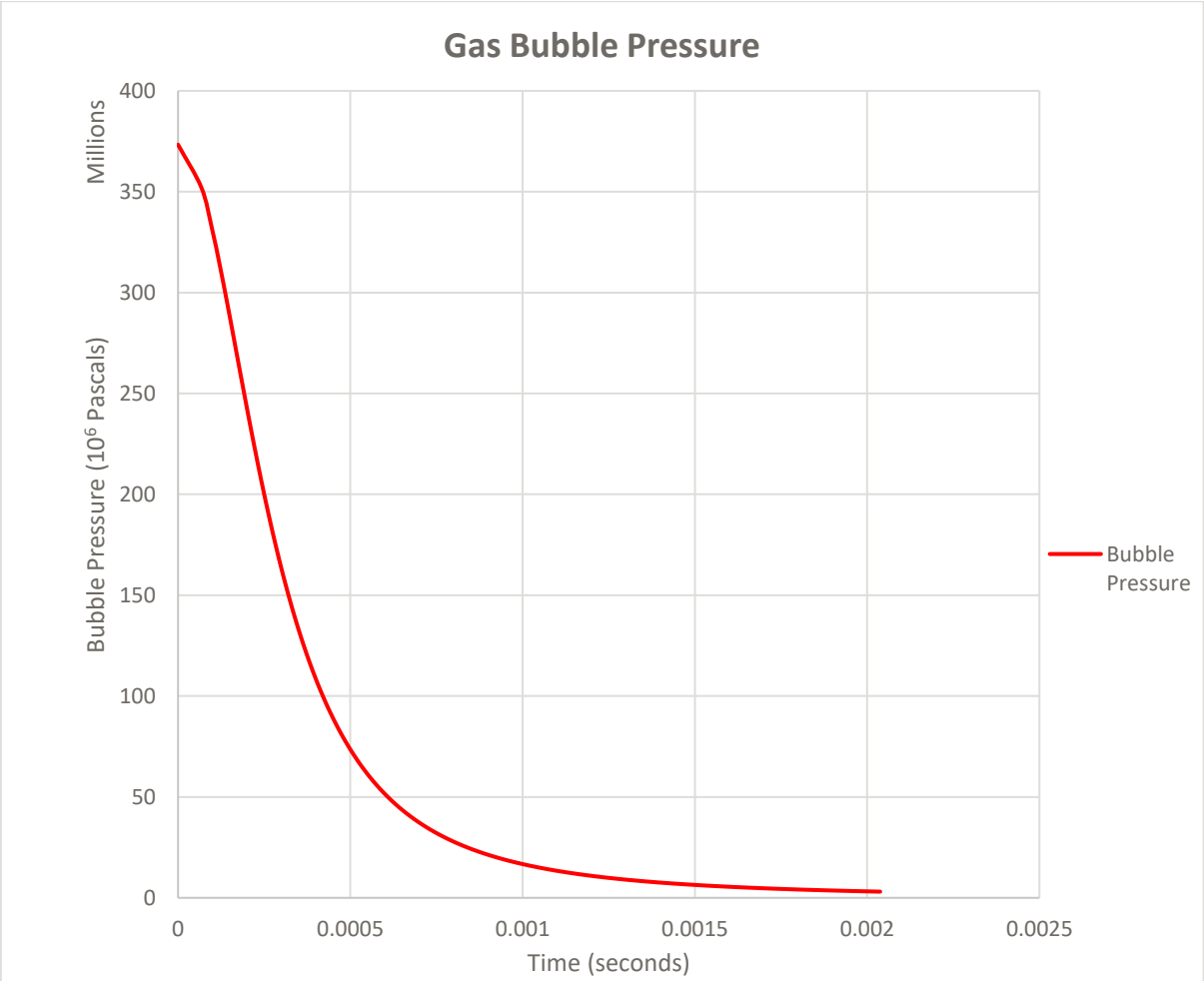
We will now look at how this gas bubble expands into the water surrounding it and how the pressure inside changes as the gas bubble expands (very rapidly!)

- We need the initial volume of the gas bubble (for instance, an explosive with a radius of 0.3m)
- And we need the initial pressure inside the gas bubble (3,750 atmospheres - 1 atmosphere = 100,000 N/m^2 of pressure!)

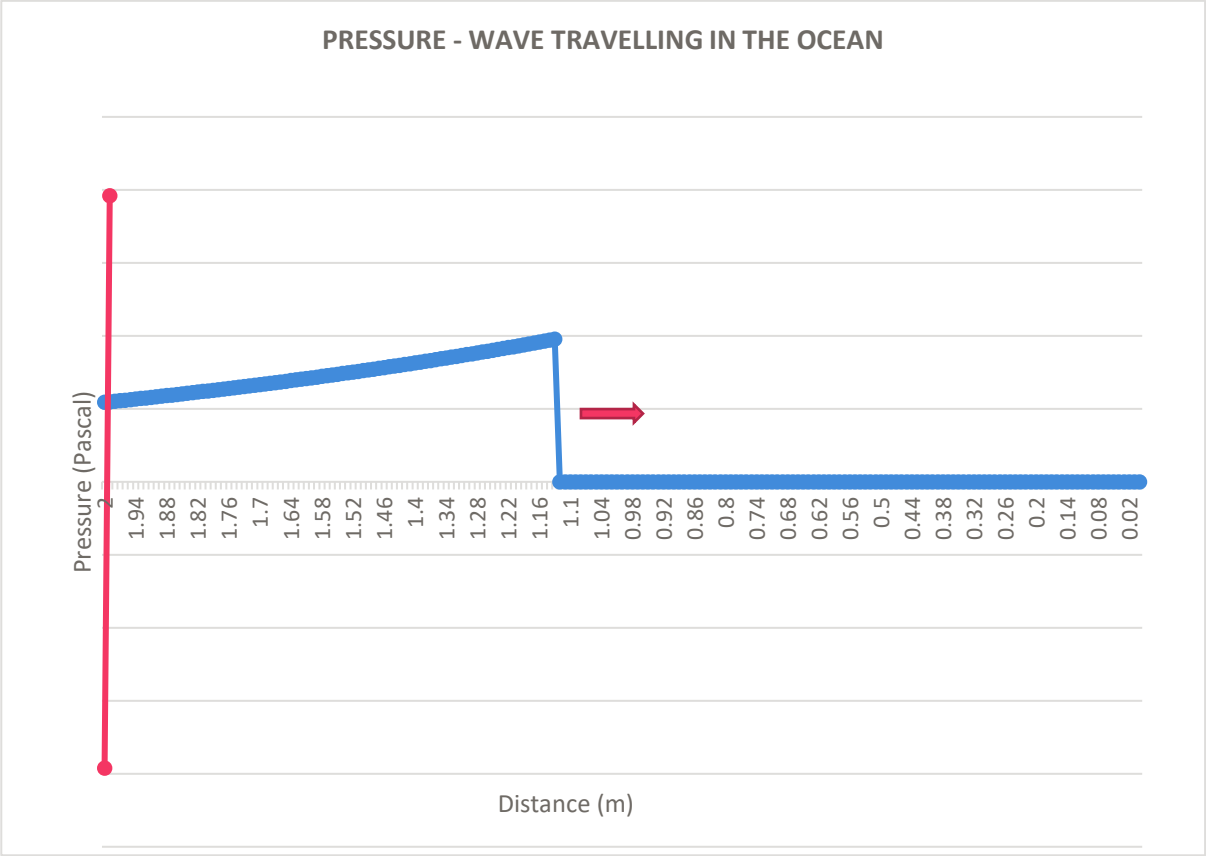
HOW CAN WE WORK OUT HOW THE PRESSURE IN THE BUBBLE CHANGES AS IT GROWS?

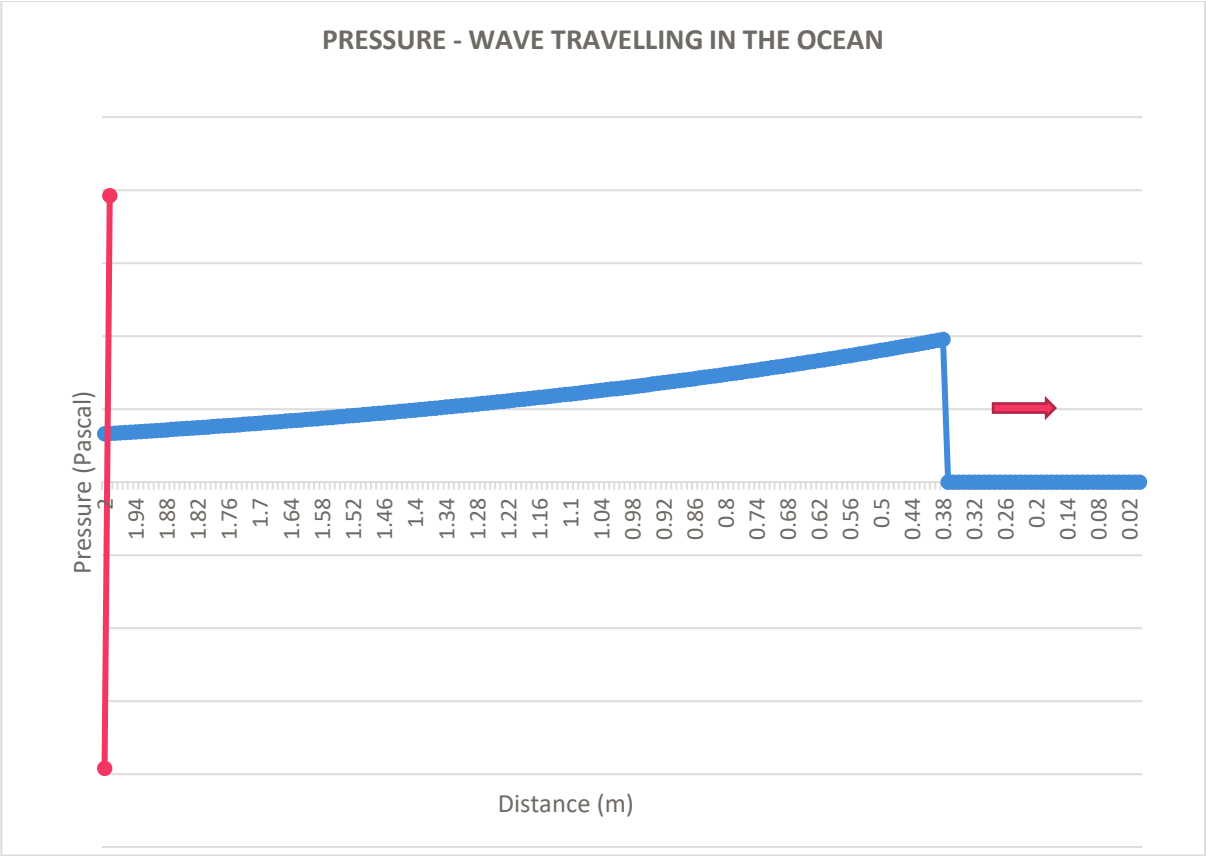
Key words: Pressure-Volume; Adiabatic expansion; Gamma - the adiabatic constant

The Relation between Pressure and Volume for the Gas Bubble



T1.2 How do pressure waves from the gas bubble spread out into the water surrounding it?





The time between these two frames, which show the pressure waves from the detonation bubble travelling into the sea, is 0.0005 seconds. How fast are the pressure waves travelling?

T1.3. How is the shape of the pressure (or shock) wave as it travels through the sea determined from the pressure "history" (the change of pressure over time) inside the detonation gas bubble as this expands?

- Think about how the front of the shock in the two diagrams above is related to the pressure in the gas bubble at the instant of detonation

- How do points in the shock wave behind the pressure front in the diagrams above relate to the pressures in the gas bubble as it started to grow?

(Think also about what happens to a shock wave as it spreads out in all directions from the initial detonation bubble)

<u>BASE LINE ASSIGNMENT:</u> Gas bubble pressures

The density of a high explosive charge is 1,630 kg/m^3 and the mass of the charge is 28kg.

- Work out the initial volume of the charge.

When the charge is detonated, it immediately vaporises into a gas bubble of the same volume and the pressure inside the bubble after detonation is 375,000,000 x 10^6 N/m^2. Use the relation between pressure and volume that we have discussed to determine the pressure in the gas bubble as follows:

- At bubble volumes of 1.5 x the original size, 2.0 x, 2.5 x and 3 x the original sizes, plot the pressures you have worked out at these bubble sizes on a graph (take Gamma = 1.9)

How long (approximately) do you think the gas bubble takes to grow to twice its volume? (Hint: look at the diagram of the bubble pressure against time shown earlier in this tutorial.)

Tutorial 2 – Reflection of Shock Waves

The surface of the water in a tank projects upwards when shock waves arrive from an underwater detonation

What is the Purpose of Tutorial 2?

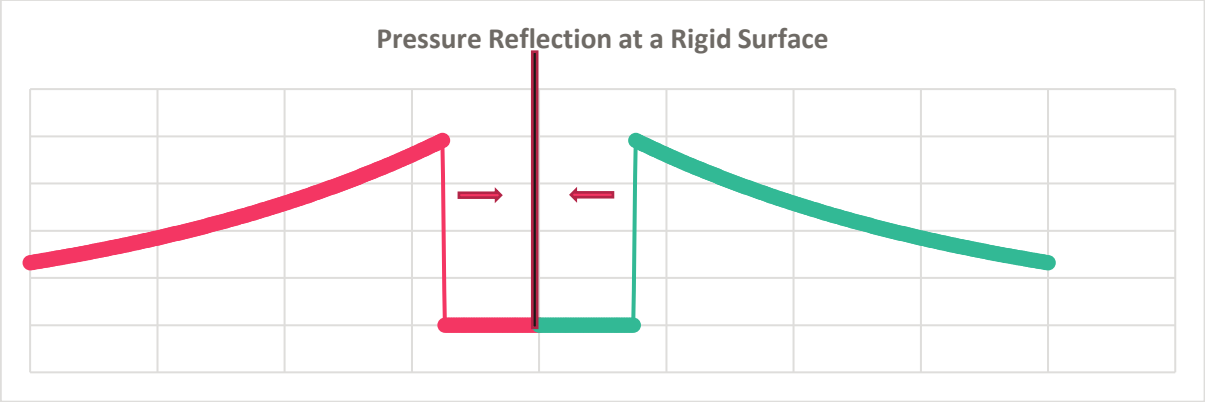
- Objective 1: To understand what happens when a shock wave hits a solid ("rigid") surface
- Objective 2: To understand what happens when a shock wave hits the surface of the water
- Objective 3: To determine the pressure and water particle velocities behind the shock waves

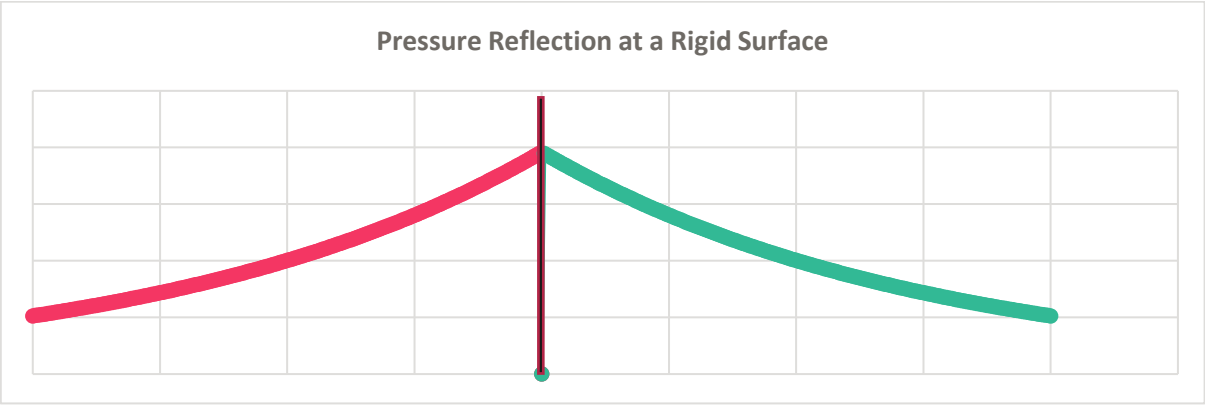
T2.1 What does the pressure in the water look like after shock waves have hit a rigid surface?

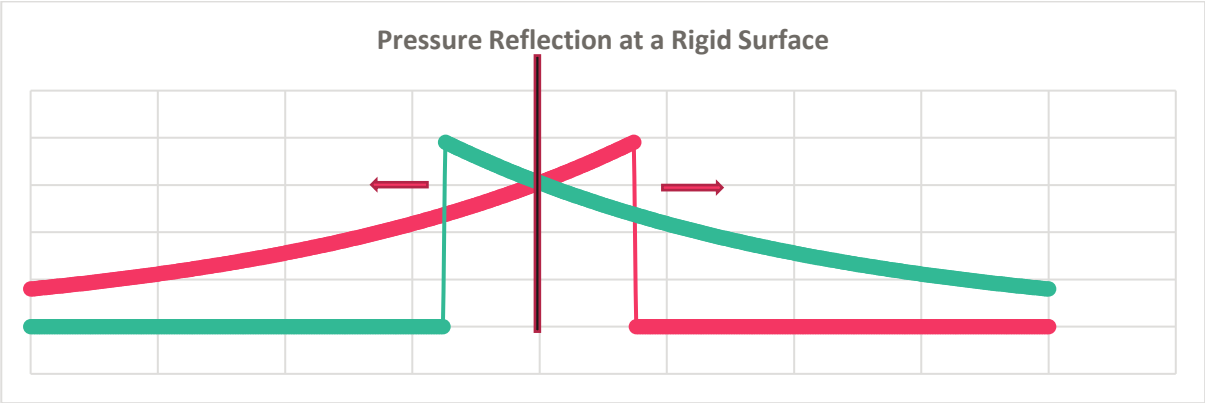
Look at the diagrams on the next page. The blue shock wave is the original wave travelling out from the detonation bubble and it is about to hit a rigid surface, a solid barrier such as a thick wall. We can work out what happens in the water after the shock wave is reflected by the rigid surface if we imagine a mirror image of the shock wave coming into the water from the right – the orange shock wave in the diagram. When these two waves "hit" (remember, the shock wave from the right is imaginary), this makes sure that what happens in the water after "reflection" is exactly the same as the shock wave bouncing off the rigid surface, ***providing we "add" together the original shock wave and the mirror shock wave in the water on the left of the rigid surface.*** The technical term for adding two waves is "superposition" and this is something that is met all the time in Physics.

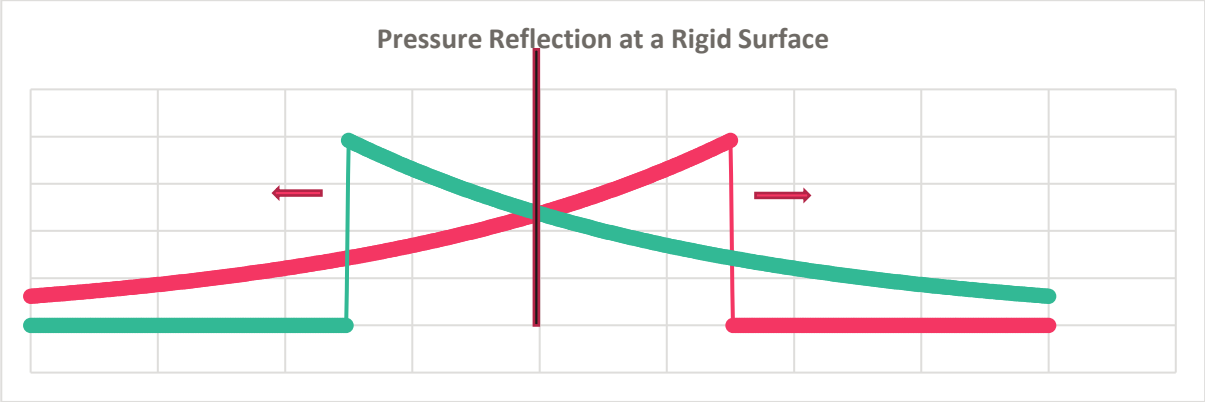
How do we add together the original shock wave and the mirror shock wave to get the overall reflected wave in the water?

Use the graph paper provided, which shows the original shock wave and the mirror shock wave in the water, and "add" these together to find the resultant shock after the shock has been reflected at the rigid surface.

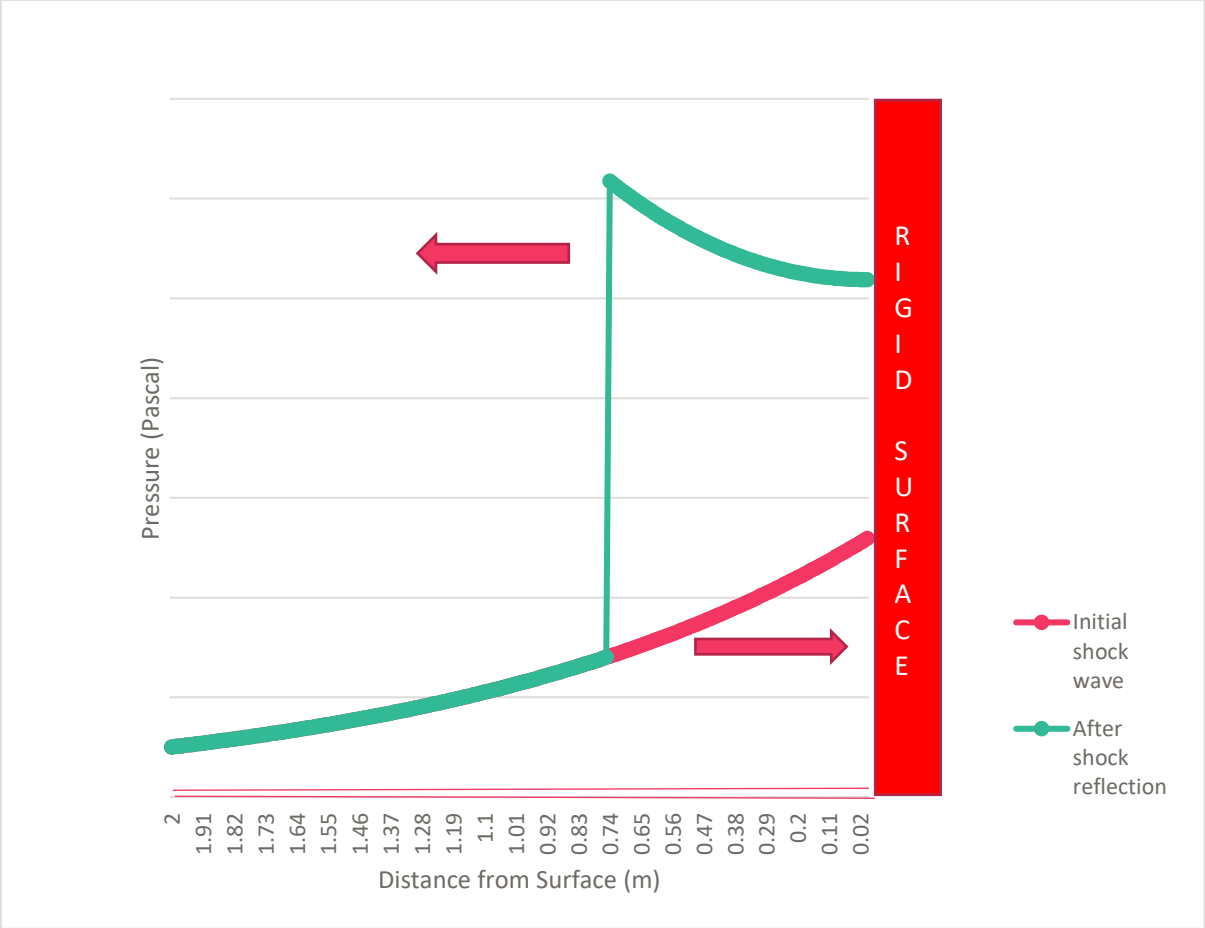

Pressure Reflection at a Rigid Surface


Pressure Reflection at a Rigid Surface


Pressure Reflection at a Rigid Surface


Pressure Reflection at a Rigid Surface

SUM OF THE INITIAL AND REFLECTED WAVES AFTER A SHOCK HITS A RIGID SURFACE

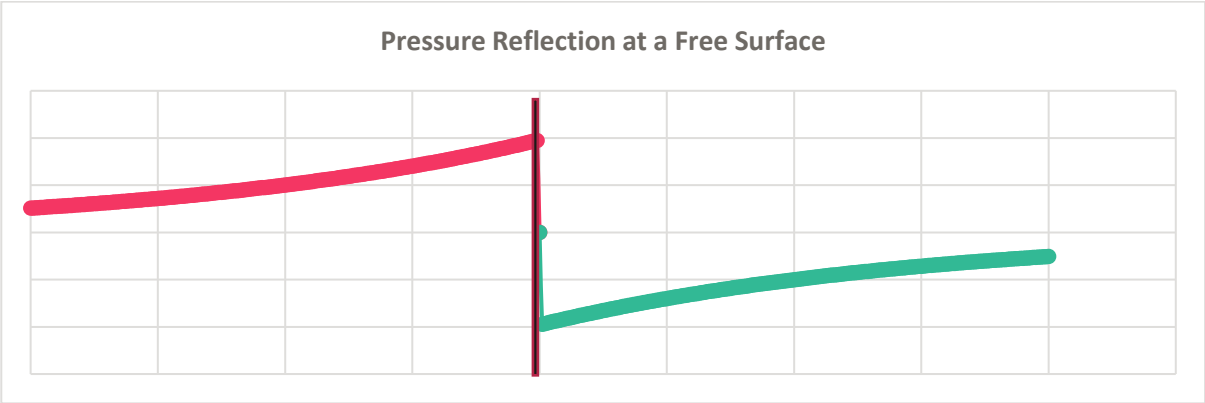


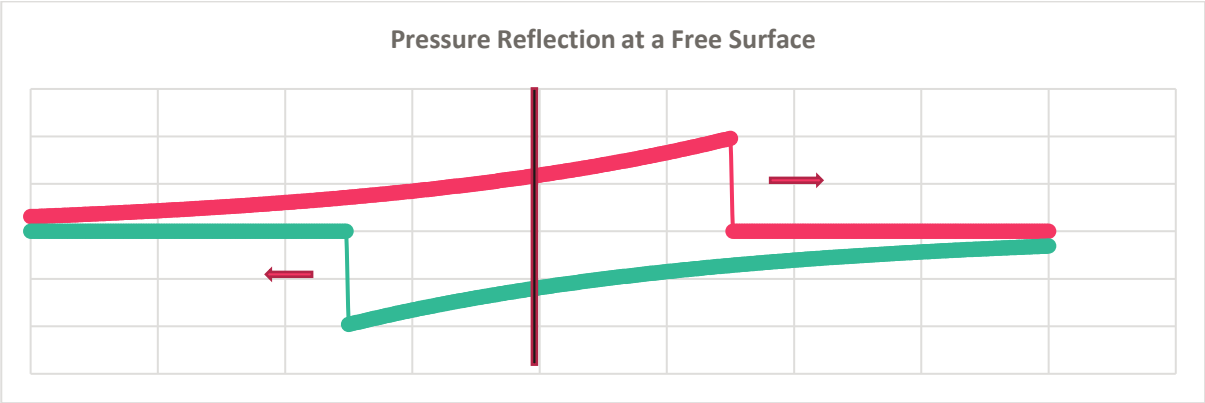
T2.2. What does the pressure in the water look like after a shock wave has hit the "free" surface (this means the surface of the water with air above it)

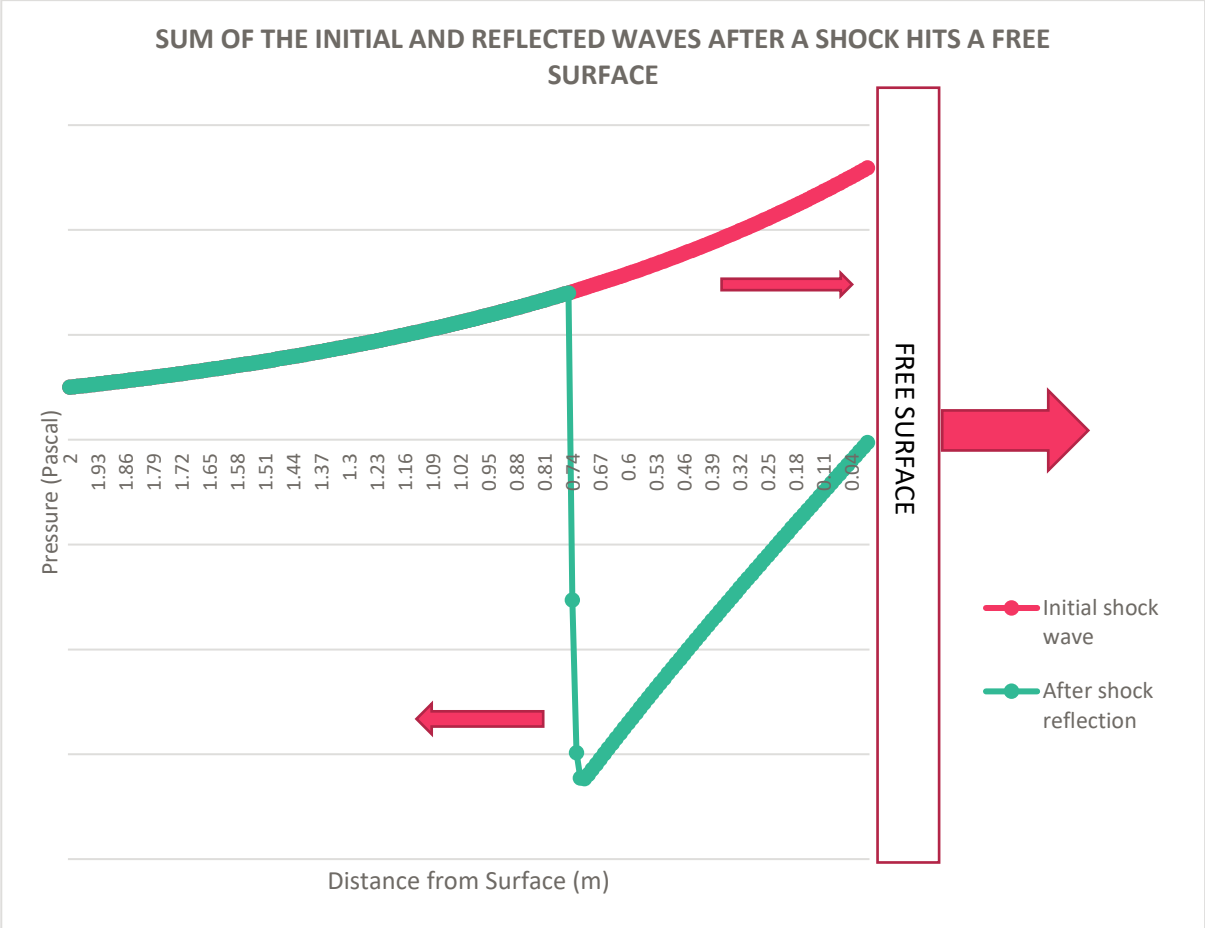
What is a "free surface"? A free surface is the technical term for the surface of water, such as the surface of the ocean. The important feature is that it is the opposite of a rigid surface – there is only air above a free surface and so, when a shock wave hits a free surface, there is no resistance to the shock.

We can work out what happens when a shock wave hits a free surface by imagining a "negative" shock wave coming in from the right, the same as for a rigid surface, but now the mirror shock wave is a negative one. This will have the effect of ensuring that the pressure at the free surface is zero, because the pressure in the original shock wave from the left is exactly cancelled out by the "negative pressure" in the mirror image from the right. This is what must happen at a free surface, the pressure at the surface must be zero, because there is no water above it, only air which is very light.

The addition of the original wave and the reflected "negative" wave is determined in the same way as adding the two waves in the case of a rigid surface but the following PowerPoint presentation, which shows the motion of the original wave and the reflected wave, in the cases of a rigid surface and a free surface, will illustrate this very clearly.


Pressure Reflection at a Free Surface


Pressure Reflection at a Free Surface


SUM OF THE INITIAL AND REFLECTED WAVES AFTER A SHOCK HITS A FREE SURFACE
Pressure (Pascal)
2
1.93
1.86
1.79
1.72
1.65
1.58
1.51
1.44
1.37
1.3
1.23
1.16
1.09
1.02
0.95
0.88
0.81
0.74
0.67
0.6
0.53
0.46
0.39
0.32
0.25
0.18
0.11
0.04
FREE SURFACE
Initial shock wave
After shock reflection
Distance from Surface (m)

WHAT DO YOU NOTICE ABOUT THE PRESSURE IN THE RESULTANT WAVE AFTER SHOCK REFLECTION AT THE FREE SURFACE?

T2.3. What is the velocity of the water after a shock wave has hit the free surface? How can we work out what the pressure and velocity of the water particles are behind shock waves?

The velocity of water particles behind a shock wave can be determined from the following formula:

Pressure = Density x Speed of Sound x Velocity

Or: Velocity = $\frac{\text{Pressure}}{\text{Density x Speed of Sound}}$

We can use this formula, together with the information that the density of water is 1,000 kg/m^3 and the speed of sound in water is 1,500 m/s to work out the velocity of water particles after a shock wave has passed through the water.

Use the graphs you drew earlier to work out the velocity of the water immediately after the initial shock has passed at four different points after the leading edge. Write these values on the graph itself.

We can use the Pressure-Velocity relation to work out the velocity of a free surface after a shock wave has hit it. The result for a free surface is:

$$\text{Velocity}_{\text{Free Surface}} = \frac{2 \text{ x Pressure}}{\text{Density x Speed of Sound}}$$

WHERE DOES THE FACTOR OF TWO IN THIS FORMULA ORIGINATE FROM?

Think about contributions to the velocity of the water from the original wave and from the reflected negative wave. Do not get confused between the first formula, which is the velocity of water particles after just the original shock wave has passed, with the velocity of water particles after the original wave has hit the surface and been reflected – that is the sum of <u>two</u> waves, not just one!

WHY DOES THERE APPEAR TO BE A SPRAY, IN THE PHOTO AT THE TOP OF THIS TUTORIAL, ON THE SURFACE OF THE WATER AFTER DETONATION OF AN UNDERWATER CHARGE? (Look at the cover of this handbook – what can you see on the surface of the ocean?)

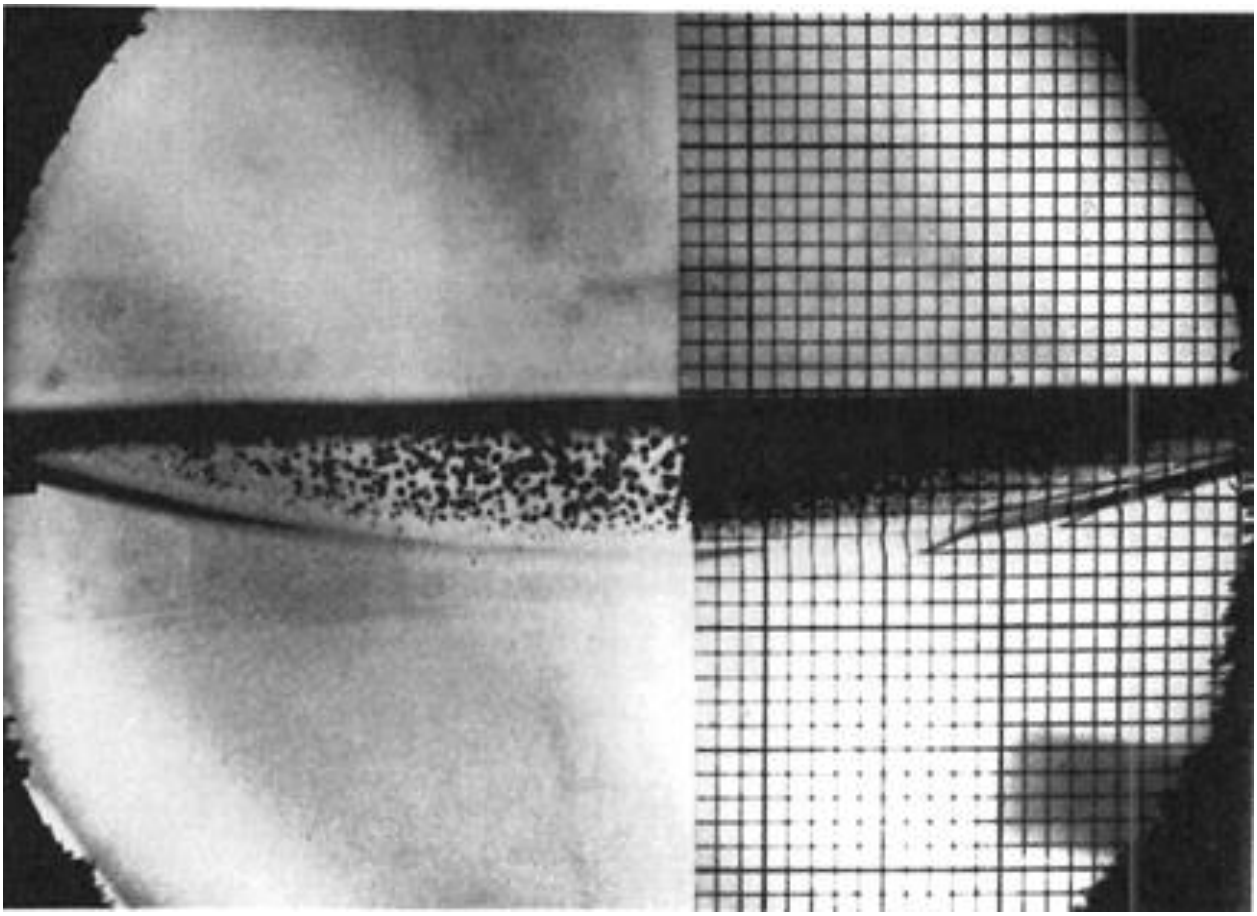
HOMEWORK – TUTORIAL 2: Reflection of Shock Waves

The handout shows the pressure shock wave at the instance that it hits a free surface. Draw the original wave after it has moved forward for a further 0.5 milliseconds (remember that the speed of sound is 1,500m/s) – that is, at a time 0.5 milliseconds later - and then draw the negative wave reflected from the free surface. Use these two waves to draw the resultant wave in the water 0.5 milliseconds after the original shock wave hits the free surface.

What do you notice about the pressure in the water after the initial shock wave has been reflected?

Use the Velocity-Pressure relation to work out the velocity of water at the free surface 0.1, 0.2, 0.3, 0.4 and 0.5 milliseconds after shock reflection and draw these results on the graph paper provided.

Tutorial 3 – Cavitation and how it affects Underwater Explosions



The development of cavitation bubbles in water 6 μs (6 millionths of a second) after a shock wave has been reflected from the free surface (the bubble radii are about 1mm at this stage but grow bigger!)

What is the Purpose of Tutorial 3?

- Objective 1: To understand how and why cavitation takes place
- Objective 2: To look at how cavitation bubbles grow
- Objective 3: To determine how the effect of cavitation modifies shock waves in the water

T3.1 What do you remember about the pressure in the water after a shock wave has hit the free surface and been reflected?

There is nothing strange really in the concept of "negative" pressures in the water after a shock wave has been reflected from the free surface. The cause of this is that the original shock wave hits the surface and the pressure unloads against …… nothing! (or almost nothing, just the air above which is very light). Normally the pressure in the shock wave is resisted by water ahead of it which is made to speed up *(Pressure = Density x Speed of Sound x Velocity)* and this is where the shock pressure is used up. It is like a wave or series of compressed springs travelling forward with each spring pushing in turn against resistance (the water!) and using the compression in the springs to speed up the water. When the spring which hits the free surface has nothing to push against, it "decompresses" and then over extends itself into a state of tension – this is exactly what the water does, it becomes stretched into tension, or "negative pressure", which travels back into the water beneath the free surface.

T3.2 Water is like a bottle of pop, particularly sea water, there are lots of tiny bubbles of air too small to see trapped within it. What happens when the pressure around these bubbles falls?

Demonstration: Shake up a bottle of soda water and ***slowly*** unscrew the top. Describe what you are seeing and then describe what would happen if you unscrewed the cap of the bottle quickly.

Try to explain what is happening as you carry out this demonstration. Think about:

- What happens to the pressure in the bottle when you shake it up with the lid tightly screwed on? Can you see anything in the bottle at this stage?
- Why are the bubbles growing and where do they come from as you unscrew the cap?
- What happens to the pressure inside the bottle as you unscrew the cap? Where does the original pressure go?
- Why does the soda water spray out if you do all of this quickly?

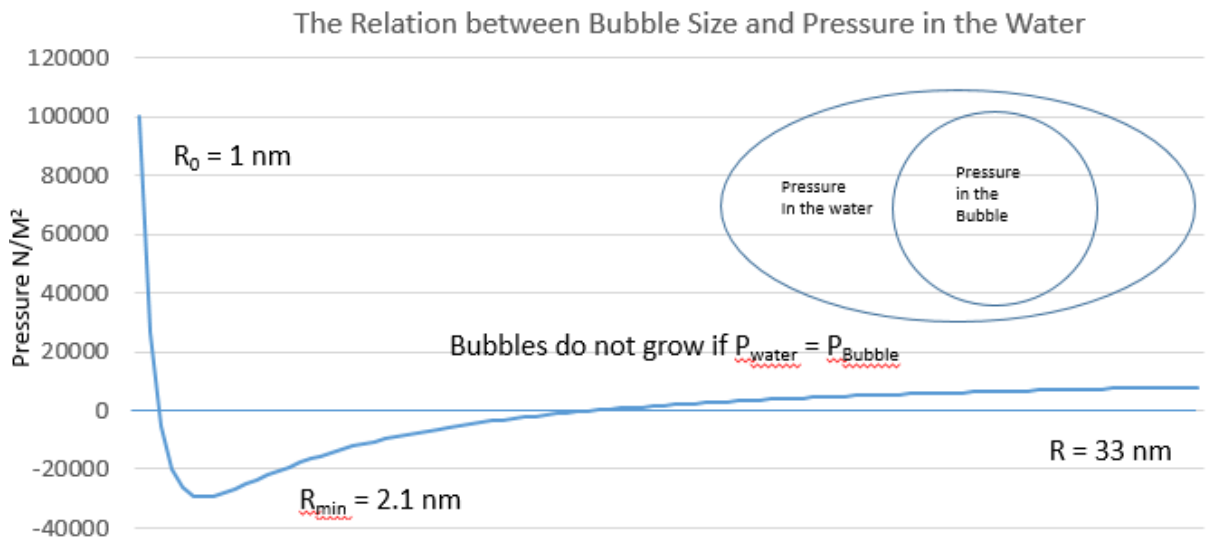
T3.3. What are the tiny bubbles in the sea like, how big are they and what happens when the water is in tension around them?

The sea is full of tiny bubbles, much too small to see, usually gathered around particles of grit, which are known as "nucleation" sites. These bubbles can be as small as a few nanometres (1 nanometre = 1 millionth of a millimetre!) and each will contain a tiny amount of gas and water vapour.

When the pressure in the sea is large and positive, for instance at increasing depths, these bubbles shrink as small as it is possible for them to be, but as the pressure in the sea falls, that is nearer the surface, the bubbles begin to get larger.

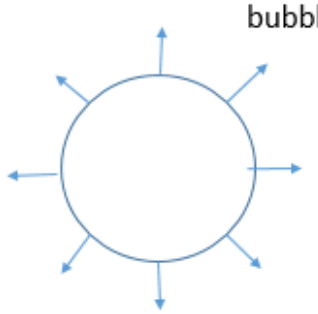
The graph below shows what the pressure in the sea must be if the bubbles are to remain in equilibrium – that is, they neither get smaller nor grow.

(in this diagram, *nm* = 1 nanometre, *R* refers to the bubble radii)

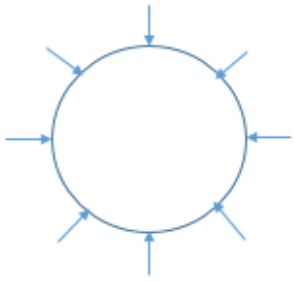


GROWTH OF BUBBLES IN WATER

Tension (the opposite of Pressure) causes bubbles to grow



Pressure causes collapse of bubbles



Look at the two diagrams above and answer the following questions:

- Try to work out what happens to the bubbles as the pressure in the sea begins to fall below one atmosphere (100,000 N/m^2).
- What happens to the bubbles if the pressure in the sea falls below zero?
- Under what circumstances do you think that the pressure in the sea might fall below zero?
- Do you think cavitation bubbles might grow after a shock has been reflected from the surface of the sea? (Look at the photograph at the beginning of this tutorial). Why might they grow?

Watch this video of hydrogen bubbles rising up through water and, as they do so, the pressure is falling around them because they are getting nearer the surface. Watch carefully what suddenly happens when they get past a certain point. Can you understand now why this happens?

The growth of cavitation bubbles behind a shock wave that has reflected from a free surface is like the growth of bubbles in a pop bottle – they begin to grow because the pressure in the liquid surrounding them is less than the pressure in the bubbles themselves. When cavitation bubbles grow in the sea because they are surrounded by negative pressure, or tension, such as in the aftermath of shock reflection, this growth of the bubbles takes out the tension in the water – the bubbles themselves rip apart and grow and reduce the tension in the water surrounding them to zero. Another way of looking at this is that, as the bubbles grow (see the photo at the beginning of this tutorial), they squeeze or compress the water surrounding them ***and the negative pressure, or tension, in the water which caused them to grow, disappears!***

When cavitation bubbles grow behind a shock wave reflected from a free surface, the tension immediately falls back to zero – the bubble growth wipes out negative pressures which would otherwise travel into the ocean layers.

<u>HOMEWORK – TUTORIAL 3</u>: Cavitation and its Effects

Go onto the internet and find out as much as you can about the phenomena of cavitation and where and when it occurs – after a shock wave has been reflected in the ocean is only one example of this. Write between 300 and 500 words about other circumstances in which cavitation takes place and the effect that this has in those circumstances. Hint: start by looking up underwater propellers.

Tutorial 4 – Shock Loads on a Ship's Hull

An Australian destroyer being blown in half in an underwater torpedo test

What is the Purpose of Tutorial 4?

- Objective 1: To understand how the hull of a ship can be "modelled" (this means how we can set up equations which describe what happens with the hull) when it is hit by an underwater explosion
- Objective 2: To investigate what happens when a shock wave hits a ship's hull
- Objective 3: To determine the phases of the motion of the hull plates

T4.1. Consider an underwater explosion caused by a depth charge or mine in the vicinity of a submarine. List the main factors which you think might determine how much damage is done to the plates which make up the hull of a ship.

(Do not turn over this page yet!)

Factors which affect damage to a ship's hull in an Underwater Explosion

An underwater explosion and the effects that it has on the hull of a submarine is an extremely complicated matter. The main factors to consider are as follows:

- the magnitude of the pressure wave when it hits the hull; this in turn depends upon:
    - the initial pressure in the detonation bubble created by the explosive – this depends upon the type of explosive used
    - the size of the initial detonation bubble – this depends upon the mass and density of the explosive (volume = mass/density); the bigger the mass, the greater the size of the detonation bubble, the stronger the shock wave will be that acts on the hull when it reaches it
    - how far away from the hull that the explosion took place
    - the depth of charge – this does not have a great effect but the deeper that the charge goes off, the less the effect because the pressure difference between inside the detonation bubble and the surrounding sea is smaller

- the construction of the submarine's hull:
    - The density, mass and thickness of the plates which make up the hull
    - The yield strength of the steel making up the plates
    - The size of the plates – how big they are and the distance between supporting struts in the framework of the submarine's structure

- The properties of seawater:
    - the density of water
    - the speed of sound
    - whether the seawater cavitates (we will assume that it does!)

Consider each of these factors and try to determine which way they will affect the damage that an underwater explosion will cause; for instance, you have been given that: the deeper the charge, the less damage it will cause (although this is a relatively small effect); and the greater the mass of explosive charge, the more damage (obviously!). Try to reason the same for the other factors and predict what you think the effect will be.

T4.2. Use of Spreadsheets – how we will work out the damage done to the plates of a submarine hull when it is hit by the shock wave from an underwater explosion.

We will use a spreadsheet (an extremely valuable computational tool which can be set up to do any calculations you want – this has already been set up ready for you to use) to work out the effect of an underwater explosion on the plates making up the hull of a submarine. The "inputs parameters" we will use to "model" the situation and typical values for these input parameters are as follows:

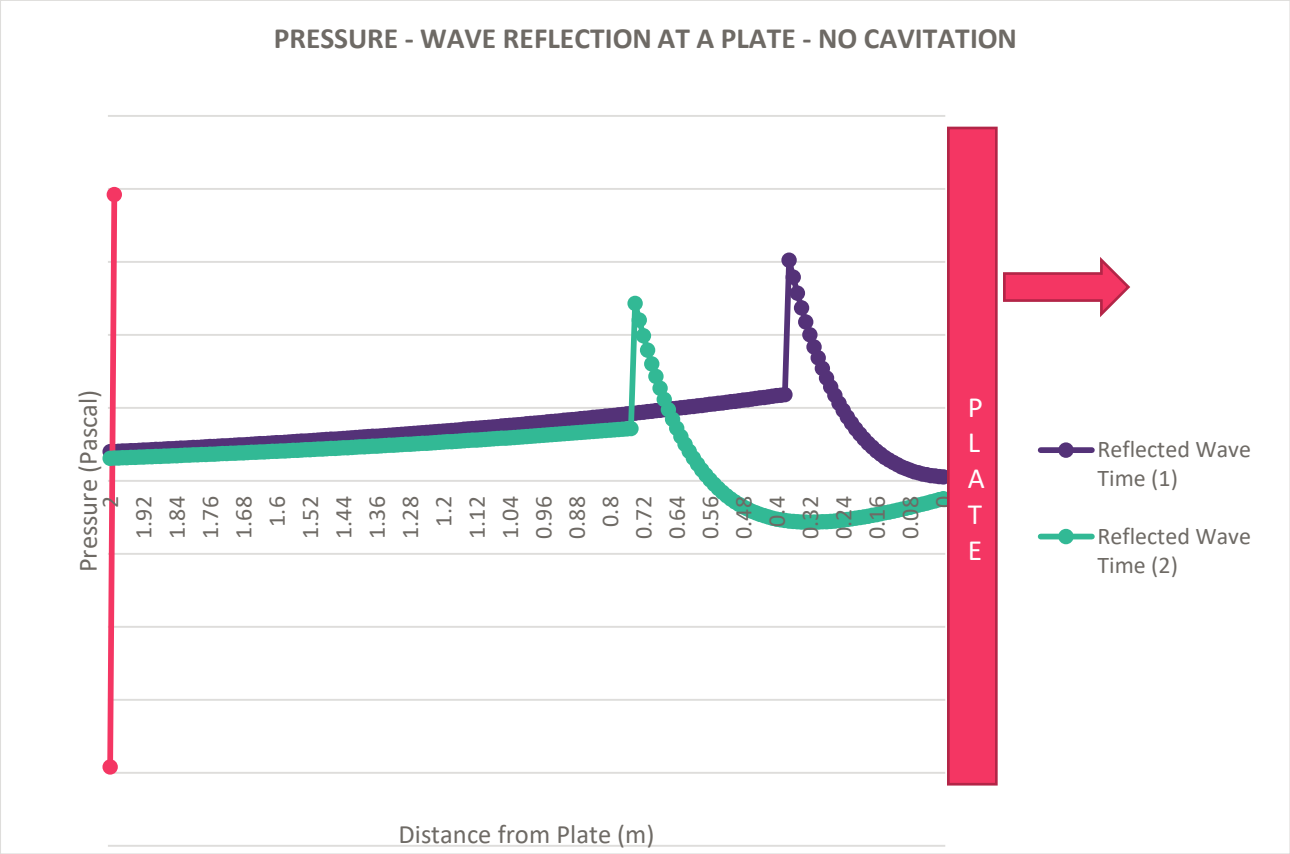
UNDERWATER EXPLOSION - CONTROLLING PARAMETERS

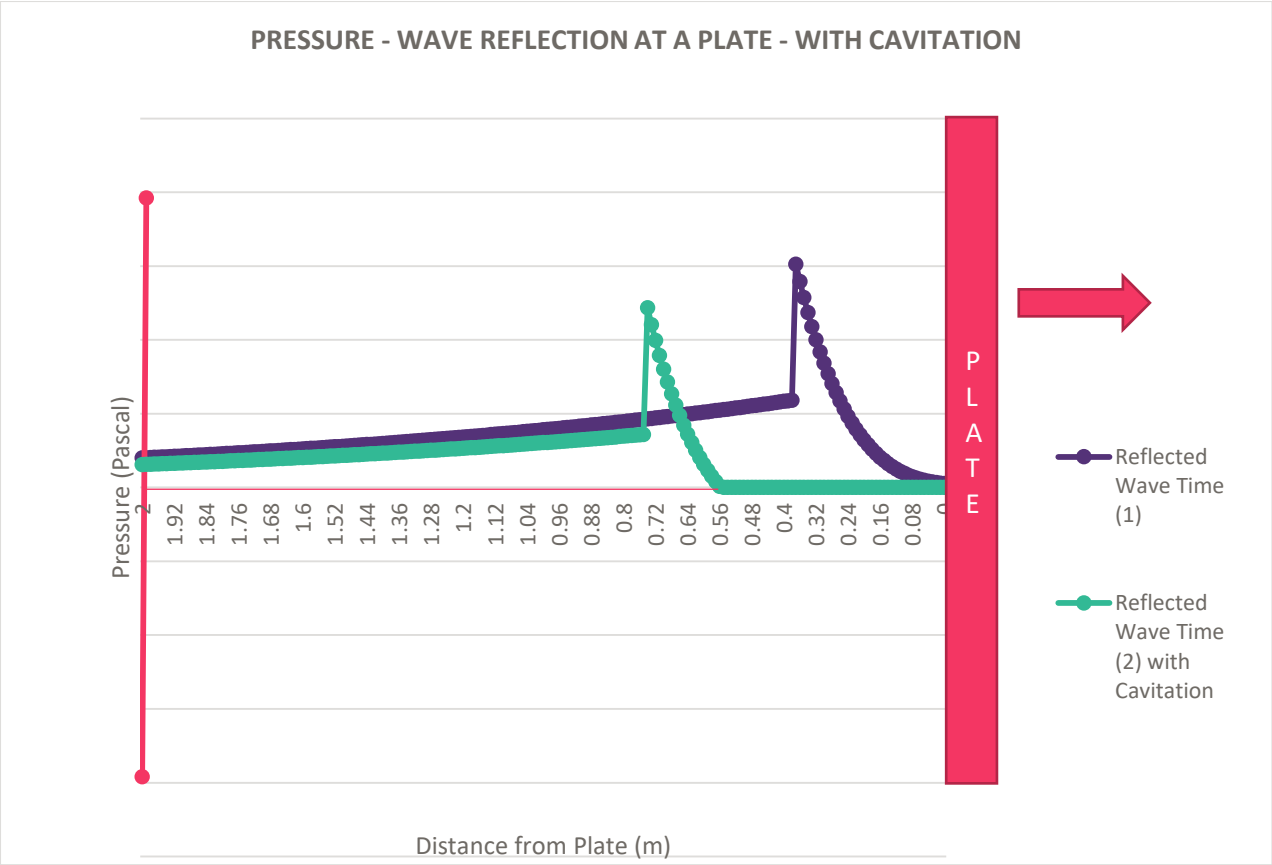
All Units are S.I. (The International System of Units - Kg, m, s)

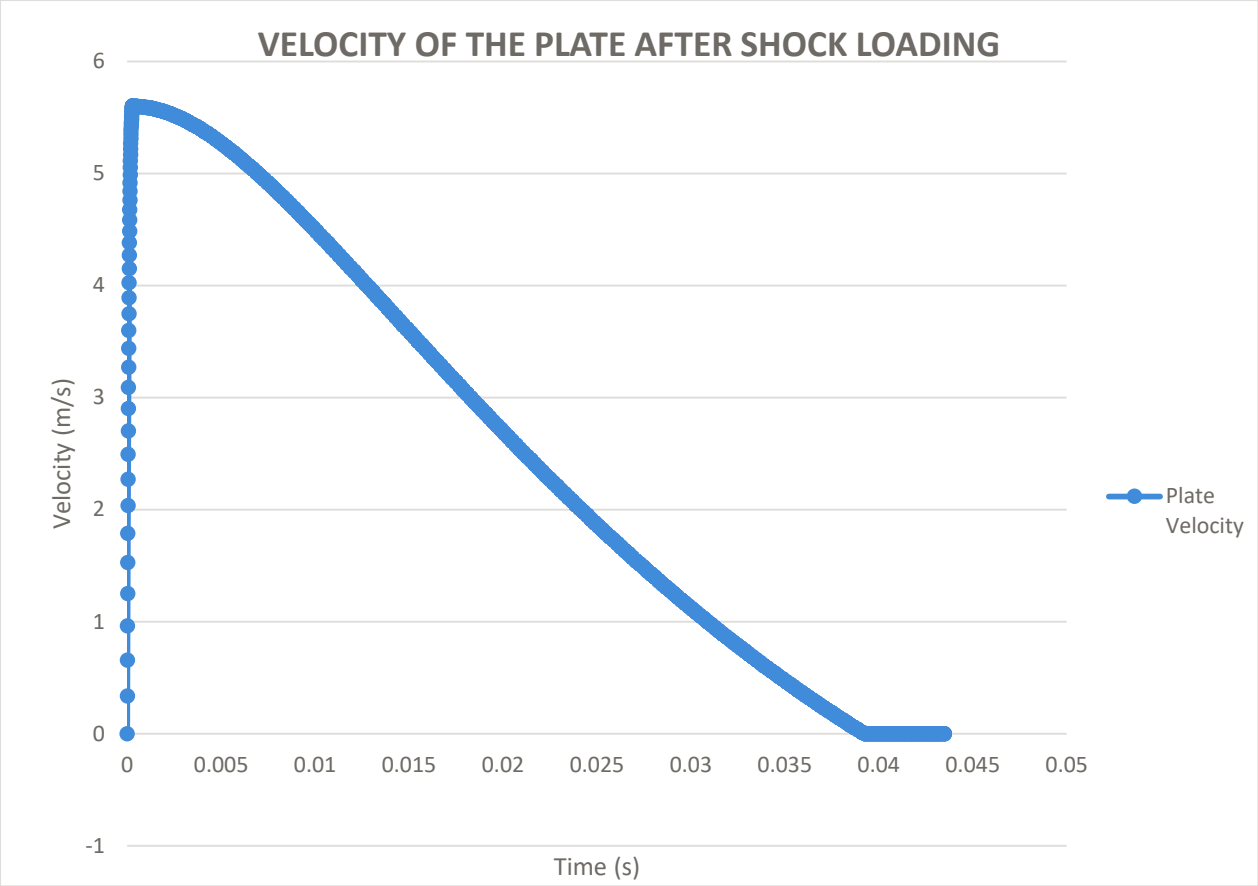
σ_y	248,000,000	Steel Yield Stress (N/m^2)
d	0.025	Thickness of the Hull Plates (m)
$Plate_R$	5.0	The effective size of the Hull Plates (m)
ρ_S	8,000	Density of Steel (Kg/m^3)
P_G	1,457,549,023	Pressure near the explosion bubble (N/m^2)
ρ_{HE}	1,630	Density of Charge (High Explosive) (Kg/m^3)
M_{HE}	200	Mass of Charge (High Explosive) (Kg)
R_{HE}	0.31	Radius of Charge (High Explosive) (m)
R	40	Distance to hull from the explosion (m)
Depth	20	Depth of Charge (m)
P_0	5,967,228	Pressure of shock wave at the hull (N/m^2)
ρ_w	1,000	Density of water (Kg/m^3)
c_w	1,500	Speed of sound in water

What are the parameters that you can control in this set and how would they help you to design for how much damage is caused in an underwater explosion?

T4.3 The Outputs of the Spreadsheet






VELOCITY OF THE PLATE AFTER SHOCK LOADING
Velocity (m/s)
6
5
4
3
2
1
0
-1
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05
Time (s)
Plate Velocity

DISPLACEMENT OF THE PLATE AFTER SHOCK LOADING
Distance (m)
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05
Time (s)
Plate Displacement

HOMEWORK – TUTORIAL 4: The Physics of Shock Waves

Consider the analysis carried out in today's tutorial of an underwater explosion shock loading the plate of a submarine. Write up to 500 words in response to the following questions:

- What factors determine the initial size and pressure inside the detonation bubble?
- What determines the magnitude of the pressure front in the shock loading of the hull plates?
- Why does cavitation occur in front of the plate after the shock has hit the plate?
- What effect does the occurrence of cavitation has on the damage sustained to the plate?
- What factors about the plate itself control how much damage is caused?

Tutorial 5 – Consolidation and Final Assignment

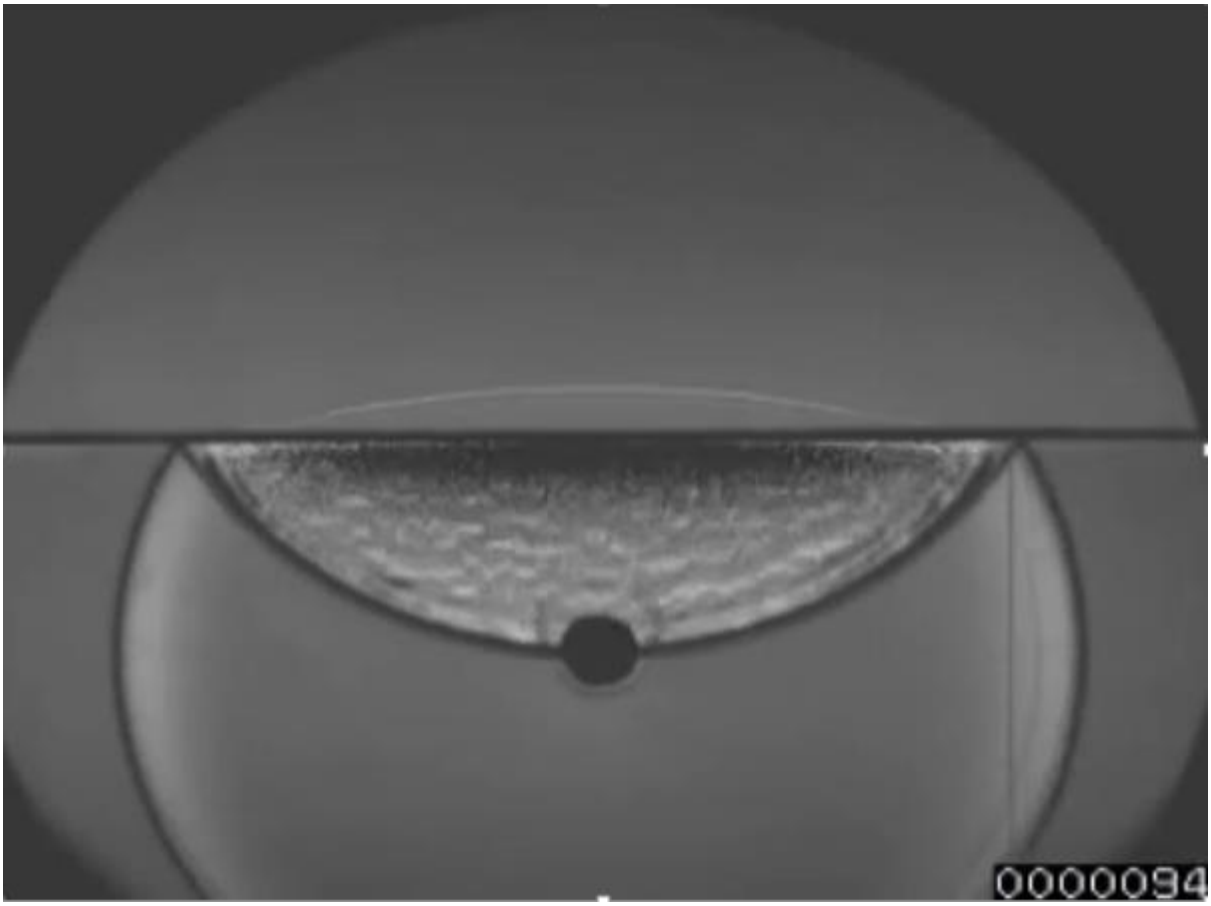
What is the Purpose of Tutorial 5?

- Objective 1: To consolidate understanding of the processes involved in underwater explosions and shock reflection
- Objective 2: To confirm students are confident with using each of the features in the prepared spreadsheet
- Objective 3: To introduce the final assignment

T5.1. What are the key processes during an underwater explosion?

What happens when a shock wave from an underwater explosion hits the free surface of the ocean?

(Watch the slow motion film below and describe successive stages)



T5.2. Take the example in Tutorial 4 and see what happens to plate damage when the following parameters are changed:

- The size (mass) of the explosive charge
- The distance from the explosion to the hull of the submarine
- The yield strength of steel
- The thickness of the hull plates
- The size of the hull plates

Be methodical and try to determine trends based upon varying these parameters

THE FINAL ASSIGNMENT

HMS <SECRET> – DAMAGE FROM AN UNDERWATER EXPLOSION: DATE <SECRET>; LOCATION: <SECRET>

The attached field report sets out details of damage to the hull of a submarine when an underwater explosion occurred, as a result of the detonation of a seabed mine, at (LOCATION OF INCIDENT REMOVED] on [DATE OF INCIDENT REMOVED]. Several of the plates on the starboard bow were buckled to the extent that the sea flooded into the main forward torpedo compartment. The submarine was able to surface without loss of life but there was extensive damage caused, which led to a long and expensive repair programme.

As Head of Naval Architecture, the Admiralty Board of the Navy requires you to submit a report which includes an analysis of the data provided in the attached field report. Your report on the incident should give a detailed commentary about the physical processes involved which led to the damage that the submarine sustained. In writing your report, you should consider the following aspects:

- What were the physical processes taking place in the vicinity of the submarine
- What were the key characteristics of the hull which determined how much damage was caused
- Did cavitation occur in the vicinity of the hull; if so, what effect did this have on final damage caused

(You should use the spreadsheet provided to help in understanding the details of the processes involved and consider how you can use the graphs and tables that the spreadsheet will produce to illustrate your report).

Refer to available research as appropriate and draw conclusions on the overall cause of the breach to the submarine's hull.

The Admiralty Board is concerned with the extent of the damage caused and that this was down to poor design. You are requested to:

- Make recommendations, for future submarine designs, on how to strengthen the hull so that damage in a similar situation would not lead to a similar breach
- With the new design of hull that you propose, determine how effective it would be against different size/weight of a mine detonation and how far from a detonation the submarine would be able to survive without a breach in the hull

Comment in your report on what effect these design adjustments might have on the performance and cost of future vessels.

(Message ends)

[Your report should be about 2,000 words in total].

REFERENCES

1. Bogdan Szturomski, "The effect of an underwater explosion on a ship", Scientific Journal of Polish Naval Academy Volume 2, 2015.

2. Andrew B Wardlaw, Jr, Hans U. Mair, "Spherical solutions of an underwater explosion bubble", Shock and Vibrations Volume 5, 1998.

3. A. H. Keil, "The response of ships to underwater explosions", Annual Meeting of The Society of Naval Architects and Marine Engineers, 1961.

4. H. N. V. Temperley, "Theoretical investigation of cavitation phenomena occurring when an underwater pressure pulse is incident on a yielding surface: 1". Underwater Explosions Research, Office of Naval Research, 1950.

Tutorial 6 – Feedback tutorial

What is the Purpose of Tutorial 6?

- To receive feedback on final assignments.
- To share examples of best practice with the other pupils in your group.
- To write targets for improvement in school lessons.
- To reflect on the programme including what was enjoyed and what was challenging.

Final assignment feedback

What I did well…	What I could have improved on…
•	•
•	•
•	•

My target for future work is…

Reflecting on Uni Pathways

What did you most enjoy about Uni Pathways?
•   •   •

What did you find challenging about the programme?	How did you overcome these challenges?
• • •	• • •

Appendix 1 – Referencing correctly

When you get to university, you will need to include references in the assignments that you write, so we would like you to start getting into the habit of referencing in your Brilliant Club assignment. This is really important, because it will help you to avoid plagiarism. Plagiarism is when you take someone else's work or ideas and pass them off as your own. Whether plagiarism is deliberate or accidental, the consequences can be severe. In order to avoid losing marks in your final assignment, or even failing, you must be careful to reference your sources correctly.

What is a reference?

A reference is just a note in your assignment which says if you have referred to or been influenced by another source such as book, website or article. For example, if you use the internet to research a particular subject, and you want to include a specific piece of information from this website, you will need to reference it.

Why should I reference?

Referencing is important in your work for the following reasons:

- It gives credit to the authors of any sources you have referred to or been influenced by.
- It supports the arguments you make in your assignments.
- It demonstrates the variety of sources you have used.
- It helps to prevent you losing marks, or failing, due to plagiarism.

When should I use a reference?

You should use a reference when you:

- Quote directly from another source.
- Summarise or rephrase another piece of work.
- Include a specific statistic or fact from a source.

How do I reference?

There are a number of different ways of referencing, and these often vary depending on what subject you are studying. The most important to thing is to be consistent. This means that you need to stick to the same system throughout your whole assignment. Here is a basic system of referencing that you can use, which consists of the following two parts:

1. **A marker in your assignment**: After you have used a reference in your assignment (you have read something and included it in your work as a quote, or re-written it your own words) you should mark this is in your text with a number, e.g. [1]. The next time you use a reference you should use the next number, e.g. [2].
2. **Bibliography**: This is just a list of the references you have used in your assignment. In the bibliography, you list your references by the numbers you have used, and include as much information as you have about the reference. The list below gives what should be included for different sources.

    a. **Websites** – Author (if possible), title of the web page, website address, [date you accessed it, in square brackets].

    E.g. Dan Snow, 'How did so many soldiers survive the trenches?', http://www.bbc.co.uk/guides/z3kgjxs#zg2dtfr [11 July 2014].

    b. **Books** – Author, date published, title of book (in italics), pages where the information came from.

    E.g. S. Dubner and S. Levitt, (2006) *Freakonomics*, 7-9.

    c. **Articles** – Author, 'title of the article' (with quotation marks), *where the article comes from* (newspaper, journal etc.), date of the article.

    E.g. Maev Kennedy, 'The lights to go out across the UK to mark First World War's centenary', Guardian, 10 July 2014.

Appendix 2 – Using the VLE

VLE username	
VLE password	

Please remember the following key details…

- You are able log into the VLE either through the link on our website (www.thebrilliantclub.org) or going directly to the VLE site at (https://portal.thebrilliantclub.org/sign-in).
- Please update your profile with your full name and email address- this will allow you to retrieve forgotten passwords or usernames
- If you forget your log-in details you can request them to be emailed to you by clicking the link on the VLE home page. (If you are still having problems you can email: schools@thebrilliantclub.org)

What is the VLE?

The VLE is a virtual learning environment for all pupils on Uni Pathways it is used for:

- messaging your tutor
- submitting homework
- submitting your final assignment
- accessing resources for your tutorials
- finding out more information about university and careers

How should I use the VLE?

The VLE is a professional academic environment in which pupils are able to message their PhD Tutor. Here are a few things to consider:

- Ensure you keep a professional tone in the messages you send to your tutors.
- Ensure you always reply to your tutors in a timely manner.
- Thank your tutor for the effort they are putting in to give you your feedback etc.
- Submit all homework to your tutor on time.

IMPORTANT: Final assignment

- When you submit your final assignment, please remember that you need to do so through the 'My Activities' tab and not as an attachment to a message.

Notes

Notes

Notes

UNI PATHWAYS

UNI PATHWAYS

Ships, Shocks and Cavitation – The Physics of Underwater Explosions

Key Stage 4 Programme

researchersinschools.org