Mapping our Marine Resources

For thousands of years people have noticed that sounds produced at a distance take time to travel. ***Thunder*** is usually heard several seconds after the ***lightning*** flash that caused it. For every kilometre it has to travel, sound is delayed by three seconds. But what exactly is sound? Is it a thing or substance? What actually travels from the source to the hearer? Does it travel at a fixed speed? Can sound travel through water? Can sound be reflected? This lesson will answer some of these questions and may help you to re-examine your concept of sound. It will also illustrate how sound can be used to construct detailed images of the seabed and help determine its composition.

What exactly is sound?

Waves on water have the following properties: they can travel, they can carry *energy* from one place to another and they generally have a regular repeating pattern of *oscillation* and a *wavelength*. Some other properties are less obvious; waves can add together, they can cancel out one another, they can bend around corners and their speed can change, depending on the *medium*.

More than 2000 years ago some Greek philosophers speculated that the propagation of sound was similar to the propagation of waves on water. In the 1600s Mersenne was to first to measure the *frequency* of a note and correctly interpreted how notes whose frequencies were in simple ratios produced harmony.

Robert Boyle showed that sound could not travel through a vacuum; it needed a medium. In 1686 Newton proposed that sound was a pressure disturbance that was propagated through the air or another medium.

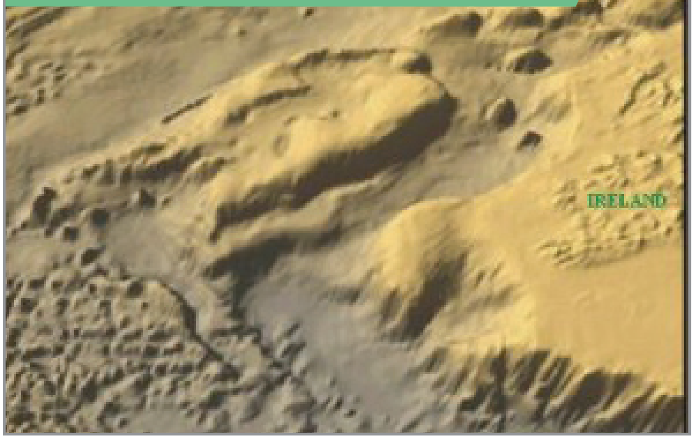
Because sound exhibits many of the properties that are associated with water waves, over the last 300 years sound has been described in terms of waves.

Sound waves are not material things; they do not have an independent existence. They are merely disturbances of a medium (air, water etc.). Although a water wave can travel, the water itself does not – it just moves up and down; what travels is the disturbance.

How is sound used for scanning and measuring?

The speed of sound depends on the medium; in air at sea-level it is about 330 m/s, in seawater it is about 1500 m/s, increasing with depth and temperature. Sound emitted by a source, such as a *loudspeaker*, bounces off surfaces; the reflected sounds or echoes can be detected by one or more *microphones*. The time it takes to travel is proportional to the distance travelled. Over small distances the time is quite small – less than 1 ms (millisecond) to travel a total distance of one metre in water. Using an array of microphones several echoes are detected for each sound pulse emitted. Calculations based on the position of the sound source, the location of the microphones and the times of the echoes can be used to compute the distance to various surfaces. Using sophisticated computer software this process can be automated and the resulting data can be used to construct *virtual 3-D images* of surfaces (Fig. 1). The sharpness or *resolution* of the images depends on the density of the measurements and on the wavelength of the sound. High-pitched sounds have higher frequencies and shorter wavelengths

Fig.1 **Virtual 3-D image of Ireland and continental shelf**



than low-pitched sounds, and are used to produce higher resolution images. The human ear can detect sounds in the frequency range from 16 *Hz* to about 16 kHz. Sound whose frequency is above about 20 kHz is not audible (to people) and is called *ultra-sound*.

INFOMAR/INSS – Mapping the Irish Seabed

The Geological Survey of Ireland is currently carrying out a survey of the seabed around the coast of Ireland, particularly of the continental shelf on the West Coast and all major bays and harbours – covering an area of 525,000 sq. km. Several ships are engaged in the survey and many different techniques are used to collect information on water depth, the nature of the seabed and the structure of the underlying rock.

Methods

The following techniques are used to collect data;

- *multibeam sonar*, which is the principal method used in the survey
- single beam echo sounder
- *sub-bottom profiler (shallow seismic)* which enables layers of subsea geological structures to be detected (Fig. 2)
- measurement of salinity, conductivity, temperature and speed of sound
- seabed *ground-truthing* (direct measurement to verify other data)
- *sidescan sonar*
- *gravity* and *magnetics*
- airborne laser bathymetry for use in clear shallow water (Fig. 3)

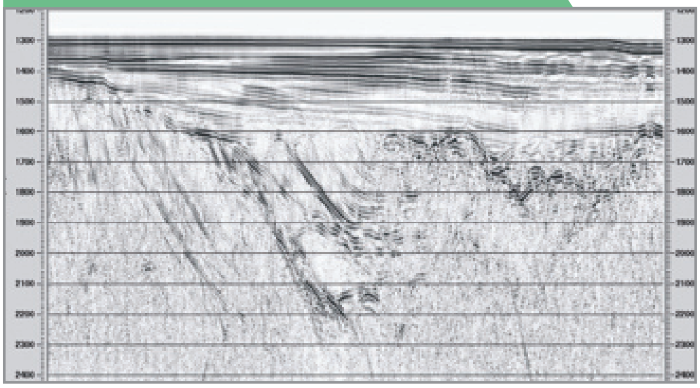
GPS information is used to provide *coordinate* data.

Single-beam echo sounders

In this process a short burst of sound (a 'ping') is emitted by a transducer attached to the underside of a ship. The sound is reflected from the seabed and, using the time taken for the reflected sound (echo) to return, the distance can be calculated. If the delay is, say 8 seconds then the distance the sound travelled is 8 x 1500 m = 12,000 m. The depth is therefore half of this distance since the sound had to travel out and back again.

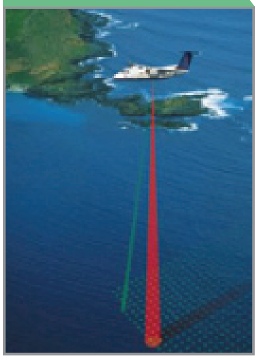
Mapping our Marine Resources

Fig.2 Seismic image of seabed layers



Multibeam sonar

Fig.3 Airbourne laser bathymetry



This *acoustic* technique is providing detailed *bathymetry* (water depth) data and knowledge of the nature of the seabed and its overlying sediment.

Up to one hundred high frequency *transducers* ('speakers') are arranged along the hull of the survey ship in a precise pattern. The returning echoes are processed to generate water depth information *(bathymetry)* and contour maps. Different frequencies are used for different conditions.

This type of scan can be carried out at about 10 km/h; the width of the scanned area is about twice the water depth.

Sidescan sonar

Fig.4 A towfish

In this technique a torpedo-shaped device called a *towfish* (Fig. 4) is towed through the water close to the seabed at a speed of about 2 km/h. The towfish contains *ultrasonic transducers* and underwater microphones (hydrophones). Very high frequency ultrasound pulses (typically 100 kHz to 500 kHz) are directed laterally and the echoes are picked up by the hydrophones. The resulting data is processed to produce images of extraordinary resolution (down to a few centimetres).

Ground-truthing

This involves the direct verification of the interpretation of sonar and other indirectly obtained data. The following are some of the techniques used:

- direct measurement of water depth
- direct sampling of the seabed and subsequent biological, geological and chemical analysis in onshore laboratories
- deployment of video cameras to inspect objects and features that are indicated by indirect scanning methods.

Ireland's seabed area is an important national resource. INFOMAR/INSS, managed jointly by the Geological Survey of Ireland (GSI) and the Marine Institute in co-operation with other strategic partners, is a first attempt to truly understand this resource.

The survey area is approximately ten times the size of Ireland's land area and represents one of the largest seabed mapping projects undertaken anywhere in the world. The information collected will inform decisions about the management and sustainable development of Ireland's marine resources.

Objectives

The main objectives of the survey are:

- To provide detailed information about the seabed around Ireland
- To develop national marine expertise and to spread this expertise across government agencies, third level institutions and a strengthened private sector

The survey area

Ireland's designated waters extend over 1000 km out into the Atlantic Ocean to depths of more than 4500 metres. For surveying purposes it has been divided into three distinct areas or contours:

- 0 – 50 m contour (Zone 1)
- 50 – 200 m contour (Zone 2)
- 200 – 4500 m contour (Zone 3)

The survey generates a vast amount of data which requires storage, verification and analysis and sophisticated manipulation to convert it into easily accessible formats such as 3-D images. Detailed maps and other information are made available on a commercial basis by INFOMAR.

Scientists from many different disciplines are involved in the Irish National Seabed Survey (INSS). While many of these work onshore some spend time on the survey vessels involved in data collection. There are many university projects arising from INSS data covering topics as diverse as geohazards, telecommunication cabling, carbonate mounds and ancient landscapes.

You can find out more about the work of the **Geological Survey of Ireland** (GSI) at **www.gsiseabed.ie** or at **www.sta.ie**

Syllabus Reference

Leaving Certificate Physics

Properties of waves
Wave nature of sound

Junior Certificate Science

Section 3B5 – Sound

Learning Objectives

On completing this lesson the student should be able to:

- Appreciate that high-frequency sound can be used to measure water depth and to scan the seabed
- Explain why high-frequency (ultrasonic) sonar has better resolution than audible sound
- Distinguish between the main sonar scanning methods used by INFOMAR/INSS
- Explain what is meant by ground-truthing and why it is necessary
- Appreciate the magnitude of the task of surveying a very large area.

General Learning Points

- Sound is not an entity in itself; it is a physical disturbance that propagates through a medium. It therefore cannot travel through a vacuum.
- Audible sounds are in the frequency range 16 Hz to about 16,000 Hz (16 kHz).
- Ultrasound refers to sound whose frequency is higher than about 20 kHz.
- Sound travels about 330 m/s in air – about a million times more slowly than light.
- The time of travel of reflected sounds (echoes) can be used to measure distances.
- We can easily and unconsciously identify the direction from which a sound comes to us; the minute time difference between the arrival of the sound in our left and right ears enable us to do this.
- People who are blind, and sighted people who are blindfolded, can learn to use echolocation to detect objects around them – walls, doors, the size of rooms etc.
- Bats use high-frequency sound to facilitate catching their prey. Using echo location alone they can identify the position and speed of an insect and distinguish between different kinds of insect.
- Sonar involves the use of sound to measure distances to objects that are under water.
- Modern sonar systems in conjunction with computer hardware and software can be used to map the seabed.
- High-energy 'sounds' (seismic waves) are used to map geological structures below the seabed.

Practical Activities

Investigative Activities

If you lightly rub the surface of a table with your finger you cause a local disturbance of the wood that is propagates through the table. If you put your ear to the table you will find that the lightest touch can still be heard. Get someone else to lightly tap a long piece of wood or a wall the see how far the disturbance can travel.

Put on a blindfold and get someone to lead you into several rooms of different size. Try to determine the relative size of the rooms merely by listening to a simple sound such as a finger click. Record your results and try to explain them.

Can you devise a way to test whether sound travels faster through the ground (or through water) than through the air. Investigate the origin of the phrase "ear to the ground".

True or False

Indicate whether the following are true (T) or false (F) by drawing a circle around T or F.

(a) The unit of frequency is the hertz (Hz). **T F**

(b) Ultrasound is sound whose frequency is less than 16 Hz. **T F**

(c) Sound can travel through interplanetary space. **T F**

(d) Sound can bounce off objects. **T F**

(e) Sound reflects more strongly from hard surfaces than from soft ones. **T F**

(f) Sonar is the use of radio waves to detect objects. **T F**

(g) The International Space Station used sonar to map the oceans **T F**

(h) The INFOMAR/INSS survey area is 500,000 m^2. **T F**

(i) The first person to show that sound could not travel through a vacuum was Aristotle. **T F**

(j) Sound travels faster in water than in air. **T F**

(k) Direct verification of sonar data is called ground-truthing. **T F**

Check your answers to these questions on www.sta.ie

Examination Questions

2006 Leaving Certificate Higher Level

Describe an experiment to demonstrate that sound is also a wave motion.

Sound travels as longitudinal waves while light travels as transverse waves. Explain the difference between longitudinal and transverse waves.

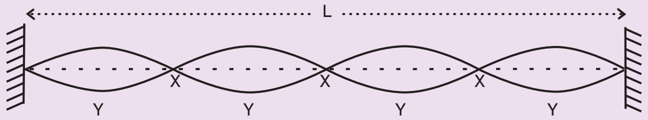
2004 Leaving Certificate Ordinary Level

Sound from a vibrating object can cause diffraction and interference.

Explain the underlined terms.

Describe an experiment to demonstrate the interference of sound.

The diagram shows a stationary wave (standing wave) on a vibrating stretched string.



What is the name given to the points on the string marked (i) X, (ii) Y?

How many wavelengths are contained in the distance marked L?

State two factors on which the natural frequency of a stretched string depends.

A note of wavelength 1.4 m is produced from a stretched string. If the speed of sound in air is 340 m s^{-1}, calculate the frequency of the note. ($c = f\lambda$)

2003 Leaving Certificate Ordinary Level

In an experiment to measure the speed of sound in air, a student found the frequency and the wavelength of a sound wave.

Draw a labelled diagram of the apparatus used in the experiment.

Describe how the student found the wavelength of the sound wave.

How did the student find the frequency of the sound wave?

How did the student calculate the speed of sound in air?

Give one precaution that the student took to get an accurate result.

For further examples of past paper questions check www.sta.ie

Did You Know?

- Speed of sound increases with depth and temperature; in the sea it travels more quickly at the surface (due to higher temperature). The speed falls with depth for the first 1000 m or so and thereafter increases (due to increasing pressure and relatively constant temperature). In the sea, sounds propagate horizontally for long distance at a depth at which sound has its minimum speed – about 1000 m. Sounds that 'stray' upwards or downwards are refracted back to this layer.
- Some animals (elephants, whales) communicate using subsonic frequencies. Whales can hear one another over tens or even hundreds of kilometres.
- Bats use both audible sound and ultrasound (10 kHz to more than 100 kHz). Higher-frequencies sounds have shorter wavelengths and provide more detailed 'information'.
- Ultrasound is used to monitor the development of unborn babies.
- The speed of sound is about 330 m/s in air, about 1500 m/s in water, about 4000 m/s in rocks, 13,000 m/s in beryllium, and 3000 to 6000 m/s in most other metals.
- Small children can hear frequencies up to about 20 kHz – a few notes higher on the musical scale than the upper limit for adults.
- Ultrasonics can be used to detect discontinuities in materials, such as tiny cracks in metal structures that are induced by repetitive stress.
- Ultrasonic transducers (high-frequency 'speakers') are used to deter household vermin such as mice.

Biographical Notes

Marin Mersenne 1588 - 1648

In 1636 the French natural philosopher published a book called *Les preludes de l'harmonie universelle* in which he proposed a theory of music and harmony. He made the first direct measurement of the frequency of a note (it happened to be 84 Hz). He is known as the father of acoustics (the science of sound). He concluded that the frequency of notes that together produced a harmonious sound were in a simple ratio (1:2, 2:3).

In 1640 he measured the speed of sound in air by timing echoes over known distances; his estimate was 316 m/s.

Robert Boyle 1627 - 1691

Robert Boyle, the seventh son of the Earl of Cork, was born in Lismore Castle, County Waterford. From the age of eight he studied in England and in continental Europe. In 1654 he settled in Oxford and with the help of Robert Hooke began to study the the relationship between the pressure and the volume of a gas. He discovered that sound could not travel through empty space; it needed a medium. He also showed that air was necessary for combustion.

He was the first to use the term 'element' in the modern sense to describe a substance that could not be broken down into simpler substances but which could combine with other elements to form compounds.

Boyle together with other scientists formed the Royal Society in London in 1660. It is an independent scientific academic society dedicated to promoting excellence in science.

Read more about other famous scientists at www.sta.ie

Revise the Terms

Can you recall the meaning of these terms? Reviewing the terminology is a powerful aid for recall and retention.

Wave; wavelength; frequency; reflection; refraction; interference; medium; hertz; kilohertz; sonar; ultrasonic; seismic; ground-truthing; acoustic; bathymetry; transducer; hydrophone; microphone.

Check the Glossary of Terms for this lesson at www.sta.ie