Archimedes and the 2000-year-old computer

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MARCELLUS and his men blockaded Syracuse, in Sicily, for two years. The Roman general expected to conquer the Greek city state easily, but the ingenious siege towers and catapults designed by Archimedes helped to keep his troops at bay.

Then, in 212 BC, the Syracusans neglected their defences during a festival to the goddess Artemis, and the Romans finally breached the city walls. Marcellus wanted Archimedes alive, but it wasn't to be. According to ancient historians, Archimedes was killed in the chaos; by one account a soldier ran him through with a sword as he was in the middle of a mathematical proof.

One of Archimedes's creations was saved, though. The general took back to Rome a mechanical bronze sphere that showed the motions of the sun, moon and planets as seen from Earth.

Special admiration

The sphere stayed in Marcellus's family for generations, until the Roman author Cicero saw it in the first century BC. "The invention of Archimedes deserves special admiration because he had thought out a way to represent accurately by a single device for turning the globe those various and divergent movements with their different rates of speed," he wrote. "The moon was always as many revolutions behind the sun on the bronze contrivance as would agree with the number of days it was behind it in the sky."

Until recently, historians paid scant attention to this story: the description suggests a sophisticated mechanical device, beyond anything the ancient Greeks were thought to have been capable of. Furthermore, Cicero had no technical training, and did not explain how the device worked. He could have made the story up for effect.

Now, however, research on the battered remains of a mysterious ancient device suggests that Cicero was telling the truth. While the Antikythera mechanism is not the same one seen by Cicero - it was not made until a century later - it proves that clockwork mechanisms like the one he described really did exist, and that ancient Greek technology was far more advanced than thought. Freshly deciphered inscriptions on its dials also hint at the origins of this technology.

Ancient shipwreck

The device was discovered more than a century ago by sponge divers from the Aegean island of Symi. In 1900, after a gale blew them off course, they took shelter by a barren islet called Antikythera. When the storm abated, they went diving. Instead of sponges, the divers found a large heap of bronze and marble statues. They had happened upon an ancient shipwreck.

The Greek government immediately hired the men to salvage the wreck. It was dangerous work: during the 10-month expedition one of the men died and two were paralysed as a result of the bends. But they brought back incredible treasures: bronze and marble statues, jewellery, glassware and furniture, including an ornate bronze throne.

In all the excitement, nobody noticed a corroded lump of rock dumped in a crate in the courtyard of the National Archaeological Museum in Athens. That changed a few months later when it cracked open, revealing traces of gearwheels, precisely marked circular scales and inscriptions in ancient Greek.

The lump cracked open, revealing traces of gearwheels

The battered artefact became known as the "Antikythera mechanism", and it caused excitement and consternation. Until then, not one gearwheel, pointer or scale had been found from antiquity. Nor have any been found since; the Antikythera mechanism remains unique.

A hoax?

Some scholars thought it was a hoax, others that it had come from a modern ship that sank on the ancient wreck site by chance. The only clues to its purpose were a reference to the signs of the zodiac - used for astronomy as well as astrology - and the word "Pachon", which was a month name used by the ancient Greeks. As the years passed, the mechanism sank into obscurity. With no answers, historians of technology tended to mention it as an afterthought, if at all.

In recent decades, however, a series of researchers have dedicated large parts of their lives to studying the mechanism. From their combined efforts, including X-raying its internal workings, we at last have a fairly complete picture of what the Antikythera mechanism did. It turns out that it was a hand-wound clockwork device used to calculate the motions of the sun, moon and planets as seen from Earth, as well as to predict solar and lunar eclipses (see "How it worked").

The complexity of the design, and the fact that it incorporated state-of-the-art astronomical knowledge, suggest that the maker cared a great deal about the accuracy of the mechanism. So where did it come from, and what was it used for?

Long-lost loot

Studies of the Antikythera wreck and the cargo it carried suggest the ship set sail in around 65 BC, heading west from Asia Minor. It was a Roman ship, carrying looted Greek treasures back to Rome. At this time, the fearless young general Pompey was sweeping his way through Asia Minor, so the ship could have belonged to him.

The presence of supply jars from Rhodes suggests the vessel stopped off at the island shortly before sinking. The astronomer Hipparchus, whose theories are embodied in the mechanism's gearwork, worked on Rhodes just a few decades before, leading some scholars to suggest that the Antikythera mechanism was made on the island.

Cicero also visited Rhodes around this time. In fact, he wrote about a second bronze model of the heavens "recently constructed by our friend Posidonius, which at each revolution reproduces the same motions of the sun, the moon and the five planets that take place in the heavens each day and night". Posidonius was a philosopher with a school on Rhodes in the first century BC, just at the time the Antikythera ship sailed.

A gift

General Pompey admired the teachings of Posidonius, and several times stopped off to see him. Perhaps Posidonius gave the mechanism to Pompey as a gift.

But there is a twist in the tale. Researchers including Alexander Jones of the Institute for the Study of the Ancient World in New York and John Steele of Durham University, UK, are still deciphering the mechanism's inscriptions. They recently discovered that the month names used on the Antikythera mechanism are from a local calendar used only in western Greece (Nature, vol 454, p 614).

One of the main contenders for the origin of the calendar is the powerful city state of Syracuse, founded by Greek settlers, hinting that the mechanism was made by - or for - someone there. This is puzzling because the ship was sailing west towards Sicily on its way to Rome before it sank (see map). It is possible that the mechanism was made on Rhodes for a wealthy owner in Syracuse. However, the inscriptions on the device date it to around 150 to 100 BC, suggesting that it was already a few decades old when the ship sank. It now seems more likely that it was originally made in Syracuse then taken east - to show off to the scholars on Rhodes, perhaps, or simply because its owner moved there. Later, the Romans put it on a ship heading back west.

Archimedes

The most intriguing thing about the latest finding, however, is that Syracuse was Archimedes's home city. He lived a century before the Antikythera mechanism was made, so he could not have created this particular device. But the link to Syracuse, plus Cicero's description of Archimedes's model, hint that he could have been the original inventor of this type of gadget, with the Antikythera mechanism part of a technological tradition that he started.

We know from ancient texts that Archimedes pioneered the use of gearwheels to achieve different force ratios - to lift weights, for example. And one of the few biographical details we know about him is that his father was an astronomer. So it wouldn't be completely unexpected if he had the idea of using his gearwheels to model the motions of the heavens. Tantalisingly, one of his lost treatises was entitled "On sphere-making".

The theory of epicycles was very new when Archimedes lived, if it existed at all, and astronomers had no way to model the elliptical orbits of the moon and sun. So his original design might have been relatively simple, perhaps a schematic model showing the sun, moon and planets rotating around the Earth at various but constant speeds. Later, other craftsmen could have built on this, coming up with more sophisticated gearwork to incorporate the latest astronomical knowledge - including that of Hipparchus - as it became available, with the designs being shipped across the Greek world. Hipparchus is chiefly known for his insistence on what now seems obvious to us: that astronomical theories should accurately match observations. Perhaps he or his work influenced a switch from a schematic spherical model to a mathematical calculator that displayed the precise timing of celestial events on flat dials.

Earliest steam engine

Modelling the heavens with geared devices ran alongside a parallel tradition of modelling living creatures such as people, animals and birds. These did not use gearwheels, but were instead powered by steam, hot air and water. This seems to have started with the engineer Ctesibius in Alexandria in the third century BC, who specialised in water clocks incorporating automated figures. Archimedes worked with Ctesibius in Alexandria before he moved to Syracuse, so perhaps the seeds of both traditions - modelling planets and living creatures - were sown there.

The engineer Hero, working in the first century AD, continued their work. He built many automated figures, as well as inventing a steam engine, a vending machine that dispensed holy water, a wind-operated organ and a geared device for lifting heavy weights.

Historians have often scoffed at the Greeks for wasting their technology on toys rather than doing anything useful with it. If they had the steam engine, why not use it to do work? If they had clockwork, why not build clocks? Many centuries later, such technology led to the industrial revolution in Europe, ushering in our automated modern world. Why did it not do the same for the Greeks?

Divine order

The answer has a lot to do with what the Greeks would have regarded as useful. Models of people and animals, like those of the cosmos, affirmed their idea of a divine order. Gadgets like Hero's were also used to demonstrate basic physical laws in pneumatics and hydraulics.

It has been suggested, for example, that Hero built his steam engine, in which steam escaping from nozzles in a metal sphere caused the sphere to spin, to disprove Aristotle's argument that movement could only be generated by pushing on something "unmoved and resisting" - the Prime Mover. Despite Hero's demonstration, Christians later adapted Aristotle's argument as proof that their God exists.

Rather than being toys, devices like the Antikythera mechanism were seen as a route to understanding and demonstrating the nature of the universe - a way to get closer to the true meaning of things. To what better use could technology be put?

For more information, visit Decoding the Heavens

The players...

CTESIBIUS OF ALEXANDRIA, c. 285 - 222 BC

Greek inventor and mathematician. His water clocks showed the movements of the sun and were adorned with whistling birds, moving puppets and ringing bells.

ARCHIMEDES OF SYRACUSE, 287 - 212 BC

Engineer and mathematical genius. He built war machines and invented calculus, but probably did not run about naked shouting "Eureka!" after a bath-time brainwave.

MARCUS CLAUDIUS MARCELLUS, c. 268 - 208 BC

Roman general and conqueror of Syracuse. Was very upset that his men had killed Archimedes, and he ensured that the mathematician was buried in a suitably grand tomb.

HIPPARCHUS OF RHODES, c. 190 - 120 BC

A leading astronomer of the ancient world. He compiled the first star catalogue, developed trigonometry and discovered the precession of the constellations through the sky.

POSIDONIUS OF RHODES, 135 - 51 BC

One of the most revered philosophers of ancient Greece, and Rhodes's ambassador to Rome. He subscribed to the Stoic view that the cosmos is a single organism.

MARCUS TULLIUS CICERO, 106 - 43 BC

A high-flying Roman lawyer, politician and author, who loved Greek philosophy. He clashed with Pompey and Julius Caesar, and was killed by Mark Anthony's men.

GNAEUS POMPEIUS MAGNUS (POMPEY), 106 - 48 BC

Bold general and rival of Julius Caesar, Pompey was one of the most important men of the Roman Republic. In the 60s BC his armies swept through Asia Minor.

HERO OF ALEXANDRIA, c. 10 - 75 AD

Greek geometer and inventor. He invented many devices including a steam engine. He specialised in automated figures driven by air, steam and water.

How it worked

The Antikythera mechanism was enclosed in a wooden box and driven by a handle on the side. As the user turned the handle, they could wind backwards or forwards in time to see the positions of heavenly bodies at any chosen moment.

On the front of the box was a large bronze dial on which revolving pointers showed the relative position in the sky of the sun, moon and probably the five known planets, along with the date. A rotating black-and-white ball displayed the phase of the moon. Around the dial were inscriptions detailing the risings and settings of the stars at different times of the year.

On the back (see diagram) were two spiral dials, each with an extendable pointer. Once the pointer reached the end of a spiral, it could be lifted by hand and reset to the beginning - a bit like the stylus on a record player. The top dial showed a repeating 19-year calendar used to track the motions of the sun and moon. This timescale was chosen because 235 lunar months fit almost exactly into 19 solar years. The bottom dial was used to predict eclipses, and showed the 223 months of an 18-year cycle over which eclipse patterns repeat. Inscriptions marked the months in which to expect a lunar or solar eclipse, as well as its exact time and duration.

Incredibly, all of this was achieved by intermeshing bronze gearwheels, which multiplied the speed of rotation by precise mathematical ratios depending on the number of teeth on each wheel. Turning the handle drove a "mean sun", or date pointer, which revolved around the sky once per year. Three pairs of gearwheels then multiplied that speed of rotation by 235/19, to calculate the mean motion of the moon.

Beyond that, things got more complicated. For example, the moon's speed as seen from Earth is not constant. The moon has an elliptical orbit, so it is sometimes closer to us (when it moves faster) and sometimes further away (when it slows down). The alignment of this ellipse rotates around Earth about once every 9 years. The idea of an ellipse would have been blasphemy to the ancient Greeks - they were convinced that celestial orbits, which they saw as divine, involved only perfect circles.

Wheels within Wheels

Instead, in the second century BC the astronomer Hipparchus came up with a theory to account for the moon's varying speed by superimposing one circular motion onto another with a different centre. The gears inside the Antikythera mechanism precisely model this theory. One gearwheel sits on top of another, but on a slightly different axis. A pin sticks up from the bottom wheel into a slot in the wheel above. As the bottom wheel turns it drives the top wheel round, but because the two wheels have different centres, the pin slides back and forth in the slot. This causes the speed of the top wheel to vary, even though the speed of the bottom wheel is constant.

This pin-and-slot mechanism was carried around on a much larger turntable, with one rotation equalling 9 years, to model the shifting axis of the moon's orbit. This combined motion was then superimposed onto the mean speed of the lunar pointer, so that it matched the speed of the actual moon.

The gearing for the sun and planets is lost, but the Antikythera mechanism almost certainly modelled these too. The planets' motions appear particularly erratic to us because they orbit the sun and not Earth. The Greeks accounted for this by superimposing small epicycles onto larger circular orbits. There is evidence that the Antikythera mechanism calculated these using what is still known today as epicyclic (or "planetary") gearing - small wheels riding around on bigger wheels.

Jo Marchant is the author of a book about the Antikythera mechanism called Decoding the Heavens: Solving the mystery of the world's first computer (Heinemann, 2008)