COVER STORY

Like many great discoveries, the Antikythera Mechanism was found by accident. In 1900, sponge divers came across a shipwreck off the coast of the Greek island of Antikythera, and over the next year or so, they retrieved a number of artifacts—statues, coins, jewelry, and so on. One item they brought to the surface was not immediately recognized: a lump of corroded bronze and wood, broken into several calcified fragments. The artifacts were all sent to the National Museum of Archaeology in Athens for cataloguing and restoration, but the bronze lump sat almost unnoticed. When researchers finally turned their attention to it, they couldn’t agree on what it was. The bronze lump seemed to contain gears and dials, suggesting it was a navigational device or perhaps even a clock. Some archaeologists suggested that it was a mechanism too advanced for the date of the shipwreck—the first century B.C.—and thought it might have been lost at sea more recently.

In time, however, analysis using X-ray and other advanced imaging revealed its true nature, and the Antikythera Mechanism is now considered as important for technology and sciences as the Acropolis for the architecture and arts. The object is the remains of the earliest known analog computer. Now we know that it was an extremely advanced mechanism that could be used to calculate and predict astronomical events. Detailed studies of the mechanism by various researchers have shown that it could predict with astonishing accuracy the position of the sun, moon, and the planets on the sky. It could also determine the phases of the moon, adjust the calendar, determine the dates of the ancient Olympic Games, and predict solar and lunar eclipses.

But before researchers like myself could make that assertion with full confidence, we would have to go beyond simply observing the artifact with sophisticated imaging tools. We would have to use that data to create a working model, and test our theories against the recreated mechanism itself.

IDENTIFYING THE COMPONENTS

Almost since the Antikythera Mechanism was first subjected to X-ray imaging, people have tried to reconstruct it. The unsolved purpose of the artifact often attracted amateurs and scientists operating outside their field of expertise. Ioannis Theofanidis, a Greek naval officer turned historical researcher, worked on the problem in the 1920s and 1930s; the English physicist Derek John de Solla Price published analyses of the device beginning in 1959; Allan Bromley, an Australian
A transparent model of the Antikythera Mechanism—three times larger than the original—allows researchers to better see the interior and observe the movements of the shafts, axles, and gears.

The front of the Mechanism had pointers showing the location of the sun and moon against the zodiac, and a rotating spherule that indicated the moon's phase. Incriptions suggest that the machine could also compute the location of the known planets.

Photo: Department of Mechanical Engineering Aristotle University of Thessaloniki

A rotating spherule, adapted with a crown gear to the pointer of the Moon, displayed the phases of the Moon. The movement of the Moon is not circular but elliptical. The display of this movement, which compensates for the anomaly caused by its eccentic orbit around the Earth, was achieved by the use of two eccentric gears, the axes of which are offset by 1.1 mm. The lower gear has a pin that engages with a slot on the upper gear, forcing it thus to rotate by a pin-and-slot arrangement. The epicyclic movement of the upper gear tracked the motion of the Moon in the sky with great accuracy.

The pointers of the two spiral dials on the back side of the mechanism had at one end a small vertical rectangular guiding pin that followed the gap of the spiral scales. The pin followed the spiral exactly like the tip of a record player needle. The pointers on the back side tracked eclipse cycles and the date of the Olympic Games.

Two more plates, attached on the internal sides of the protective wooden covers of the wooden box were fully covered with inscriptions that were likely a user's manual.

While the computed tomographic imaging could help researchers determine the dimensions and geometry of the gears of the artefact, there was a great uncertainty in how those measurements related to the original mechanism. The fragments had spent 2,100 years at the bottom of the sea and had suffered considerable damage. As a result, projecting those measurements onto the original geometrical parameters of the gears comes with large error bars.

One critical measurement for verifying the accuracy of the Antikythera Mechanism—the root and tip diameters of all gears and the teeth's root angle—could only be estimated based on the X-ray analysis. To better understand the device, we would have to construct a working model.

GEOMETRICAL PARAMETERS

The gears found in the Mechanism are the first in the history of mankind resembling the shape and philosophy of modern gears. Their triangular teeth are capable of transmitting angular motion but less so for power.

Our team at Aristotle University of Thessaloniki has been analyzing these basic geometrical parameters and the dimensions of the triangular teeth, and we have developed a mathematical model to estimate their original condition. Using the gears measured data and the equations of the mathematical model as input to an advanced software program, we found a common root angle and a common module for all gears of the Antikythera Mechanism.

The triangular tooth shape requires, beyond the theoretical approach mentioned earlier, a detailed investigation of the fragments of the Mechanism. Using the software
The Mechanism was a complex astronomical computer, featuring at least 42 gears, 21 axles and shafts, and eight pointers (shown here in a 3-D rendering). Advanced software and eight pointers (at least 42 gears, machine worked. The Mechanism is enabling us to reconstruct the Antikythera Mechanism.

Illustration: 3D Solidforms

Some have round holes, others have squares ones, and one has a pentagonal hole. The fragment’s tomographic data cannot give accurate information about the dimensions and the shapes of the shafts, the axles, and the supporting components due to the damage of the calcified fragments, which are corroded, deformed, and sometimes shattered after 2,100 years on the bottom of the sea. But the shape of the central holes enables us to determine which axles turned on the same axis.

Two pairs of shafts, for instance, are concentric, which means that one of the two shafts passes between the other; the two shafts rotated independently. Also there is an axis which has two eccentric cylindrical bearing points for two gears.

We started to create a new model of the device via parametric design. For each part, the geometric and dimensional values were examined in a way that those parts could be changed easily without the need of redesigning the other functional elements. Through an iterative process, we developed a design of the mechanism and simulated its operation, then were able to study how all the parts and the various elements operated. When we were satisfied with the results of the design process, we finally built a physical model for testing.

The hope was that we could address a still-open question about the purpose of the Mechanism: Whether it was originally a teaching tool for the astronomical schools of antiquity or a calculator and its mean annual position. A realistic simulated model confirms the theoretical conclusion: it is much easier and more precise to operate the mechanism through the moon pointer or by rotating the axis the pointer is attached.

Our research also uncovered a heretofore unnoticed calculation the mechanism could perform. Among the fragments pulled from the seafloor was one labeled “D.” In modern studies, fragment D is considered as a lone foil, whose function had yet to be discovered. After an extensive study of fragment D, our team produced evidence that it was part of an arrangement used to calculate the equation of time—that is, the difference between the apparent position of the Sun and its mean annual position. A realistic-simulated mechanical model that uses parts found in the fragment components, a gear and a cam, has been designed. The output of the proposed arrangement is a pointer on a scale of the front plate of the Antikythera Mechanism, which reproduces the equation of time for the epoch of its construction, and its mean annual position.

Talking into account these results, the mechanism now can be said to have had at least 42 gears, 21 axles and shafts, and eight pointers.

One difference between our model and others is the absence of pointers indicating the position of the planets. As we noted, the names of the planets known to the ancient Greeks are found on various fragments of the Mechanism, so it made sense to model-builders to assume gearing that could simulate the position of the planets using the pin-slot gearing found elsewhere in the Antikythera Mechanism. Up to now, however, no gears or axes or any other related mechanical elements that could calculate planetary position have been discovered among the fragments of the Mechanism. We cannot rule out the possibility that such gear-systems were part of the original Mechanism, but without actual evidence for their existence, our team decided not to include them in our model.

A SOPHISTICATED INSTRUMENT

In addition to the other 3-D scale model, we have also constructed a transparent model of the Antikythera Mechanism three times larger than the original ancient artifact (scale 3:1), so that during operation, one can better see the interior and observe the movements of the shafts, axes, and gears.

With the help of this model we are currently studying the accuracy of the mechanism’s predictions. The first test results show that it accurately predicts astronomical phenomena, which leads us to the conclusion that the Antikythera Mechanism was a scientific instrument, an analog computer, which predicted accurately astronomical phenomena, and which had only a secondary use as an educational tool.

The Mechanism has been called the first computer, but that is likely not accurate. Its sophistication suggests that it was not the first of its kind, but one of a sequence that had been built for astronomical calculation. In antiquity, such calculating machines may not have been common, but it’s unlikely the relic found on the sea floor off Antikythera was unique.

We might also ask ourselves, was astronomical calculation the only purpose that the ancient Greeks and others found for this sophisticated mechanism? No such machine has survived to the present, but that is not proof that none were ever constructed.