ΠΡΑΚΤΙΚΑ | PROCEEDINGS

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3rd International Conference
Ancient Greek and Byzantine Technology

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MEGARON THE ATHENS CONCERT HALL

ΟΡΓΑΝΩΣΗ
ΕΤΑΙΡΕΙΑΣ ΔΙΕΡΕΥΝΗΣΗΣ ΤΗΣ ΑΡΧΑΙΟΕΛΛΗΝΙΚΗΣ ΚΑΙ ΒΥΖΑΝΤΙΝΗΣ ΤΕΧΝΟΛΟΓΙΑΣ
NOESIS
ΚΕΝΤΡΟ ΔΙΑΔΟΣΗΣ ΕΠΙΣΤΗΜΩΝ & ΜΟΥΣΕΙΟ ΤΕΧΝΟΛΟΓΙΑΣ

Το Διοικητικό Συμβούλιο της Εταιρείας Διερεύνησης της Αρχαιοελληνικής και Βυζαντινής Τεχνολογίας (ΕΔΑΒυΤ) ανέλαβε την ανάρτηση στην ιστοσελίδα της (www.edabyt.gr), σε ψηφιακή μορφή, των εργασιών του $3^{ου}$ Διεθνούς Συνεδρίου Αρχαιοελληνικής και Βυζαντινής Τεχνολογίας (Αθήνα 19-21 Νοεμβρίου 2024).

Οι εργασίες είχαν γίνει αντικείμενο κρίσεων και σχολιασμού από την Επιστημονική Επιτροπή. Επι πλέον, έγιναν κι άλλες παρατηρήσεις και σχόλια κατά την συζήτηση που ακολούθησε μετά την προφορική τους παρουσίαση στο Συνέδριο.

Οι εργασίες αναρτώνται όπως κατατέθηκαν από τους συγγραφείς μετά την ολοκλήρωση του Συνεδρίου. Οι συγγραφείς φέρουν την ευθύνη του περιεχομένου της εργασίας τους, τόσο ως προς τις απόψεις τους όσο και ως προς την ακρίβεια και την ορθότητα των στοιχείων που παραθέτουν.

The Board of Directors of the Association for Research on Ancient Greek and Byzantine Technology (EDAByT) undertook the posting on its website (www.edabyt.gr) of the papers presented at the 3rd International Conference on Ancient Greek and Byzantine Technology (Athens, November 19-21, 2024).

The papers had been subject to reviews and comments by the Scientific Committee. Additionally, further observations and comments were made during the discussion that followed their oral presentation at the Conference.

The papers are posted as submitted by the authors after the conclusion of the Conference. The authors are responsible for the content of their work, both in terms of their views and the accuracy and correctness of the data they present.

3rd INTERNATIONAL CONFERENCE
Ancient Greek and Byzantine Technology
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THE ANTIKYTHERA MECHANISM AS A MECHANICAL ARTEFACT

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Abstract. The Antikythera Mechanism exists as a collection of fragments, of which six contain traces of its mechanical movement and dials. We review the extent to which these establish certainty about the overall arrangement and function of the instrument. Beyond that, we note that any attempt at reconstruction of the complete instrument is, in contrast, a matter of conjecture. We continue to prefer a reconstruction in which indicators on the front dial showed, on a graduated ring representing the Zodiac, the places of the planets known in antiquity together with those of the Sun and Moon. In outline at least this scheme is widely accepted as correct, but we note that other schemes of reconstruction have been brought forward and continue to be developed. We have at present little to add to this continuing discussion. Instead, here we concern ourselves mainly with the mechanical detail of the original parts of the Mechanism and with questions concerning its design and manufacture. Some commentators have laid emphasis on the supposed accuracy of the instrument, but in this they appear to refer to the indications of its displays which depended mainly on the selection of gearing that embodied ratios realising previously well-established and accurate period-relations. In contrast, both its design and the execution of its components are open to criticism in some respects. Some features of the design are surprisingly poor and we seek reasons why better alternatives were not chosen. Through the investigation of some of these design choices we are led to the conclusion that the instrument was altered in antiquity.

Keywords: Antikythera Mechanism; reconstruction; design; manufacture; technical tradition.

The Antikythera Mechanism, preserved in the National Archaeological Museum in Athens,[1] is the only known surviving artefact that bears witness to intricate mechanical activity in the Hellenistic era. More specifically, it represents the craft known in antiquity as *sphairopoiïa*, the construction of devices offering some sort of representation of the perceived universe. The genre is otherwise known only through literary references and allusions, of which a number have been noted by Edmunds (Edmunds 2014, 274 *et seq*.). The earliest is by the Roman author Marcus Tullius Cicero (Cicero), during whose lifetime (106 – 43 B.C.) the Antikythera Mechanism was lost. In common with many other authors, he ascribes the origin of mechanical *sphairopoiïa* to Archimedes, some two centuries earlier. Collectively, these literary allusions

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[1] National Archaeological Museum, Athens, Inventory Number X.15087.

suggest that a significant number of such instruments existed, and that knowledge of them, over an extended period, was fairly widespread.

The Antikythera Mechanism is incomplete and exists as a collection of many fragments. The larger fragments, including all those that are known to contain pieces of mechanism, are designated by letters. In this paper attention will be directed only to these and principally to the largest, Fragment A (figures 1, 2). There seems to be nearly universal agreement about the function and purpose of all those parts of which enough remains for their forms to be restored with confidence. They are: a substantial proportion of the internal mechanism, mostly preserved in Fragment A; and parts of a dial (known as the “back dial”) preserved in Fragments A, B, E and F. Part of another dial (the “front dial”) is preserved in Fragment C, but its status is perhaps problematic. These metallic parts were originally contained within and connected by a rectangular wooden case or frame of which the back dial formed one face and the front dial presumably formed part of the other. On the back dial were two main displays: a 235-month sequence representing a civil calendar constructed on the basis of the Metonic period-relation, an excellent approximation according to which 235 synodic months equal 19 years; and a 223-month sequence representing the so-called Saros cycle of eclipses. Both were supported by smaller subsidiary displays, the functions of which need not concern us here. These displays were connected to one another, and to the display on the front dial, by internal gearing which ensured that the indications of all the displays progressed together at commensurate rates when the gearing was set in motion.

Figure 1. Antikythera Mechanism, Fragment A, front view. Photograph taken January 1991. © M.T. Wright.

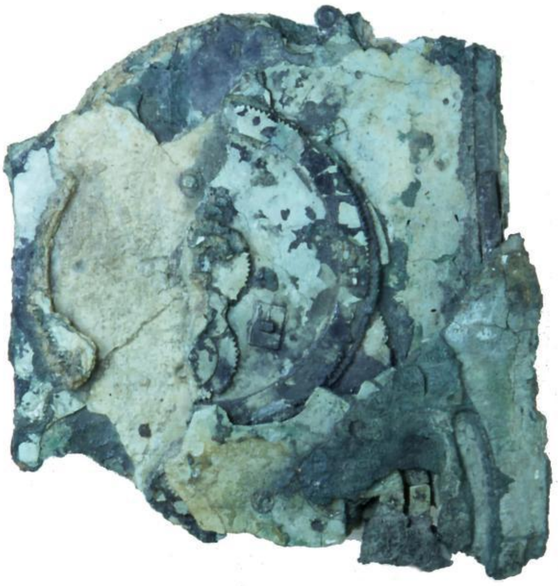

Figure 2. Antikythera Mechanism, Fragment A, back view. Photograph taken January 1991. © M.T. Wright.

The front of the instrument is less fully preserved than the back, so that reconstruction of the front dial display and of the further lost mechanism thought to have supported that display is necessarily less confidently established and is more open to debate. What is certain about the mechanical output at the front of Fragment A, leading to the front dial, is that there were concentric mobiles, rotating in the same sense, with periods in the ratio 254 : 19 – the period-relation between tropical years and tropical months which is a corollary of the Metonic period-relation mentioned above. This was suggested by Price, but his scheme, entailing an incorrect restoration, was based on a misunderstood connection in the internal gearing (Price 1974, 41), an errror that we corrected (Wright and Bromley 2003, *passim*). Indicators driven at these rates would have shown the relative motions of the Sun and the Moon, each revolution of the Sun indicator representing a tropical year and each revolution of the Moon indicator representing a tropical month, as they moved round a dial representing the Zodiac. The internal gearing is such that this display keeps pace with the displays on the back dial. Furthermore, within Fragment A lies additional mechanism which modifies the angular velocity of the mobile intended to carry the Moon pointer in such a way that it matches qualitatively, but not quantitatively, the anomalous motion of the Moon identified by Hipparchos, as reported by Klaudios Ptolemaios (Freeth *et al.* 2006, 519). Without further mechanism, however, the Sun indicator would show only its mean motion; but it could also show the passage of time on a scale marked with a calendar of the year.

Fragment C comprises what is generally thought to be a part of the instrument's front dial, parts of the so-called *parapegma* plates that lay next to it (Price 1959, *passim*), and a component identidied as the central element of the dial display (Wright 2006a, 320 *et seq.*), but we sound a note of caution: this fragment has no identifiable common interface with any of the others, and none can be seen even in early photographs, taken before extensive cleaning (Svoronos 1903). Price appears to have been mistaken in stating that he saw a 'join' (Price 1974, 13). Lacking clear contemporary evidence that it really was found with, or immediately next to, the other fragments, we regard its association with them as provisional. Although Fragment C is held under the same inventory number as the other fragments, it is not inconceivable that it might have been put with them on account of a similarity of material and workmanship, or because it was found fairly close to them. In the latter case it might, perhaps, have been part of a separate instrument, the two having simply been stowed together on the ship. Our reason for making this *caveat* will emerge below, but we accept, provisionally, the common assumption that it was indeed a part of the same instrument. The dial and other parts are compatible in both style and dimensions, and the two rings of the dial, a fixed one for the Zodiac and a moveable one for an annual calendar, correspond to the indications described above as having been driven by mechanism in Fragment A.

Fragment C is problematic in another sense. In common with most researchers we had accepted that the calendar ring was divided into the 365 days of the Egyptian calendar (Price 1974, 18), but this assumption has been challenged. Careful measurement of an image prepared from CAT data seems to show that the calendar ring may have been divided into 354 parts, seeming to imply the adoption here of a calendar year of just 354 days (Budiselic *et al.* 2021, *passim*). A year of 354 days, or occasionally 355 days, is found in calendars of traditions in which the year is taken to contain just twelve lunations, each lunation usually taken as 29½ days, a convenient but rather poor approximation. The authors of this study refer to discussion among Egyptologists about the possible existence of such a calendar in Egypt which could be matched to the Egyptian month-names that we find on the fragmentary calendar ring (Budiselic *et al.* 2021, 161, 162); but the matter seems not to be clearly resolved.[2] We find no fault with the authors' analysis, but we struggle to make sense of the inclusion of so artificial and astronomically unrealistic a calendar year in what is taken to be the principal display of an instrument that was otherwise largely designed around the Metonic period-relation, the recognition of which implies a good knowledge of the true length of the year.

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[2] R. Hannah, Honorary Professor, University of Otago, private communication.

Faced with this incongruity we recall the *caveat* expressed above. To accept that Fragment C was part of another, distinct instrument could provide a resolution of a sort, but one that we are not now prepared to explore. The matter will not, in any case, impinge on the main points that we discuss in this paper.

Inevitably, there is uncertainty and some difference of opinion about the restoration of further, lost parts. We proposed that, besides indicators for the Sun and Moon, the front dial bore five others for the planets then known, and – if the indicator for the Sun showed the Sun's true motion – a further one to indicate the date, all driven by mechanism lying between what remains in Fragment A and the front dial (Wright 2002, *passim*). We built a conjectural reconstruction of such mechanism, fitted to a partial reconstruction of the instrument (Wright 2003, *passim*), and have since refined it (Wright 2006b, 49 *et seq*. and 2013, *passim*). Others have elaborated this scheme, offering an alternative reconstruction of the planetary mechanism (Freeth *et al.* 2021, *passim*). This reconstruction may be more nearly correct, but we reserve our judgement on the soundness of some of its features that have not yet been tested in practice.

Whether or not it bore any close resembance to either of the above, we continue to believe in the essential correctness of a reconstruction of the front dial showing the places of the planets along with those of the Sun and Moon. Such a scheme is supported by the reading of inscriptions concerning the planets and parameters of their motions found on the fragments of the instrument itself (Anastasiou *et al.* 2016, *passim* and Bitsakis & Jones 2016b, *passim*). We acknowledge that a number of proposals have been made for other displays on the front dial in place of our display of the planets; the latest of which we are aware is that of Voulgaris *et al.* (Voulgaris, Mouratidis & Vossinakis 2018). However, we will not discuss their merits here because our object in this paper is not to debate reconstruction of parts that are lost, but rather to consider more closely the design of the parts that have survived.

The importance of this precious artefact transcends any question of its conjectural completion; it affords our best opportunity to see directly, not only into the tradition of *sphairopoiía*, but into a wide range of allied technical activities that surely existed in parallel, both before its time and after, which have left remarkably few material traces behind. So it is useful to view the Antikythera Mechanism purely as a mechanical artefact. Our attention now turns to the gear trains preserved in Fragment A.

The gearing diagram (figure 3) shows all the gears that we may say with confidence were present; either they survive, more or less complete, or they must have been present to engage other gears that do. The diagram is not to scale and it does not reflect the structure or layout of the original. Axes are lettered thus: A, B, C, … . Wheels on each of the axes are numbered thus: B1, B2, B3 … .

We begin with the lunar train that drives the Moon indicator on the front dial. Everything was worked by turning the contrate[3] wheel A[4] by a hand-knob (in our reconstruction). Wheel A engaged the large wheel B1 of which one full revolution represented a year. The lunar train, starting from a smaller wheel B2 riveted behind B1, multiplies that rate of rotation nearly 13.4 times to drive the Moon-indicator. It is not advantageous either to drive a spur wheel using a smaller contrate wheel or to drive a multiplying train from its slower-turning end, but our working reconstructions demonstrate that both can be done.

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[3] A *contrate* wheel is one with the teeth projecting from one face, so that it may engage a simple spur wheel, with the axes of the two set at a considerable angle, usually a right-angle.

[4] On axis A there is just one wheel.

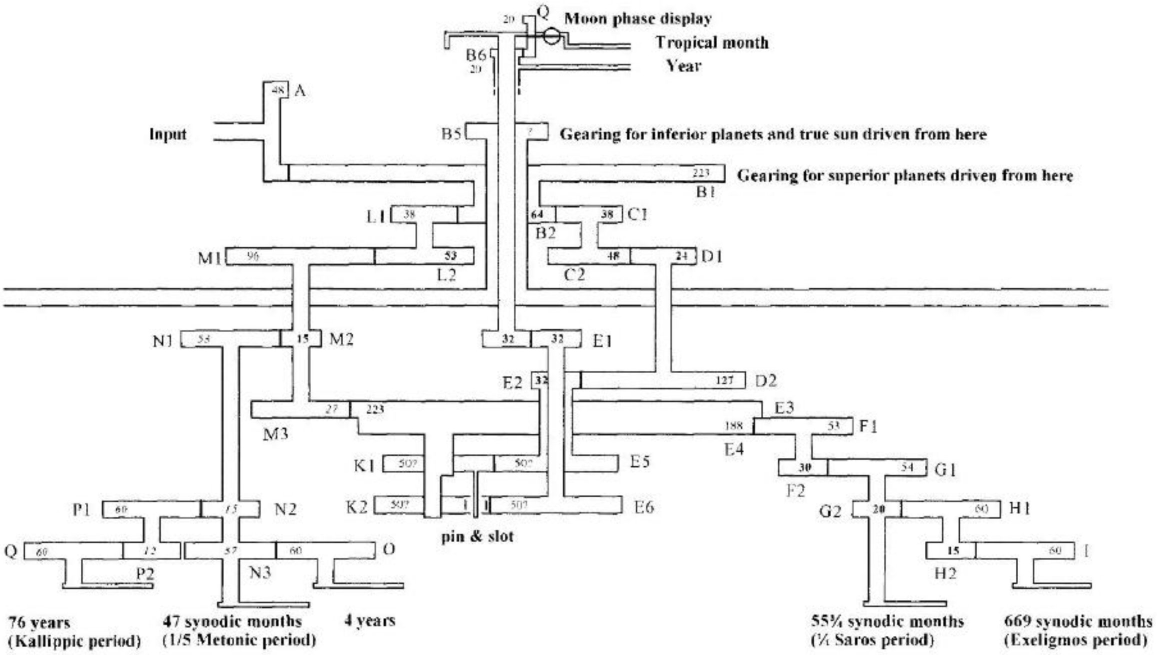

Figure 3. Antikythera Mechanism, gearing diagram. © M.T. Wright.

The basic train may be represented thus.

$$\frac{64}{38} \times \frac{48}{24} \times \frac{127}{32} \times \frac{32}{32}$$

Each number represents a wheel with that number of teeth. Each fraction signifies a gear-pair (two wheels in engagement), driving wheel above and driven wheel below. The numbers seen diagonally across a multiplication-sign, from lower left to upper right, represent two wheels turning together as a single mobile. The first numerator and the last denominator represent the first driving wheel and the last driven one, making two further mobiles. Treated as ordinary arithmetic, the line yields the velocity-ratio of the train: the number of revolutions that the final driven wheel makes when the initial driver makes just one revolution. This train is, of course, reverted; that is, the first and last mobiles – connected respectively to indicators of the places of the Sun and the Moon in the Zodiac on the front dial – are coaxial. The last engagement does not modify the rate of rotation of the final driven wheel but simply reverses the sense of rotation, so that these indicators rotate, as they must, in the same sense.

There are two significant mistakes in this design. The first was to include the small driven wheel of 24 teeth. For a wheel with few teeth, engagement takes place through a large angular displacement. Friction between the teeth, friction at the arbor, variation in transmitted torque, and backlash are all increased. These problems are exacerbated by poor tooth-form and uneven division, both of which were inevitable in gear-wheels made by simple means. The second mistake was to break the train down into more stages than necessary, which multiplied variations in transmitted torque, increased friction and backlash, enlarged the scope for problems due to play and wear, and entailed extra work in making the train in the first place.

The problems noted here could all have been reduced by using a four-wheel train of just two engagements and three mobiles, such as this.

$$\frac{128}{38} \times \frac{127}{32}$$

In reality, the lunar train includes the pin-and-slot device that models lunar theory (Freeth *et al.* 2006, 590). To show it, the “basic train” given above may be rewritten like this.

$$\frac{64}{38}\times\frac{48}{24}\times\frac{127}{32}\times\frac{50}{50}[\times]\frac{50}{50}\times\frac{32}{32}$$

The square brackets enclosing a multiplication-sign denote that in this case the two wheels do not turn as a single mobile but, rotating about separate parallel axes, are coupled by a pin which, planted in one, engages a radial slot made in the other. The arrangement introduces a fluctuation in angular velocity that models the lunar anomaly; but the mean angular velocities of the coupled wheels are equal and the overall velocity-ratio of the train is unchanged. (It is irrelevant to the present discussion that these two wheels are mounted on a slowly-rotating platform.)

The addition of these further mobiles to the train strengthens the force of our objection. The device could just as well have been inserted into our simpler, more efficient train, with the platform placed concentric with the final output on axis B (and rotating in the opposite sense).

$$\frac{128}{38}\times\frac{127}{32}\times\frac{50}{50}[\times]\frac{50}{50}$$

It is hard to imagine how, in working from the desired velocity-ratio of 254 : 19 towards devising a workable gear-train, the designer could have failed to see a simpler and better alternative such as the one that we have suggested. Why, we may ask, did he choose one that could so easily and so obviously have been improved? Or, to frame the question differently: what advantage might he have thought to gain in choosing the train that he actually used? We have no answer, but the question should be pursued, even if the conclusion should be that there was no advantage. Perhaps the designer lacked experience, and his choice was haphazard; or his work lay so near to the beginnings of the tradition of toothed gearing that collective experience had yet to be accumulated; or this was a craft practice in which precedent was followed unquestioningly, in whatever way that precedent had been set.

Now let us discuss the other gear train, again beginning with wheel B2, which works three separate outputs; it drives the upper and lower back dial displays and rotates the platform for the lunar theory. First we consider, separately, the required velocity ratios and the trains used to realise them, all of which have been sufficently explained elsewhere (Freeth *et al.* 2006, *passim*).

Upper back dial (calendar display):
5 turns in 19 years: velocity ratio 5 : 19

obtained through $\frac{64}{38}\times\frac{53}{96}\times\frac{15}{53}$

Platform for lunar theory:
447 turns in 4237 years: velocity ratio 477 : 4237 = (9 × 53) : (19 × 223)

obtained through $\frac{64}{38}\times\frac{53}{96}\times\frac{27}{223}$

Lower back dial (eclipse possibility):
4 turns in 223 synodic months: velocity ratio (235 × 4) : (19 × 223)

obtained through $\frac{64}{38} \times \frac{53}{96} \times \frac{27}{223} \times \frac{188}{53} \times \frac{30}{54}$

The way in which the three outputs are obtained through a single divided train may be seen either by comparing these notations or by inspecting the gearing diagram (figure 3).

This design is ingenious, but poor. Note that the factor 53, required to obtain the desired rate of rotation of the platform, is introduced early in the train (wheel L2), so that two further wheels of 53 teeth have to be added to negate its effect, one for each of the dial displays. Then, consider the work that the train must do. To the friction in the gear-train itself, including the further branches driving the subsidiary displays, is added the friction generated by the action of the pointers of the principal back dial displays, as they are drawn out radially by cursors running in slots; one must also recognise the risk of imposing a load due to accidental handling of the pointers or of driving a pointer beyond its intended range of travel. Altogether, the load could be very large. All three outputs of this train turn with a lower angular velocity than the input; but the velocity-ratio of the very first stage gave an increase in speed of nearly 1.7 times. Coming early in the train, this disadvantageous engagement bears the whole load. Thereafter, the angular velocity is reduced for each output, but even this is oddly managed: having been brought all the way down to that of the platform, it is then stepped up again to the lower back dial display. The design is workable but clumsy, uneconomical and mechanically objectionable. As with the lunar train that we considered above, any designer capable of devising it could easily have done better. We illustrate our point by outlining an alternative.

The velocity-ratio for the upper back dial, 5 : 19, can be achieved using a simple gear-pair:

$$\frac{5n}{19n}$$

– where *n* may be chosen to yield wheels with suitable numbers of teeth; *n* = 5 or *n* = 6 might be convenient. On rearranging the velocity-ratio for the lower back dial, we see that it can be achieved by driving from the upper dial through another simple gear-pair:

$$\frac{5n}{19n} \times \frac{188}{223}$$

– with the addition of an idle wheel if it mattered that the indicators on the two displays should turn in the same sense. Finally, comparing the velocity-ratios for the lower back dial and for the platform for the lunar theory, we see that the platform may be driven from the lower back dial through a train of two gear-pairs, so that the whole train becomes:

$$\frac{5n}{19n} \times \frac{188}{223} \times \frac{53}{60} \times \frac{27}{47}$$

We have shown that the three outputs – upper and lower back dials and the platform – could all have been driven by a single train of four gear-pairs, rather than by the train of six gear-pairs actually adopted. The gain is greater than this comparison may suggest. The load on the train is reduced; there is less friction and there are fewer of the fluctuations in transmitted torque that arise at every engagement. There is less backlash. The velocity-ratio of each gear-pair is less than unity; that is, all the engagements are reduction gearing, which is far easier to set up than step-up gearing. It is more tolerant of errors and of wear, and works with less friction. The number of parts to be made, and the sensitive work of the correct pitching of each engagement, are all reduced. There is less to go wrong, and less to need maintenance.

We have shown that, as with the lunar train, a better gearing scheme can easily be devised, and again we may ask why the designer adopted the one that we find. We should note that our rational designs call for the fitting of two wheels on axis B in place of the single wheel B2 of 64 teeth: one with a higher number of teeth as the first wheel in the step-up train driving the Moon indicator (in the example given above we suggested 128 teeth); and one with fewer teeth (perhaps 25 or 30) as the first wheel in the reduction train that works the back dials and the platform. We will return to this point later, but here we might ask why – seeing that both the trains actually adopted begin with wheels having the same number of teeth (C1, L1, each having 38 teeth), both driven by the wheel B2 – the designer did not combine the first stage of these two trains by using a single wheel of 38 teeth. He might thereby have lessened the number of arbors and gear-pairs, reduced friction, and economised both in material and in the work of manufacture.

As with the lunar train discussed earlier, we see choices made by the designer that appear irrational; but in this case some, at least, may be explained on recalling our earlier suggestion that the instrument was altered (Wright 2006b, 55). That idea was partly prompted by our incomplete understanding of the second gear train, which was later resolved (Freeth *et al.* 2006, *passim*); but another problem, concerning the design of the instrument's wooden case, remained. We had shown that traces of woodwork found within Fragment A, which are seen yet more clearly in early photographs (Svoronos 2003), are best explained as traces of an external case that was fitted closely round the frame plate on which most of the gearing is mounted. This plate is smaller than the back dial, and so we were led to adopt a stepped design for the case, strongly suggestive of the extension of an existing small case to accommodate the addition of a larger back dial. We have fitted such cases to the models that we have made to date, including one that remains on loan to the National Archaeological Museum in Athens.

All other researchers have followed Price in assuming that the instrument was contained in a plain rectangular case, the front face of which was filled, above and below the shorter front dial plate, by the *parapegma* plates of which sufficient fragments have been found for them to be reconstructed as rectangular plates of an appropriate size (Price 1959, *passim*). We had supposed that the *parapegma* plates might either have been kept as loose components or have been fitted elsewhere. The more recent observation of a fitting on the reverse of a fragment of *parapegma* plate (Bitsakis & Jones 2016a, 77), clearly a socket intended to receive one of the bolts securing the front dial plate (Wright 2011, 12), showed that the *parapegma* plates were indeed coplanar with the front dial plate and so confirmed that these components, together, did indeed form the front face of a plain rectangular case.

With that, our interpretation of the woodwork seen in Fragment A appeared to be invalidated, and no alternative was forthcoming; but we now count this detail as one of several pieces of evidence that the instrument was indeed altered. To it, we add another point about the case. The outcome of a published attempt to reconcile the dimensions of the composite front face with those of the back dial appears doubtlful (Allen *et al.* 2016, 32). Our own more direct observations of the front and back dials suggest that the two differed in width, posing an unnecessary problem in designing the wooden case which the maker would surely have avoided if both dials had been made together. The placement of the back dial plate with respect to the front is especially odd; it projects further below the front dial than it does above. There is no good reason for this untidiness; in designing the instrument as a whole one could easily have made it symmetrical about axis B, the centre of the front dial.

Returning to internal mechanical details, we have discussed odd design choices in each of the two gear trains, and the further oddity that, although the first driving wheel is common to both, and the first driven wheel of each has the same number of teeth, they were not made to share a single driven wheel before diverging. It is stranger still that although these two mobiles turn at the same rate, serve very similar functions, and bear comparable loads, they are quite different in design. The detail is difficult to see when looking at the original, and still more so in looking at photographs. For greater clarity we illustrate the point with a photograph of these components from one of our earlier models, based on a close study of our own radiographs of the original. Wheels C1 and C2 are riveted together and turn on a stationary stud planted on the frame plate, but wheels L1 and L2 are fixed to a rotating arbor that runs in a pivot-hole in the frame plate (figure 4).[5] There is no practical reason for this difference.

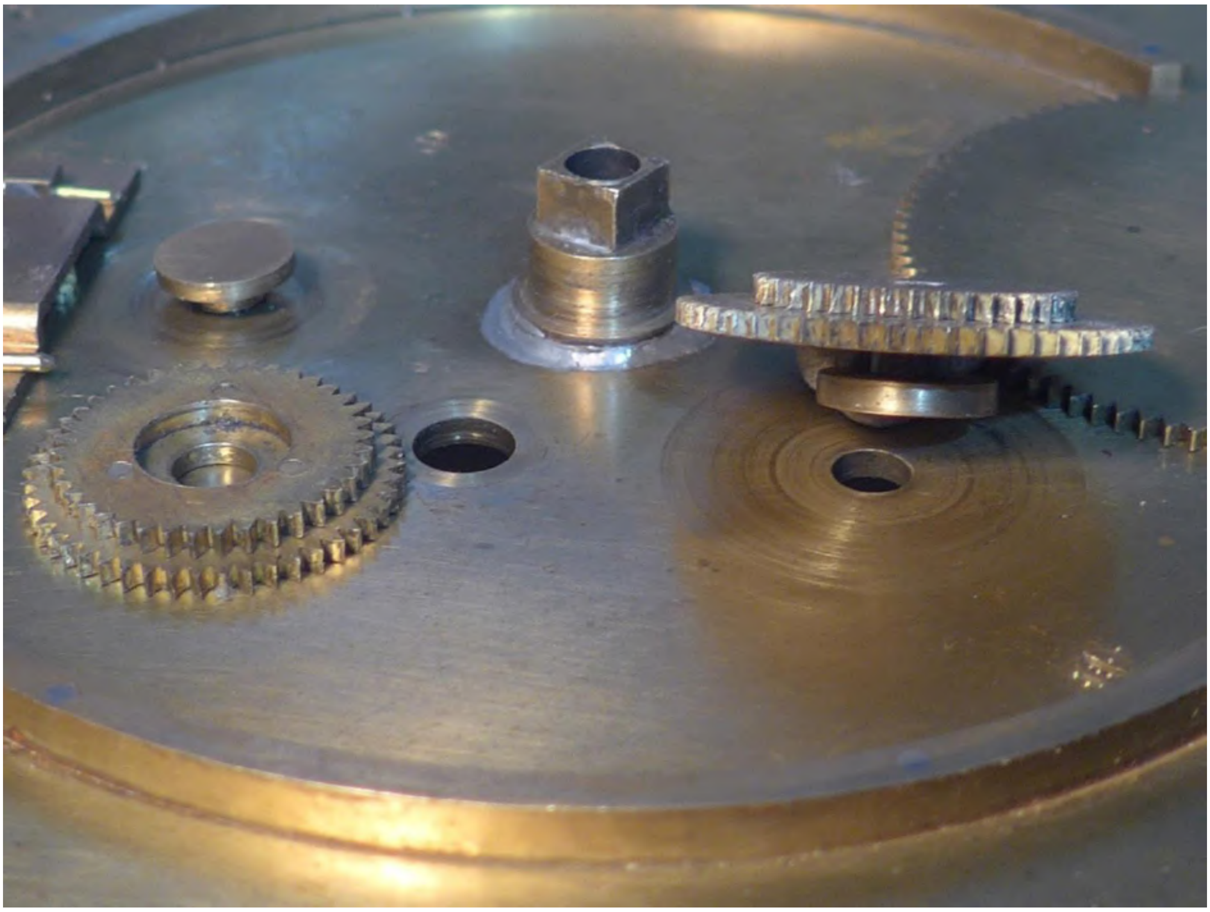

Figure 4. Antikythera Mechanism, detail showing: left, wheels C1, C2, and the fixed stud on which they rotate; right: wheels L1, L2 on their arbor. Parts of a model built 2001/2. © M.T. Wright.

Turning our attention to the next stage in each of these trains, again we find different approaches to the mechanical arrangements of two comparable mobiles. Again, we illustrate our point with photographs of these parts of our own model. Each arbor carries the motion from the front to the back of the frame plate in which it takes bearing, and in each case the

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[5] Figures 4, 5 and 6 are photographs taken of the author's first model, constructed in 2001 and 2002. Since it was essentially an exploratory model, and scholarly opinion of that time tended, mistakenly, to the view that the instrument could not work unless extremely well made and finished, the work was deliberately carried out somewhat crudely.

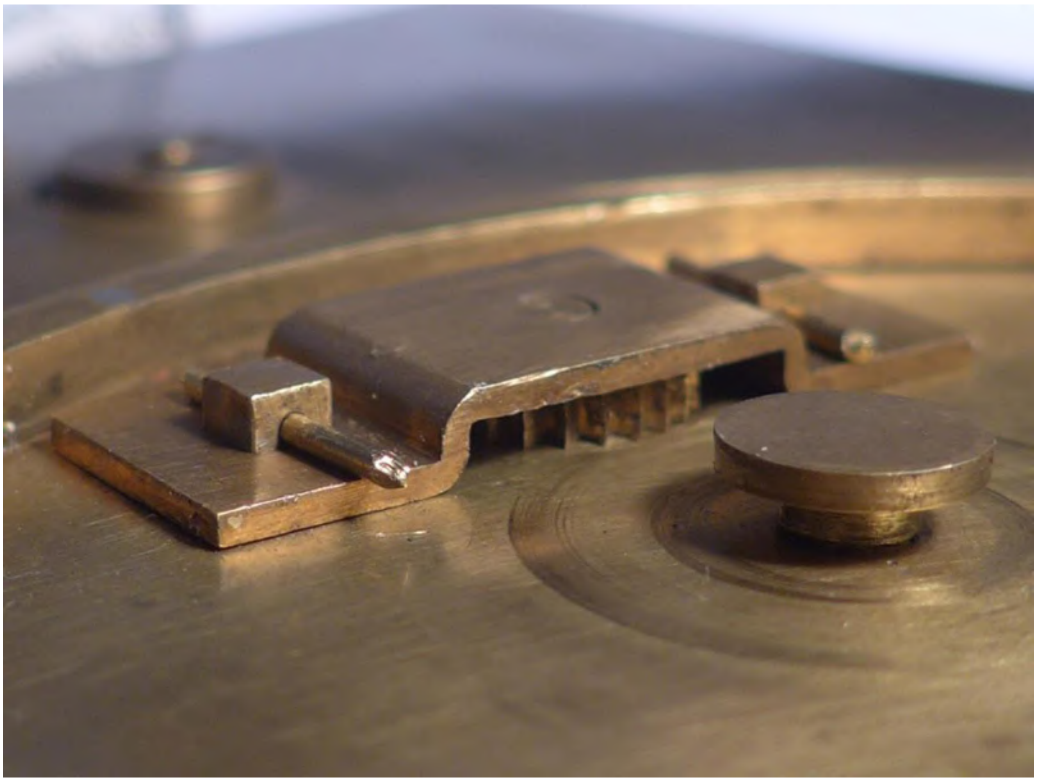

Figure 5. Antikythera Mechanism, detail showing bridge on axis D, with wheel D1 seen underneath. Parts of a model built 2001/2. © M.T. Wright.

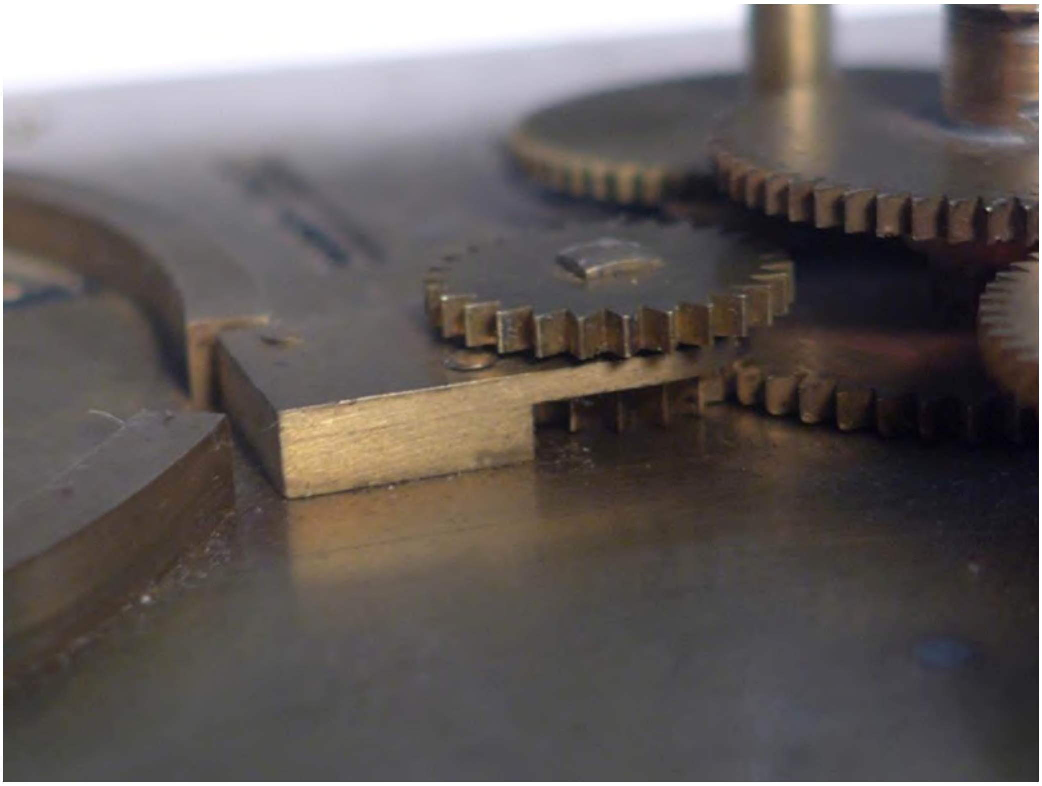

Figure 6. Antikythera Mechanism, detail showing cock on axis M, with wheel M2 seen below and wheel M3 above. Parts of a model of the Antikythera Mechanism built 2001/2, wheel M3 added 2006. © M.T. Wright.

arbor is steadied and held upright[6] by a second bearing. On axis D (figure 5) a bridge (a bearing piece with a foot at each end) spans wheel D1 on the front of the plate to provide bearing to the upper end of the arbor. This bridge, located on fixed studs, is held down by cotters; on withdrawing the cotters the bridge might be taken off. On axis M (figure 6) a cock (a raised bearing piece with a single foot) supports the arbor between wheels M2 and M3 at the back of the plate. This cock is riveted to the frame plate and so it was not readily removable. It is logical that these supplementary bearings should be on opposite sides of the frame plate in the two cases, but again there is no good reason for adopting such different designs.

The points noted above – the detail of woodwork, the lack of full dimensional correspondence between the front and back dials, the disparity between corresponding details of the two gear trains, and some (at least) of the odd design choices of the gear train to the back dial – may be interpreted as evidence that the instrument was altered at some time subsequent to its initial manufacture. Below, we outline the hypothesis that best fits this evidence.

Originally, the instrument had just one dial, bearing an astronomical display: the so-called front dial which, we believe, displayed the places of the Sun, Moon and planets in the Zodiac together with an indication of the day of the year. Such a display makes the best sense of the internal evidence of the artefact itself – the traces of lost components and the inscriptions giving information about the planets – and accords most closely with literary references to instruments in antiquity, but this is of little importance to our present argument. In any case we know that the places of the Sun and Moon were displayed. The Moon-indicator was of course driven by the first train that we discussed above, but originally the assembly modelling lunar theory was not present. In its place there was on axis E just a simple mobile: a gear, or a pair of gears fixed together, with 32 teeth. The indicator for the Moon moved with only the mean lunar motion. The instrument was housed in a case into which the frame-plate fitted closely, as indicated by the woodwork remaining in Fragment A.

This instrument was first modified by the addition of the assembly modelling lunar theory, together with just that part of the second train that worked its platform. By accepting, as a compromise, that the first engagement of this train should have a step-up ratio, and fitting a second driven wheel (L1) engaging the extant wheel B2, the mechanic avoided any need for the very considerable work that would have been entailed in making space under wheel B2 for the thickness of a further wheel on axis B. He might even have been able to fit the wheels on axes L and M with wheel B1 in place. (Wheel B1 is prevented from rising by four dogs that overlap its edge and are riveted to the frame-plate.) Since the sole duty of the second gear train, as first installed, was to drive the platform, it made perfectly good sense to fit the driving wheel of 53 teeth (L2) where it is, early in the train. The marked differences in mechanical detail between the mobiles on axes C and L, and the bearing structures at axes D and M, suggest that the work was not carried out by the original maker, and perhaps not in the same workshop.

The subsequent addition of the back dial entailed the extension of the gear train to drive its displays. In adding gearing for the upper back dial (axes N, O, P, Q) it would have been necessary to modify or replace the cock at axis M; but our earlier point still holds, that the additional bearing for this arbor was very different from that on axis D. Extending the pre-existing train, originally built to drive the platform, resulted in an unnecessarily elaborate train

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[6] In horological parlance *upright* denotes perpendicular to the frame – here, the frame plate – of the mechanism. The terms *bridge* and *cock*, as used in later in this paragraph, are also technical horological terms.

to the upper back dial (including the driven wheel N1 of 53 teeth) achieving what is, in fact, a rather simple velocity-ratio.

The extension of the gearing beyond the platform to work the lower back dial (axes F, G, H, I) begins with a gear ring, E4, mounted on the platform E3.[7] The ring was located on the platform by four rectangular studs and held down by small cotters passing through holes in the studs. It might therefore have been removed by withdrawing the cotters. We cannot imagine any particular reason for doing so at any later time, but this detail might reflect a tentative attitude on the part of the mechanic extending the gear train. We note that wheel H1 in this extended train overhangs the lower edge of the frame-plate, having the appearance of being an improvised addition to the design.

The tall back dial was accommodated by fitting the instrument into a larger wooden case enclosing some, at least, of the old one of which parts still remain in Fragment A. If, as we believe, the front dial bore a display of the places of the planets, it would have been expedient to leave much of the earlier case in place because, according to either of the two reconstructions thus far proposed of mechanism driving indicators for the planets (Wright 2002, *passim*; Freeth *et al.* 2021, *passim*), there were components that had to be held stationary in front of the frame plate; this could most easily have been done by securing them to the inner faces of the original wooden case. The greater height of the new case afforded the possiblity of placing the *parapegma* plates above and below the front dial. Previously they might have been fitted elsewhere, on the sides of the smaller case, or kept separately as loose accessories. Otherwise, they and the corresponding key-letters engraved on the front dial might have been another addition made either at this time or later.

It should not surprise us that the Antikythera Mechanism was modified. Any such instrument may be subject to the desire of its owner to have it brought up-to-date when improvements or additions become possible. As a corollary, we would point out that any attempt to accommodate every detail of the surviving instrument in a single coherent reconstruction may prove impossible, because when an instrument has been altered it is not unusual to find redundant traces of an earlier state. That the instrument should have been altered, and – we believe – altered twice, reinforces our perception that there was in Hellenistic and later antiquity a significant population of instruments, examples both of *sphairopoiía* and of other genres that entailed similar skills in design and workmanship. Equally, there must have been a continuing tradition of such work, supporting a number of workshops in which they might be made, repaired and modernised. That we have just the one fragmentary example as a material witness to the activity and accomplishment of those workshops is simply a happy threefold accident of survival: it was lost, rather than destroyed; it was recovered; and its importance has been recognised.

Bibliography

Allen M., Ambrisco M., Anastasiou M., Bate D., Bitsakis Y., Crawley A., Edmunds M.G., Gelb D., Hadland R., Hockney P., Jones A., Malzbender T., Mangou H., Moussas X., Ramsey A., Seiradakis J.H., Steele J.M., Tselikas A., Zafeiropoupou M., 2016. General Preface to the Inscriptions. *Almagest* 7,1, pp.5-35.

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[7] Note that the designation of the platform and ring as E3 and E4 respectively, introduced by Freeth *et al.* (Freeth *et al.* 2006, 590), followed by most authors since and adopted in our diagram (figure 3), reverses that of Price (Price 1974, 32 *et seq.*) according to which the ring was designated E3 and the platform E4.

Anastasiou M., Bitsakis Y., Jones A., Moussas X., Tselikas A., Zafeiropoulou M., 2016. The Front Cover Inscription. *Almagest* 7,1, pp. 250-297.

Bitsakis Y. & Jones A., 2016a. The Front Dial and parapegma Inscriptions. *Almagest* 7,1, pp.68-137.

Bitsakis Y. & Jones A., 2016b. The Back Cover Inscription. *Almagest* 7,1, pp.216-249.

Budiselic C., Thoeni A.T., Dubno M., Ramsey A.T., The Antikythera Mechanism; Evidence of a Lunar Calendar, 2021. *The Horological Journal*, 163, 3, pp. 104-112 and 163, 4, pp. 159-163.

Cicero, *de republica,* I, 21-22.

Edmunds M.G., 2014. The Antikythera Mechanism and the mechanical universe. *Contemproary Physics* 55, 4, pp. 263-285.

Freeth T., Bitsakis Y., Moussas X., Seiradakis J.H., Tselikas A., Magkou E., Zafeiropoulou M., Hadland R., Bate D., Ramsey A., Allen M., Crawley A., Hockley P., Malzbender T., Gelb D., Ambrisco W., Edmunds M.G., 2006. Decoding the ancient Greek astronomical calculator known as the Antikythera Mechanism. *Nature*, 444, pp. 587-591.

Freeth T., Higgon D., Dacanalis A., MacDonald L., Georgakopoulou M., Wojcik A., 2021. *A Model of the Cosmos in the ancient Greek Antikythera Mechanism.* https://www.nature.com/articles/s41598-021-84310-w (viewed 4/9/2024).

Price, D.J.deS., 1959. An Ancient Greek Computer. *Scientific American*, 201, 6, pp. 60-67.

Price, D.J.deS., 1974. Gears from the Greeks. *Transactions of the American Philosophical Society*, Vol. 64 No.7; reprinted as an independent monograph, Science History Publications, New York 1975. Also published in Greek by Technical Museum of Thessaloniki, 1995.

Svoronos, I.N., 1903. *Το εν Αθήναις Εθνικόν Μουσείον*, Athens.

Voulgaris, A., Mouratidis, C., Vossinakis, A., 2018. Conclusions from the Functional Reconstruction of the Antikythera Mechanism. *Journal for the History of Astronomy*, 49(2), pp. 216-238.

Wright M.T., 2002. A Planetarium Display for the Antikythera Mechanism. *Horological Journal* 144, 5, pp. 169 – 173; and 144, 6, p. 193.

Wright M.T. & Bromley A.G., 2003. Towards a New Reconstruction of the Antikythera Mechanism. In Paipetis, S.A. (*ed.*), *Extraordinary Machines and Structures in Antiquity*, Peri Technon, Patras. Proceedings of an International Symposium, Ancient Olympia, pp. 81-94.

Wright, M.T., 2003. In the Steps of the Master Mechanic. In *Η Αρχαία Ελλάδα και ο Σύγχρονος Κόσμος* (*Ancient Greece and the Modern World*), University of Patras. Proceedings of 2nd World Congress, Ancient Olympia pp. 86–97.

Wright, M.T., 2006a. The Antikythera Mechanism and the Early History of the Moon-Phase Display. *Antiquarian Horology* 29, 3, pp. 319-329.

Wright, M.T., 2006b. Understanding the Antikythera Mechanism. In *Αρχαία Ελληνική Τεχνολογία* (*Ancient Greek Technology*), Proceedings of 2nd International Conference on Ancient Greek Technology, Athens, pp. 49-60.

Wright, M.T., 2011. The Antikythera Mechanism: reconstruction as a medium for research and publication. In Staubermann, K. (ed.), *Reconstructions*, National Museums Scotland 2011, pp. 1–20.

Wright, M.T., 2013. The Antikythera Mechanism: compound gear-trains for planetary indications. *Almagest* 4, 2, pp. 4-31.

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