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Technē and Method in Ancient Artillery Construction: The *Belopoeica* of Philo of Byzantium

Abstract: In his *Belopoeica*, Philo of Byzantium presents artillery construction (*belopoiikē*) as a kind of expertise or *technē* that possesses a standardized method for attaining success. I describe this method, which consists of a set of procedures and rules that are systematically organized on the basis of general principles, and discuss Philo's claim that its discovery depended crucially on experience (*peira*). In the second part of the *Belopoeica* Philo presents several designs for artillery engines that allegedly improve on the standard method. I discuss these designs, which draw on both natural philosophy and theoretical mechanics, and conclude with a brief attempt to place Philo's picture of artillery construction as a *technē* involving both experience and theory in the context of roughly contemporary views of *technē* in philosophy and medicine.

Introduction

From the fourth century B.C. to the end of Antiquity, the discipline of artillery construction (*belopoiikē*) was one of the most important and highly developed types of professional expertise (*technē*) in the ancient Greco-Roman world.[1] Starting from the traditional bow, Greek engineers devised a wide array of mechanical shooting devices, weapons which had a significant impact on the course of history. The development of this technology was fostered by royal patronage and carried out by communities of practitioners working in major cultural and political centers such as Alexandria and Rhodes. These practitioners had a high sense

1 As is well known, the Greek term *technē* has no single English equivalent. Used to refer to disciplines as diverse as carpentry, sculpture, medicine, and geometry, its meanings include – but are by no means limited to – "art," "craft," and "science." My concern in this paper is with *technē* as a form of knowledge, a kind of "result-oriented expertise" in the formulation of Heinrich von Staden. It is a pleasure to acknowledge my debt to Heinrich for this formulation, which is only a small example of the profound impact that his work in ancient medicine and science has had on my own. I am delighted and honored to have the opportunity to dedicate this paper to him as a small token of thanks for his inspiring example and steadfast support over many years. I would also like to thank Brooke Holmes and Klaus-Dietrich Fischer for their patience and comments on an earlier draft of this essay.

of the importance of their calling and gained widespread recognition for their achievements. While much of the technical expertise that they possessed was transmitted orally, a substantial amount of evidence documenting their methods and activities survives in both the archaeological record and written texts. For these reasons, artillery construction is one of the most promising areas for studying the impact of science and technology on ancient society.[2]

In this paper I shall focus on the earliest and in many ways the richest of the literary sources documenting ancient artillery construction, the *Belopoeica* of Philo of Byzantium, probably written around 200 B.C. Of Philo's life almost nothing is known, but it seems clear that he was active in Alexandria in the late third or early second century B.C., a period which saw rapid growth in both mechanical technology and the theory of machines.[3] The *Belopoeica* originally formed part of the *Mechanical Syntaxis*, a comprehensive treatment of mechanics in nine books; in addition to artillery construction, this work covered such topics as the theory of levers, harbor construction, siegecraft, pneumatics, and the building of automata. Though most of the *Mechanical Syntaxis* is lost, several books are extant in Greek, Arabic, and/or Latin versions.[4] Philo's attempt to

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2 The standard work on the development of ancient artillery and its place in ancient society is Eric W. Marsden, *Greek and Roman Artillery: Historical Development* (Oxford: Clarendon Press, 1969) and idem, *Greek and Roman Artillery: Technical Treatises* (Oxford: Clarendon Press, 1971). Marsden's reconstructions build on the pioneering work of Erwin Schramm, e.g., his *Die antiken Geschütze der Saalburg* (Berlin: Weidmann, 1918; repr. with intro. by D. Baatz, Bad Homburg: Saalburgmuseum, 1980). Since Marsden wrote, a number of works have shed new light on the archaeological, historical, and technological aspects of ancient artillery; see especially Dietwulf Baatz, *Bauten und Katapulte des römischen Heeres* (Stuttgart: Steiner, 1994); Rubén Sáez Abad, *Artillería y poliorcética en el mundo grecorromano* (Madrid: Consejo Superior de Investigaciones Científicas, 2005); M. C. Bishop and J. C. N. Coulston, *Roman Military Equipment: From the Punic Wars to the Fall of Rome*, 2nd ed. (Oxford: Oxbow Books, 2006); and Tracey E. Rihll, *The Catapult: A History* (Yardley, Pa.: Westholme Publishing, 2007).

3 From statements in the *Belopoeica* it seems that Philo was at least one or two generations younger than Ctesibius, the great Alexandrian engineer whose *floruit* is generally placed at around 270 B.C. On Philo's date see K. Orinsky, O. Neugebauer, and A. G. Drachmann, "Philon (48)," in W. Kroll and K. Mittelhaus (eds.), *Paulys Realencyclopädie der classischen Altertumswissenschaft: Neue Bearbeitung*, vol. 20.1 (Stuttgart: J. B. Metzlersche Verlagsbuchhandlung, 1941), 53–54; Marsden, *Technical Treatises*, 7. The earliest text that attempts to provide a theoretical account of the working of machines is the *Mechanical Problems* (*Mēchanika problēmata*), a short text of disputed authorship transmitted in the Aristotelian corpus; its date is uncertain but generally thought to be relatively early in the third century. The work of Archimedes on centers of gravity and the equilibrium of plane figures represents a second crucial strand in the growth of theoretical mechanics in the third century B.C.

4 For the contents of Philo's *Mechanical Syntaxis* see Orinsky, Neugebauer, and Drachmann, "Philon"; Marsden, *Technical Treatises*, 156; Bertrand Gille, *Les mécaniciens grecs: la naissance* bring all these activities together under the rubric of a single discipline, the "art of mechanics" (*mēchanikē technē*), is an innovation that should be seen, in part, as a response to the proliferation of new technologies in the third century B.C.[5] The *Belopoeica*, which has survived in Greek, is structured in two main parts.[6] The first (49.1–56.8) describes a set of procedures for the construction of various types of artillery engines. Philo presents these procedures as a standard method that was widely diffused in actual practice. In the remainder of the *Belopoeica* (56.8–78.26), Philo makes a number of criticisms of the standard method and goes on to propose four alternative designs, one of which he claims to have developed himself. Throughout the text Philo adopts the authorial stance of an expert in artillery construction. He claims that his account of the standard method is based on personal association with engineers in both Alexandria and Rhodes, and various passages in the *Belopoeica* indicate that he was in close contact with sources familiar with Alexandrian engineering traditions.[7] The *Belopoeica* is evi-

de la technologie (Paris: Seuil, 1980); Astrid Schürmann, *Griechische Mechanik und antike Gesellschaft. Studien zur staatlichen Förderung einer technischen Wissenschaft* (Stuttgart: Steiner, 1991), 7–8. The work is dedicated to one Ariston, about whom nothing else is known. Aside from the *Belopoeica*, the only books that survive in Greek are those dealing with siegecraft. The book on pneumatics survives in both Arabic and Latin, though the relationship of these versions (which differ significantly from one another) to the original Greek text is far from clear; see Frank D. Prager, *Philo of Byzantium: Pneumatica* (Wiesbaden: L. Reichert, 1974).

5 Several passages in Aristotle (e.g., *metaph.* M 1078a16; *an. post.* 76a34, 78b37) refer to "mechanics" (*mēchanikē*, sc. *technē* or *epistēmē*) as a discipline that provides a mathematical account of the motion of physical bodies. The introduction to the *Mechanical Problems* (above, n. 3) conceives of mechanics as dealing with phenomena that take place "against" or "beyond" the ordinary course of nature (*para phusin: mech.* 847a1–b1). The paradigm example of a mechanical device is the lever, which enables a large force to be moved by a small weight (847b1–16); though the treatise discusses a wide range of devices used in particular *technai* and in daily life, its subject matter is not limited to technology. There is no parallel in any pre-Hellenistic source for Philo's conception of mechanics as a single *technē* embracing the wide range of subjects that he mentions. Cf. G. A. Ferrari, "Meccanica 'allargata,'" in Gabriele Giannantoni and Mario Vegetti (eds.), *La scienza ellenistica: atti delle tre giornate di studio tenutesi a Pavia dal 14 al 16 aprile 1982* (Naples: Bibliopolis, 1984), 227–96.

6 Text and references to the *Belopoeica* are according to Marsden's edition (Marsden, *Technical Treatises*); for the text see also Richard Schöne, *Philonis Mechanicae Syntaxis libri quartus et quintus* (Berlin: Reimer, 1893); Hermann Diels and Erwin Schramm, *Philons Belopoiika (viertes Buch der Mechanik): Griechisch und Deutsch*, Abhandlungen der Preussischen Akademie der Wissenschaften, Philosophisch-Historische Klasse, Jahrg. 1918 no. 16 (Berlin: Verlag der Akademie der Wissenschaften, 1919). My translations are based on Marsden's, though I have sometimes modified them significantly.

7 For the claim of personal association see *Belopoeica* 51.10–14 (introducing the account of the standard method): "We shall recount to you exactly what we discovered in Alexandria through dently intended for practitioners of artillery construction. Philo makes no attempt to explain the basic components of artillery engines or the terminology used for them; many aspects of his account would hardly be intelligible to a reader who lacked experience in the discipline. In this respect Philo's *Belopoeica* contrasts with the work of the same name by Hero of Alexandria. Near the beginning of his *Belopoeica*, Hero remarks that earlier writers on artillery construction wrote exclusively for experts, and states that he will explain the construction and uses of the various types of artillery engine in terms that a layperson can understand.[8] A further indication of the relatively specialized character of Philo's *Belopoeica* is the large proportion of the text that is devoted to the modified designs; this reflects the fact that Philo's concern is not only to present a standard method for constructing the best artillery engines, but also to impart the ability to improve their design. In these two aims Philo's *Belopoeica* reveals its character as a sophisticated discourse on engineering intended both to offer a canonical account of practitioners' knowledge and to shape that knowledge.[9]

Philo's *Belopoeica* stands out among the ancient literature on artillery construction for its high degree of explicit methodological reflection, much of which relates to the notion of expertise or *technē*. Philo presents artillery construction as a *technē* that possesses both a goal – "to dispatch the missile at long range, to strike with powerful impact" (τὸ μακρὰν ἀποστέλλειν τὸ βέλος εὔτονον τὴν πλήγην ἔχον, 51.8–9) – and an established method for reaching that goal. The term "method" (*methodos*) occurs some sixteen times in the text, often in emphatic assertions that a certain result is brought about "not haphazardly, but by means of a method" (*vel sim.*).[10] The idea that a *technē* needs both a goal

much association with the craftsmen engaged in such matters and through intercourse with many master craftsmen in Rhodes, from whom we understood that the most reputable engines (τὰ μάλιστα τῶν ὀργάνων εὐδοκιμοῦντα) more or less (*sunengus*) conformed to the method we are about to describe." For Philo's reliance on others for information about Ctesibius cf. n. 48 below.

8 Hero Alex. *bel.* 73–74 Wescher. Hero was probably active in the first century A.D.; in any case his *Belopoeica* certainly postdates Philo's, and his criticism of the specialized character of earlier writings may well be directed, in part, at Philo's text.

9 Philo's text is much more than just a description of successful designs such as we find in Biton's *Construction of War Machines* (Κατασκευαὶ πολεμικῶν ὀργάνων καὶ καταπαλτικῶν; Marsden, *Technical Treatises*, 66–77). At the end of the text (67 Wescher) Biton suggests that reflection on such examples is sufficient to acquire the ability for successful design: "Whatever engines we considered especially suitable for you, we have now described. For we are convinced that you will be able to work out similar designs [τὰ ὁμοιοειδῆ] by means of the ones provided."

10 Cf. *Belopoeica* 50.15–17: "it was necessary for this to be grasped not by chance or at random, but by a fixed method" (μὴ ἀπὸ τύχης μηδὲ εἰκῇ λαμβάνεσθαι, μεθόδῳ δέ τινι ἑστηκυίᾳ); 52.21–2: "This too must not be drawn at random, but by a method" (οὐκ εἰκῇ καταγραπτέον, ἀλλὰ καὶ and a method for attaining it is a widely shared view in Greek thought that goes back to the fifth century B.C.[11] But if there was general agreement on this point, there was much debate about the character that a discipline's method had to have in order for it to qualify as a genuine *technē*. At a minimum, the existence of a method implied the existence of rules of procedure and techniques, i.e., the ability to carry out the rules. Thus a doctor might recognize that a particular case falls under a general rule ("bloodletting is helpful in cases of fever") and proceed accordingly. But there was significant dispute about whether the practitioner of a *technē* also needed to be able to explain his practice in terms of some sort of general theory, and so give an account of the reason or cause (*aitia*) of his actions. For example, a doctor might justify the administration of a particular drug by saying that it is able to purge phlegm, and the patient is suffering from an overabundance of phlegm. According to an influential line of thought represented by Plato, Aristotle, and some of the early Hippocratic treatises, the practitioner of a genuine *technē* needed to be able to give such explanations, which often appealed to the nature (*phusis*) of the subject matter of the discipline in question. Both Plato and Aristotle contrasted *technē* with experience or *empeiria*, understood as a collection of rough generalizations and rules of thumb that were not based on an explanatory theory.[12] In the early Hellenistic period, however,

τοῦτο μεθόδῳ τινί); 55.12: "it is necessary that there be a method" (δεῖ δὲ καὶ μέθοδόν τινα ὑπάρχειν); 69.26: "there was need of another method" (προσεδεῖτο δὲ ἄλλης μεθόδου).

11 The association between *technē* and method may go back to the fifth-century Sophists; see Felix Heinimann, "Eine vorplatonische Theorie der τέχνη," *Museum Helveticum* 18 (1961): 105–30. But it is first clearly attested in some of the Hippocratic treatises that can plausibly be dated to the late fifth century; see especially Hipp. *vet. med.* 1–2, 1.570–74 L. (= 118–20 Jouanna) and *art.* 5, 6.8 L. (= 229–30 Jouanna).

12 For the view that medicine needs to be based on a theory of human *phusis* see Hipp. *vet. med.* 20, 1.620–24 L. (= 145–48 Jouanna); the doctrine of the four canonical humors – blood, phlegm, yellow, and black bile – stated in the Hippocratic treatise *On the Nature of Human Beings* is only the most famous such theory. Important Platonic passages on the nature of *technē* include *Gorg.* 464b–466a, *leg.* 720a-e and 857c-e, and *Phdr.* 268a–270e, where Socrates argues that the genuine doctor needs more than just mastery of a set of effective procedures to cure patients effectively; only an understanding of human *phusis* will enable him to know when, to what extent, and to which patients he should apply those procedures. For Aristotle, the genuine doctor is distinguished from the empiric by the possession of explanatory knowledge: for example, it is a matter of *empeiria* to know that heat cures fever, but a matter of *technē* to know that this is so because heat counteracts bile, which is the cause (*aitia*) of fever (cf. *metaph.* A 981a5–12). Yet Aristotle also remarks that as far as practice is concerned, *empeiria* seems equivalent to *technē*, and that practitioners with experience are more successful than those who have theory without experience; cf. *metaph.* A 981a12–24. For a full discussion of these and other relevant Platonic and Aristotelian passages see Mark J. Schiefsky, *Hippocrates "On Ancient* the notion that a *technē* must be based on explanatory knowledge was called into question by the so-called Empiricist school of medicine, which took the position that *empeiria*, understood as a body of more or less general correlations based solely on observation, was entirely sufficient to account for both the discovery and practice of medicine.[13]

The dispute between the Empiricists and their so-called Rationalist opponents – who argued that explanatory theory was essential – dominated the methodological debate in medicine for several centuries, and raised general issues that pertained to the very nature of expertise. This debate is relevant for assessing Philo's picture of artillery construction as a *technē* in more than one way. In this paper I shall attempt to clarify Philo's position on the two key issues in this debate: the nature of the generalizations on which the *technē* of artillery construction is based, and the roles of theory and experience in it. As we shall see, Philo takes a distinctive and nuanced approach to these questions, one which emphasizes the importance of both explanatory generalizations and the essential role of experience or *peira* in the discovery and practice of the artillery builder's *technē*.

A second important methodological issue raised in the *Belopoeica* concerns the uses of mechanical and physical theory in artillery construction. What sorts of theories should the practitioner bring to bear in designing and building artillery engines, and how should he make use of them? Here Philo had a wide range of sources at his disposal, including the Aristotelian *Mechanical Problems* (above, n. 3) and the works of Archimedes for theoretical mechanics, as well as the works of thinkers such as Aristotle and his Hellenistic successor as head of the Lyceum, Strato of Lampsacus, for physical theory. The relationship between mechanics and physics had already been raised as an issue in the *Mechanical Problems*, which sets out a conception of mechanics as concerned with phenomena that take place "against" or "beyond" the ordinary course of nature

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Medicine": Translated with Introduction and Commentary, Studies in Ancient Medicine 28 (Leiden: Brill, 2005), 345–59.

13 The most accessible introduction to Empiricism is Michael Frede and Richard Walzer, *Galen: Three Treatises on the Nature of Science* (Indianapolis: Hackett, 1985); the fundamental collection and study remains Karl Deichgräber, *Die griechische Empirikerschule: Sammlung der Fragmente und Darstellung der Lehre* (Berlin: Weidmann, 1930). The origin of the school can be traced back to Philinus of Cos (*fl.* ca. 250 B.C.), a renegade pupil of the Alexandrian physician Herophilus (Deichgräber, *Die griechische Empirikerschule*, 163–64). The connection between the Empiricists' conception of *empeiria* and the Platonic and Aristotelian discussions referred to in the previous note is explored in Frede's introduction and Schiefsky, *Hippocrates*, 345–59. That the Empiricist sect was named for a methodological position rather than a founder is a further indication of the importance of methodological discussion in the third century B.C.

(*para phusin: mech*. 847a11–b10). Such a formulation obviously raises the question of the sense in which mechanics is based on the study of nature; we shall see that Philo takes an interesting approach to this issue as well.

Finally there is the issue of the values that guided the artillery builder in the practice of his *technē*. A number of passages in the *Belopoeica* suggest that these included factors such as economy of construction and aesthetic beauty as well as performance. Given the wide range of ancient Greek *technē* – which included activities such as the fine arts as well as disciplines such as medicine and mathematics — this should come as no surprise. However, it does suggest that Philo's conception of artillery construction as a *technē* with a unitary goal – the achievement of long range and powerful impact – does not fully capture the range of motivations that guided the activities of its practitioners.

Philo's *Belopoeica* thus offers a precious window into the methodological disputes of an age of great scientific creativity and controversy, and a view of the nature of expertise that is informed both by close association with communities of practitioners and by familiarity with broader trends in Greek philosophical and scientific thought. The aim of this paper is to offer a preliminary assessment of Philo's handling of the methodological issues outlined above through a close examination of the text. Part I discusses Philo's account of the standard method, focusing on his conception of the role of experience or testing (*peira*) in its discovery. Part II discusses the modified designs proposed in the second part of the *Belopoeica*, with an emphasis on Philo's conception of the role of physical and mechanical theory in artillery construction. Throughout both parts I shall draw attention to Philo's concern with values such as beauty and economy. In the conclusion I will briefly sum up Philo's conception of expertise and attempt to place it in a wider context.

I Philo on *Peira:* The Standard Method

I begin with a brief outline of the technological background to Philo's account in the first part of the *Belopoeica* (49.1–56.8).[14] The invention of artillery may plausibly be dated to around 399 B.C., when the tyrant Dionysius of Syracuse brought together a large number of craftsmen with the specific goal of developing new military technology.[15] The earliest artillery was based on extending the power

14 For fuller accounts of the developments mentioned here see Marsden, *Historical Development*; Rihll, *Catapult*, 26–75.
15 Diodor. Sic. 14.41; Marsden, *Historical Development*, 48–64; Rihll, *Catapult*, 26–45.

of the traditional bow, as in the so-called "belly-bow" or *gastraphetēs* (fig. 1). At some point in the mid-fourth century B.C. it was realized that the resilient properties of animal sinew could provide much more power than the composite bow; a typical example of this type of engine, known as torsion artillery, is shown in figure 2. Long strands of sinew were wound through the frame, and the arms of the engine were placed inside the bundles of strands (see the front elevation "c" in fig. 2). Different types of torsion engines were designed for shooting arrows and stones.

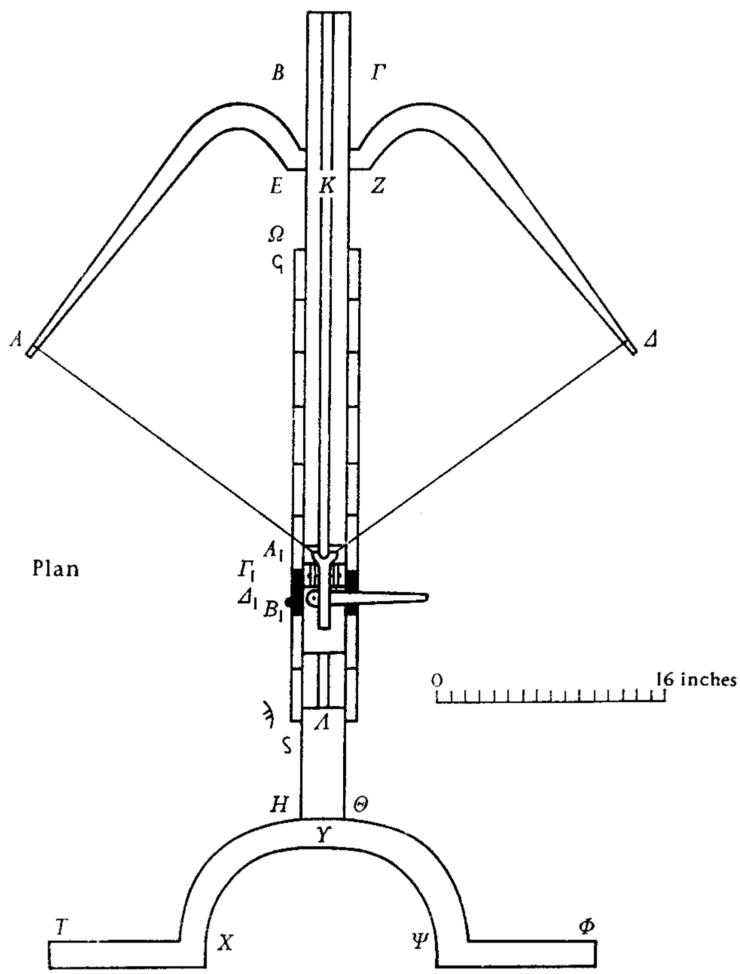

Fig. 1 The belly-bow or *gastraphetēs* (Marsden, *Technical Treatises*, 47)

At a certain point in the early third century B.C., two important advances were made in artillery design. First, lists of dimensions were set out, specifying the size of all components of an artillery engine down to the smallest detail in terms of a single unit: the diameter of the holes in the frame through which

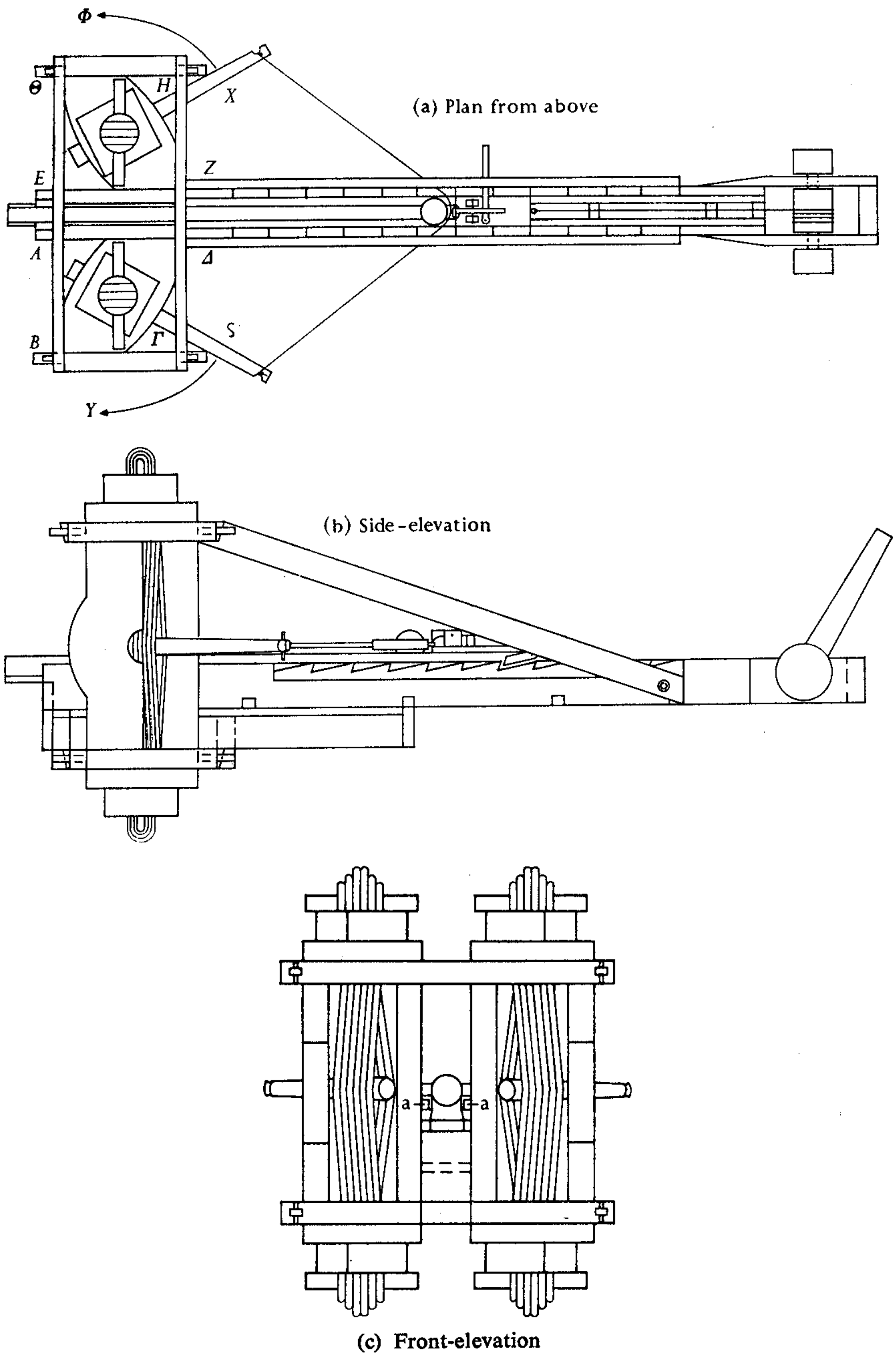

Fig. 2 Torsion artillery (Marsden, *Technical Treatises*, 56)

the spring cords were strung. Thus the size of all the parts of an engine was related to the force it could produce: a larger hole meant a larger bundle of springs and thus a more powerful engine. Second, quantitative relationships were derived, correlating the weight of the stone or the length of the arrow the engine was designed to shoot with the diameter of the spring hole. In the case of arrow-throwing engines, the diameter of the hole was specified as one-ninth the length of the arrow. For stone throwers the diameter of the hole was obtained by taking the cube root of the weight of the shot, then adding one-tenth of that root. Taken together, these spring hole relations and dimensional lists made it possible for a practitioner to construct an artillery engine for a missile of any given weight or length.

Turning to Philo, I shall begin by considering his general characterization of the standard method and what it brings to the artillery builder's activity. Philo contrasts the existence of a method in his own day with the haphazard situation in which earlier engineers found themselves:

> I suppose you are not unaware that the art [*technē*] contains something unintelligible and baffling to many people; at any rate, many who have undertaken the building of engines of the same size, using the same design, similar wood, and identical metal, without even changing its [i.e., the metal's] weight, have made some with long range and powerful impact and others which fall short of the ones mentioned. Asked why this happened, they could not give the reason [*aitia*]. Hence the remark made by Polycleitus the sculptor is pertinent to what I am going to say. He maintained that excellence is achieved gradually through many numbers.[16] Likewise, in this art [*technē*], since products are brought to completion through many numbers, those who deviate slightly in particular parts produce a large total error at the end. Therefore, I maintain that we must pay close attention when adapting the design of successful engines to a distinctive construction, especially when one wishes to do this while either increasing or diminishing the scale.[17] (*Belopoeica* 49.12–50.12)

16 The reference is presumably to the numerical proportions between the different components of a Polycleitan sculpture, which Philo takes as analogous to the numerical proportions between the dimensions of the components of the artillery engine.

17 ὅτι μὲν οὖν συμβαίνει δυσθεώρητόν τι τοῖς πολλοῖς καὶ ἀτέκμαρτον ἔχειν τὴν τέχνην, ὑπολαμβάνω μὴ ἀγνοεῖν σε· πολλοὶ γοῦν ἐνστησάμενοι κατασκευὴν ὀργάνων ἰσομεγεθῶν καὶ χρησάμενοι τῇ τε αὐτῇ συντάξει καὶ ξύλοις ὁμοίοις καὶ σιδήρῳ τῷ ἴσῳ οὐδὲ τὸν σταθμὸν αὐτοῦ μεταβάλλοντες, τὰ μὲν μακροβολοῦντα καὶ εὔτονα ταῖς πληγαῖς ἐποίησαν, τὰ δὲ καθυστεροῦντα τῶν εἰρημένων· καὶ ἐρωτηθέντες, διὰ τί τοῦτο συνέβη, τὴν αἰτίαν οὐκ εἶχον εἰπεῖν· ὥστε τὴν ὑπὸ Πολυκλείτου τοῦ ἀνδριαντοποιοῦ ῥηθεῖσαν φωνὴν οἰκείαν εἶναι τῷ μέλλοντι λέγεσθαι· τὸ γὰρ εὖ παρὰ μικρὸν διὰ πολλῶν ἀριθμῶν ἔφη γίνεσθαι. τὸν αὐτὸν δὴ τρόπον καὶ ἐπὶ ταύτης τῆς τέχνης συμβαίνει διὰ πολλῶν ἀριθμῶν συντελουμένων τῶν ἔργων μικρὰν ἐν τοῖς κατὰ μέρος παρέκβασιν ποιησαμένους μέγα συγκεφαλαιοῦν ἐπὶ πέρας ἁμάρτημα· διό φημι δεῖν προσέχοντας

Without a method, the artillery designer is at a loss even when attempting to copy a successful design; he is unable to explain (to give a reason, *aitia*) why some engines are more effective than others. Conversely, the existence of a reliable method enables the builder to adapt a successful design to the requirements of a particular situation (i.e., to a particular length of arrow or weight of shot). The reference to the *Canon*, a lost work of the famous Greek sculptor Polycleitus, emphasizes the quantitative precision of the method and its character as a norm or standard.[18] The *Canon* was an attempt to describe the ideal human figure by giving numerical proportions between its various parts.[19] Just as Polycleitus had set out ideal proportions between the parts of the body, so Philo gives an exhaustive list of the dimensions of all components of the engines he describes in terms of the spring hole diameter. Artillery engines thus display harmony and proportion between their various components, and even the slightest deviation from these proportions will result in diminished performance. The reference to Polycleitus further suggests that the *technē* of artillery construction aims at the attainment of an aesthetic ideal comparable to that achieved by a great work of sculpture. Finally, we may note that Philo emphasizes the established character of the method, as at 58.32–5: "though very many years have passed since this design [*suntaxis*] was invented and there have naturally been many machine and artillery makers, no one has dared to depart from the existing method."[20]

In setting out the content of the standard method, Philo begins by giving several alternative procedures for determining the size of the spring hole for a stone-throwing engine (*Belopoeica* 51.15–52.19). (1) The first option is to calculate the size of the hole from the weight of the shot by applying the spring hole relation directly. This requires converting the weight to drachmae, taking the cube root of the result, and adding a tenth of that root; the result of this procedure is the diameter of the hole in "finger-breadths" (dactyls). In case the cube root is not a whole number, Philo recommends a method of approximation: take as the diameter the whole number closest to the root, then diminish it slightly if it is larger

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μεταφέρειν τὴν ἀπὸ τῶν ἐπιτετευγμένων ὀργάνων σύνταξιν ἐπὶ τὴν ἰδίαν κατασκευήν, μάλιστα δέ, ὅταν τις εἰς μεῖζον μέγεθος αὔξων τοῦτο βούληται ποιεῖν καὶ ὅταν εἰς ἔλασσον συναιρῶν.

18 On *kanōn* as a norm or standard see Herbert Oppel, *Kanōn. Zur Bedeutungsgeschichte des Wortes und seiner lateinischen Entsprechungen (regula-norma)* (Leipzig: Dieterich, 1937).

19 See Andrew Stewart, "The Canon of Polykleitos: A Question of Evidence," *Journal of Hellenic Studies* 98 (1978): 122–31. Cf. Gal. *de temper.* 1.566 K. and *de plac. Hipp. et Plat.* 5.448 K. (where Chrysippus is praised for holding that beauty [*kallos*] lies in the *summetria* of the parts of the body, and Polycleitus' *Canon* is cited as advocating the same view.)

20 πολλῶν σφόδρα ἐτῶν διεληλυθότων, ἀφ' οὗ τὴν σύνταξιν εὑρῆσθαι τήνδε συμβαίνει, καὶ πολλῶν γεγονότων, ὅπερ εἰκός, καὶ μηχανικῶν καὶ βελοποιῶν, μηθένα τετολμηκέναι παρεκβῆναι τὴν ὑποκειμένην μέθοδον.

than the root but increase it slightly if it is smaller. (2) To enable the practitioner to avoid having to extract a cube root, Philo gives a table providing the correspondences between weight of shot and hole size for a number of standard weights (*Belopoeica* 51.21–26); such tables were no doubt much in use among practitioners.[21] (3) Still another alternative (51.28–52.19) would enable a practitioner to find the diameter of the hole for a given weight assuming that the correct diameter for another weight was known; here Philo gives a geometrical procedure for finding two mean proportionals.[22] Once the diameter of the spring hole had been determined, the practitioner would go on to construct the other parts of the engine by referring to the list of dimensions (*Belopoeica* 53.8–54.16). Throughout his account of the standard method Philo notes the importance of symmetry (*summetria*) and precision (*akribeia*), continuing the emphasis on these qualities suggested by the Polycleitus reference.[23] Philo's account is intended for a practitioner who is familiar with the technical terminology of artillery construction and who has mastered certain mathematical techniques; at the same time, his concern to present alternative methods for finding the spring

21 Vitruvius, whose account of artillery in *arch.* 10.10–12 is clearly intended for the practitioner, gives only a list of standard weights with corresponding sizes of shot and does not state the spring hole relation in its full generality. The reason he gives for including the table is "in order that even those ignorant of geometry may have a convenience, so that they will not be held up by calculations in the dangers of war" (*ut etiam, qui geometrice non noverint, habeant expeditum, ne in periculo bellico cogitationibus detineantur*, 10.11.2).

22 The reasoning behind this is as follows (cf. Hero Alex. *bel.* 113.8–119.2 Wescher). (1) The diameter of the hole is equal to the cube root of the weight times a constant. Thus, for two different weights, the ratio of the weights is equal to the ratio of the cubes of the respective diameters, i.e., $W_1:W_2 = D_1^3:D_2^3$. In a practical situation W_1, W_2, and D_1 will be given, and we will need to find D_2. (2) Suppose for the sake of argument that we wish to construct an engine for a shot of triple the weight, i.e., $W_1:W_2= 1:3$. We must now find x such that $D_1:D_2 = D_2:x = x:3D_1$; then $D_1^3:D_2^3 = 1:3$, as desired. D_2 and x are the two "mean proportionals" between D_1 and $3D_1$. (3) From line D_1, we construct a line of length $3D_1$, and then construct the two mean proportionals between them. The construction cannot be accomplished by the standard Euclidean uses of ruler and compass; the method Philo gives involves rotating a ruler around a given point until certain conditions are fulfilled, and it is thus inherently approximate (see Marsden, *Technical Treatises*, 59–60, 158–59). The problem is essentially that of "doubling the cube," i.e., given a cube, construct another with double the volume. Greek mathematicians devised a variety of solutions to this problem; it is clear that its importance in artillery construction was a major stimulus to their efforts. Cf. Thomas L. Heath, *A History of Greek Mathematics*, 2 vols. (Oxford: Clarendon Press, 1921), 1:244–70; Philo's construction, which is essentially the same as that given by Hero, is discussed at 262–64.

23 For *summetria* see *Belopoeica* 53.24–25, 54.15, 54.21; for *akribeia* see 55.13, 55.19, 55.29. Cf. 54.15–16 for the injunction to avoid error in the proportions (*analogiai*) between different parts.

hole diameter suggests an effort to communicate with practitioners at different levels of mathematical competence.[24]

I turn now to Philo's account of the discovery of the standard method:

> Among the ancients, some were on the way to discovering that the element [*stoicheion*], principle [*archē*], and measure [*metron*] for the construction of engines was the diameter of the hole. This[25] had to be obtained not by chance or at random, but by a fixed method which could produce the correct proportion at all sizes. It was impossible to obtain it except by increasing and diminishing the perimeter of the hole on the basis of experience [*ek peiras*]. Now the ancients did not bring this to a conclusion, as I say, nor did they determine the size, since their experience [*peira*] was not based on many trials [*erga*], but they did hit on what to look for. Those who came later, by drawing conclusions from previous mistakes, and by looking for a fixed element on the basis of later tests [ἐκ τῶν μετὰ ταῦτα πειραζομένων], introduced the principle and beginning [ἀρχὴν καὶ ἐπίστασιν] of construction, I mean the diameter of the circle that receives the spring. The craftsmen at Alexandria achieved this first, being heavily subsidized because they had kings who were lovers of reputation and craftsmanship [φιλοδόξων καὶ φιλοτέχνων]. For the fact that it is not possible for everything to be grasped by reasoning and the methods of mechanics [τῷ λόγῳ καὶ ταῖς ἐκ τῶν μηχανικῶν μεθόδοις], but that many things are also discovered through experience [διὰ τῆς πείρας], is clear both from many other things and not least from what is about to be said.[26] (*Belopoeica* 50.14–29)

In this passage, Philo identifies the spring hole diameter as the fundamental parameter in the construction of artillery; it is the "element" [*stoicheion*), "princi-

24 Among the other procedures that Philo discusses in his account of the standard method are a technique for drawing the shape of the so-called "hole-carrier" or *peritrēton*, the part of the frame into which the spring holes were drilled (52.20–53.7), and a general method for enlarging and reducing figures in a given ratio (55.12–56.8). The construction of an arrow-throwing engine receives only a brief mention at 54.25–55.11.

25 I.e., the diameter of the spring hole.

26 Ἐπὶ γὰρ τῶν ἀρχαίων τινὲς ηὕρισκον στοιχεῖον ὑπάρχον καὶ ἀρχὴν καὶ μέτρον τῆς τῶν ὀργάνων κατασκευῆς τὴν τοῦ τρήματος διάμετρον· ταύτην δ᾽ ἔδει μὴ ἀπὸ τύχης μηδὲ εἰκῇ λαμβάνεσθαι, μεθόδῳ δέ τινι ἑστηκυίᾳ καὶ ἐπὶ πάντων τῶν μεγεθῶν δυναμένῃ τὸ ἀνάλογον ὁμοίως ποιεῖν. οὐκ ἄλλως δὲ ἦν ταύτην λαβεῖν, ἀλλὰ ἐκ πείρας αὔξοντάς τε καὶ συναιροῦντας τὸν τοῦ τρήματος κύκλον. τοὺς γοῦν ἀρχαίους μὴ ἐπὶ πέρας ἀγαγεῖν, ὡς λέγω, μηδὲ ἐνστήσασθαι τὸ μέγεθος, οὐκ ἐκ πολλῶν ἔργων τῆς πείρας γεγενημένης, ἀκμὴν δὲ ζητουμένου τοῦ πράγματος· τοὺς δὲ ὕστερον ἔκ τε τῶν πρότερον ἡμαρτημένων θεωροῦντας καὶ ἐκ τῶν μετὰ ταῦτα πειραζομένων ἐπιβλέποντας εἰς ἑστηκὸς στοιχεῖον ἀγαγεῖν τὴν ἀρχὴν καὶ ἐπίστασιν τῆς κατασκευῆς, λέγω δὲ τοῦ κύκλου τὴν διάμετρον τοῦ τὸν τόνον δεχομένου. τοῦτο δὲ συμβαίνει ποιῆσαι τοὺς ἐν Ἀλεξανδρείᾳ τεχνίτας πρώτους μεγάλην ἐσχηκότας χορηγίαν διὰ τὸ φιλοδόξων καὶ φιλοτέχνων ἐπειλῆφθαι βασιλέων. ὅτι γὰρ οὐ πάντα δυνατὸν τῷ λόγῳ καὶ ταῖς ἐκ τῶν μηχανικῶν μεθόδοις λαμβάνεσθαι, πολλὰ δὲ καὶ διὰ τῆς πείρας εὑρίσκεται, φανερὸν μὲν καὶ ἐξ ἄλλων πλειόνων ἐστίν, οὐχ ἥκιστα δὲ καὶ ἀπὸ τοῦ μέλλοντος λέγεσθαι.

ple" or "beginning" [*archē, epistasis*], and unit of measure or standard of reference [*metron*]. That the diameter of the spring hole has this character was discovered through a long process of empirical investigation, "by increasing and diminishing the perimeter of the hole on the basis of experience [*ek peiras*]." This investigation, furthermore, was a highly directed and systematic one that was carried out with state support. The ancients did not discover the fundamental role of the spring hole diameter "since their experience [*peira*] was not based on many trials [*erga*]"; they succeeded only when the Alexandrian kings provided a subsidized context for research, and by "drawing conclusions from previous mistakes" and "looking for a fixed element on the basis of later tests." Summing up, Philo draws a contrast between what is discovered by "reasoning [*logos*] and the methods of mechanics" and by experience [*peira*], and places the importance of the spring hole diameter in the latter category.

The key term in Philo's account is *peira*, which commonly means "trial" or "attempt." In the *Belopoeica* the term can generally be translated as "test," but it sometimes seems to refer to knowledge acquired on the basis of testing, that is, "experience."[27] In any case, Philo's meaning here is clear: in order to find the optimal size of the spring hole for a given missile, the only possible procedure is to vary its size and evaluate the effect of the variation on the range and force of the missile. If one takes account of the results of one test in setting up the next, eventually one will zero in on the optimal size for the hole. Philo reinforces the systematic character of this procedure by drawing a parallel with architecture. It was not from a single attempt [*peira*] that people discovered how to shape columns in the way that produced the most symmetric and harmonious appearance in buildings, but by evaluating the effects of many slight modifications to the shapes of the individual parts:

> For instance, the correct proportions of buildings could not possibly have been determined right from the start and without the benefit of previous experience [*peira*], as is clear from the fact that the old builders were extremely unskillful, not only in general building, but also in shaping the individual parts. The progress to proper building was not the result of a single or chance experience [*peira*]. Some of the individual parts, which were equally thick and straight, seemed not to be so, because the sight is deceived in such cases by the difference of distance. By experimentally [διὰ τῆς πείρας] adding to the bulk here and subtracting there, by tapering, and by conducting every possible test, they made them appear

27 For the broader sense cf. *Belopoeica* 50.20 (in the passage just quoted in the text): "since their experience was not based on many trials" (οὐκ ἐκ πολλῶν ἔργων τῆς πείρας γεγενημένης) and 53.29–30: "for this reason those who have acquired their experience in action commanded them to make use of the above-mentioned size" (διὸ ἐκέλευσαν ἔργῳ τὴν πεῖραν εἰληφότες τῷ προειρημένῳ μεγέθει χρᾶσθαι).

> regular to the sight and quite symmetrical: for this was the aim in that art [*technē*].[28] (*Belopoeica* 50.30–51.7)

Several features of this remarkable account of discovery are worthy of comment. First, Philo asserts that the Alexandrian engineers worked out both (1) the relation between the spring hole and the weight of the shot and (2) the specifications of the dimensions of the various parts in terms of the spring hole diameter, in the course of a program of systematic, controlled testing. The process evidently involved (1) keeping the dimensions of the engine fixed and varying the size of the hole, and (2) keeping the size of the hole fixed and varying the dimensions of the different components. The latter procedure is suggested by Philo's account of the dimensional list for stone-throwing engines, where he remarks that those who speak "from experience" (ἐκ τῆς πείρας) gave the optimal dimension for the height of the spring: any larger, and the engine would achieve long range but little force on impact; any smaller, and the range would be impaired.[29] Furthermore, the method of discovery that Philo describes does not involve any antecedent commitment to theory; what drives the process is the evaluation of the impact that modifications in construction have on performance.

At the same time, it is crucial to note that the account culminates not just in the discovery of the spring hole relations and dimensional lists, but also in the recognition that the diameter of the spring hole is the fundamental "element" (*stoicheion*), "principle" (*archē*), and "measure" (*metron*) in construction. Each of these terms has a long history in Greek thought in contexts that are relevant to the development of a concern with systematic explanation, such as Presocratic philosophy, Hippocratic medicine, and mathematics. By suggesting that each of them can be used of the spring hole diameter, Philo signals a concern to sys-

28 τοὺς γὰρ τῶν οἰκοδομικῶν ἔργων ῥυθμοὺς οὐ δυνατὸν ἦν ἐξ ἀρχῆς συστήσασθαι μὴ πρότερον πείρας προσαχθείσης, καθ' ὅτι καὶ δῆλόν ἐστιν ἐκ τῶν ἀρχαίων καθ' ὑπερβολὴν ἀτεχνῶν οὐ μόνον κατὰ τὴν οἰκοδομίαν, ἀλλὰ καὶ ἐν ταῖς κατὰ μέρος εἰδοποιίαις. μετετέθη οὖν ἐπὶ τὸ δέον οὐ διὰ μιᾶς οὐδὲ τῆς τυχούσης πείρας. τινὰ δὲ τῶν κατὰ μέρος ἐν αὐτοῖς ὑπαρχόντων ἰσοπαχῆ τε ὄντα καὶ ὀρθὰ ἐδόκει μήτε ἰσοπαχῆ μήτε ὀρθὰ εἶναι διὰ τὸ ψεύδεσθαι τὴν ὄψιν ἐπὶ τῶν τοιούτων μὴ τὸ ἴσον ἔχουσαν ἀπόστημα· διὰ τῆς πείρας οὖν προστιθέντες τοῖς ὄγκοις καὶ ἀφαιροῦντες καὶ μύουρα ποιοῦντες καὶ παντὶ τρόπῳ πειράζοντες κατέστησαν ὁμόλογα τῇ ὁράσει καὶ εὔρυθμα φαινόμενα· τοῦτο γὰρ ἦν τὸ προκείμενον ἐν ἐκείνῃ τῇ τέχνῃ.

29 *Belopoeica* 53.17–23; cf. 53.25–30, where Philo makes a similar remark about the length of the arms. As Marsden has noted (*Historical Development*, 25), the Alexandrian engineers were engaged in three closely related investigations: (1) determining the optimal relationship between diameter and height of the spring, (2) determining the optimum size of the spring for a given weight of shot, and (3) demonstrating that all measurements are dependent on the spring hole diameter.

tematize the rules of the standard method in terms of underlying general principles. This in turn suggests that his emphasis on the importance of *peira* in the discovery process should not be understood as a denial of the importance of seeking general explanations. Indeed, the intuition that the power of an artillery engine is connected with the volume of the bundle of spring cords – which in turn depends on its diameter and height – presumably played some role in discovering the cube-root relation between the weight of shot and the diameter of the hole, and Philo's account leaves this possibility open.[30] What he does insist on is the need for constant reference to practical testing. The contrast that he introduces between discovery by "reasoning [*logos*] and the methods of mechanics" and discovery by *peira* should be understood as a contrast between purely theoretical inquiry and research that depends on continued testing and modification.

To be sure, Philo's account of the standard method reflects a certain amount of simplification and idealization. The emphasis on the quantitative precision of the spring hole relations and dimensional lists contrasts with the fact that practitioners would often need to resort to approximation in practice, e.g., when it was necessary to extract a cube root. Philo's conception of the goal of artillery construction as the attainment of both long range and powerful impact ignores the possibility that a practitioner might sometimes need to achieve a very powerful impact at short range.[31] A further problem involves the sense in which the spring hole relations and dimensional lists can be said to yield optimal artillery engines. One might expect that longer range and more powerful impact would be attained by using a lighter shot than that for which the engine had been designed according to the spring hole relations. Evidently these relations are based on consideration of factors other than just performance, i.e., factors such as the size and portability of the engine and the expense of construction.[32] In general, it is unlikely that the practice of artillery construction conformed as closely as Philo suggests to his picture of a standard, established method for attaining a single goal. But that does not diminish the interest of his attempt to

30 In his description of the method of finding two mean proportionals at *bel.* 114.8–119.2 Wescher, Hero suggests one way in which theoretical considerations might have influenced the discovery of the spring hole relation for stone-throwers. That a cube root is involved may have been suggested by reflecting on the fact that the force produced by the engine is directly related to the volume of the cylinder made up of the spring cords: a larger weight requires a spring cylinder of proportionally larger volume, and since the ratio of the volumes of two similar cylinders is that of the cubes of their base diameters, we immediately have the relation $W_1:W_2 = D_1^3:D_2^3$ (above, n. 22).

31 Cf. Marsden, *Technical Treatises*, 160–61.

32 Marsden, *Historical Development*, 37–39.

standardize what was presumably a somewhat diverse set of practices. Moreover, Philo is surely correct to emphasize the importance of systematic testing in the development of artillery. The artillery builder's work faced critical tests in battle situations, and the idea of state-sponsored research into military technology is – as modern experience indicates – all too plausible.

To sum up, in the first part of the *Belopoeica* Philo argues that artillery construction possesses a method that enables its practitioners to achieve successful results in a reliable fashion. This method rests on two types of quantitatively precise rules: the spring hole relations and dimensional lists. Philo evidently expects practitioners to know these rules, though he also provides shortcuts (such as the lists correlating the weight of shot and the size of the spring hole) that would make it easier to apply them in practical situations. Yet by identifying the spring hole diameter as the fundamental element, principle, and standard of measure in construction, he asserts that the standard method is based on a principle of greater generality. A grasp of the importance of the spring hole diameter unifies the rules of the artillery builder's *technē* and in a certain sense explains them. It accounts for the different results that were attained in practice by the earlier designers who lacked proper method. And it is the role of the spring hole diameter as a general principle – not just the dimensional lists and spring hole relations – that the Alexandrian engineers are said to have discovered. Philo's stress on the role of *peira* in the discovery process should be understood not as a rejection of the need for explanation, but as a way of emphasizing that the discovery could only have been made by the systematic evaluation of the results of practical tests. In his account of the standard method Philo does not explain *why* the spring hole diameter is fundamental in construction (by appealing to the relationship between the volume of the spring and the power it can generate, for example). Nonetheless, by pointing to its importance, he takes a significant step beyond a conception of *technē* as just a set of practical rules and techniques.

II Philo on Theory: The Modified Designs

I turn now to the second part of the *Belopoeica*, in which Philo presents his criticisms of the standard method and suggests a number of alternative designs. In contrast to the emphasis on experience in the first part of the text, theoretical considerations play a prominent role in Philo's account of these innovations. Philo portrays his own contribution as building on the admirable achievements of his predecessors, a sentiment that finds numerous parallels in the technical literature of other fields such as medicine.[33] In this section I shall consider three of the four modified designs that Philo discusses, each of which illustrates the role of theory in mechanics as he conceives of it.

1 Philo's Wedge Engine

At *Belopoeica* 56.8–67.27 Philo proposes a modified design for an arrow-shooting artillery engine and attempts to show that it avoids various deficiencies in the standard design. The basic technological problem that Philo's modifications were intended to address concerned the need to keep the springs of a piece of torsion artillery at a high state of tension. There was a natural tendency for the springs to loosen after use, and they would then require re-tightening. In an engine of the standard design, this re-tightening would be accomplished by twisting the springs using tightening bars on the top and bottom of the frame. Philo objects to this procedure as weakening the spring cords and proposes that the re-tightening should be done by using wedges, thus increasing the tension of the spring in the vertical direction without any horizontal twist (fig. 3). At 56.18–24 he claims that the excellence of his wedge engine is evident in six respects: (1) it can shoot far; (2) it retains its strength in the heat of battle; (3) it is easy to construct; (4) it is easily assembled, strung, and disassembled; (5) it is "in no way deficient in appearance" (τὴν ὄψιν οὐθὲν καταδεεστέραν) to the standard design; and (6) it is less expensive. This list gives a good idea of the various factors that the ancient practitioner of artillery construction had to keep in mind in his attempt to build a machine that would attain long range and a powerful impact: ease of construction, transportation, and expense, as well as aesthetic considerations.[34]

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33 *Belopoeica* 58.26–32: "Yet one must praise those who originally invented the construction of these engines, for they were the authors of the invention and of its characteristic form: they discovered something superior to all other weapons, both in shooting range and in weight of missiles, I mean weapons like the bow, javelin, and sling. To have an original idea and to bring it to completion is the work of a greater nature [μείζονος φύσεως]; to improve or modify something that already exists seems appreciably easier." In the Hippocratic Corpus the closest parallel is *vict.* I 1, 6.466–68 L. (= 122–23 Joly/Byl); cf. also *vet. med.* 2, 1.572–74 L. (= 119–20 Jouanna) on the need to build upon prior discoveries and *art.* 1, 6.2 L. (= 224–25 Jouanna) for the praise of discovery in general.

34 For the importance of aesthetic factors in the wedge engine, see *Belopoeica* 61.29–62.15 and esp. 62.12–14: the frame, since it is smooth and has no protuberances, "presents a fine appearance" (καλὴν τὴν ὅρασιν ἀποδιδόναι). Cf. also 66.18–19, where Philo, having just finished

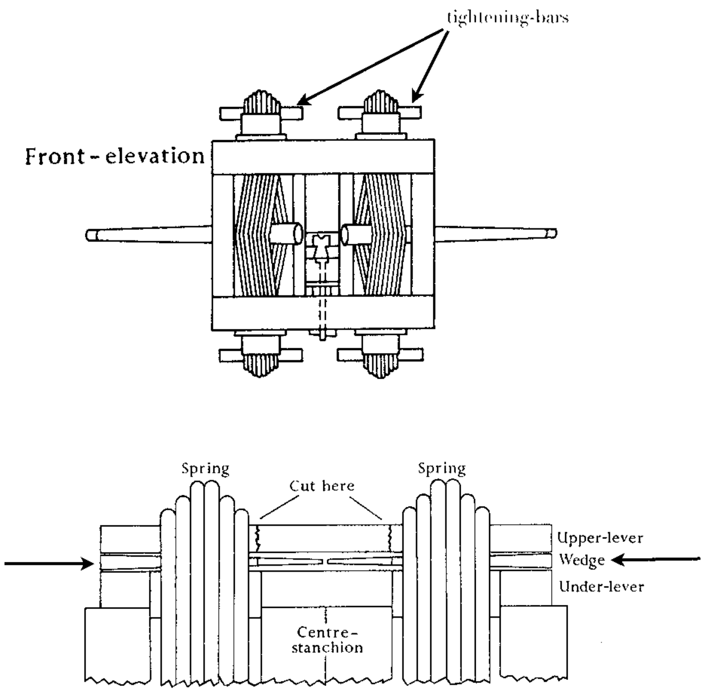

Fig. 3 Tightening bars in the standard design (Marsden, *Technical Treatises*, 57) vs. the wedges in Philo's modified engine (Marsden, *Technical Treatises*, 174)

At *Belopoeica* 59.1–62.21 Philo goes through each of these six points in sequence, arguing systematically for the excellence of his modified design. I shall focus on the argument for claim (1), the ability of the wedge engine to attain a longer range than a standard-design arrow shooter. Philo announces that he will demonstrate this by means of both "mechanical demonstrations" (*mēchanikai apodeixeis*) and "physical arguments" (*phusikoi logoi*, 59.8–10). His appeal to a mechanical demonstration runs as follows:

> Since larger circles overpower smaller ones which lie about the same center, as we have proven in our discussion of levers, and for the same reason [people] also move loads more easily with levers, when they place the fulcrum as near as possible to the load (for the fulcrum has the position of the center; hence when it is brought close to the load it diminishes the circle, through which it happens that ease of motion comes about) – the same thing, indeed, must be imagined [*noēteon*] in the case of the engine. For the arm is an in-

explaining how to construct the frame, remarks that "the frame, thus built and strung, is ready for shooting, but it is a little too ugly in appearance [τῇ ὄψει μικρῷ ἀπρεπέστερον], for it seems to have no head, as is the case." He goes on to explain how to build a cover for the frame, which "produces a good appearance [τήν τε ὄψιν ἀποδίδωσι καλήν], conceals the area around the wedges, and protects the spring" (66.30–31). For Philo there is no question of aesthetic factors *conflicting* with considerations of efficiency.

> verted lever: the fulcrum is the part of it ⟨in the middle of the string⟩, the [imaginary] load [*baros*] is the bowstring, which is fastened to the end of the arm and sends forth the [actual] load [*baros*]. Now if one arranges the spring cords by spacing them out as much as possible starting from the heel, the fulcrum will clearly be nearer the load and the force [*dunamis*] further from the fulcrum. If this is done, the discharge of the missile will be violent and forceful.[35] (*Belopoeica* 59.11–22)

Philo begins by stating the proposition, which he says he has already proved in his work on levers (τὰ μοχλικά, the lost second book of the *Mechanical Syntaxis*), that "larger circles overpower smaller ones which lie about the same center" (*Belopoeica* 59.11–12). He then notes that it is easier to move heavy loads with a lever when the fulcrum is placed close to the load; this corresponds to the common experience that increasing the length of a lever arm makes it easier to move a load. The proposition about the circles explains this well-known fact: if one imagines the fulcrum to be the center of a circle and brings it close to the load, then the effort will move over a greater circle than the load, and thus "overpower" it (cf. fig. 4). Now, just as the fulcrum of the lever can be considered as the center of a circle, so the arm of the arrow-shooter can be imagined as a lever turning about a fulcrum at the center of the point of contact between the spring cords and the arm (fig. 5). The bowstring corresponds to the load; the effort is provided by the spring cords, which exert a rotatory force on the arm. What Philo proposes is to change the arrangement of the spring cords so that the distance between the load (the end of the arm) and the imaginary fulcrum is less (fig. 6b). This, he claims, will make the discharge more violent and forceful.[36]

35 ἐπεὶ γὰρ οἱ μείζονες κύκλοι κρατοῦσιν τῶν ἐλασσόνων τῶν περὶ ⟨τὸ⟩ αὐτὸ κέντρον κειμένων, καθάπερ ἐν τοῖς μοχλικοῖς ἀπεδείξαμεν, διὰ δὲ τὸ ὅμοιον καὶ τοῖς μοχλοῖς ῥᾶον κινοῦσι τὰ βάρη, ὅταν ὡς ἐγγύτατα τοῦ βάρους τὸ ὑπομόχλιον θῶσιν (ἔχει γὰρ τὴν τοῦ κέντρου τάξιν· προσαγόμενον οὖν πρὸς τὸ βάρος [δὲ] ἐλασσοῖ κύκλον, δι' οὗ τὴν εὐκινησίαν συμβαίνει γίνεσθαι)· τὸ αὐτὸ δὴ νοητέον ἐστὶ καὶ περὶ τὸ ὄργανον. ὁ γὰρ ἀγκών ἐστι μοχλὸς ἀντεστραμμένος· ὑπομόχλιον μὲν γὰρ γίνεται τὸ ἐν ⟨μέσῳ τοῦ τόνου⟩ μέρος αὐτοῦ, ἡ δὲ τοξῖτις νευρὰ τὸ βάρος, ἥ τις ἐξ ἄκρου τοῦ ἀγκῶνος ἐχομένη τὸ βάρος ἐξαποστέλλει. ἐὰν οὖν τις τὸν τόνον ὅτι πλεῖστον ἀπ' ἀλλήλων διαστήσας ἀπὸ τῆς πτέρνης θῇ, δηλονότι τὸ μὲν ὑπομόχλιον ἔγγιον ἔσται τοῦ βάρους, ἡ δὲ δύναμις μακρότερον ἀπὸ τοῦ ὑπομοχλίου· τούτου δὲ γενομένου συμβήσεται τὴν ἐξαποστολὴν τοῦ βέλους σφοδρὰν καὶ βίαιον γίνεσθαι.

36 The point of remarking that the arm is an "inverted lever" (μοχλὸς ἀντεστραμμένος) is explained by the fact that the distance between the fulcrum and the effort (which must be imagined to be exerted at the end of the arm closest to the spring cords) is less than the distance between the fulcrum and the load (the bowstring). Marsden is quite right (*Technical Treatises*, 165) to compare the discussion of the unequal-armed balance (i.e., the steelyard) in the Aristotelian *Mechanical Problems* (854a10–11), where the steelyard is said to be a μοχλὸς ἀνεστραμμένος because in it the effort is regarded as exerted by the weight that is closer to the point of suspension.

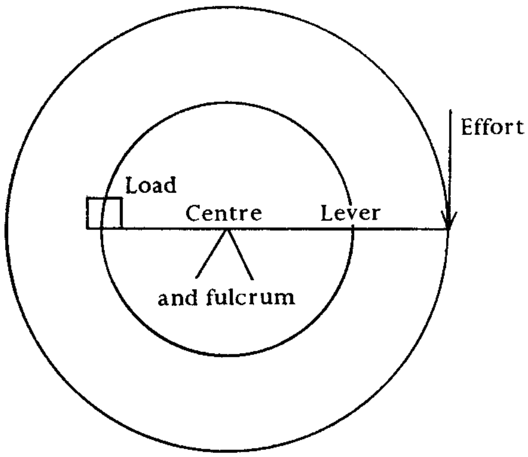

Fig. 4 The lever and concentric circles (Marsden, *Technical Treatises*, 165)

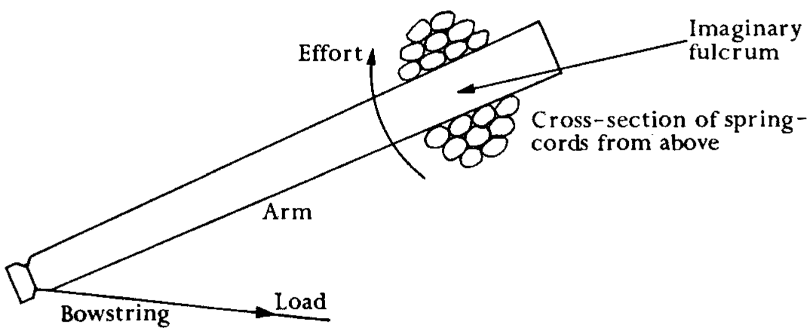

Fig. 5 The arm as a lever (Marsden, *Technical Treatises*, 166)

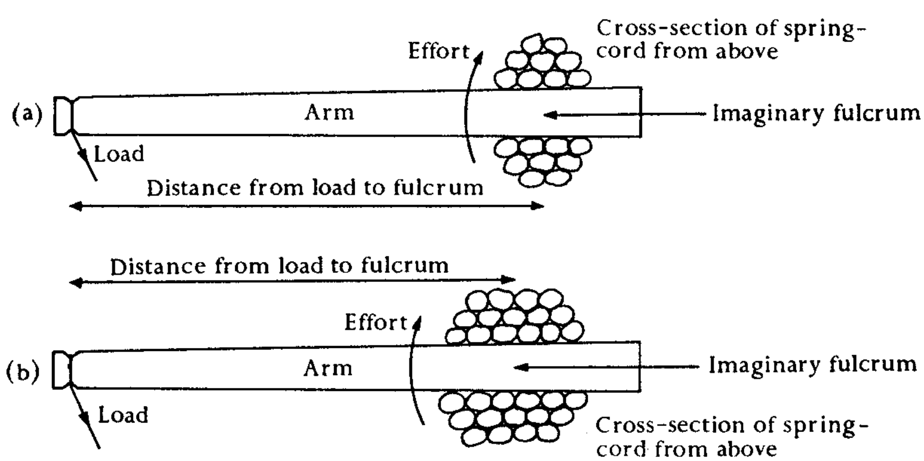

Fig. 6 Arrangement of the spring cords: (a) standard design; (b) Philo's modification (Marsden, *Technical Treatises*, 167)

Several points about this procedure are notable. First, despite the reference to "mechanical demonstrations," the crucial step is not a deductive inference, but the recognition that the arm of the artillery engine can be viewed as a lever for the purpose of the analysis. Philo makes no attempt to prove the proposition about greater circles "overpowering" smaller ones, but refers to the demonstration he has already given elsewhere. The conclusion – that the force will be increased if the spring cords are arranged in the way that Philo suggests – follows immediately once it is realized that the arm can be viewed as a lever. This kind of analysis of the components of complex machines in terms of simpler ones is characteristic of other Greek mechanical texts such as the Aristotelian *Mechanical Problems*, which begins by stating that the circle is the primary cause (the ἀρχὴ τῆς αἰτίης, 847b16–17) of all the wondrous phenomena that take place in mechanics; this amounts to the claim that all mechanical movements can be "reduced" (*anagetai*) to the circle, i.e., explained in terms of the movement of concentric circles.[37] After showing how the balance can be explained in terms of the circle and the lever in terms of the balance, the author goes on to show how a number of puzzling mechanical phenomena can be explained in terms of the lever. These analyses are carried out in a linguistically standardized way, with *baros* used to denote the load moved by the lever, *hupomochlion* the fulcrum, and *dunamis* or *ischus* the effort, i.e., the power or force that causes the movement.[38] In this way, the author of the *Mechanical Problems* employs the lever as a model for understanding the operation of a wide variety of more complex machines; this is exactly the procedure followed by Philo in the present passage.[39]

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37 *Mech.* 848a11–14: "Now the things that come about with the balance are reduced to the circle, those that come about with the lever are reduced to the balance, and practically everything else that is concerned with mechanical movements is reduced to the lever" (τὰ μὲν οὖν περὶ τὸν ζυγὸν γινόμενα εἰς τὸν κύκλον ἀνάγεται, τὰ δὲ περὶ τὸν μοχλὸν εἰς τὸν ζυγόν, τὰ δ' ἄλλα πάντα σχεδὸν τὰ περὶ τὰς κινήσεις τὰς μηχανικὰς εἰς τὸν μοχλόν).

38 Cf. 850b10–16: "Why do the rowers in the middle of the ship contribute most to its movement? Is it because the oar is a lever [*mochlos*]? For the thole-pin becomes the fulcrum [*hupomochlion*], for it is fixed, and the load [*baros*] is the sea, which the oar pushes away; the mover [*ho kinōn*] of the lever is the sailor. And, always, the further the mover of the load [*baros*] is from the fulcrum [*hupomochlion*], the more load it moves; for the line from the center (i.e., the radius) is greater, and the thole-pin, which is the fulcrum, is the center." For further discussion of the use of model-based reasoning in the *Mechanical Problems* see my paper, "Structures of Argument and Concepts of Force in the Aristotelian *Mechanical Problems*," *Early Science and Medicine* 14.1–3 (2009): 43–67.

39 The linguistic standardization associated with the application of the lever model explains Philo's initially puzzling use of the term *baros* in the passage quoted above, whereby it first

Secondly, Philo's claim that larger circles "overpower" (*kratousi*) smaller ones placed around the same center expresses a principle that in one form or another was fundamental to much of ancient Greek theoretical mechanics. The author of the *Mechanical Problems* bases all his explanations on a proposition about concentric circles: given two such circles, a force applied to the circumference of the larger circle causes a greater movement than the same force applied to the circumference of the smaller circle, because a point on the larger circle covers a greater distance in the same time (assuming the two circles turn at the same angular speed); in this sense, the greater circle may be said to "overpower" the lesser.[40] Pappus of Alexandria, writing in the fourth century A.D., states that "it was proved in Archimedes' *On Balances* and the *Mechanics* of Philo and Hero that larger circles overpower (*katakratousin*) smaller circles when they turn around the same center."[41] How Philo proved the principle of concentric circles is not clear, though his tendency to associate force and movement suggests an approach closer to the *Mechanical Problems* than to that of Archimedes, which is based on an analysis of static equilibrium.[42] At any rate, the type of generalization about the lever that is important for the present passage ("the closer the load to the fulcrum, the more easily it is moved") is much closer to the *Mechanical Problems*, where the law of the lever in its exact quantitative form is only hinted at, than to Archimedes' works, in which the inverse proportionality of weights and distances from the center of the balance beam is stated,

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refers the bowstring as the "imaginary" load (i.e., the load in terms of the lever model), then to the "actual" load, i.e., the missile that is discharged.

40 See *mech.* 848b1–849b22, esp. 848b3–5 and 849b19–22. At 850b2–6 the principle is applied to the lever. For further discussion of the author's application of the circular motion principle see Schiefsky, "Structures of Argument."

41 Pappus 1068.20 Hultsch: ἀπεδείχθη γὰρ ἐν τῷ περὶ ζυγῶν Ἀρχιμήδους καὶ τοῖς Φίλωνος καὶ Ἥρωνος μηχανικοῖς, ὅτι οἱ μείζονες κύκλοι κατακρατοῦσιν τῶν ἐλασσόνων κύκλων, ὅταν περὶ τὸ αὐτὸ κέντρον ἡ κύλισις αὐτῶν γίνηται. Cf. Hero Alex. *dioptra* 312.20 Schöne.

42 The argument of the *Mechanical Problems* is roughly as follows (for a fuller analysis see Schiefsky, "Structures of Argument"). Given two points on two concentric circles turning at the same angular speed, the point farther from the center will move more quickly, i.e., it will cover a greater distance in the same time. Now if we imagine the two points as lying at the ends of a balance beam or a lever, we can ask what downward force is exerted by the same body at each of the two points. If we consider the force exerted by a body to depend on its speed as well as its weight, then the force exerted by a body at the end of the longer radius will exceed the force exerted by a body of the same weight acting at the end of the shorter radius, for it will cover a greater distance in the same time. Thus a body placed at the end of the longer radius will "overpower" a body of the same weight that is closer to the center. Similarly, Philo closely associates the concepts of force (*dunamis*) and speed (*tachutēs*); cf. *Belopoeica* 69.1–5 and 73.8–13, with the discussion in the text below, p. 638–42.

proved, and applied.[43] Philo makes no attempt to provide a quantitative estimate of the gain in performance that could be attained by the modification that he suggests; he remarks only that his engines shoot farther than standard ones of the same caliber (*Belopoeica* 59.4–8).

It is notable that Philo presents this analysis not only as a justification of his claim that the modified engine will achieve greater range, but also as a consideration which actually suggested that modification. Immediately after the passage just quoted, he goes on as follows:

> I saw that, in existing engines, the spring cords converged on each other, and that most artificers realized that this was what was harming the shooting, but were unable to alter it because this characteristic was naturally [*phusikōs*] inherent in the design and because it could not be removed in any other way. I tried, for this reason … to change the form and the entire disposition. … The most important innovation in this design is that the spring cords do not converge, but run parallel, and this, most of all, must produce long range.[44] (*Belopoeica* 59.23–31)

The rearrangement of the spring cords, suggested by the analysis of the arm as a lever, is the fundamental innovation that improves the range.

What of the "physical arguments" (*phusikoi logoi*) that are supposed to establish the superior range of Philo's wedge engine? Philo's reference to the spring cords converging "naturally" (*phusikōs*) in the passage just quoted suggests that by "physical" considerations he has in mind the inherent properties of materials such as animal sinew that provided the motive power for the engine. In an earlier passage criticizing the standard design, Philo remarks that one reason for its limited range is that the re-tightening necessary after a certain amount of use can only be accomplished by twisting the spring cords in a way that is

43 The author of the *Mechanical Problems* states the law of the lever in its exact quantitative form ("as the weight moved is to the moving [weight], so the distance [sc. from the fulcrum] is to the distance, inversely"; 850a39–b2). But he neither proves the inverse proportionality of weights and distances nor makes use of it in his analysis of machines (see Schiefsky, "Structures of Argument"). For Archimedes' proof of the lever principle see his *aequil.* 1.6–7.

44 ὁρῶν οὖν ἐν τοῖς προϋπάρχουσιν ὀργάνοις καταλλήλους πίπτοντας τοὺς τόνους, καὶ νοοῦντας μὲν τοὺς πλείστους τῶν ἀρχιτεκτόνων, ὅτι τὸ λυμαινόμενον τὴν τοξείαν τοῦτό ἐστιν, ἀδυνατοῦντας δὲ μεταθεῖναι διὰ τὸ φυσικῶς ἐν τῇ συντάξει τοῦτον ὑπάρχειν τὸν τρόπον καὶ ἄλλως ἂν μὴ δύνασθαι μεταχθῆναι, ἐπειράθην καὶ διὰ τοῦτο καὶ διὰ τὰ λοιπὰ τὰ προσόντα τῇ συντάξει δύσχρηστα μεταθεῖναι τὸ σχῆμα καὶ τὴν ὅλην διάθεσιν, ὅπως ὃν ἐγὼ βούλομαι τρόπον ἐν πᾶσιν ἀναστραφῶ μηδενὸς ἐμποδίζοντος ἡμῖν. τοῦτο μὲν οὖν μέγιστόν ἐστι τῶν εὑρημένων ἐν τῇδε τῇ συντάξει, τοὺς τόνους μὴ καταλλήλους, ἀλλὰ παραλλήλους πίπτειν, καὶ τοῦτο μάλιστα ἀναγκάζει μακροβολεῖν.

“contrary to nature” (*para phusin*) and which causes them to lose their natural (*kata phusin*) force and tension:

> In the heat of shooting and pulling back, the spring experiences a slackening and needs tightening again. The range of the shooting deteriorates because of the relaxation. But those who wish to tighten it cannot apply the re-stretching vertically and in a straight line, but do it by extra-twisting, imparting an extra-twist unnaturally [*para phusin*], greater than is suitable. … The engine loses its springiness because the strands are huddled up into a thick spiral and the spring, becoming askew, is robbed of its natural [*kata phusin*] force and liveliness through the excessive extra-twisting.[45] (*Belopoeica* 58.7–16)

In contrast, he claims that his modified design, in which the re-stretching is achieved by driving in the wedges rather than by twisting, makes it possible to

> impart a very strong, natural [*kata phusin*] extra-tension, which will be enduring throughout and can in no way diminish. I maintain that, while there is a tendency in continuous shooting, as we have shown, for relaxation of the spring to occur on account of frequent pullings-back, I can produce additional stretch immediately, not by extra-twisting (for we have shown this to be injurious), but by stretching naturally [*kata phusin*] and vertically all the strands at once, just as they were originally stretched when the machine was being strung.[46] (*Belopoeica* 61.14–21)

It is thus a mark of the superiority of Philo’s design that it takes full advantage of the natural properties of the components of the engine, rather than trying to work against them. The clear implication is that a machine functions better when its components are acting “according to nature” (*kata phusin*), even if the resultant effect produced by the machine may be viewed as in some sense “against nature” (*para phusin*; for example, in the sense that it causes a heavy body to move in a way that is contrary to its natural tendencies). However the

45 ἐν γὰρ ταῖς τοξείαις καὶ ταῖς πυκναῖς καταγωγαῖς χάλασμα λαβὼν ὁ τόνος ἐπιτάσεως πάλιν προσδεῖται. τὸ γὰρ τῆς τοξείας μῆκος ἀπολήγει διὰ τὴν γεγενημένην ἄνεσιν. συμβαίνει οὖν βουλομένους ἐπιτείνειν αὐτὸν εἰς ὀρθὸν μὲν μὴ δύνασθαι μηδὲ κατ’ εὐθεῖαν διδόναι τὴν ἐπέκτασιν, ἐπιστρέφοντας δὲ τοῦτο ποιεῖν διδόντας παρὰ φύσιν ⟨πλείονα⟩ τῆς καθηκούσης ἐπιστροφῆς, ὑπολαμβάνοντας μὲν βοηθεῖν, μέγα δὲ λυμαινομένους τὴν τάσιν καὶ ποιοῦντας, λέγω, τὴν τοξείαν βραδυτέραν καὶ ἀσθενεστέραν ταῖς πληγαῖς, ἀτόνου τοῦ ὀργάνου γινομένου διὰ τὸ τοὺς στήμονας εἰς πυκνὴν ἕλικα ἀνάγεσθαι καὶ πλάγιον γεγονότα ⟨τὸν τόνον⟩ τοῦ βιαίου καὶ εὐτόνου ⟨τοῦ⟩ κατὰ φύσιν ἐστερῆσθαι διὰ τὴν ὑπεράγουσαν ἐπιστροφήν.
46 ἐπιστροφήν τε δώσειν τὴν ὑπάρχουσαν κατὰ φύσιν κρατίστην, μένουσαν δι’ ὅλου καὶ μεταπεσεῖν οὐθενὶ τρόπῳ δυναμένην. ἐπεὶ δὲ καὶ ἐν ταῖς συνεχέσι τοξείαις συμβαίνει, καθότι δεδηλώκαμεν, ἀνέσεις γίνεσθαι τοῦ τόνου διὰ τὰς πυκνὰς καταγωγάς, ἐπεντείνειν παραχρῆμα μὴ ἐπιστροφὴν διδούς (τοῦτο μὲν γὰρ ἐδείξαμεν βλαβερὸν ὑπάρχον), ἀλλὰ κατὰ φύσιν εἰς ὀρθὸν ἐντείνων τοὺς στήμονας πάντας ἅμα, καθάπερ ἐξαρτυομένου τὴν ἀρχὴν ἐξετάθησαν.

effect produced by the machine is viewed, it can be understood in terms of the natural behavior of the machine's components.[47] In order to produce the most efficient design, the artillery builder needs knowledge of the natural properties of the materials with which he is working, as well as the principles of theoretical mechanics.

2 The Bronze-Spring Engine (*chalkotonon*)

A second, more far-reaching modification of standard-design artillery that Philo discusses is the bronze-spring engine or *chalkotonon*, in which motive power was supplied by specially manufactured bronze plates rather than animal sinew (fig. 7). When the string is pulled back, the ends of the arms press against the bronze springs; these then recoil and produce the forward thrust when the trigger is pulled. Philo credits Ctesibius, the brilliant Alexandrian engineer of the third century B.C., with the original invention of the bronze-spring engine, but he also claims to have made substantial improvements to Ctesibius' design.[48] He begins his discussion by calling for a general inquiry into the problem of attaining long range:

> As we intend to recount the peculiarity of the springs, we think it a good idea, in this case also, to examine the old engines first and to reckon what is the cause [*aitia*] of their ability to hurl the missile over a long range. We shall not make the inquiry about minor causes [*mikras aitias*], as mentioned above – lengthening or contracting of the springs, extending or shortening of the arms, making them lean further back or further forward, or the merit of sinew or hair. These have been investigated before, as I have said previously; they are public and common to everyone, and have already been tested [*pepeiramena*] frequently and thoroughly. Now we must make a thoroughgoing examination of the problem as a whole

47 On this understanding of the working of machines, the *technē* of mechanics can be understood as completing what nature leaves unfinished, a common Aristotelian view of the relationship between art and nature (e.g., *phys.* 199a15–17). I develop this view in my paper "Art and Nature in Ancient Mechanics," in Bernadette Bensaude-Vincent and William R. Newman (eds.), *The Artificial and the Natural: An Evolving Polarity* (Cambridge, Mass.: The MIT Press, 2007), 67–108.

48 Ctesibius (*fl.* ca. 270 B.C.) is credited with important inventions in many different areas of technology, including the water pump, water organ, water clocks, and automata, as well as various types of artillery engine. On his achievements see especially Gille, *Les mécaniciens grecs*, and Aage G. Drachmann, *Ktesibios, Philon, and Heron: A Study in Ancient Pneumatics* (Copenhagen: E. Munksgaard, 1948). From the way in which Philo introduces his discussion of the bronze-spring engine, it is clear that he relies on the reports of others for his knowledge of Ctesibius' work; cf. *Belopoeica* 67.28–68.2.

> [*peri tōn katholou*], since we intend to introduce a completely revolutionary proposition that is both unique in its design and far different from previous ones.[49] (*Belopoeica* 68.7–17)

The general inquiry described here is contrasted with the investigation of the effects of varying the dimensions of different components: such "minor causes" (*mikrai aitiai*) have been thoroughly investigated and tested (*pepeiramena*) by experience. With this clear reference to the development of the standard method Philo signals that that method too rests on an understanding of causes, in a sense. But if the goal is to make a fundamental improvement to the range of an artillery engine a deeper understanding of the principles that underlie its operation is necessary. Indeed, Philo's emphasis on the need for a general or universal (*katholou*) inquiry into the cause (*aitia*) of long range is strikingly reminiscent of Aristotle's doctrine that that it is the grasp of the universal (*katholou*) and the cause (*aitia*) that marks the transition from experience (*empeiria*) to art (*technē*).[50]

Philo's discussion of the problem of long range is remarkable, both for the dynamical assumptions on which it is based and for the consistency with which he applies them to the analysis of a technological device. He begins by reducing the problem to an analysis of the force provided by the springs. The force with which the arms are propelled determines the speed at which they move and therefore the range: the quicker the movement of the arms, the faster the missile travels, and the longer the range (68.18–29). The springs, in turn, are responsible for the force with which the arms are propelled; the problem thus becomes one of analyzing the force produced by the springs. Now the arm of a piece of torsion artillery, when inserted into the bundle of spring cords, is situated between two "half-springs" or *hēmitonia* (fig. 8). Philo claims that the force with which the arm is moved depends only on one of these half-springs, not on both, because the two half-springs exert equal forces (*dunameis*) and move at the same speed:

49 μέλλοντες οὖν περὶ τῆς τῶν τόνων ἰδιότητος ἀπαγγελεῖν καλῶς ἔχειν ὑπελαμβάνομεν καὶ ἐπὶ τούτου πρῶτον ἐπισκέψασθαι περὶ τῶν ἀρχαίων ὀργάνων καὶ συμβάλλειν, τίς ἐστιν ἡ αἰτία τοῦ μακρὰν ἀποστέλλειν δύνασθαι τὸ βέλος, μὴ περὶ μικρὰς αἰτίας τὴν θεωρίαν ποιούμενοι καθάπερ ἀνώτερον δεδηλώκαμεν, περὶ τὸ μακροτονεῖν ἢ συναιρεῖν τὸ μῆκος τῶν τόνων ἢ τοὺς ἀγκῶνας ἐπεκτείνειν ἢ συστέλλειν ἢ προσεστηκότας ἢ ἀναπεπτωκότας μᾶλλον ποιεῖν ἢ τὴν τῶν νεύρων ἢ τριχὸς ἀρετήν· ταῦτα μὲν γὰρ καὶ προεζήτηται, καθάπερ εἶπον ἐν τοῖς πρότερον, καὶ ἐν μέσῳ κείμενα κοινὰ πᾶσιν ὑπάρχει πολλάκις ἤδη καὶ παντοδαπῶς πεπειραμένα· νῦν δὲ ὁλοσχερῆ τινα δεῖ τὴν ἐπίσκεψιν περὶ τῶν καθόλου ποιήσασθαι μέλλοντας δὴ καὶ προσάγειν ὁλοσχερές τι θεώρημα καὶ ἴδιον τῇ διαθέσει καὶ πολὺ παρηλλαγμένον τῶν πρότερον.

50 *Metaph.* A 980a27–981b6; *an. post.* 100a3–b5.

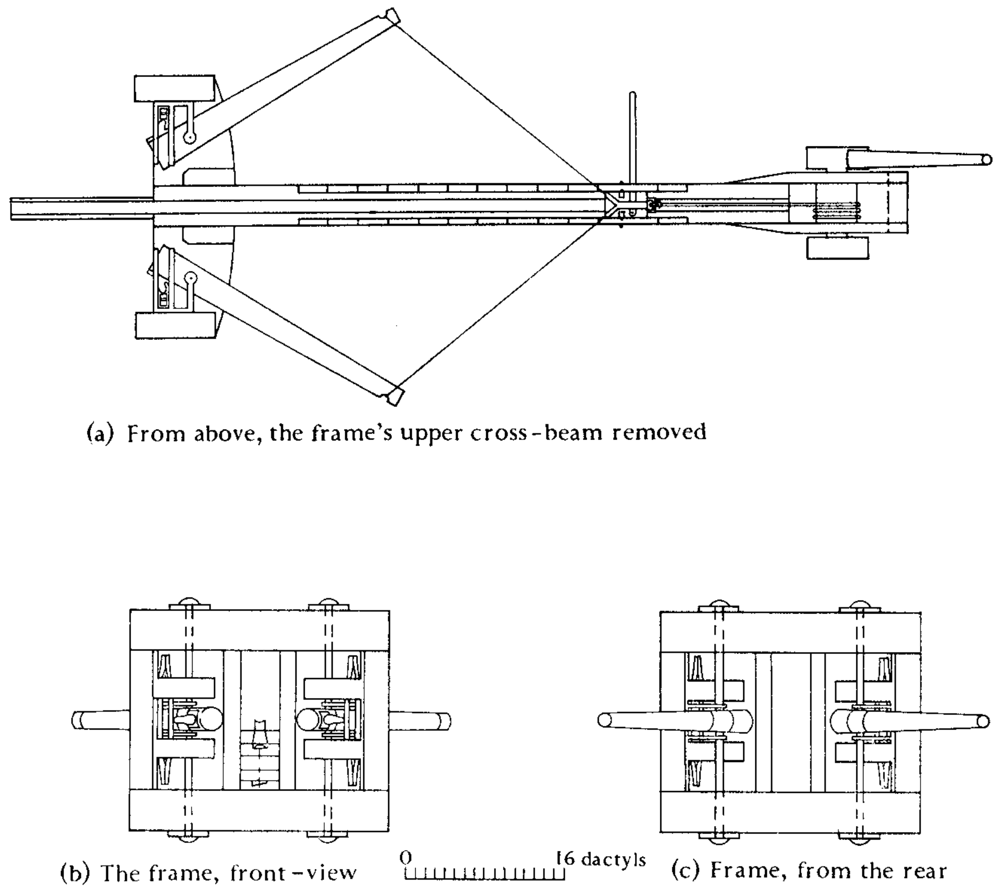

Fig. 7 Ctesibius' bronze-spring catapult (Marsden, *Technical Treatises*, 174)

> On the pulling of the trigger, the two forces [*dunameis*] of the half-springs simultaneously move the bowstring, since they have exactly equal speeds [*isotacheis*] because they are composed of equal and like forces [*dunameis*]. Now, the one force would not add to the speed of the arm unless it were greater than the other; for then it would overpower [*katakratoiē*] the lesser and increase the speed.[51] (*Belopoeica* 69.1–5)

To support this claim Philo presents a thought experiment, based on what he takes to be the acknowledged fact that heavier weights fall faster than lighter ones:

51 ἔν τε τῷ σχάσματι τὴν τοξῖτιν ἅμα συμβαίνει ἀμφοτέρας τὰς τῶν ἡμιτονίων δυνάμεις κινεῖν ἰσοταχεῖς αὐταῖς συνυπαρχούσας διὰ τὸ ἐξ ἴσων καὶ ὁμοίων δυνάμεων συνεστάναι. οὐκ ἂν οὖν πρὸς τὸ τάχος τοῦ ἀγκῶνος ἡ μία συμβάλλοιτο δύναμις, εἰ μὴ μείζων εἴη τῆς ἄλλης· οὕτω γὰρ ἂν κατακρατοίη τῆς ἐλάσσονος καὶ ἐπισυνάπτοι τῷ τάχει.

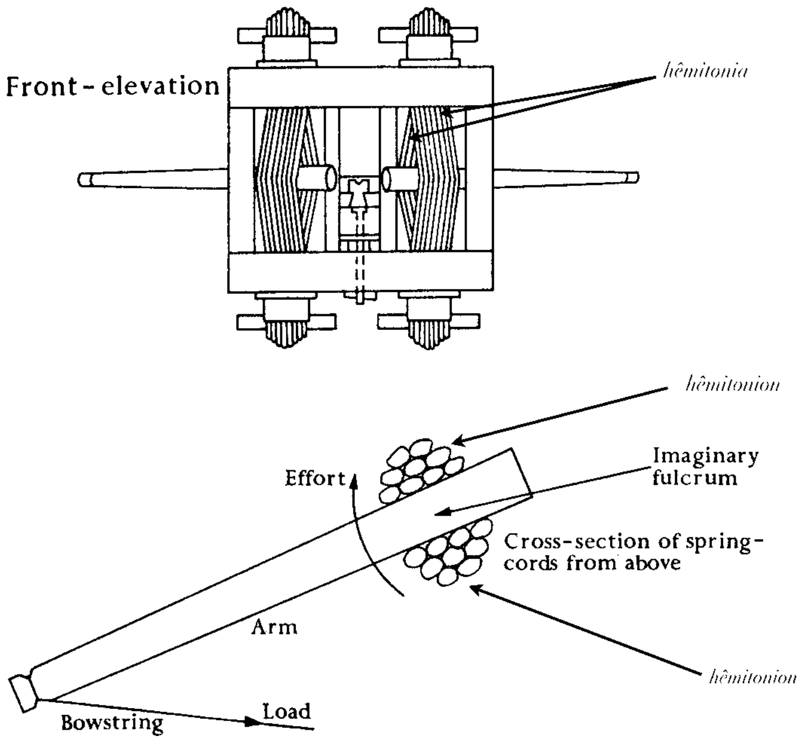

Fig. 8 "Half-springs" (*hēmitonia*), based on Marsden, *Technical Treatises*, 57 and 166

> If one takes two weights, alike in substance and shape, the one of one mina, the other of two minae, and lets them drop simultaneously from a height, I maintain that the two-minae weight will drop far more quickly. In the case of other weights the same account holds: the larger always falls proportionately [*ana logon*] more quickly than the smaller, whether because the greater weight, as some of the natural philosophers [*phusikoi*] say, can displace and disrupt the air more easily, or because greater inclination [*rhopē*] follows upon greater weight [*baros*], and the greater inclination [*rhopē*] increases the motion in the vertical direction.[52] (*Belopoeica* 69.8–14)

A weight of two minae will fall "far more quickly" than a one-mina weight, and the larger falls "proportionately" more quickly than the smaller.[53] Philo indicates

52 ἐὰν γάρ τις λαβὼν δύο βάρη, ὅμοια τῷ γένει καὶ τῷ σχήματι, τὸ μὲν μναϊαῖον, τὸ δ' ἄλλο δίμνουν, ἅμα ἀφ' ὕψους ἀφῇ φέρεσθαι, λέγω ὅτι τὸ δίμνουν παρὰ πολὺ τάχιον οἰσθήσεται· καὶ ἐπὶ τῶν ἄλλων δὲ βαρῶν ὁ αὐτὸς ὑπάρχει λόγος, ἀνὰ λόγον ἀεὶ τὸ μεῖζον τοῦ ἐλάσσονος ὡς τάχιον φέρεσθαι, εἴθ' ὅτι τὸ μεῖζον βάρος, καθάπερ φασί τινες τῶν φυσικῶν, μᾶλλον ἐκρομβεῖν δύναται καὶ διαστέλλειν τὸν ἀέρα, εἴθ' ὅτι τῷ μείζονι βάρει καὶ ῥοπὴ πλείων παρέπεται, ⟨ἡ⟩ δὲ πλείων ῥοπὴ μᾶλλον αὔξει τὴν κατὰ κάθετον φοράν.

53 This of course does not imply that a two-mina weight falls twice as fast as a one-mina weight; much more plausibly, it can be taken to mean that the speed of fall increases in constant ratio to the increase in the weight.

his familiarity with various explanations of this phenomenon given by natural philosophers without committing himself to a single alternative.[54] But then he goes on to develop the example further: a two-mina weight, he argues, will fall more swiftly not only than a one-mina weight, but also more swiftly than two one-mina weights joined together, and indeed more swiftly than several one-mina weights joined together:

> Again, because what has been said comes about, if one takes two weights of one mina and, having connected and fastened them together as well as possible, lets them drop, I affirm that the weight of two minae will once more drop more quickly than the two weights of one mina joined together. Even if three or more are connected together, they will likewise drop more slowly. It becomes clear from this that, when several forces [*dunameis*] equal to each other are connected together, their combined speed will not exceed the natural [*phusikē*] speed belonging to one weight alone.[55] (*Belopoeica* 69.14–20)

On this view, each weight is considered to have a natural force or capacity (*dunamis*) to fall at a certain speed; even if one fastens together two one-mina weights "as well as possible," the combination will not possess the natural *dunamis* of a two-minae weight. This, Philo claims, supports his view that only one of the half-springs contributes to the speed of the arm's motion. The two half-springs correspond to the two equal weights, which when joined together do not augment the natural motion of one weight alone: "Since this is so, it has been clearly shown that the one half-spring does not contribute to the movement of the arm at all, because its speed is equal to that of the other" (69.20–22).[56] Now it is impossible to do away with one half-spring in the case of standard torsion artillery, since the arm is wedged in between the two half-springs. This, Philo suggests, is the motivation for the introduction of the bronze-spring en-

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54 Cf. Arist. *phys.* 216a11–21, esp. 18–20, on the reason why heavier objects fall more quickly through a medium: "for the object that is moving or thrown divides either by its shape, or by the inclination which it possesses" (ἢ γὰρ σχήματι διαιρεῖ, ἢ ῥοπῇ ἣν ἔχει τὸ φερόμενον ἢ τὸ ἀφεθέν). The problem of free fall was investigated further by Strato of Lampsacus in the early third century B.C.; see fr. 73 Wehrli (= Simpl. *in phys.* 916.4–31) for a report of a test similar to Philo's.

55 πάλιν, ὅτι γίνεται τὸ ῥηθέν, ἐὰν δύο βάρη λαβὼν μναϊαῖα καὶ συνθεὶς ἔπειτα καὶ συναιωρήσας ὡς δυνατόν τις ἀφῇ φέρεσθαι· λέγω δή, ὅτι ταχύτερον οἰσθήσεται πάλιν τὸ δίμνουν βάρος ἢ τὰ δύο αὐτοῖς συγκείμενα μναϊαῖα βάρη· βραδύτερον δέ κἂν τρία καὶ ἔτι πλείονα συντεθῇ, ταὐτὸ ποιήσει. φανερὸν οὖν γίνεται καὶ ἐκ τούτου, διότι πλειόνων δυνάμεων ἐπὶ τὸ αὐτὸ συντεθεισῶν, ἴσων δὲ αὐταῖς οὐσῶν, οὐθὲν ἡ φορὰ κατὰ κοινὸν μᾶλλον αὔξεται τῆς ὑποκειμένης φυσικῆς τῷ ἑνὶ μόνον βάρει.

56 τούτων δὴ τοιούτων ὑπαρχόντων ἐδείχθη σαφῶς τὸ ἓν ἡμιτόνιον μηθὲν συνεργοῦν τῇ τοῦ ἀγκῶνος φορᾷ διὰ τὸ ἰσοταχὲς τῷ ἄλλῳ.

gine, in which a single spring forged from bronze plates provides all the motive power for each arm.

It is easy to dismiss Philo's thought experiment as a piece of purely armchair speculation. To be sure, Philo's claims are unlikely to be based on actual empirical tests with falling bodies. However, the argument is quite Aristotelian in spirit. The basic idea is that two one-mina weights when joined together do not unite into a single substance with the natural motion of a two-mina weight; this would require a genuine fusion of the two weights into a single nature (*phusis*).[57] Similarly, two half-springs acting together will not produce the same motion as a single spring with twice the resiliency. From the point of view of the Aristotelian distinction between forced and natural motion, it is remarkable that Philo draws an analogy with the natural motion of falling bodies to explain the motion of the arms of the artillery engine. There is no suggestion of any fundamental difference between the natural motion of falling bodies and the forced motion of the arms; instead, understanding the former is crucial for understanding the latter. A knowledge of "physical arguments" (*phusikoi logoi*) that includes the behavior of the natural motion of bodies is thus essential to understanding the forced motion of the arms of an artillery engine, and so to improving its design.

Philo applies the analogy with falling bodies quite consistently. At *Belopoeica* 72.24–73.20 he goes so far as to criticize Ctesibius for using more than one bronze spring for each of the arms in his design. This, he says, was due to a failure to grasp the truth revealed by the thought experiment; that is, Ctesibius held the mistaken belief that "more forces [*dunameis*] of equal speed [*isotacheis*] and alike in strength [*ischus*], when joined together, would produce a more violent

57 Similar issues about the additivity of forces are discussed by the Aristotelian commentators; cf. Shmuel Sambursky, *The Physical World of Late Antiquity* (London: Routledge, 1962), 65–68. I note in passing that Philo's analysis shows that a famous thought experiment found in early modern authors such as Galileo was not nearly as conclusive as it is sometimes taken to be. According to this thought experiment, if we imagine two one-pound weights first falling side by side, then coming together as they fall, on the Aristotelian view we would have to conclude that they would suddenly speed up and fall twice as fast – a conclusion so implausible that it would imply the falsity of the Aristotelian view. But Philo's passage shows that an Aristotelian could quite easily accept the absurdity of the conclusion but reject the inference leading to it: indeed, he might say, two one-pound weights joined together do not fall as quickly as a single two-pound weight, but this is because they do not make up a single body with the corresponding natural motion. Only if the two weights really fused into a single two-pound weight would an Aristotelian be committed to the claim that the speed of motion would double; but such a fusion, it could be argued, goes well beyond what was envisioned in the original thought experiment.

thrust [*bia*]" (72.26–28). Just as only one of the half-springs contributes to the movement of the arm in a standard-design engine, so only one bronze spring will contribute to the movement of the arm in the bronze-spring engine; the inclusion of multiple springs just makes the arms harder to pull back, while contributing nothing to the range. Underlying all of Philo's dynamical reflections is a consistent association between force and speed: a greater force is assumed to correspond directly to a greater speed of movement. Now if one thinks of a force simply as a capacity to produce a motion of a certain speed, it might seem reasonable to suppose that a combination of forces, each of which produces a motion of the same speed, will not produce a movement that is any faster than each of the forces taken individually. This at any rate seems to be the idea behind the following passage, from Philo's criticism of Ctesibius:

> Many forces [*dunameis*] of equal speed [*isotacheis*], when joined together, and when all are being compressed, produce a resistance proportional to the sum of their forces, so that the sum total of thrust [*bia*] is considerable. But, in their recoil, as there is no difference in their speed, they all move simultaneously. How then can one of them alone acquire additional speed, when it, too, has the same speed?[58] (*Belopoeica* 73.8–13)

Philo's view is certainly strange from the point of view of modern (i.e., Newtonian) mechanics, and might seem open to obvious criticism even from an ancient perspective. Surely, one might think, if two bronze springs (or half-springs in a torsion engine) acting together dispatch the missile quickly, one will dispatch it with half the speed, or perhaps not provide enough force to move it at all.[59] But this misses the point of Philo's association between force and speed. Philo assumes that both springs have the capacity (*dunamis*) to move the arm at a certain speed when employed individually; if this is so, he might ask, why suppose that the two together would move it more quickly? After all, it is not as though one spring will move more quickly than the other when it recoils.

Philo's discussion of the construction of the bronze springs themselves at *Belopoeica* 70.35–72.4 provides further information about his conception of the

58 αἱ γὰρ πολλαὶ δυνάμεις, ἰσοταχεῖς δ' οὖσαι, ὅταν αὐταῖς συζευχθῶσιν, ἐπισπώμεναι μὲν ἅπασαι τὴν ἀντίβασιν ποιοῦνται κατὰ τὴν ὑπάρχουσαν αὐταῖς δύναμιν, ὥστε πολλὴν τῆς βίας ἄθροισιν γενέσθαι· ἀναπίπτουσαι δὲ καὶ οὐθὲν ἀλλήλων τῷ τάχει διαφέρουσαι πᾶσαι ἅμα φέρονται. πῶς οὖν δυνατόν ἐστι προσλαμβάνειν τάχος τὴν μίαν τούτων μόνην, ἔχουσαν καὶ αὐτὴν τὸ ὅμοιον τάχος;
59 Cf. Aristotle's famous analysis of forced motion in *phys.* 249b27–250b7: if "force" (*ischus, dunamis*) A moves load B over distance D in time T, then 2 A will move B over distance 2D in time T, but it does not follow that A/2 will move B at all.

role of *phusikoi logoi* in artillery design. His chief concern is to respond to the objection that bronze is not naturally resilient in the way that is necessary if it is to be used for powering an artillery engine. As an example of material with the necessary degree of resiliency Philo cites the iron of "so-called Celtic and Spanish swords" (71.9), which can be bent repeatedly but always return to their normal straightness. Philo remarks that the reason (*aitia*, 71.17) why these swords behave in this way has been the subject of special investigation; the answer lies in the way they are made, which involves beating them gently to create hardness on the outside while leaving the middle soft and flexible. The need to justify this procedure leads Philo to appeal once again to the views of natural philosophers:

> Firings soften iron and bronze, because the bodies [*sōmata*] become rarer, as they say; while coolings and beatings harden them, for both processes cause the bodies [*sōmata*] to become tightly packed, because their parts [*moria*][60] move closer to one another and the interstices of void are removed.[61] (*Belopoeica* 71.27–31)

The combination of a corpuscularian theory of matter with the hypothesis of interspersed void is characteristic of Hellenistic matter theories, especially those associated with Strato of Lampsacus.[62] As in the case of the wedge engine, a knowledge of the natural constitution of the components of the machine is necessary for understanding its operation; this is best provided, at least in some cases, by an up-to-date knowledge of the work of natural philosophers.[63]

60 These "parts" are the small pieces of matter which, along with the interspersed void space, make up the larger bodies.

61 αἱ μὲν οὖν πυρώσεις τόν τε σίδηρον καὶ χαλκὸν μαλακύνουσιν ἀραιουμένων τῶν σωμάτων, ὥς φασιν, αἱ δὲ ψύξεις καὶ κροτήσεις σκληρύνουσιν· ἀμφότερα γὰρ αἴτια γίνεται τοῦ πυκνοῦσθαι τὰ σώματα συντρεχόντων τῶν μορίων πρὸς ἄλληλα καὶ τῆς τοῦ κενοῦ περιπλοκῆς αἰρομένης.

62 Strato adopted a theory of interspersed void to explain such phenomena as the transmission of light and heat through substances such as air and water; see fr. 65a Wehrli (= Simpl. *in phys.* 693.10–18). Philo's term for "resilience" is *eutonia*, ascribed to the iron of the Celtic and Spanish swords at *Belopoeica* 71.22 and 72.1; it is notable that this concept plays a large role in the theory of matter propounded by Hero of Alexandria in the introduction to the *Pneumatics* (proem lines 76, 249), which itself goes back ultimately to early Hellenistic antecedents (including Strato).

63 That *phusikoi logoi* are in question here is made absolutely clear by the conclusion of the discussion of the resiliency of bronze at 72.1–4: "Let this be enough about bronze-spring engines and the construction entailed therein, lest we inadvertently digress too far and enter deeper into physical arguments [εἰς τοὺς φυσικοὺς … λόγους]."

3 Ctesibius' Air-Spring Engine (*aerotonos*)

A third innovation in artillery construction that Philo presents as drawing on theoretical knowledge is the air-spring engine or *aerotonos* also invented by Ctesibius (*Belopoeica* 77.9–78.22). In this design, precisely manufactured bronze cylinders and pistons are attached to the arms of a stone-throwing engine. When the arms are pulled back, the pistons are pressed into the cylinders, compressing the air in them; on pulling the trigger, the impulse of the air to return to its natural state pushes the pistons out with great force and propels the arms forward. Philo emphasizes the fact that the air-spring engine has both a "physical" and a "mechanical" character (μηχανικὴν δὲ πάνυ καὶ φυσικὴν εἶχε διάθεσιν, 77.11–12). According to his account, Ctesibius based the invention on his knowledge of pneumatics, the study of the behavior of air in closed vessels, especially under compression; drawing on this knowledge and his experience in mechanics, he realized that the power of compressed air could impart high speed to the arms (77.12–18). The chief technical challenge involved was the construction of the airtight cylinders and pistons. Philo describes the procedure followed in some detail, and responds to those who might doubt the possibility of such construction by citing the example of a well-known mechanical device that also makes use of cylinders and pistons, the water organ (77.27).[64] The "mechanical" excellence of the air-spring engine is reflected in the fact that Ctesibius aimed not only at long range but also at an attractive design.[65] Philo relates how Ctesibius demonstrated the natural compressibility and force of air, as well as the possibility of constructing cylinders with the requisite properties:

> Ctesibius, it was explained to us,[66] demonstrated the nature [*phusis*] of air – namely that it has violent and swift movement – and, at the same time, the fabrication entailed by the cylinders which contain the air; he smeared the cylinder with carpenter's adhesive, set a protective edging over the circular mouth [sc. of the cylinder], and with wedge and mallet drove in the piston with very great force. It was possible to see the piston making gradual progress; but, when the air inside was once compressed, it gave way no more even to the strongest blow on the wedge. On the application of force and the removal of the wedge, the

64 Philo also notes a parallel with medicine: the cylinders were shaped "like doctors' medicine-boxes" (ὅμοια πυξίσιν ἰατρικαῖς, 77.18–19).

65 "He aimed not only at strength, but also fine appearance so that it should seem to be a [genuine] instrument" (οὐ μόνον τῆς ἰσχύος, ἀλλὰ καὶ τῆς ὄψεως στοχαζόμενος, ὅπως ὀργανικὴ φαίνηται, 78.11–12).

66 The Greek is peculiar (see next n.), but should be understood in light of Philo's reliance on others for information about Ctesibius; cf. n. 48 above.

> piston shot out with great force from the cylinder. It often happened that fire came out, too, since the air rubbed against the vessel in the speed of its motion.[67] (*Belopoeica* 77.29–78.7)

Once again the construction of a mechanical device is said to depend on knowledge of physics; the speed of the arms is traced back to the natural tendency of air to expand when it has been compressed. The "physical" and "mechanical" character of the air-spring engine thus results from the fact that it makes creative use of natural principles to achieve a beneficial and aesthetically pleasing result.

The three examples[68] we have discussed in this section suggest the following conclusions about Philo's conception of the role of mechanical and physical theory in artillery construction. First, mechanical theory is not applied deductively; rather, a knowledge of theoretical principles guides the practitioner in his attempt to understand the working of a complex piece of artillery and improve its design, by suggesting analogies between the components of complex machines and simple machines such as the lever. Second, the appeal to theory does not result in greater quantitative precision; Philo's appeal to the law of the lever is much closer to the Aristotelian *Mechanical Problems* than to Archimedes' quantitatively precise formulation. Third, a knowledge of "physical arguments" dealing with such phenomena as the resiliency of materials, the natural motion of falling bodies, and the compressibility of air is essential to the process of discovery; this is because the optimal functioning of a machine depends on its components acting in ways that are natural for them. Far from suggesting an opposition between the "mechanical" and the "natural," Philo argues that their proper combination is one hallmark of an excellent machine like Ctesibius' *aerotonos*.

67 ἐπεδείκνυτο δὲ ἡμῖν ὁ Κτησίβιος παραδεικνύων τήν τε τοῦ ἀέρος φύσιν, ὡς ἰσχυρὰν ἔχει καὶ ὀξεῖαν κίνησιν, καὶ ἅμα τὴν περὶ τὰ ἀγγεῖα ὑπάρχουσαν χειρουργίαν τὰ τὸν ἀέρα συνέχοντα, περιθεὶς κολλητήριον τεκτονικὸν περὶ τὸ ἀγγεῖον καὶ πρόθεμα ἐπιθεὶς τῷ κυκλίσκῳ, καὶ σφηνὶ καὶ σφύρᾳ εἰσωθῶν τὸ τυμπάνιον μετὰ βίας μεγίστης. ἦν δὲ ὁρᾶν μικρὰν μὲν ἔνδοσιν ποιούμενον τὸ τυμπάνιον, ὅτε δὲ ἅπαξ ὁ ἀπειλημμένος ἀὴρ ἔσω πιληθείη, μηκέτι εἶκον μηδὲ ἐκ τῆς ἰσχυροτάτης πληγῆς πρὸς τὸν σφῆνα· καὶ βίας προσαχθείσης ἐκκρουσθέντος τε τοῦ σφηνός καὶ τὸ τυμπάνιον ἐξήλλετο μετὰ βίας πολλῆς ἐκ τοῦ ἀγγείου. πολλάκις δὲ συνέβαινε καὶ πῦρ συνεκπίπτειν διὰ τὴν ὀξύτητα τῆς φορᾶς παράτριψιν λαβόντος τοῦ ἀέρος πρὸς τὸ τεῦχος.

68 The fourth modified design that Philo discusses is the so-called repeating catapult invented by Dionysius of Alexandria (73.21–77.8). This was an engine that could shoot a large number of arrows in rapid succession. Although he praises this design for its inventiveness (φιλότεχνον, 76.22, μὴ ἀμηχάνως, 77.8), he claims that it is useless in battle: since the operator normally faces a moving target, repeated shots to the same location would only result in a waste of missiles. The account of the repeating catapult does not involve any theoretical considerations.

Conclusion

Let me now sum up by offering a general characterization of Philo's conception of expertise in light of the foregoing analysis and attempting to place it in a wider context. We have seen that a concern with general explanations runs throughout Philo's account of the artillery builder's *technē*. The rules of the standard method are based on recognizing the character of the spring hole diameter as the fundamental principle of construction, while the practice of artillery design, as reflected in the second part of the *Belopoeica*, demands a general inquiry into the cause (*aitia*) of long range. In keeping with this picture, Philo views both theory and experience as crucial to the *technē* of artillery construction, though the emphasis is different in the two parts of his account. The discussion of the standard method stresses the importance of testing or *peira*; on the other hand, the modified designs depend crucially on an understanding of basic principles of theoretical mechanics such as the law of the lever, as well as knowledge of physics, understood broadly to include the properties of materials, natural motion, and the behavior of compressed air. Physical and mechanical theory is applied in a flexible, non-deductive manner, with a view towards qualitative improvements in performance and in order to ensure that the components of the artillery engine behave in ways that are natural for them. Finally, despite Philo's claim that artillery construction is a *technē* with a unitary goal, his many references to aesthetic and other factors suggest that the ancient practitioner of this *technē* was motivated by the need to balance the competing claims of a variety of goals.

In its concern with generalization and explanation Philo's conception of *technē* shows clear affinities with the Platonic and Aristotelian discussions mentioned in the Introduction. Indeed, by insisting on the need for the modified designs to be based on theoretical understanding, Philo arguably goes beyond Aristotle, who sometimes grants that *empeiria* is sufficient for practice (above, n. 12). Philo's emphasis on the importance of *peira* is characteristic of the early Hellenistic period, as exemplified by the rise of the Empiricist school of medicine in the third century B.C. Yet Philo's stress on the systematic, directed nature of the discovery process sharply differentiates his conception of the role of *peira* from that of the Empiricists. As Philo puts it, it was not just one chance observation that led the Alexandrian engineers to their discovery, but a program of directed research that was only possible with state support. The Empiricists did accord an important role in discovery to repeated testing: on their view, a generalization such as "bloodletting cures fever" needed to be confirmed on many occasions if it was to be accepted as part of the medical *technē*.[69] Yet they were quite willing to acknowledge that the ultimate source of the propositions they put to the test was chance observation. The overall impression given by the Empiricist accounts of the discovery of medicine (as far as we can judge from the sources) is that it is a passive process driven by chance factors, not the kind of active, directed investigation that Philo associates with the Alexandrian engineers.[70] Two other features that distinguish Philo's spring hole relations and dimensional lists from the types of generalizations normally associated with *empeiria* in medical and philosophical sources are their universal character and their exactness.[71] Finally, we may note that Philo's emphasis on the need for theory to make innovations in artillery design resonates with one of the charges frequently directed against the Empiricists, viz., that their rejection of theory made it impossible for them to deal with new diseases.[72]

In conclusion, the particular combination of concerns with generalization, systematic testing, and mechanical and physical theory that we have discerned in Philo's conception of the *technē* of artillery construction finds no exact parallel in any ancient philosophical or medical source. Rather than viewing Philo's conception of expertise as the result of influence from a particular thinker or school, we should see it as the result of sophisticated reflection on the methodological situation in the discipline of artillery construction as Philo encountered it, informed by broad familiarity with philosophical and scientific thought.

69 This is the so-called "mimetic" (*mimētikon*) type of experience, which arises when cures suggested by chance or some other source are "put to the test" (εἰς πεῖραν ἄγηται, Gal. *de sectis* 2, 1.67 K. [= 3.7–8 Helmreich]).

70 Only the procedure known as "transition to the similar" (ἡ τοῦ ὁμοίου μετάβασις), which involved applying cures effective against certain diseases to other similar diseases, or cures effective on certain parts of the body to other similar parts, could be said to involve the formulation of hypotheses on the basis of specialized experience. This procedure did not result in discovery until confirmed by a test known as πεῖρα τριβική (Gal. *de sect.* 2, 1.67–68 K. [= 3–4 Helmreich]). But the Empiricist attitude to this procedure was highly ambivalent, and many refused to recognize its legitimacy. See Heinrich von Staden, "Experiment and Experience in Hellenistic Medicine," *Bulletin of the Institute of Classical Studies* 22 (1975): 178–99.

71 For quantitative precision as distinguishing *technē* from *empeiria* cf. Plat. *Phlb.* 55e1–56c7. The Empiricists acknowledged that the generalizations on which medicine was based were typically not universally valid, and they developed a fourfold classification: some held in all cases, others in most, others half the time, others only rarely (Gal. *subf. emp.* 45.24–30 Deichgräber; *de exp. med.* 15 [112–13 Walzer]).

72 For a closer medical parallel to Philo's position we might look to the doctor Erasistratus. According to Galen (*de sectis* 5, 1.75 K. [= 9.13–19 Helmreich]), Erasistratus claimed that experience was sufficient for the discovery of "simple" cures, such as antidotes, but not for more complex cures, where theory was needed.

Philo's picture of artillery construction is a response to the distinctive features of a field of technology that had developed, through empirical investigation, a quantitatively precise set of rules and procedures that exerted significant influence on its practice. In attempting to bring together the various strands of this most dynamic of ancient technological traditions under the rubric of a unified conception of *technē*, Philo offers one of the most detailed, sophisticated, and distinctive accounts of expertise that we have from the ancient world.

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