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Archimedes' Weapons of War and Leonardo

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INTRODUCTION

Leonardo's fascination with Archimedes as well as with his mathematics is well known. There are three fairly extensive and eccentric comments in the surviving notebooks: on his military inventions; on his part in an Anglo-Spanish conflict and on his activities, death and burial at the siege of Syracuse. Reti has examined the first of the three, that about the *Architronito* or steam cannon, mainly considering the origin of the idea for the cannon and its attribution to Archimedes, but with comments on the later influence of Leonardo's ideas. Marshall Clagett has produced the most comprehensive attempt to try to identify Leonardo's sources for the third.[1]

Reti's analysis can be supplemented and extended in the light of more recent comments and Sakas' experimental demonstration of a miniature working model, and Clagett's proposed sources modified. The origins of the other reference, Leonardo's belief that Archimedes played a part in an Anglo-Spanish war, can also be rendered slightly less baffling. Any conclusions must necessarily be tentative given the generally accepted opinion that much less than half of Leonardo's manuscripts survive.[2]

ARCHITRONITO

Leonardo's earliest surviving mention (late 1480s–1490) of Archimedes' weapons of war is perhaps the most startling (Ms.B 33r):[3]

> Architronito. Gunsight. Ensure that the rod cn is placed over the centre of the table fixed beneath so that the water can fall with a single shot on to this table.
>
> The *Architronito* is a machine of fine copper, an invention of Archimedes, and it throws iron balls with great noise and violence. It is used in this manner:—the third part of the instrument stands within a great quantity of burning coals and when it has been brought to white heat you turn the screw d, which is above the cistern of water abc, at the same time

1 N. de Toni, 'Saggio di onamastica Vinciana,' *Raccolta Vinciana*, 1930–34, **XIV**, pp. 54–117, pp. 61–62, Spellings 'Archimedes' and 'Archimenides' recorded indifferently; *The Notebooks of Leonardo da Vinci*, 2nd edn (ed. and tr. E. McCurdy), 2 vols., London, 1954,: de Toni's nos, 94–97 *Codex Atlantico* not given; editing inconsistent, 'Archimenides' sometimes left, sometimes 'Archimedes' substituted; all four references in the B. M. Arundel Ms. 263, 279v are given as 'Archimedes', ii, p. 526, but first two 'Archimenide' in original, [L. Reti, 'Il Mistero dell Architronito,' *Raccolta Vinciana*, 196x), 19, pp. 171–183 177]. Reti ibid., pp. 171–183; Marshall Clagett, *Archimedes in the Middle Ages*, Philadelphia, 1978, 'The fate of the Medieval Archimedes, 1300–1565,' pt. 3, iii, pp. 480–481.

2 I. Sakas, reported by Mario Modiano, Athens, May 14, *The Times*, London, 15 May 1981; A. Marinoni, 'Leonardo's Writings,' in *Leonardo the Scientist*, London, 1980, pp. 72–73.

3 Lénard de Vinci, *Manuscript B de l'Institut de France*, (transcrib. N. de Toni, tr. into French, F. Authier, intro., A. Corbeau), Grenoble, 1960, pp. 92, 94 (Italian), pp. 93, 95 (French) (Ms. B 33r), tr. based upon E. MacCurdy, op. cit. (1), ii, pp. 176–177, 1st and 3rd paras added.

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that you turn the screw below the cistern and all the water it contains will descend into the white hot part of the barrel. There it will instantly become transformed into so much steam that it will seem astonishing, and especially when one notes with what force and hears the roar that it will produce. This machine has driven a ball weighing one talent six stadia.

Coke. Water. How the *architronito* is carried on to the field of battle.

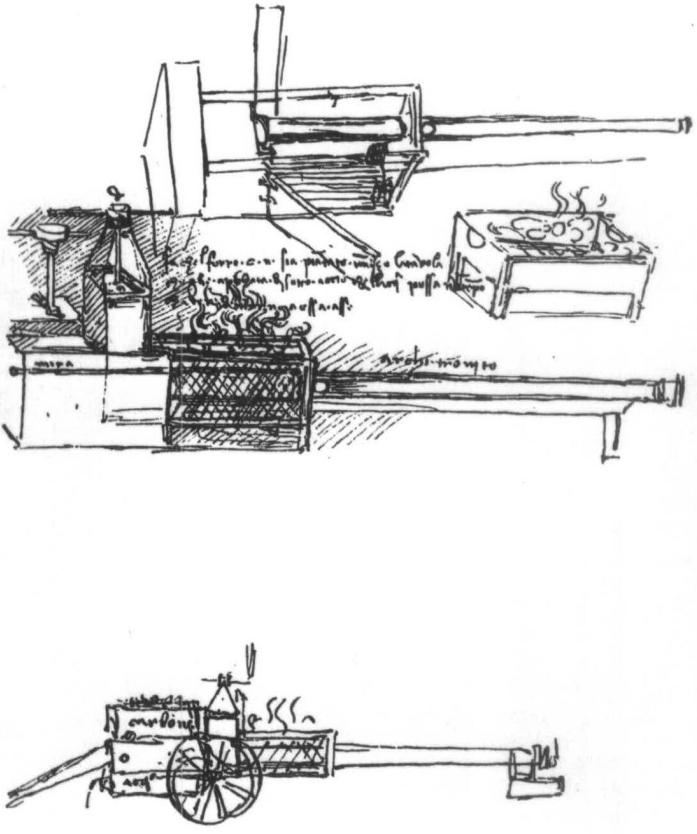

Figure 1. Leonardo's sketches of the Architronito.

Combining Leonardo's description with the information from the three sketches (Fig. 1) suggests that the cannon consisted of a long gun-barrel made of copper; about one-third of its lower end (what would be the powder-chamber or breech in the more customary gunpowder barrel) was buried within a fuel chamber burning coal. A hollow vertical tube with a funnel at its top was fixed to the top of the barrel near to the closed end. A water cistern was placed above the fuel chamber with a vertical tube rising from its top to a screw valve directly above it. A horizontal hollow tube closed at one end and open at the other, connected to the screw valve with the open end, was placed directly above the funnel. When the barrel was white hot, the upper screw valve was opened, and the lower valve immediately afterwards; these two operations released water into the horizontal pipe. This water then ran through the vertical pipe into the white hot barrel. Its sudden conversion into steam created enough expansion power

to eject a cannon-ball violently. Reloading the cannon should present few difficulties, and the water in the cistern would remain hot enough so that a second and third round could follow soon after.

The third sketch and the third paragraph are about the working device: this appears to have been slightly simpler.

Origins of the attribution

Reti demonstrated that Leonardo's source of the idea for this weapon was the drawings of cannons in *De Re Militari* by Valturius, who stated that the cannon had been invented—*ut putatur*—by Archimedes. Leonardo had a copy of Valturius in his library, which he annotated and from which he devised other inventions. He even used Valturius' own figures and units (Classical Greek talent and stadia) for the weight of the ball and the distance that it would carry. Leonardo had transmuted an idea in a primitive drawing into a new weapon, using a new motive power, 'steam', in place of the already well-established 'gunpowder' and invented the steam cannon long before Bourgeois in 1605; indeed, the gun used in the American Civil War resembled that designed by Leonardo. Reti therefore hailed him as the true precursor of Watt in utilizing steam as a prime mover, since there was evidence, following in part Duhem, that his ideas had been utilized by later inventors such as Cardan, Della Porta, Branca and De Caus as well as Bourgeois. He had merely failed to understand the measure of his achievement.[4]

This failure is all the more astonishing, because on the previous page of the notebook Leonardo had described another *architronito*, but one that used gundpowder and not steam (Ms.B 32r):[5]

> Architronito. This has a breech of fine copper with a bowl of iron and it is good (effective). After charging it with powder and allowing the powder to settle, you will make with an arrow a small hole and you will fill the bowl with fine powder.

Valturius almost certainly took the belief that Archimedes had invented the cannon from Petrarch's *De Remediis*, but Reti did not examine whether Leonardo knew Petrarch's book. He did own one of his works, but Richter suggested that it was probably a collection of canzonieres or sonnets.[6] However, Pedretti argued that one quotation of Leonardo came indirectly from *De Remediis*; 'Thou, O God, dost sell us all good things at the price of labour.'

> No doubt Leonardo intended his text as a quotation from Horace, but its deviation from the original can be explained by the source he had possibly (my underlining) that is, Petrarch's *De remediis utriusque fortunae* (bk, 2,12): . . . Petrarch quotes Horace first and then an

4 L. Reti, op. cit. (1), especially pp. 176–180, p. 181 (inspired by Valturius, Italian ed, of 1483), (Bourgeois first steam cannon, 1605), pp. 181–183 (Cardan *et al.*,); P. Duhem, Etude no. 6, 'Lénard de Vinci, Cardan, et Bernard Pelissey,' in *Etudes sur Leonard de Vinci*, 3 vols, Paris, 1956, i, pp. 222–223.

5 Op. cit. (3), p. 90, p. 91; my translation.

6 *The Literary Works of Leonardo da Vinci*, 3rd edn (ed. and tr., J. P. Richter), 2 vols., London, 1970, i, p. 368, n. 15, p. 384, n. 8, 9, 10. M. Clagett, op. cit. (1), pp. 1329–1341, p. 1340. (Petrarch's comments rested in part on Livy and Orosius).

unidentified poet. With an overlapping of recollection, Leonardo took the second quotation, attributing it to the author of the first. He was not after literary accuracy but after a suitable motto for his scientific researches.

To support his argument, Pedretti pointed out that the Italian translation of *De Remediis* by Giovanni Passiminato, made in the 1420s, has that same sentence in a form almost identical to Leonardo's text. Since Pedretti's date for the Leda Ms. (*c.* 1507) is much later than the drawing of the steam cannon, Leonardo read *De Remediis* after he had concluded that Archimedes had invented the steam cannon, and if he noticed the passage in Petrarch about Archimedes' invention of the ordinary cannon, either he did not realize its import for, or had forgotten, his own attribution.[7]

Given Reti's demonstration of its origin in Valturius, there is no good reason to suppose that Leonardo was confusing Archimedes with Heron of Alexandria as Hart seems to imply. Heron, it is true, had described a steam-operated device (*Pneumaticorum*, bks 2, 6 and 11) and Leonardo possessed some knowledge of his work, either directly or through secondary sources, but this only made Leonardo aware that steam could be used as a prime mover. Additionally, Leonardo's knowledge of Heron is likely to have come after he had designed the *architronito*, not before.[8]

Does the *Architronito* work?

No serious commentator has doubted that Leonardo's *Architronito* would function. A mock-up model was built for IBM, now in the Leonardo Museum in Vinci, but it is only recently that a Cretan engineer, Ioannis Sakas, has built a working model based upon Leonardo's sketches.[9]

He is reported as believing that the original model had a five-foot wooden barrel and fired a 22-pound stone ball to 3000 feet with the help of (a) steam pressure of at least 30 atmospheres'. His own version, built on a scale of one to five, has a one-foot-long wooden barrel with a 2½-inch bore, fixed on a steam cylinder made of thick copper which is heated by an open fire (made of twigs) to 400 degrees centigrade.

After inserting the cannon ball and propping it with sticks to allow for pressure to build up, he poured five grams of water into a protruding pipe. Then seconds after switching the valve to let the water into the empty hot chamber, the steam sent the ball off to a distance of 150 feet. He used thin wooden splints to prop the ball for fear high pressure would send the missile to well over 600 feet.

Sakas' machine is reported to have projected a missile, a 10 oz. tennis ball filled with hardened cement, to a distance of 150 ft to 200 ft within seconds.

7 C. Pedretti, *Leonardo: A study in Chronology and Style*, London, 1973, p. 176 (quotations), 101 (Leda Ms.).

8 E. Solmi, 'Le Fonti dei manoscritti di Leonardo da Vinci,' *Giornale storico della Letteratura Italiana*, Turin, 1908 and 1911, Supp. 10–11, pp. 143–146, 143, 143 footnote 2 (W. Schmidt, 'Leonardo da Vinci und Heron von Alexandria,' *Bibliotheca Mathematica*, 3rd series, 1902, 3, pp. 180–187, 181); I. B. Hart, *The World of Leonardo da Vinci*, London, 1961, p. 295; N. de Toni, op. cit. (1), pp. 116–117, (nos. 1031–1037).

9 M. Guerrini, *Il Museo Leonardiano di Vinci*, Vinci, 1986, pp. 54–55 (description is inaccurate; water falls into the heated gun barrel not on the burning coals); I. Sakas, op. cit., (2).

'The secret of this machine', Sakas said, 'is that the ball must be held down for a few seconds by the wooden splints so that when the ball is fired it should acquire adequate speed.'

'I believe', he concluded, 'that this miniature model functions on scale exactly as the original built by Archimedes.'

Some allowance has to be made for the reporter who must be taken to have given his own version and translation of what Sakas actually said, but there seems no reason to question the main details. He appears to have ignored Leonardo's second screw valve. If his explanation be correct, rather than the reporter's version, his principal, important, innovation is the use of wooden splints to hold back the ball until the pressure in space behind it in the barrel is high enough to ensure that its initial (muzzle) velocity is high.

Other than this necessary modification, and a simplified valve system, the machine is as described by Leonardo, but with a wooden barrel instead of the copper one prescribed by Leonardo. Sakas is not reported as giving any explanation why he used wood instead of copper. He might have believed that a copper barrel was beyond the craftsmen of Archimedes' time. The discovery of four bronze pumps with very accurately bored cylinders and close-fitting pistons suggests that some craftsmen of the period could have constructed the barrel in copper for Archimedes, had he conceived of, designed, and built the device.[10]

Sakas' model, functioning as effectively as it did, is a tribute to his engineering skill. As Leonardo gave no measurements on his drawings, the basis for Sakas's claim, if he is being reported accurately, that his model is fifth-scale, is not obvious. However, increasing the scale should not affect the operation of the cannon, provided that sufficient water can enter the chamber at the same time to generate sufficient power sufficiently quickly.

There is no need to follow Sakas in his belief that Leonardo had access to Archimedes' original plans, since, *unfortunately*, presumably lost, or that Petrarch specifically referred to the steam cannon.[11]

Was the *Architronito* ever tested?

Payne is quite adamant that none of the group of weapons described in Leonardo's letter to Ludovico, Duke of Milan, was ever built or employed in warfare.[12]

> He can imagine terrible engines of war, but only on paper. His machines would not work.

and again

> We forget that the claims made by Leonardo are beyond reason and could only be made by a sick man in a state of manic exaltation.

10 J. G. Landels, *Engineering in the Ancient World*, London, 1978, p. 83. J. Briggs, personal communication, (cannon of Petrarch's day and a little later were made of wrought iron staves held together by wrought iron bands).

11 I. Sakas., op. cit. (2); D. L. Simms, *The Times*, London, May 21, 1981; D. L. Simms, 'Archimedes and the Invention of Artillery and Gunpowder,' *Technology and Culture*, 1987, **28**, pp. 67–79.

12 R. Payne, *Leonardo*, London, 1979, p. 66, 69.

Calvi believed to the contrary that the projects in Ms.B were the realization of the programme proposed by Leonardo in his letter to Ludovico. More specifically Gibbs-Smith and Rees argue that

> Since Leonardo quoted figures of how far the *Architronito* would drive a cannonball of given weight, it is possible that one was actually built.[13]

Dibner also thought that Leonardo's language indicated that the gun had actually been made and that he had carried out experiments with ballistic missiles.[14] Admittedly, Leonardo could hardly have calculated the distance that he claims the ball would travel theoretically, but Reti showed that the measurements were taken directly from Valturius. The figures cannot therefore be used to claim that the *Architronito* was built.[15]

Moreover, although there are at least three passages in his notebooks which support the idea that he had carried out some experiments on ballistic missiles they are all later than MS.B. The first is (I. 102V–103V):

> . .A very small object should be moved as rapidly as thought itself . . . If one shoots a small grain with gunpowder (from a cannon) it should by this reasoning be sent a million miles in the time when a thousand pounds of ball will go three miles . . . You investigators should therefore not trust yourselves to authors who by employing only their imaginations have wished to make themselves interpreters between nature and man, but only to those who have exercised their intellects with the results of experiments.

A later page in the same folio has a drawing showing how the trajectory of a ball discharged from a mortar varies with the angle of the mortar to the vertical, taking account of the effects of air resistance. (I. 128v) Provided that the reasonable, but necessary, assumption is made that the muzzle velocity is the same for each angle shown, the drawing shows a better understanding of the actual flight of a projectile than anyone before Galileo. Leonardo's statements, cited in the claims of MS.I. 102v–103v, require these drawings to be based on actual experiments, but all of them are later than the design of Architronito. Reti argued, on the evidence of the Codex Madrid (I. fol. 60r), that Leonardo had tried to measure the energetic equivalent of gunpowder, comparing it with a crossbow. However, most if not all of the other passages on missiles suggest questions to which he wished to determine the answers experimentally, but had not done so.[16]

Whether Leonardo actually fired the gun cannot be determined on the evidence now remaining. If, as is most probable, he never built it, then the fact that it works almost exactly as sketched is yet more evidence of his quite remarkable and very rare engineering skill.

13 G. Calvi, 'I manoscritti di Leonardo da Vinci,' *Instituto Vinciana*, (Roma), 6, Bologna, 1925, p. 79; C. Gibbs-Smith and G. Rees, *The Inventions of Leonardo da Vinci*, London, 1978, reprinted, 1985, p. 47.

14 B. Dibner, 'Machines and Weaponry,' in *Leonardo the Inventor*, (eds L. H. Heydenreich, B. Dibner and L. Reti) London, 1981, pp. 72–123, 116.

15 L. Reti, op. cit. (1), p. 175 (quoting R. Valturius, *De Re Militari*, Verona, 1472, bk, 10, p. 261), p. 180.

16 M. Kemp, *The Marvellous Works of Nature and Man*, London, 1981, p. 142 (I. 102v–103v), p. 143 (I. 128v); L. Reti, 'Leonardo,' in *D.S.B.*, (ed. C. G. Gillespie), New York, 1973, viii, pp. 192–245, 209 (Codex Madrid, i, fol 60r); E. MacCurdy, op. cit. (1), ii, pp. 192–195 (I. 133 [85] v), p. 200 (Forster II 57r, 58r, 62r, 71r).

An engineering or technological invention?

Was the *Architronito* an invention based upon engineering insight or one which arose from the application of knowledge of physical phenomena and experiments?

Leonardo not only knew of Heron, he also certainly experimented with steam himself. Reti claimed that a number of experiments described in the Codex Leicester 'show amazing knowledge of vapour, pressure and temperature for gases and vapours'; as an example, Leonardo realized that a vacuum is created by steam condensing (MS E, back cover). He also understood that the reverse effect existed; its explosive force had been known in the Middle Ages, but Leonardo was the first to devise a calorimeter to measure its expansion power (Codex Leicester fol. 10r). The experiment, crude though it be, is nonetheless sufficient to give a qualitative idea of the enormous expansion power of steam, the idea behind the concept of the *Architronito*.[17]

Needham, Gibbs-Smith and Rees and Gille all believed that his experiments with steam had a practical intent, giving the design of the *Architronito* as an example.[18] Pedretti denied this: he argued that this group of experiments were part of Leonardo's consideration of geological problems and not on the use of steam as motive power. Nonetheless, once the experiments were carried out they would leave Leonardo with a firm understanding of the potential of steam for obtaining explosive power. It is the dates that are conclusive. Pedretti dated this Codex 'not before 1503–4, but presumably about 1506–8, and the compilation itself could be closer to 1510'. MS. B is certainly much earlier, so that if there be any relationship between the experiments and the steam cannon, which appears highly unlikely, the *Architronito* stimulated the experiments, not the other way round. It was an engineer's invention, not an applied scientist's.[19]

COMMENTARY

Clearly, as Reti demonstrated, Leonardo invented the *Architronito*, or steam cannon, himself and took the attribution to Archimedes from Valturius' book, despite its really being only the source of the idea of the gun, and despite Leonardo using the same name for a cannon using gunpowder. There is no evidence whatsoever to support claims that he had any information about an original Archimedean manuscript now lost. Clearly, too, comparing Leonardo's drawings and descriptions with the version recently demonstrated by Sakas, the cannon operates more or less as designed. Whether Leonardo ever tested the weapon is very doubtful indeed. It is almost certain that his principal experiments on the motive power of steam took place much later than the design of the cannon; if anything, therefore, the concept of the gun may have influenced

17 L. Reti, 'Leonardo the Technologist; the problem of prime movers,' in *Leonardo da Vinci: Technologist*, (eds L. Reti and B. Dibner), Norwalk, Connecticut, 1969, pp. 63–96, 92 (Ms. E back cover; Codex Leicester, fol. 10r, fol. 15r); Lynn White, Jr., *Medieval Technology and Social Change*, Oxford, 1962, p. 92.

18 J. Needham, 'The pre-Natal history of the Steam Engine,' in *Clerks and Craftsmen in China and the West*, Cambridge, 1970, pp. 136–202, 143, n. 2; B. Gille, *The Renaissance Engineers*, (tr. unknown), London, 1966, p. 188; C. Gibbs-Smith, op. cit. (13), p. 68.

19 *The Codex Leicester by Leonardo da Vinci*, (intro. C. Pedretti), London, 1980, pp. 11–16, (date of experiments).

the experiments and not, as some have argued, the other way round. The evidence presented by Reti and Duhem, that Cardan and Della Porta knew something of Leonardo's experiments, is sufficiently plausible to suggest that Bourgeois knew of the *Architronito* when he devised his steam cannon around 1605.[20]

AN ANGLO-SPANISH WAR

The second quotation (Bib. Nat. Ms.2037, 9v), dating from 1487–1490, contains the extraordinary story of the part played by Archimedes in an Anglo-Spanish war:[21]

> I have found in a history of the Spaniards that, in their wars with the English, there was Archimedes of Syracuse, who at that time was living at the court of Ecliderides, King of the Cirodastri. And in maritime warfare he ordered that the ships should have tall masts, and on their tops there should be placed a spar fixed forty feet long and a third of a foot thick. At one end there was a small grappling iron and at the other a counterpoise! To the grappling iron was attached twelve feet of chain; and at the end of the chain as much rope as would reach from the chain to the base of the top where it was fixed with a small rope; from this base it ran to the bottom of the mast where a very strong spar was attached, and to this was fastened the end of the rope. But to go on to the use of the machine; I say that below this grappling iron was a fire which with a tremendous noise threw down its rays and a shower of burning pitch, which pouring down upon the enemy's top compelled the men to abandon the top. The anchor being lowered, clung with the sharp hooks to the edges of the top, and instantly the rope was cut which had been placed at the base of the top to support the rope which went from anchor to capstan. And drawing the ship . . .

Richter noted that:

> Archimedes never visited Spain. Leonardo seems to quote here from a book, perhaps by some questionable medieval writer. Professor Justi writes to me from Madrid that Spanish savants have no knowledge of the sources from which this story may have been derived.

Since Richter sought a Spanish source, he had obviously ruled out the possibility that there might be an Italian one. No one has since proposed one. Clagett agreed, but he did note an approximately contemporaneous reference linking Archimedes to Spanish history, but to the Roman period, without suggesting that Leonardo knew of it.[22]

Nonetheless, there had been an Anglo-Spanish conflict during the Hundred Years War. Edward I had engaged a Castilian fleet off Sluys and in 1367 the Black Prince had come to the assistance of Pedro the Cruel, the dethroned King of Castile against the usurping Enrique II, Pedro's half-brother. Later, in 1371, John of Gaunt, Duke of Lancaster, who had married Pedro's daughter, claimed the throne in her name on her father's death. Next year, the Castilian galleys won a crucial advantage by:

> 'their defeat of an English convoy at anchor at La Rochelle . . . his ships (The Earl of Pembroke's) were rammed by the Castilians (galleys), who sprayed the English rigging and decks with oil which they ignited by means of flaming arrows. From high poops or 'castles' taller than the enemy's they threw stones down upon the English archers.'

20 L. Reti, op. cit. (17), p. 63; I. Sakas, op. cit. (2); L. Reti, op. cit. (1), pp. 181–183; P. Duhem, op. cit. (4), pp. 222–223.

21 J. P. Richter, op. cit. (6), ii, p. 374, note 1498; C. Pedretti, *Commentary on Richter*, op. cit. (6), 2 vols., Oxford, 1977, ii, p. 374 (date); E. MacCurdy, op cit. (1), ii, pp. 209–210.

22 J. P. Richter, op. cit. (6), ii, p. 374, note 1498, footnote 6; M. Clagett, op. cit. (1), p. 480 and footnote.

and Froissart recorded that:[23]

> . . . the Spaniards flung out grappling hooks with chains of iron.

These weapons are similar to those described by Leonardo. Elsewhere in the same notebook he describes very similar weapons in current use, with a diagram showing their operation. A third note gave his own recipe for making burning pitch, which he calls Greek Fire, together with instructions on its use against ships. These weapons are sufficiently similar to those used by the Hellenistic and Roman fleet for Leonardo to find nothing incongruous in attributing so early a date to their use, though he might have queried the fact that the weapons had changed so little over so long a period.[24]

The first question to ask is whether Leonardo could have found descriptions of similar weapons attributed to Archimedes. There are undoubted resemblances between the weapon using an anchor and counterpoise and those described by Livy and Plutarch, and found in Valturius. None of them refers to the use of burning pitch. Dijksterhuis commented that Lucian (*Hippias*. c. 2) mentioned a similar weapon without claiming that Leonardo knew of it. In fact, the *Hippias* states only that Archimedes used scientific means to set fire to the Roman ships. Besides the first reference to it in the Archimedean tradition it does not appear until two hundred years later.[25]

The other two references to the use of fire by Archimedes are in Silius Italicus' *Punica* and in Galen (*De Temp*. c. 3, 2). Both can be disregarded as sources for Leonardo. Admittedly, the *Punica* had been rediscovered in 1417, but since Archimedes' name does not appear in the text, because the metre precludes it, this passage in the *Punica* has only rarely appeared in the Archimedean tradition.[26]

There is no doubt that Leonardo knew of Galen, but there is nothing specific to suggest that he knew of *De Temperamentis*. However, he may have known of the particular passage from his friend, Luca Pacioli, who was the first Renaissance writer to refer to Archimedes' use of burning mirrors at Syracuse, almost certainly on the basis of this reference in Galen. Thus, whilst 'burning pitch' is a possible, though not

23 *The Life and Campaigns of the Black Prince*, (ed. and tr. R. Barber), London, 1979, pp. 74–75; *Sir John Froissart's Chronicles*, (tr. T. Johnes), 5 vols., Hafod, 1803, i, p. 383 (sea-battle of Sluys), ii, pp. 100–103 (no mention of weapon of fire at La Rochelle); p. 103 (grappling hooks), p. 103 footnote (Du Guesclin, *Coll. Memoires Historiques*—fireships used), i, p. 432; Barbara W. Tuchman, *The Distant Mirror*, U.K. edn, London, 1979, pp. 264–265 (crucial advantage); Murray [K. E. Murray, 'Shipping,' in *Medieval England*, (ed. A. L. Poole), Oxford, 1958, i, p. 183,] stated: 'As early as 1190 northern long ships had discovered when operating against Saracens in the Mediterranean that it was hard to grapple with a dromon because the enemy could pour brimstone and burning pitch over their heads.'

24 E. MacCurdy op. cit. (1), ii, pp. 205–210 (other descriptions of galleys and their operations); J. P. Richter, op. cit. (6), ii, p. 230, n.1128 (Tr. 43a). and p. 222, n.1115 (B. N. 2037. 1b).

25 Titus Livy, *Ab Urbe Condita*, (tr. F. G. Moore), London, 1966, p. 461; *Plutarch's Lives, Marcellus*, (tr. B. Perrin), London, 1968, p. 487; R. Valturius, op. cit. (15), p. 265. E. J. Dijksterhuis, 'Archimedes,' (tr. C. Dikshoorn), *Acta historica scientarum naturalium et medicinalium*, 1965, **12**, 28; possibly in J. A. Fabricius, *Bibliotheca Graeca*, Hamburg, 1716, ii, p. 551 (bk. 3, c. 22); '*Hippias*', (tr. Vincentus Obsopeus), in *Lucian, Opera*, Frankfurt, 1543, pp. 250r–252r, (first published tr. into Latin), p. 251r (ref. to Archimedes). No refs to Archimedes in side col., summary (p. 250r) or index.

26 Silius Italicus, *Italica*, (tr. K. D. Duff), 2 vols., London, 1934, ii, p. 295 (14, 300–315). I. Schneider, 'Die Enstehung der Legende um die kriegstechnische Anwendung von Brennspiegeln bei Archimedes,' *Technikgeschichte*, 1969, **36**, pp. 1–11.

accurate and fairly uncommon translation of Galen, had Leonardo been aware of it, he would have accepted the translation 'burning mirrors'.[27]

No one else has ever put the classical references together in this way to describe this particular group of weapons, with or without the Anglo-Spanish war, so that it is highly improbable that Leonardo did.

This argues that the first stage of an explanation for the story of the Anglo-Spanish war and the weapons used in it may be that Leonardo is recalling having heard of, despite his claim of reading about, a battle between the Castilian galleys and an English fleet. The curious names may be his bad memory or another example of his making mistakes about names in his notes. He twice referred to Callimachus (Callimaco and Calljmacho in his Italian), the Architect, as the inventor of Greek Fire instead of the Byzantine Callinocos (Callinoco in Italian). A man who could confuse Cato with Cicero and Callimaco with Callinoco could well, when making notes in haste, write Ecliderides instead of Enrique, and Cirodastri for Castile.[28]

The second stage to explain Leonardo's introduction of Archimedes into the story is much more difficult. However, some links can be found. The first, between the English and Syracusans, could have come to Leonardo from the same source that told him of the Anglo-Spanish wars. At Poitiers, the Black Prince is recorded by the contemporary chronicler, Geoffrey le Baker, although not by Froissart, as making a speech to his troops listing, and somewhat exaggerating, the successes of the Plantagenet Kings: they had tried to conquer all the other nations in the British Isles and hold their possessions in France, whilst Richard Coeur de Lion had rampaged in both parts of the Kingdom of Sicily and conquered Cyprus on his way to the Crusades:[29]

> Their (predecessors) lively couragiousenesse tamed the Frenchmen, the Ciprians, the Syracusans, the Calabrians, the Palestines and brought under the stiff-necked Scots and unruly Irishmen, yea, and the Welchmen also which could well endure all labour.

The second possible link is in Diodorus, who attributed the invention of the screw to Archimedes, as a way of removing the water produced by subterranean streams in the gold mines of Spain. Since Leonardo referred to the discourses of Diodorus (C.A. 325rb), it is reasonable to assume that he knew the reference. Leonardo could have assumed a visit by Archimedes to Spain on the basis of this passage in Diodorus, just as Libri was later to do from Leonardo's story. Finally, Clagett has shown that there

27 Galen, *De Temperamentis*, ed. O. Helmreich, *Bibliotetheca Scriptorum Graecorum et Romanorum*, (Stuttgart, 1969, 2nd edn) p. 93 (c. 3,2); D. L. Simms, 'Archimedes and the Burning Mirrors of Syracuse,' *Technology and Culture*, 1977, pp. 28, 1–24, 5 and 5 n, 21; N. Toni, op. cit. (1), p. 79 (two refs to Galen in Leonardo's mss.); Luca Pacioli, *De Viribus Quantitatis*, p. 200v, Ms. 250, Library, University of Bologna, undated, no. 306 in G. Mazzatintti, *Catalogue of Italian Mss. in University Libraries*, (Forli, 1910) 17, p. 68.

28 N. de Toni, op. cit. (6), pp. 82/83 (Ms. 30r), pp. 89/90 (Ms. B 32r); E. MacCurdy, op. cit. (5), ii, p. 174 (B 30v), 184, 184 footnote 5 (B. 50v). As this same confusion—Callimachus for Callinocus—was made by Della Porta, [G. B. Della Porta, *Magia Naturalis*, Naples, 1589, *Natural Magick*, (tr. unknown), London, 1658, p. 291] it strengthens the case made by Reti [op. cit. (1), p. 183] that Della Porta was familiar with parts of Leonardo's works.

29 John Stow, *The Annales of England*, London, 1605, p. 410; Barber, op. cit. (23), p. 75 (orations almost certainly Geoffrey le Baker's own). Johnes, op. cit. (23), p. 427 (Froissart gives Black Prince's speech as a general one).

was one contemporary reference to Archimedes and Spain, suggesting the possibility that he heard someone talk of it.[30]

Thus, Leonardo having heard vaguely of an Anglo-Spanish war, the weapons employed at sea and the names of the participants, somehow or other associated the name of Archimedes with the story without reflecting on the historical absurdity of the idea.

Archimedes' tomb

The third quotation (BM Arundel MS. 279v), dating from about 1515, is:[31]

> Had anyone discovered the range of the power of the cannon in all its varieties and imparted his secret to the Romans, with what speed would they have conquered every country and subdued every army? And what reward would have been deemed sufficient for such a service? Archimedes, although he had wrought great mischief to the Romans at the storming of Syracuse, did not fail to be offered very great rewards by these same Romans. And at the sack of Syracuse diligent search was made for Archimedes, and when he was found to be dead there was a greater lament made in the senate and among the Roman people than if they had lost all their army, and they did not fail to honour him with obsequies and (a) statue, their leader being Marcus Marcellus.
>
> And after the second destruction of Syracuse the tomb of this same Archimedes was rediscovered by Cato among the ruins of a temple, and so Cato caused the temple and the tomb to be restored most elaborately; and as to this Cato is recorded to have said that he did not glory in any of his actions so much as in having paid this honour to Archimedes.

Obviously, this account is far from accurate. Clagett suggested that Leonardo's source for the first paragraph reflected either Plutarch's Life of Marcellus (Lives, 19, 3) or Valerius Maximus (*Memorabilia*, 8, 7) or was derived from one of the several mediaeval accounts based on him. There is, however, little in common between what Leonardo recorded and the comments of Valerius Maximus, nothing beyond the fact that they both have a reference to Archimedes' part in the siege of Syracuse and his death there, with the implication that his life should be spared. Between Plutarch's account and the second half of Leonardo's first paragraph there is more common ground, although rewards were not offered to Archimedes, but instructions given to ensure his safety, and the distress felt by Marcellus in Plutarch's record of events became in Leonardo's version 'the great lament in the senate and among the Roman people.'[32]

Moreover, the first three sentences are not found in any classical source and must be Leonardo's own. The first two directly contradict his earlier belief that Archimedes had invented the cannon. The notion of the Romans offering rewards in the second

30 Diodorus of Sicily, *Universal History*, (tr. C. Oldfather), London, 1961, iii, pp. 197–198 (5, 37). First five Books, (tr. by Poggio), Bologna, 1472); J. P. Richter, op. cit. (5), ii, p. 422, (Diodorus); G. Libri, *Histoire des Sciences Mathématiques en Italie*, 2 vols., Paris, 1838, i, p. 208, n.5.

31 E. MacCurdy, op. cit. (1), ii, p. 175; L. Reti, op. cit. (1), pp. 176–177 (original Italian); C. Pedretti, op. cit. (1), ii, p. 371 (date).

32 M. Clagett, op. cit. (1), pp. 480–481, (medieval biographical accounts). Valerius Maximus, *Factorum et Dictorum Memorabilium Libri Novem*, rescensit Carolus Kemp, Leipzig, 1888, p. 391, (bk, 8, cap, 6, ext. 5–10); *Romae Antiquae Descriptio*, (tr. S. Speed), London and Westminster, 1678, p. 399 (Marcellus was sensible that his victory was much delayed by his (Archimedes') engines); Plutarch, op. cit. (32), v. p. 487 (death) (19,3), p. 481 (tomb) (17,7).

and third sentences, Kemp suggested, probably arose from a combination of Leonardo's recognition of his own true standing and his desire for financial rewards for his work.[33]

For the rest of the first paragraph, the account given by Livy (*Ab Urbe Condita*, 25, 31) is closer to Leonardo's than Valerius Maximus and at least as close as that by Plutarch. Livy, too, referred to Marcellus' grief at his death and providing for Archimedes' burial and enquiring after and protecting his relatives. The idea of the *general* lament, Solmi suggested, was derived from a passage in Firmicus Maternus:[34, 35]

> This is Archimedes of Syracuse, my fellow-citizen, who often overthrew Roman armies by [his] mechanical arts. When Marcellus was set up in the triumphal procession for his victory and was placed in the midst of the soldiers' jubilant shouts and the triumphant laurels, he lamented Archimedes' death with mournful grief.

Solmi's suggestion adds nothing to what is found in Livy. Moreover, although an edition of this fourth century writer having been published in 1497, there is a passage in Cicero [*Against Verres*,(58, 131–32)] that contains the same idea of Marcellus' grief and likely to be Firmicus' source:

> Indeed Marcellus is even said to have searched for that brilliant and learned man Archimedes, and to have been deeply distressed when told that he had been killed.[36]

For the second paragraph, Clagett gave the original source, Cicero (*Tusc. Disp.*, 5, 64–65), pointing out that it was Cicero who sought out the tomb and who ordered its restoration, and that he did not use quite such extravagant language about his achievement; Leonardo has confused Cato for Cicero. Richter called this mistake a slip of the memory and commented that: 'the grave was not found *'nellio ruine d'un tempio'*—which is highly improbable as relating to a Greek—but in an open spot'. Leonardo was very unlikely to have known that Greeks were not buried near temples. A second error is that whilst it was strictly correct that Marcellus was responsible for the second historical sacking of Syracuse, since Dionysius had sacked the City at the time of Dion, there had not been another sack between Marcellus' capture of the City and the restoration of the tomb, *not* a statue. The need for the restoration by Cicero had arisen because the City did not, or could not afford to, maintain the necropolis.[37]

Clagett's conjectured sources are thus insufficient to account for the content of both paragraphs and they are too complicated. Two other sources available to Leonardo can be dismissed: both Valturius and Luca Pacioli drew upon Plutarch. Leonardo could have taken some of the material from three books to be found in his library, two classical works, by Livy and Pliny, and the rest from Alberti's *De Re Aedificatori*, which gave a reasonable and succinct account of Cicero's actions and his attitude to

33 M. Kemp, op. cit. (16), p. 179

34 Livy, op. cit. (25), vi, p. 461, (death) (25, 31, 9–10).

35 E. Solmi, op. cit. (8), p. 65, footnote 2 (Firmicus Maternus, 1497 ed.); J. Firmicus Maternus, *Matheseos* Bk, 7, (eds W. Kroll and S. Skutsch), 2 vols., Leipzig, 1913, ii, p. 148 (bk, 6, cap. 3, lines 23—27).

36 Marcus Tullius Cicero, *Against Verres*, (tr. L. G. H. Greenwood), London, 1936, ii, p. 441 (58, 131–32).

37 Marcus Tullius Cicero, *Tusculanarum Disputationum*, (tr. J. E. King), London, 1966, i, pp. 491–493 (5, 23, 64–66); J. P. Richter, op. cit. (5), ii, p. 370, footnote. *Plutarch's Lives, Dion*, tr. B. Perrin, London, 1968, vi, p. 87 (sack of city) (61).

them. This, too, is unlikely. In fact, Leonardo's account is not dissimilar in order and content to passages in Petrarch. In his essay on Archimedes in *De viris illustribus*, as Clagett showed, Petrarch had begun with a portion of Valerius Maximus, and had then combined the passage in Livy about the siege with that in Cicero about the tomb; he had also made a reference to Julius Firmicus—without mentioning the lament. Petrarch's essay was known; at least one contemporary of Leonardo, Volaterranus, must have derived his commentary from him.[38]

This suggests that it was Petrarch's essay on Archimedes in *De viris illustribus* that was Leonardo's original source, with some allowance made for his own additions, particularly the first three sentences at the beginning of the first paragraph—Kemp has given adequate reasons for these being Leonardo's own ideas—and the general lament at the end, which may well be just an exaggeration. The errors are sufficiently serious to make it unlikely that Leonardo was quoting directly from the essay.

Leonardo was in good company in making them. Vasari, his biographer, stated that:

> The Romans so revered the arts that when Marcellus was despoiling the city of Syracuse, he ordered that an *illustrious artist* (my italics) should be treated with the greatest respect.

Vasari's ignorance of who it really was is all the more unexpected because Alberti, who understood Cicero's actions, was the subject of a biography by him.[39]

OPINIONS OF THE MILITARY ENGINEER

The inaccuracies and the confusions in all three extracts from Leonardo's manuscripts serve to confirm how unfinished and uncorrected they were, and that in producing them, he relied heavily on his memory and the thoughts of the moment, but in his day and a little later, as the extract from Vasari shows, the habit of checking references even in published work had not then been developed. For example, having described an *architronito* which used gunpowder as its propellant, one page later in the same notebook he can describe another version using steam and attribute its invention to a Greek. More than that, he did not hesitate, later, to state that the Romans did not have the cannon, nor did he remember the implications of Francesco di Giorgio's sharp and irrefutable rebuttal of those who believed that the ancients had, in a work he had

38 M. Clagett, op. cit. (1), pp. 480–481; Valturius, op. cit. (15) p. 265 (Plutarch); L. Pacioli, *De Divina Proportione*, Venice, 1519, cap. 2, pp. 2v-r, Pliny, *Historia Naturalis*, (tr. H. Rackham), London, 1942, ii, pp. 589–591 (bk. 7, cap. 37); 'Archimedes also received striking testimony to his knowledge of geometry and mechanics from Marcus Marcellus, who at the capture of Syracuse forbade violence to be done to him only—had not the ignorance of a solider foiled the command,'; E. MacCurdy, op. cit, (1), ii, p. 508 (owned Livy and Pliny); C. Pedretti, op. cit. (6), ii, p. 357 (Alberti in Leonardo's library). L. Alberti, *Ten Books on Architecture*, (ed. J. Rykwert, tr. J. Leoni), London, 1955, bk. 8, cap. 4, p. 170; cf. M. Clagett, op. cit. (1), iii, pt. 4, appendix 3, pp. 1336–1341 (Petrarch on Archimedes); F. Petrarch, *De Viris Illustribus*, (ed. G. Martellotti), Florence, 1978, pp. 122–123; F. Petrarch, *De Rerum Memorandum Libri*, (ed. G. Billanovich), Florence, 1943, v, bk. 1, sect. 23 (Archimedes); Maffeius Volaterranus, *Commentaria Urbana*, Paris, 1511, bk. 14, fol. 89 (refers to Plutarch's Lives and Cicero on Archimedes' tomb).

39 G. Vasari, *Lives of the Artists*, rev. edn (tr. with intro. and notes by G. Bull), London, 1965, 1981 (1st edn 1550, 2nd edn 1568), p. 28 (illustrious artist), p. 469 (knowledge of Alberti's book).

himself studied. These are, however, notes made by a writer for his own purposes and not drafts for a book and they ought to be treated as such.[40]

Perhaps, with that proviso, they do throw some light on the controversial question of Leonardo's attitude to war. The passages normally quoted to show that he detested war are:

> most bestial madness . . .
> . . . it is an infinitely atrocious thing to take away the life of a man;

or as modified to take in the notion of the just war:

> When besieged by ambitious tyrants I find a means of offence and defence in order to preserve the chief gift of Nature, which is liberty: (B.N. Ms. 2037, 10r);

or to justify the withholding of an invention:

> How by an appliance many are able to remain for some time under water. How and why I do not describe my method of remaining under water for as long a time as I can remain without food; and this I do not publish or divulge, on account of the evil nature of men, who would practise assassinations at the bottom of the seas by breaking the ships in their lowest parts and sinking them together with the crews who are in them. (Leicester Ms. 22v)

Lewis Mumford, writing between the two World Wars, charitably commented that:

> Though Leonardo wasted much of his valuable time in serving warlike princes and in devising ingenious military weapons, he was still sufficiently under the restraint of humane ideals to draw the line somewhere.

Mumford thought the line was the submarine: 'too satanic to be placed in the hands of unregenerate men'.
MacCurdy, publishing in 1938, recognized that:

> All the most characteristic developments of the Great War, those which distinguish it from all in the long roll of its predecessors—the use of the bombing aeroplane, the use of poison gas, the tank, and the submarine—all afford examples of his prescience . . . It may seem something of an enigma . . . in one who stigmatized warfare as bestial madness. The clue to its solution is to be found . . . in the BN. Ms.2037, 10r in which he refers to the difference between offensive and defensive warfare.

Again, MacCurdy could not believe that the Leonardo who wrote: 'it is an infinitely atrocious thing to take away the life of a man' would have regarded the use of poison gas against the civilian population as permissible under any circumstances, although he knew that Leonardo proposed its use against combatants. (C. A. 346v, a, B 69v) Even so, MacCurdy recognized that Leonardo did not understand that the invention and use of aircraft might become the wings of war.

Writing at the same time, General Parsons described Leonardo's work as a military engineer with some enthusiasm. He commented that the notes fairly bristle with modernisms . . . built-up wire-wound guns, conical and explosive shells. Parsons agreed

40 Francesco di Giorgio Martini, *Trattato di architettura civile e militare*, 3 vols., Turin, 1841, ii, pp. 129–150, 129; L. Reti, 'Francesco di Giorgio Martini's Treatise on Engineering and its Plagiarists,' *Technology and Culture*, **4**, 1963, pp. 287–298, 287–288.

with Mumford, that Leonardo did draw a line somewhere, but drew it in a different place:

> His fine feelings in relation to the terrible features (of war) have unfortunately not been shared by the nations of modern times. About the uses of the second weapon, poison gas, he had no scruples, as he could probably see no difference between shooting an adversary and suffocating him.

Few of the weapons Leonardo invented were actually used. As Payne put it, he 'unveiled many engines of war in the quietness of his study'. Payne continued: 'these engines of war remained unknown until his manuscripts were discovered, and there is no evidence that any of them were made or used.' Payne clearly believed that this secrecy was deliberate.[41]

Kemp was less sure; he suggested that a certain ambivalence is apparent in Leonardo's attitude to military engineering. 'He was irresistably attracted by the possibility of perfecting weapons. But against such attractions we have to set his undoubted abhorrence of war in human terms.'[42]

There may be that conflict in Leonardo. He may have celebrated liberty, but it does not seem to have prevented him offering his military services either to Cesare Borgia, although he did not stay in his company long, or to the Duke of Milan in that famous letter. Neither is normally celebrated for their regard for freedom. The descriptions of the manufacture and use of Greek Fire and of fireships, and of poisonous and asphyxiating gases seem full of the now notorious idea of 'technological sweetness'; there is no evidence of any moral repugnance in the description of any of these weapons. If he objected to the use of, and suppressed the invention of the submarine, each generation, from Archidamus of Sparta onwards, has protested at the introduction of new weapons.

Winder was less impressed; he contrasted Leonardo's devoting some of his genius to constructing machines of war with the earlier Arab engineer, al-Jazari. 'The Book of Knowledge of Ingenious Devices' contains no examples of machines with military applications.[43]

Yet had Leonardo not been equivocal, he might have made an operating version of the *architronito*, or was that omission, if failure is not a more appropriate expression, only another sign of his inability to finish almost any task, this man in whom 'the desire outran the performance'?[44]

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41 L. Mumford, *Technics and Civilisation*, London, 1934, p. 85; E. MacCurdy, op. cit. (1), i, pp. 24–25, ii, p. 204, p. 206; W. B. Parsons, *Engineers and Engineering in the Renaissance*, Cambridge, Massachusetts, 1939, reprinted 1967, p. 45, 48; R. Payne, op. cit. (12), p. 186.

42 M. Kemp, op. cit. (16), p. 177.

43 R. B. Winder, '*al-Jazari*,' in *The Genius of Arab Civilization*, 2nd edn (ed. J. R. Hayes), Cambridge, Massachusetts, 1983, p. 216.

44 M. Kemp, op. cit. (16), p. 179; G. Vasari, op. cit. (39), p. 264 (quotaton from Petrarch).

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