ARCHIMEDES' CANNONS AGAINST THE ROMAN FLEET?

Cesare Rossi
D.I.M.E. Department of Mechanical Engineering for Energetics
University of Naples "Federico II"
Via Claudio, 21 80125 Naples, Italy
e-mail: cesare.rossi@unina.it
Tel.: +39 081 7693269
Fax: 081 2394165

ABSTRACT In the paper is discussed the possibility tat Archimedes built and used against the Roman fleet a steam cannon.

It is well-known that Archimedes, during the siege of Syracuse, designed and built several war machines to fight against the Romans. Among these war machines, the legend about the large concave mirrors that concentrated the sun rays burning the Roman ships is rather interesting. On this topic are also interesting some drawings by Leonardo Da Vinci where a steam cannon is described and attributed to Archimedes.

Starting from passages by ancient Authors (mainly Plutarchos, Petrarca and Da Vinci), the author investigates on the possibility that Archimedes built a steam cannon and used it to hit the Roman ships with incendiary proiectiles.

1. INTRODUCTION

Everybody knows the legend telling that Archimedes, during the siege of Syracuse (214–212 B.C.), designed and built several war machines to fight against the Roman fleet. Among these war machines, the legend about the burning mirrors is rather interesting. According to the legend, these burning mirror consisted in large concave mirrors that concentrated the sun rays in a point, a Roman ship, burning it; a scheme is reported in figure 1.

There is not any doubt that a parabolic mirror can burn a piece of wood as it was demonstrated by a Greek engineer (Joannis Stakas) in 1974 [1]; in addition such devices are commonly used nowadays in applications of the solar energy. In particular, by modern linear mirrors, it is possible to heat a fluid mix of salts flowing in a pipe (that is located in the locus of the

S.A. Paipetis and M. Ceccarelli (eds.), *The Genius of Archimedes – 23 Centuries of Influence on Mathematics, Science and Engineering*, History of Mechanism and Machine Science 11,
DOI 10.1007/978-90-481-9091-1_8,

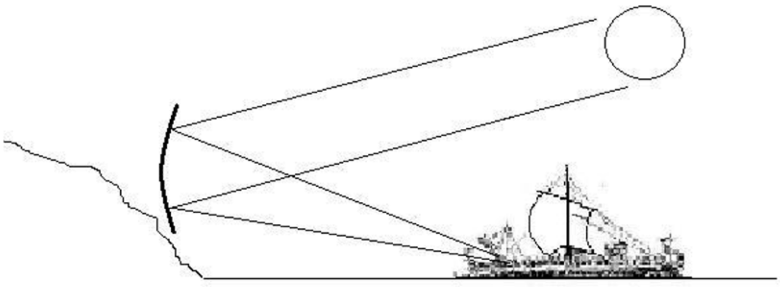

Fig. 1. Working principle of a burning mirror.

parabola's foci) up to 600°C. Nevertheless, the use of such mirrors as a weapon against ships is rather difficult to believe [2–5]. The described device, in fact, can work only if the ship's wood is located in the focus of the parabola. Hence if the ship moves forwards or backwards respect to this point, the only way to "adjust" the device could be to change the mirror's curvature. As far as this aspect is concerned, some Authors suggested the use of a device that consisted in a "composite burning mirror" made up by a number of (plain) mirrors that could be adjusted in order to concentrate the sun rays at different distances from the device itself. Experiments with such devices were carried on by some scientists (see e.g. [6,7]).

Nevertheless, even if a point of the ship (made of rather wet wood) was lighted, it is quite impossible to concentrate in this point enough energy to sustain the fire; in addition, the fire could be easily put out by few bucket of water. This aspect has been already remarked by other Authors (see e.g. [4,5]).

At the end of the XV century, Leonardo Da Vinci drew a steam cannon that he ascribed to Archimedes and, for a tribute to Archimedes, was called "architronito" (Tunder of Archimedes); the drawing is reported in figure 2.

On the same folio is reported also the working principle:

Architronito è una macchina di fine rame, invenzione di Archimede, e gitta ballotte di ferro con grande strepito e furore. E usasi in questo modo. La terza parte dello strumento istà in fra gran quantità di foco di carboni, e quando sarà bene da quelle infocata, serra la vite d, ch'è sopra al vaso dell'acqua abc; e nel serrare di sopra la vite e' si distopperà di sotto, e tutta l'acqua discenderà nella parte infocata dello strumento, e lì subito si convertirà in tanto fumo che parirà maraviglia, e massime a vedere la furia e sentire lo strepido.

Questa cacciava una ballotta, che pesava un talento, sei stadi. …

Architronito is a machine of pure copper, invented by Archimedes, and throws iron balls with great noise and fury. It is operated as follows. The third part of the device is located in a big quantity of fire by coal, and when it is well made red-hot by it (coal), the valve d is closed, that is on the water reservoire abc; and by closing the valve above e' it will be stopped below, and all the water will go down in the heated part of the device, and there suddenly will be converted in so much smoke (vapour) that it will appeas as astonishing, and even more by seeing the fury and hearing the noise.

This (device) threw a ball weighting one talent (≈26÷38 kg), (with a range of) six stadia (≈1100 m). ...

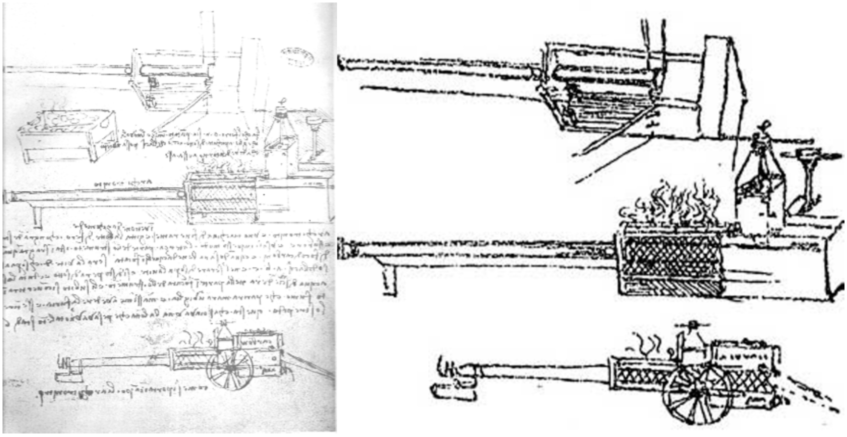

Fig. 2. Drawings by L. Da Vinci (Ms. B, f. 33 v) of the architronito.

Several authors also described similar devices; among them we can cite Francesco Petrarca (1304–1374) that, in a minor work (De Remediis Utriusque Fortunae) describes a steam cannon about one century before Da Vinci:

Straordinario, se non anche le palle di bronzo, che vengono scagliate con tuono orribile. Non era abbastanza l'ira di Giove che tuonava dal cielo, se il piccolo uomo (o crudeltà unita alla superbia) non avesse tuonato anche dalla terra: la violenza umana ha imitato il non imitabile fulmine, come dice Virgilio. E quello che di solito è scagliato dalle nuvole, e mandato con uno strumento sì di fuoco, ma infernale. Ed alcuni ritengono che questo sia stato inventato da Archimede, nel tempo in cui Marcello assediava Siracusa. Per la verità lo escogitò per difendere la libertà dei suoi cittadini, sia per allontanare sia per differire la rovina della patria; e voi vene servite, invece, per opprimere i popoli liberi o col giogo o con la distruzione. Questa peste non molto tempo fa rara, ora siccome gli animi sono succubi alle cose più malvagie, è comune come qualsiasi genere di armi.

It is extraordinary, if not only the bronze balls, that are thrown with orrible thunder. It was not enough the anger of Jove that thundered from the sky if the little man (oh cruelty of the haughtiness) had not thundered also from the heart: the human violence imitated the non imitable lightning, as Virgil says. And what usually is thrown by the clouds, is (now) thrown by a device that is also made by fire but hellfire. Some people believe that this (device) was invented by Archimedes when Marcellus besieged Syracuse. In truth he invented it to defend the freedom of his fellow citizens and to retard and defer the ruin of its Country; you, instead, use it to oppress free people with yoke or destruction. This plague not many time ago was rather rare, now, since the minds are dominated by the most wicked things, is common like any other kind of weapon.

It must also be considered that parabolic mirrors were used during the Renaissance for brazing the copper. In addition, nowadays, parabolic mirrors are used to obtain energy from the sun; in some application a fluid mix of salts is heated (in a pipe located in the locus of the foci of a parabolic linear mirror) up to 600°C.

The Greek historian Plutarchos (later Roman citizen as Lucius Mestrius Plutarchus ≈ A.D. 46–120), in his *Vite parallele,* vol. II, *Pelopida e Marcello* 14-15, tells that, during the siege of Syracuse, when the Romans saw something that was similar to a pole protruded from the walls ran away shouting :"Archimedes is going to throw something on us now". Now, let us consider that no ancient throwing machine (such as onager, ballista or catapult) looks like a pole [8]. In the appendix, some examples of the main pieces of the Roman artillery are reported.

Very interesting is also a piece cited by Simms [3]: in it, it is reported that Niccolò Tartaglia (Italian mathematician, about 1499–1557) wrote that Valturius (Roberto Valturio, Italian engineer and literary man 1405–1475) in his treatise De re militari, *"... States that ... there are many references to Archimedes having designed a device made from iron out of which he could shoot, against any army, very large and heavy stones with an accompanying loud report."*

Finally, as it was already remarked by several investigators, no mention about burning mirrors was made by the historians of the Greek-Roman era but this legend appears only during the middle age.

For the all the reasons above reported it seems plausible to suppose that Archimedes used burning mirrors to heat the breech of steam cannons. In the next paragraphs the possibility to use a such device is investigated.

2. A RECONSTRUCTION OF THE ARCHIMEDES' STEAM CANNON

In figure 3 is reported a possible scheme of parabolic mirror fitted to heat the breech of a cannon.

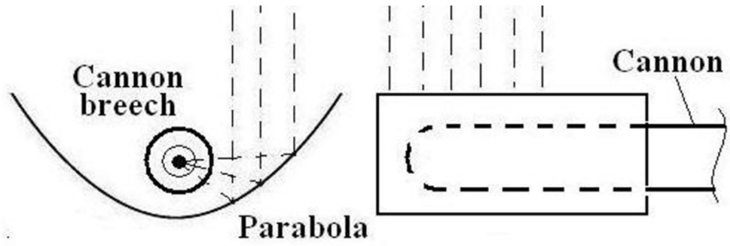

Fig. 3. Possible scheme of parabolic mirror heating the breech.

In figure 4 is reported a scheme of the device that was probably used to inject the water in the breech. It is mainly based on the drawings and the brief description by Da Vinci's manuscript and the steam cannon model built by I. Sakas [9]. It must be said that, the Sakas' reconstruction of the Archimedes' steam cannon, the ball was constrained down in the barrel by two wooden stick: a first stick is put inside the barrel, a second stick is put at the muzzle, orthogonal to the barrel axis and hooked to the muzzle by two rings. When the pressure was high enough to break the second stick, the ball could start. In this way rather high steam pressures and thereby high muzzle velocities could be achieved. This solution or similar ones invented by several modern steam cannon builders are rather dangerous and they could not be easily adopted by a military weapon of the age of Archimedes.

Since neither in the drawings by L. Da Vinci nor in any other bibliographical source the author could found any evidence of the equipment used by Sakas, in the following it was not considered.

A proper amount of water is put in the reservoir A, then the valve B_1 is opened and the water fills the tank C. Next the valve B_1 is closed and the valve B_2 is opened: the water flows in the chamber of the cannon and vaporizes. Through the pipe D, the pressure in the tank C is equalized to the one in the chamber of the cannon. The steam pressure throws the ball E outside the barrel.

It must be pointed out what follows:

1. By a burning mirror and the described working cycle, it is difficult to achieve high energy and hence high ball muzzle velocities.
2. In order to shoot at a (moving) ship from a city wall it is necessary that the cannon ball has a rather flat trajectory; otherwise it is rather difficult to hit the target.

Naturally, low muzzle energies could carry to a low muzzle velocity if the ball mass was about 30 kg as described by Da Vinci. This would permit only a parabolic trajectory that was unsuitable to hit a moving ship.

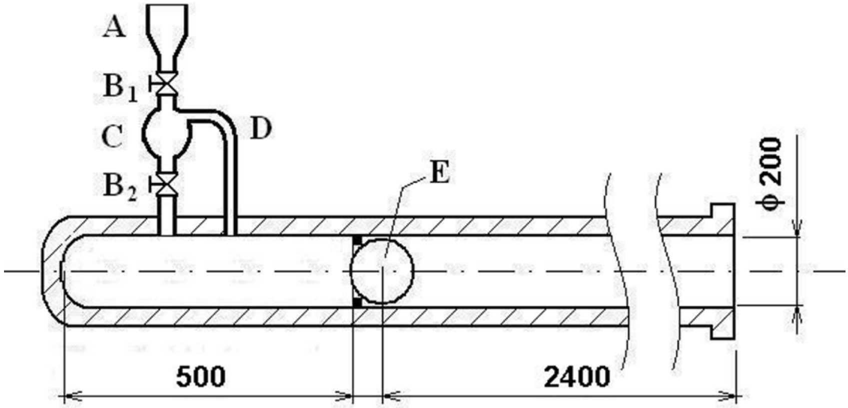

Fig. 4. Scheme of the Archimedes' steam cannon.

On the other side, we must remember that, up to the middle of the XIX century, the calibre of a gun was given as a weight; the latter indicated a barrel which diameter was the one of a ball (made of cast iron for cannons and of lead for guns) having that weight. Also for the Archimedes' steam cannon it could be the same.

In this case, we can suppose that the cannon could throw rather lightweight hollow balls made of clay and filled by incendiary mixture that was well-known by the Greeks. These balls could reach an higher muzzle velocity and hence a flatter trajectory and, when hit the ship, they broke off spreading the incendiary mixture, setting fire on the ship. The possibility that the roman ships were burned by Archimedes by means of somewhat like the famous "Greek fire" is also suggested by Simms; in [4], in fact, it is reported that Galen (Aelius Galenus or Claudius Galenus or Galen of Pergamum 129–216) in his De Temperamentis says that "… Archimedes sat on fire the enemy triremes by means of πυρεια." Now this word, in ancient Greek indicates something used to light fire or can be translated as "brazier" but can not be translated as "burning mirror".

As for the incendiary mixture known as "Greek fire" it has to be said that its exact composition is unknown; nevertheless, the main components very probably were sulphur, liquid bitumen, pitch and calcium oxide. It is also well-known the use of a mixture that could burn underwater or even be ignited by water (that the Byzantines named marine fire or Roman fire) and even the use of flamethrowers for sea warfare in the Greek-Roman era [10].

It is also known the use incendiary projectiles (*vasa fictilia*) that consisted in *"clay containers filled with flax soaked in a mixture of liquid bitumen, pitch and sulphur, with a sulphonated fuse. They were hurled using special machines. When they fell, the vase broke and the incendiary composition came into contact with the object it struck. These types of projectiles are mentioned by: Appiano, Dionysius of Halicarnassus, and Frontino. They were widely used in many locations, especially by Demeritus during his naval attack against Rhodes (304 B.C.), and in the naval battles that took place during the second Punic wars. They also launched porous rocks after filling their cavities with flammable material and setting them on fire"*[10].

In figure 5 is reported a possible incendiary projectile made by hollow clay ball that was filled by incendiary mixture. From the proposed dimensions, that are reported in figure, the mass of such a ball could be round 6 kg; this could bring to reasonably flat trajectories, as it will be shown in the following paragraph.

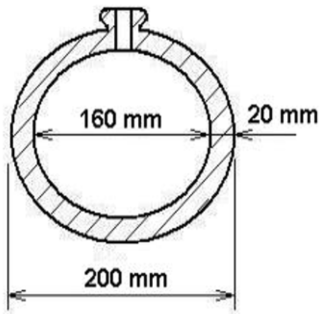

Fig. 5. Hollow clay ball.

Balls like the one described are shown in figure 6. The one on the top left is from the fortress of Chania (X–XII Century) and presently are at the National Historical Museum, Athens, Greece, the picture at the top right is reported a representation of a gun (a fire lance) and a grenade (upper right), from the cave murals at Dunhuang, c. 950 A.D., those in the lower part of the image are ceramic bombs found on the 1281 shipwreck of the fleet who attempted to invade Japan. In the figure it is possible to observe an hole from which the incendiary mixture was filled and that was closed by a cork bringing the fuse.

Fig. 6. Incendiary projectiles.

3. ROUGH EVALUATION OF ENERGIES AND TRAJECTORIES

In this paragraph the possibility that the device described before could be effective against a ship is roughly evaluated. It must be pointed out that all the assumptions and the computations are rough since the main purpose is to asses whether such a device, conceptually, could "work" or not.

3.1. The Projectile Muzzle Energy

As it was told before, it was supposed that the projectile diameter was 200 mm and it's mass was 6 kg; moreover, the barrel length covered by the ball was 2,4 m. In the following paragraph it will be shown that a suitable ball's muzzle velocity is 60 m/s. So, from these assumption and supposing that the ball's acceleration in the barrel is constant, it is easy to obtain:

Ball's muzzle energy Eo = 10,8 kJ
Ball's time to cover the barrel length t = 0.08 s

Now lat us assume that:

- the water temperature, when introduced in the breech, was 30°C,
- the mean breech temperature during the vaporisation process was 430°C (i.e. mean $\Delta t = 400°C$),
- the surface wetted by the water was half the breech inner surface,
- the heat transfer coefficient between the breech and the water spray can be assumed, very conservatively, $K = 10$ kJ/m^2/s/°K [6], then the heat that was transferred from the breech inner surface to the water is: $Q \approx 53$ kJ.

Now, it seems reasonable that 20% of this energy was transferred to the ball; this means a ball's muzzle energy Eo = 10,6 kJ and a ball's muzzle velocity Vo = 59,44 m/s.

It must be observed that in the scheme reported in fig. 4, the ratio between the barrel length and its diameter is only 12 (very little if compared to modern cannons and near to the ratio of the I WW howitzers) while from the table by L. Da Vinci it is possible to observe a ratio of about 30. This suggests that in ancient devices, probably, the time required by the ball to cover the barrel length was comparably higher and the steam worked more efficiently.

3.2. The Projectile Trajectory

In order to evaluate the projectile energy, because of it's low speed, it was considered a simple model for the drag force R due to the air:

$$R = \tfrac{1}{2}\rho\, V^2 A \tag{1}$$

Where:

ρ is the mass density of the air = 1,225 kg/m^3,
V is the speed of the object relative to the air,
A is the area of the projectile's cross section.

The equations of motion:

$$\begin{aligned} -m\ddot{x} + R &= 0 \\ -m\ddot{y} - mg \pm R &= 0 \end{aligned} \tag{2}$$

were solved numerically. It must be observed that, naturally, the sign of R in the second of the equations (2) depends on the sign of the vertical component of the velocity.

In figure 7 is reported a simple scheme showing the gun position on the sea level, the gun elevation β and the range.

In figure 8 is reported a trajectory that was computed by assuming a muzzle velocity Vo = 60 m/s, an elevation angle β = 10° and that the gun was 10 m above the sea level.

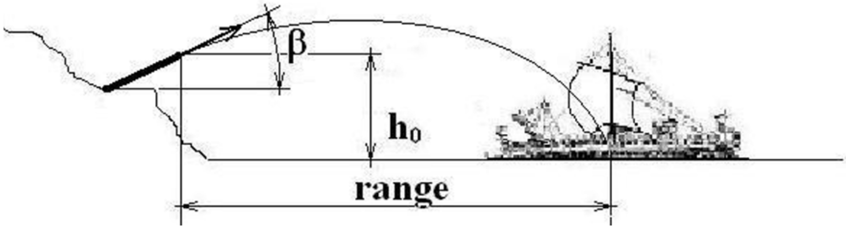

Fig. 7. Scheme of the cannon shooting.

From the figure it is possible to observe that the range is about 150 m and the trajectory is rather flat (the scales of the axes in fig. 7 are isometric); that is to say the maximum elevation of the projectile over the line of sight is very small if compared to the range. The range seems to be adequate to the use of the device while the rather flat trajectory is important for the anti-ship fire.

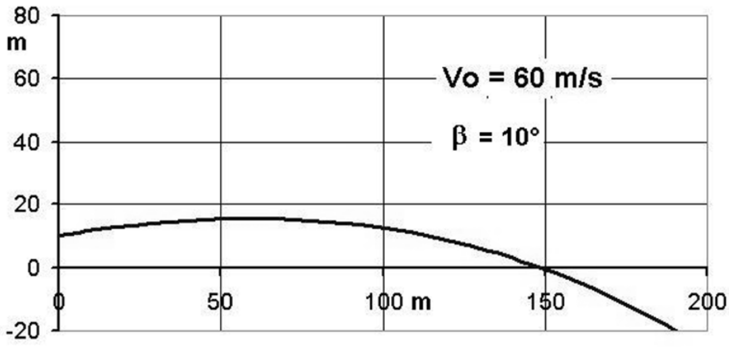

Fig. 8. Projectile's trajectory.

In figure 9 are reported some other trajectories, near the target, with different muzzle velocities and gun's elevation, all hitting the target.

The latter is represented by a 6 m wide and 3 m high silhouette (approximately the dimensions of a Roman trireme's cross section), placed at a distance of 100 m in the plane of the ball's trajectory.

It is possible to observe that if the muzzle velocity is Vo = 60 m/s the target is hit with elevations ranging from β = 3.1° to β = 5.1°, while if the elevation is fixed to β = 4°, the target is hit with muzzle velocities ranging from Vo = 57 m/s Vo = 64 m/s. This means that at those ranges, it was not necessary a very high accuracy in the pointing neither was necessary a very high repeatability of the muzzle velocity.

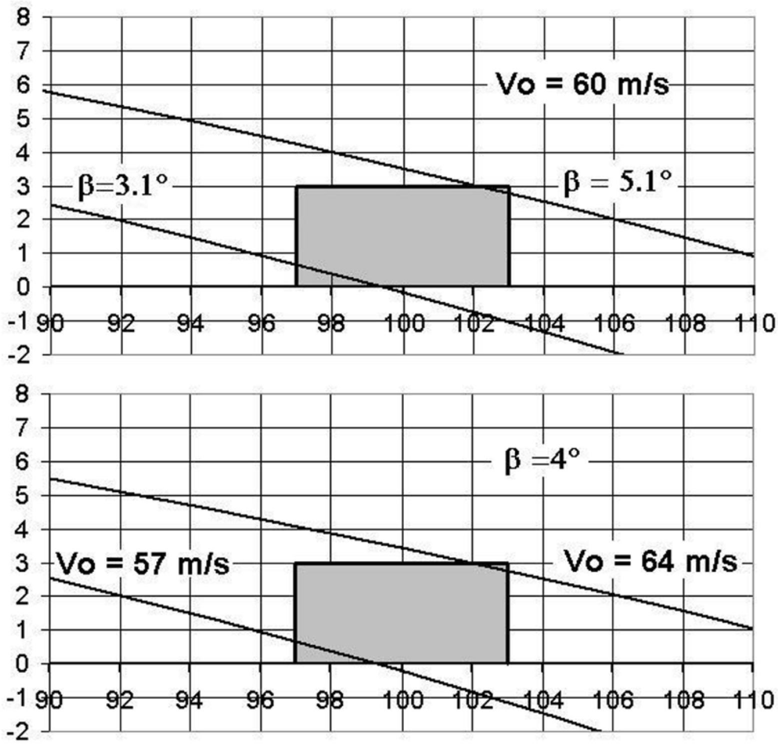

Fig. 9. Different trajectories hitting the target.

It must be observed that, by assuming the target silhouette shown in fig. 9, it was supposed that the ship moved in a direction orthogonal to the plane of the projectile's motion; this condition is the one in which the ship offers the smaller section in the plane of the projectile's motion. This is shown in fig. 10, where a ship is represented in it's plane of motion that is orthogonal to the plane of the projectile's motion.

In the figure the dashed dotted lines are the intersections between the projectile plane of motion with the ship's plane of motion hence the lines A-B or A'-B' represent the width of the silhouette reported in fig. 8. It is evident that if the ship moves in a direction non orthogonal to the cannon's barrel, the "apparent width" of the target increases.

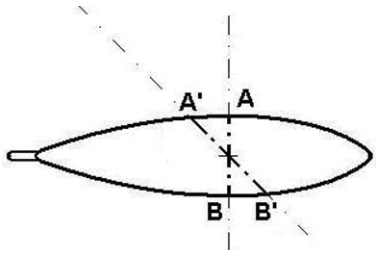

Fig. 10. Ship's silhouette in it's plane of motion.

4. CONCLUSIONS

A possible reconstructions of the performances of a steam gun by Archimedes was proposed.

Computations and assumptions are rather rough since the main aim is to asses whether the device was capable to hit and burn a Roman ship or not. Naturally, if it was possible, this (alone) doesn't mean that it happened.

Nevertheless, it seems reasonable to believe that the only possibility that Archimedes had to burn Roman ships by mirrors was to use the described device for two main reasons:

I) First of all is rather difficult to built a bursting mirror suitable for those applications; in fact a concave mirror having a diameter of (say) 4 meters that concentrates the sunrays at a distance of (say) 100 meters has a concavity of few millimetres. In some experiments (1973 Sakas and Stamatis and 2005 MIT) were used a number of plane mirrors and little boats or mock-ups were really burned; nevertheless a practical use of such a device during a battle seems not very realistic. In fact it must be considered that in the experiment by Sakas and Stamatis about 50 sailors of the Greek Navy were necessary to point the mirrors and in the experiment at the MIT 300 mirrors were used; in addition, in both cases, the target was absolutely motionless. Very different conditions take place during a battle, hence it is difficult to believe that a big number of mirrors can be pointed on a moving target efficiently.

Then it must be considered that a fire lighted in this way could be extinguished very easily. Really the wood starts to burn at about 250°C and at temperatures a little higher than the latter burns with flames even without any further external supply of heat; but smoke and flames were clearly visible and, also, were the main threat for wooden ships. So, it is difficult to understand the reason why nobody had extinguished those initial fires, just by few buckets of water.

II) The second reason is that, as already told, there are no historical sources in the Archimedes' age telling about the use of burning mirrors for warfare. Silius Italicus (~25-101 A.D.), about 3 centuries after the siege of Syracuse, in his poem "Punica" does not tell about any mirror but mentions a tower from which Archimedes threw incendiary projectiles against the Roman ships. Valerius Maximus (Factorum et dictorum memorabilium libri IX ~31 A.D.) is probably the first who mentions burning mirrors. Later, Lucian of Samostata (~125 – after 180) refers about Roman ships burned but without indicating how the fire was set on them. Finally, as already mentioned, Galen of Pergamum says that Archimedes burned some Roman ships but the term he used can not be translated as "burning mirror". The use of a set of articulated plain mirrors is supposed for the first time by Anthemius of Tralles (~474 – before 558 A.D.) in his treatise "*Perì paradòxon mesantmaton"* (On the paradoxes of the Mechanics) [5,12].

As for the steam cannon, it must also be remarked that the described technology (valves, pipes etc.) was available in those ages [10]. Also, steam cannons where used till in the XIX century [10]. Finally, a number of writings (e.g. Plutarchos, Francesco Petrarca, Leonardo Da Vinci etc.) strongly suggests that Archimedes built and used such a device.

5. APPENDIX

In the introduction a piece by Plutarchus has been cited in which the Roman Soldiers were frightened by a weapon, similar to a pole, that Archimedes used against them. Since, as already told, no heavy weapons looked like a pole, it could be interesting a very brief review on some examples of the main Greek-Roman artillery pieces. Since the Roman artillery was almost "copied" by Greek designs, some drawings of Roman artillery pieces will be shown.

First of all it must be pointed out that in the III century B.C., thanks to Greek engineers, the motor of the throwing machines was mostly the torsion motor that was made generally by women's hair or horse air [8, 10, 15-18] as shown in figure 11.

The main pieces were the catapult (and the scorpio that was a little catapult), the ballista and the onager (in Latin: onagrum), all powered, as told, by torsion spring motors.

It must be pointed out that during the Roman Empire the word "catapult" (probably from the ancient Greek katà pelte = through the shield) was used for a machine that throws darts, while the word ballista (that also comes from the Greek worḍ βαλλω (ballo = I throw) was used for a machine that throws balls. During the Middle Age the words were used with the opposite meaning : ballista for a dart throwing machine and catapult for a ball throwing one.

In figure 12 is reported a pictorial reconstruction of a Greek-Roman catapult [10].

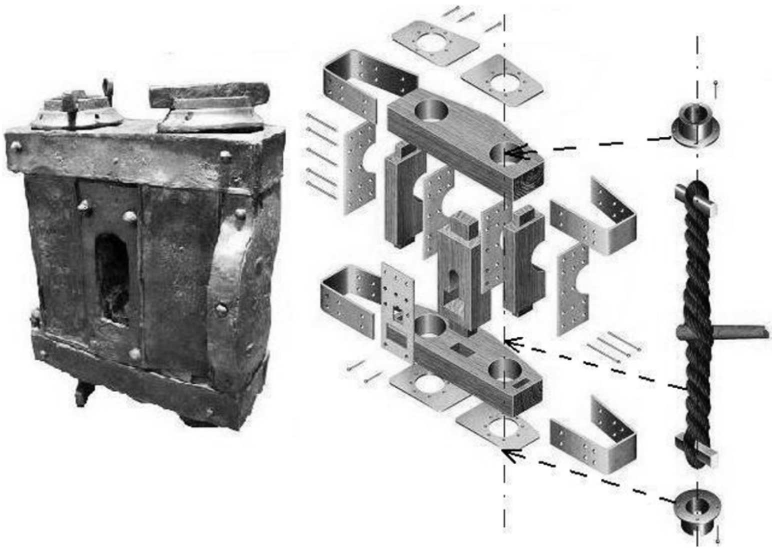

Fig. 11. Torsion motor: find (left) and reconstruction (right).

Fig. 12. Pictorial reconstruction of a catapult.

In figure 13 are reported a pictorial reconstruction of an eutyntonon ballista on the left and a pictorial reconstruction of the large ballista found at Hatra (palintonon ballista) on the right [8].

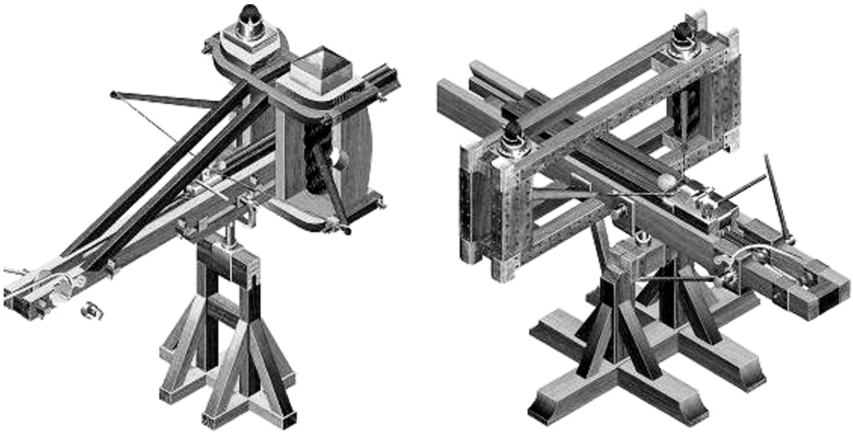

Fig. 13 a). Pictorial reconstruction of ballistae: eutyntonon (left) and palintonon (right).

It must be observed that while in the eutyntonon ballista the arms, during the run, are always in the same half-plane respect the frame, in the palintonon ballista the arms pass through the frame as shown in the sceme in figure 13. This permitted to the arms to rotate by a larger angle and, hence, an higher efficiency of the palintonon [8, 19, 20].

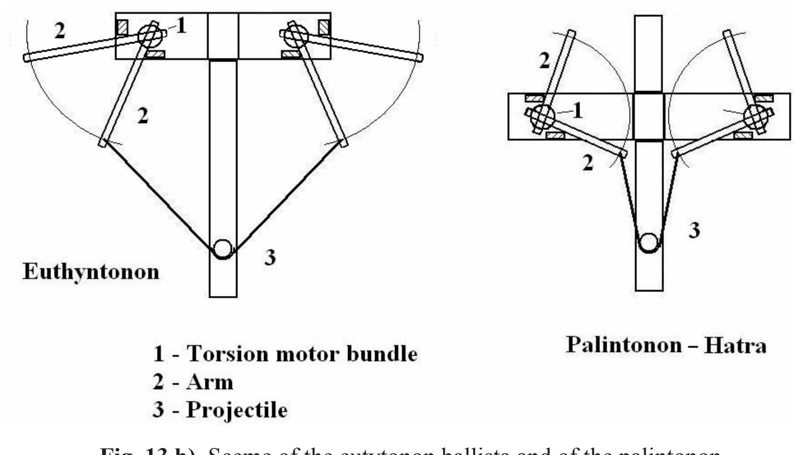

Fig. 13 b). Sceme of the eutytonon ballista and of the palintonon.

The studies on the throwing machines technology was certainly carried on till the I century B.C. when a repeating catapult [15, 16, 21, 22] was developed The device was described by Philon of Bizantium and attributed to Dionysius of Alexandria and, apparently, it was used around the I century B.C.; it was a part of the arsenal of Rhodes that may be considered as a concentration of the most advanced mechanical kinematic and automatic systems of the time, many of which show working principles and a conceptions that still can be considered as “modern”. A pictorial reconstruction is shown in figure 14 and a cinematic reconstruction of the automatisms can be found in [23].

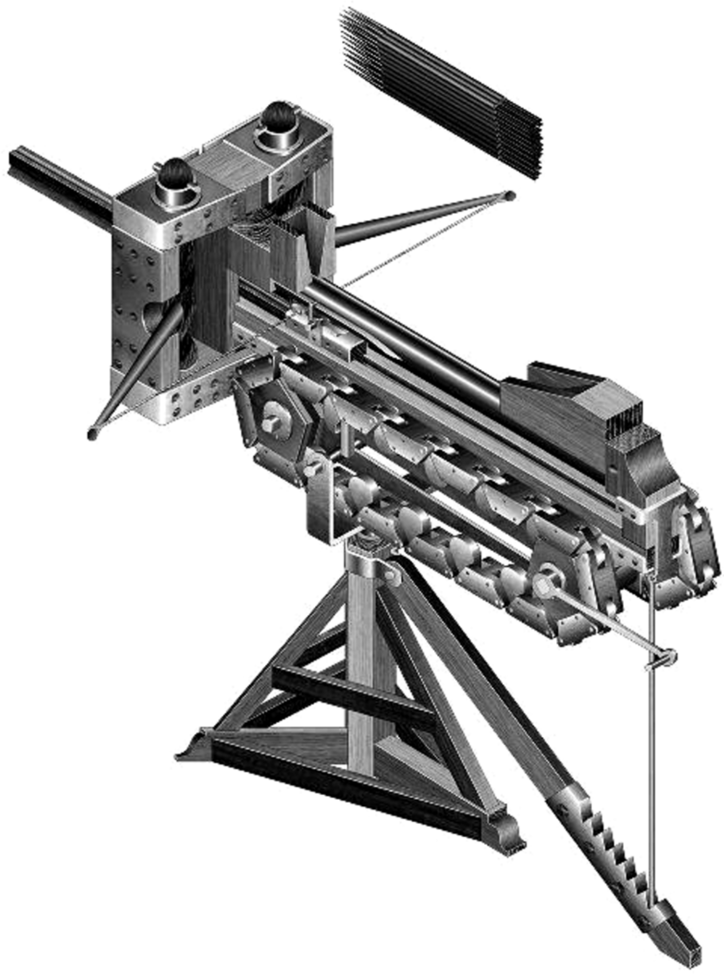

Fig. 14. A pictorial reconstruction of the repeating catapult [23].

In figure 15 is reported a drawing of the fully automatic mechanism, as it was proposed in the reconstruction by the author [23].

From this figure, that is based on previous studies [15, 16, 23, 22] and on the author's study of the description given by Philon of Bizantium, it is easy to understand the "modernity" of the Greek weapon designers.

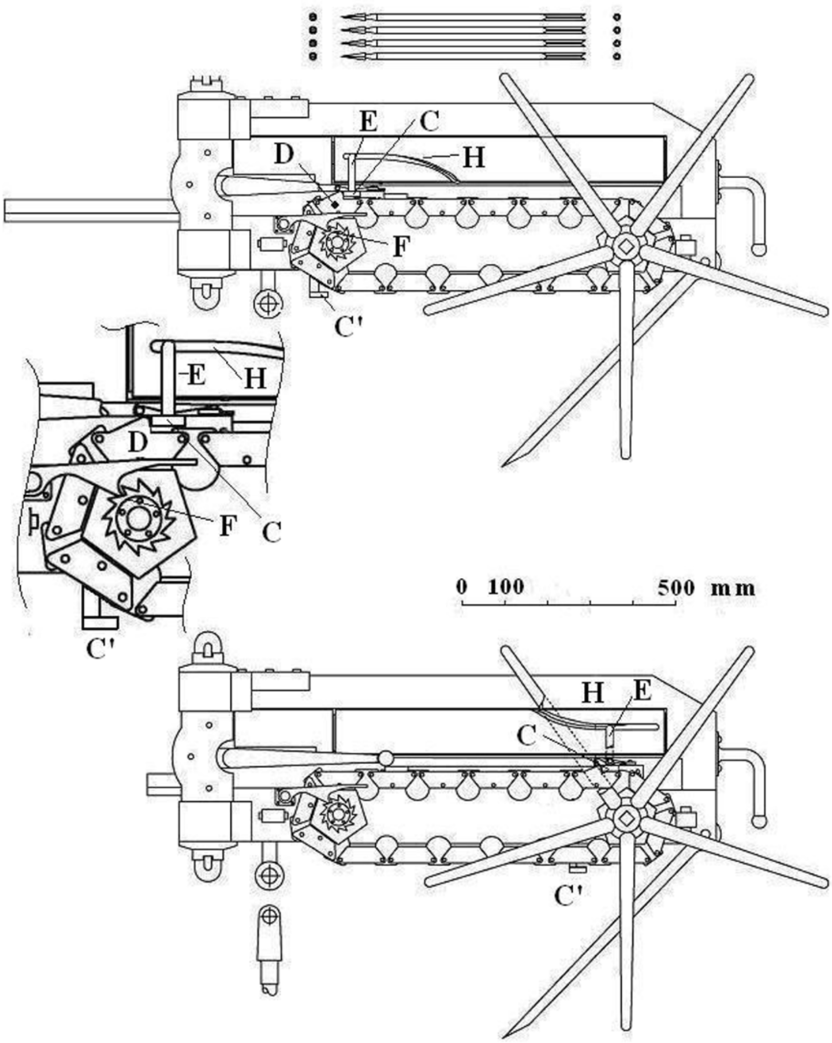

Fig. 15. The mechanism of the repeating catapult.

Finally, in figure 16 is reported a pictorial reconstruction of an onager. From the figure it is easy to understand that the projectiles (stones or similar round objects) thrown by this weapon could describe only parabolic trajectories like those of an howitzer and not flat ones.

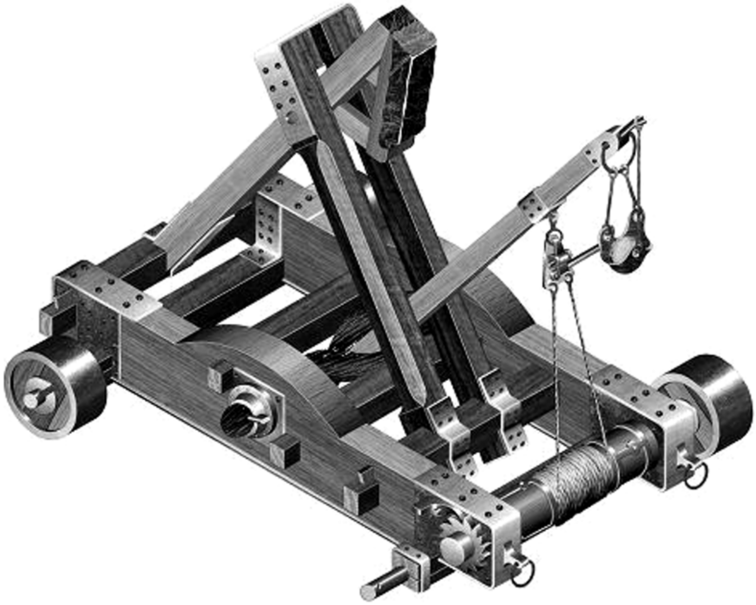

Fig. 16. Pictorial reconstruction of an onager.

From the brief notes reported above, it is evident that the steam cannon was something of very different either for what the shape is concerned and (even more) from a conceptual point of view. As far as the latter aspect is concerned, the extraordinary modernity of the Archimedes' cannon is evident.

REFERENCES

[1] A.S. Papadogiannis, N.S. Papadogianni, A. Carabelas, S. Tsitomeneas, P. Kyraggelos and T.G. Chondros (2008). The Mirror Weapon in Archimedes Era. Proceedings of EUCOMES 08, 29-36 DOI: 10.1007/978-1-4020-8915-2_4 pp. 29–36.
[2] B.L. Simms (1977). Archimedes and the Burning Mirrors of Syracuse. Technology and Culture, vol. 18, no. 1 (jan. 1977), pp. 1–24.
[3] B.L. Simms (1987). Archimedes and the invention of Artillery and Gunpowder. Technology and Culture, vol. 22, no. 1 (jan. 1987), pp. 67–79.
[4] B.L. Simms (1991). Galen on Archimedes: Burning Mirrors or Burning Pitch?. Technology and Culture, vol. 32, no. 1 (jan. 1991), pp. 91–96.

[5] F. Russo (2010) Il Cannone a vapore di Archimede nelle fonti Medioevali. Medioevo, no. 3.
[6] D. Brewster (1837) A treatise on Optics. Carey, Lea & Blanchard, Philadelphia 1837, available on the web page: http://books.google.it/books?id=Phc5AAAAMAAJ&pg=PA264&lpg=PA264&dq=buffon+burning+mirrors&source=bl&ots=SaVohfwWcR&sig=rFlnzgB7Ux_ENFBt_maxvcInt8Y&hl=it&ei=LWZES9-MMqHsmwOd-dyBBw&sa=X&oi=book_result&ct=result&resnum=4&ved=0CBYQ6AEwAzgK#v=onepage&q=buffon%20burning%20mirrors&f=false
[7] W.E. Knowles Middleton (1961) Archimedes, Kircher, Buffon, and the Burning-Mirrors The University of Chicago Press on behalf of The History of Science Society Isis, vol. 52, no. 4 (Dec., 1961), pp. 533–543.
[8] F. Russo (2004) L'Artiglieria delle legioni romane (The Artillery of the Roman Legions) Libreria dello Stato, Istituto Poligrafico e Zecca dello Stato S.p.A, Roma.
[9] Schematics of steam cannon built by I. Sakas; from "Archimedes: The Ingenious Engineer" by Christos Lazos, Athens, 1995 (in Greek) pages 183; available on the web page: http://www.cs.drexel.edu/~crorres/bbc_archive/steam_cannon_schematic.jpg
[10] C. Rossi, F. Russo and F. Russo – Ancient Engineers' Inventions, Precursors of the Present. – Springer, 2009, ISBN: 978-90-481-2252-3.
[11] J.P. Delgado - Relics of the Kamikaze (2003) by the Archaeological Institute of America - www.archaeology.org/0301/etc/kamikaze.html
[12] C. Zamparelli (2005) Storia, Scienza e leggenda degli specchi ustori di Archimede. Available on the web page: http://www.webalice.it/c.zamparelli/Cartella%20scritti%20personali/scritti%20personali.htm
[13] A.C. Clauss – On Archimedes' Burning Glass. (1973) Applied Optics, vol. 12, no. 10.
[14] R.W. Bonner, R.P. Wadell and G. Popov (2008) Local Heat Transfer Coefficient Measurements of Flat Angled Sprays Using Thermal Test Vehicle. Proc. 24th Annual IEEE Semiconductor Thermal Measurement and Management Symposium, 16–20 March 2008 San Jose, CA, pp. 149–153. ISSN: 1065-2221 ISBN: 978-1-4244-2123-7.
[15] E.W. Marsden (1969) Greek and Roman Artillery Historical Development, Oxford University Press II.
[16] E.W. Marsden (1971) Greek and roman artillery. Technical treatises, Oxford, pp. 106–184.
[17] F. Russo (2007) Tormenta Navalia. L'artiglieria navale romana, USSM Italian Navy, Roma.
[18] Chondros T.G. (2008) The development of machine design as a science from classical times to modern era HMM 2008 International Symposium on History of Machines and Mechanisms November 11-14, 2008, Tainan, Taiwan. Proceedings Published by the Springer, Netherland, ISBN 987-1-4020-9484-2 (Print) 978-1-4020-9485-9 (Online).
[19] V.G. Hart and M.J.T. Lewis "The Hatra ballista: a secret weapon of the past?" Journal of Engineering Mathematics Springer Netherlands published on line, ISSN 1573-2703 DOI: 10.1007/s10665-009-9317-8.
[20] A. Iriarte (2003) The Inswinging Theory. Gladius XXIII 2003, pp. 111–140.
[21] E. Shramm (1918) Die antiken Geschütze der Saalburg. Reprint, Bad Homburg: Saalburg Museum, 1980.
[22] V. Soedel and V. Foley (1979) Ancient Catapults. Scientific American, March 1979.
[23] C. Rossi and F. Russo (2009) A reconstruction of the Greek–Roman repeating catapult. Mechanism and Machine Theory. On line: doi:10.1016/j.mechmachtheory.2009.07.011. Paper: vol. 45, Iss. 1, Jan. 2010, pp. 36–45.