“Augustus’s Victory Monument, 3D Modeling, and New Directions for Warship Research”

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Summary

Thanks to 3D laser-scanning technology, we can now visualize the different sizes and shapes of warship rams displayed by Augustus on his Victory Monument at Nikopolis. Starting with computer models of the monument’s ram sockets, we have reverse-engineered 3D ram models to fit each socket. Such visualization techniques enable us to move beyond older scholarship, which focused primarily on how ancient warships were rowed, to consider the ramming capabilities of late Hellenistic warships. Furthermore, these data can now help us understand warships from other eras and regions. For example, the Nikopolis data provide a fixed metric by which to evaluate a set of warship rams recently discovered off the western coast of Sicily by the RPM Nautical Foundation and the Sicilian Soprintendenza del Mare. Artifacts associated with these rams make it certain that they were lost in the final naval battle of the First Punic War, the Battle of the Aegates Islands (241 BCE). The current collection of 10 Egadi rams (as of 2 July 2012) are revealed by their small size to be no larger than rams from *triēreis*, a fact that invites a reassessment of the ancient battle narratives as well as our understanding of Roman and Carthaginian “threes.” The paper concludes by announcing the creation of a new online database to be hosted by the University of South Florida. The website, called RAM^{3D}, will present data of all kinds (including measureable 3D models) that are relevant to the study of warship rams. The database will be aimed at facilitating research by international teams in order to advance our understanding of ancient warships through computer modeling and ramming simulation experiments.

Περίληψη

William M. Murray: "Το Μνημείο της Νίκης του Αυγούστου, τρισδιάστατη αναπαράσταση των εμβόλων και οι νέοι ορίζοντες στη μελέτη των αρχαίων πολεμικών πλοίων"

Χάρη στην τεχνολογία της τρισδιάστατης σάρωσης με λέιζερ τώρα μπορούμε να σχηματοποιήσουμε οπτικά τα διαφορετικά μεγέθη και μορφές των πολεμικών εμβόλων που είχε εκθέσει ο Αύγουστος στο Μνημείο της Νίκης στη Νικόπολη. Χρησιμοποιώντας ως βάση τα ηλεκτρονικά ομοιώματα των οπών στον τοίχο όπου είχαν αναρτηθεί τα έμβολα, δημιουργήσαμε τρισδιάστατα ομοιώματα εμβόλων που συμφωνούν με το μέγεθος και σχήμα κάθε οπής. Μια τέτοια οπτική σχηματοποίηση μας επιτρέπει να προχωρήσουμε πέρα από τα επιτεύγματα των προηγούμενων μελετών, τα ενδιαφέροντα των οποίων εστιάζονταν κυρίως στον τρόπο με τον οποίο τα αρχαία πολεμικά πλοία κωπηλατούνταν, και να θεωρήσουμε τις εμβολιστικές δυνατότητες κατά την όψιμη Ελληνιστική περίοδο. Επιπλέον, αυτά τα στοιχεία μας βοηθούν να κατανοήσουμε τα πολεμικά πλοία όχι μόνο άλλων εποχών αλλά και άλλων περιοχών. Για παράδειγμα, τα στοιχεία από τη Νικόπολη μας δίνουν τη δυνατότητα να δημιουργήσουμε ένα σύστημα επιμέτρησης βάσει του οποίου μπορούμε να αξιολογήσουμε τα πολεμικά έμβολα που ανακαλύφθηκαν πρόσφατα από το Ναυτικό Ίδρυμα RPM και το Σικελικό Soprintendenza del Mare κοντά στη δυτική ακτή της Σικελίας. Ευρήματα που σχετίζονται με αυτά τα έμβολα επιβεβαιώνουν ότι αυτά χάθηκαν κατά την τελευταία ναυμαχία του πρώτου Καρχηδονιακού πολέμου στις νήσους Αιγούσσες (241 π.Χ.), που σήμερα ονομάζονται Egadi. Τα έμβολα της συλλογής Egadi, που μέχρι τις 2 Ιουλίου 2012 απαριθμούνταν σε δέκα, είναι πια φανερό ότι λόγω του μικρού τους μεγέθους δεν είναι μεγαλύτερα από τα έμβολα των τριήρων, γεγονός

που μας επιτάσσει να επανεξετάσουμε όχι μόνο τις αρχαίες περιγραφές ναυμαχιών αλλά και τις απόψεις μας για τις ρωμαϊκές και καρχηδονιακές τριήρεις. Η παρουσίασή μου καταλήγει με μια ανακοίνωση για τη δημιουργία ενός νέου ηλεκτρονικού αρχείου πληροφοριών που θα εδράζεται στο πανεπιστήμιο της Νότιας Φλόριδας. Η ιστοσελίδα, που ονομάζεται RAM^{3D}, θα περιέχει κάθε είδους στοιχεία που συνδέονται με τη μελέτη εμβόλων πολεμικών πλοίων (συμπεριλαμβανομένων και τρισδιάστατων ομοιωμάτων που οι διαστάσεις τους μπορούν να καταμετρηθούν). Σκοπός του αρχείου είναι η συνδρομή στις έρευνες των διεθνών επιστημονικών ομάδων ώστε να διευρυνθούν οι γνώσεις μας για τα αρχαία πολεμικά πλοία μέσω ηλεκτρονικών ομοιωμάτων εμβόλων και μέσω αναπαραστάσεων ναυτικών εμβολισμών.

Introduction.

In 2001, when Konstantinos Zachos agreed to let me try to visualize the rams originally displayed at Augustus' Victory Monument, I had no idea what was about to happen. The original plan was to make 3D computer models of five or six rams and perhaps one physical model at a 1:1 scale if the cost was not too much.[1] Over the past 11 years that we have worked on this project, there has been a revolution in 3D technology and this has impacted every aspect of our original plan. The new technology has not only allowed us to visualize the rams more accurately, it has also enabled new ways of thinking about warships and how they functioned.

When we first began our work in 2002, we started with the largest well-preserved socket on the monument—the 4th surviving one from the western end of the main retaining wall.[2] Working from measurements recorded by hand in 1986 along with some detailed photographs, we produced a rough 3D model of this socket, which I present in Figure 1 (left image).[3] I was assisted in this process of 3D modeling by Donald Sanders and Geoffrey Kornfeld (among others) of the Institute for the Visualization of History.[4] In order to make a warship ram with the correct size and shape to fit our digital socket, we next made a 3D computer model of an authentic warship ram—the so-called Athlit ram, found off the coast of Israel in 1980 (Figure

[1] The intention was to make the model out of fiberglass or dense urethane foam.

[2] See Murray 2007 for a description of our first attempt to create a ram from this monument. Our numbering sequence for the monument's sockets begins with the first preserved one on the western end of the main retaining wall. It should be noted that there is room for an additional socket (A) to the left of the first preserved one.

[3] See Murray 2007, I: 448 and II: 338, Fig. 12.

[4] Dr. Sanders is President of the Institute and Mr. Kornfeld is a graphic artist skilled in 3D modeling.

2).[5] Working from this 3D model of the Athlit ram, we next enlarged it to fit the outline and contours of socket #4. Since this procedure resulted in a ram that was too long and bulky to fit on the ram terrace at Nikopolis, we next adjusted its overall proportions, using as our guide the large warship rams sculpted on a triumphal arch built during the reign of Tiberius at Arausio (modern Orange) in southern France.[6] Our first attempt at producing a ram to fit socket #4 was then presented to the members of the Second International Nicopolis Symposium in September 2002. I reproduce it here as Figure 3 (= Murray 2007, II: 341, Fig. 17).

3D Scanning and Model Building.

Between 2002 and 2005, we continued to refine the appearance of this ram, which I presented at various conferences in hopes of receiving feedback we could use to make further adjustments.[7] I found that the more I learned about warship rams, the less I liked what we had

[5] For the Athlit ram, see Casson and Steffy 1991, and Murray 2012, 31-38. The data behind this model were extracted from a number of sections of the ram recorded by J. R. Steffy; see Casson and Steffy 1991, 13-15 (Figs 2-9, 2-10 and 2-11).

[6] For the Arch at Orange, see Amy 1962. We chose the rams from Orange as our guides because they are roughly contemporary in date (indeed, they may be modeled after Actian rams), because their blocky proportions correspond to a marble ram found at Nikopolis in 1940 (now lost), and because their rear profiles match the profiles of the Actian sockets (see Murray 2007, I: 448-49). Finally, the ratio between their heights and lengths match those of the socket heights and forward edges of bases placed in front of each one to receive the weight of its ram. The full details of these ratios will be presented in a future publication.

[7] Papers were presented in January 2004 at the annual meeting of the Archaeological Institute of America in San Francisco ("Computer Modeling of Warship Rams from the Battle of Actium"), in January 2005 at the AIA Gold Medal Session in honor of Lionel Casson in Boston ("Recent Developments in Ancient Warship Studies"), and in August 2005 at the 9th International Symposium on Ship Construction in Antiquity at Agia Napa in Cyprus ("Reconstructing the Ram of a *Dekeres* from the Battle of Actium").

produced. Our ram, for example, was too closely modeled on the Athlit ram, an early 2nd century weapon that exhibited graceful curves not seen in sculpted or painted rams from Roman contexts of the late Republic and early Empire. Other problems stemmed from our socket model, which did not account for the shifting of the wall's blocks. And finally, our data points—roughly 200 in number—were too few to reproduce the real complexities of the socket's interior. Since I planned to use ram #4 as a guide to help us model weapons for other sockets, I wanted to make sure that our first model was as reliable as possible. I therefore decided to model the sockets with the aid of a recent technology based on 3D laser scans because I felt this would provide the level of detail we needed. So, in 2009, Dr. Zachos authorized a program of 3D laser scanning for the Monument of Augustus. The work was carried out by Drs. Lori Collins and Travis Doering, co-directors of the University of South Florida's Alliance for Integrated Spatial Technologies (USF-AIST).

Over the course of a five day period, USF-AIST carried out a program of 3D laser scanning on the monument's main retaining wall, its inscription blocks and a number of detached blocks that originally came from sockets on the western and eastern ends of the monument. They employed a Faro LS 880 phase shift laser scanner to capture overlapping views of the monument and its sockets, as well as straight-on scans of the sockets we were most interested in modeling. A Konica Minolta VIVID 9i scanner was used to scan socket #13 (the best preserved example) and the "ORBEL" inscription block at a higher resolution for the purposes of comparison with the Faro scans.[8] Both scanners create photorealistic point clouds that allow measurements to be

[8] The Faro LS 880 scanner offers ±3 mm systematical distance error at 25 m. The Konica Minolta VIVID 9i scanner enables 3D measurement accuracy of 50 microns (0.002 inches). We found that the increase in detail offered by the Minolta VIVID 9i scanner did not offset the efficiency of the Faro scanner, which produced scans of

taken directly from the scans as well as the creation of 3D polygonal computer models. We used software developed by Faro (Faro Scene) to manipulate the point clouds and Geomagic Studio for the creation of polygonal models. USF-AIST processed the raw scans recorded at the site, removed excess “noise,” and then created a seamless 3D view of the entire monument and hillside by merging 28 files together through a process called registration. Detailed socket models were created by cropping the point clouds to include only the socket of interest and then using Geomagic Studio 12 (later upgraded to Studio 2012) to convert the point clouds into polygonal models. A comparison between the models produced in 2002 and 2011 for socket #4 (Figure 1) reveals the superiority of the new model based on scan data.

Additionally, our new model allowed us to isolate each block in the socket so that individual stones could be adjusted, thus removing the worst effects of the wall’s deformation.[9] The grid in Figure 4 represents the original plane of the wall’s vertical alignment and reveals how the unadjusted socket is slightly skewed. Although barely perceptible to the eye, the blocks of the left side of the socket, when viewed from the front, are currently pushed inward (i.e., into the hillside) away from the plane of vertical alignment. Our model of the socket allowed us to realign these blocks by moving them outward a few centimeters so that they lined up correctly

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satisfactory quality when placed directly in front of the individual socket or inscription block that was being recorded.

[9] The integrity of the main retaining wall has been broken, probably by an earthquake, and the resulting earth slippage at the break has caused the wall to slump downward from sockets #1 to #26 and then rise sharply back to socket Ω at the eastern corner of the monument. In other words, the top of the first course block at socket # 26 is 2.4 m below the top if the first course block at socket #1 on the western end of the wall, and 2.1 m below the top of the first course at the eastern most end of the wall (at socket Ω). Along with this general slumping, the blocks of each socket have also experienced other deformations that have shifted them out of their original alignment.

with the other blocks. The result of this realignment can be seen in Figure 5, which shows the differences in shape between a new model adjusted to fit this new socket and the ram produced and refined between 2002 and 2005. The light gray surface represents the model before straightening and the dark gray surface the straightened model.

Our methodology for making further adjustments to ram #4 involved two major steps: 1) insuring that the ram's exterior touched the back exterior of the socket cutting from top to bottom, and 2) making the ram's interior come as close as possible to the uncarved core (i.e., the central portion of each socket) at the surface of the wall from top to bottom.[10] Figure 6 shows the ram in its socket, sectioned at the surface of the 1st course so that one may see the weapon's exterior and interior in relation to its cutting and core blocks. Since we were dealing with a three-dimensional object, each refinement involved a number of related decisions, which we recorded in a set of "build doctrines" or "modeling rules" to insure consistency from model to model and allow others to check our work. After finishing the ram for socket #4, we then moved to socket #6, then to #8 and so forth through #11, #13, #18, and #22. As I prepare this draft (January 2013), the work on the rams is still in progress. I present our current versions of rams #4, #6, #8 and #13 in Figure 7, while Figure 8 presents ram #4 alongside the Athlit weapon for comparative purposes. Although too many uncertain details still remain for me to consider these second-

[10] Exceptions had to be made with some of the sockets, like #22, whose core blocks were trimmed back so far that the resulting angle from the back exterior of the socket to the core resulted in an obviously deformed ram. In these cases, we chose to leave gaps between the interior surfaces of our model and the core blocks of the socket. Presumably, these gaps would have been filled by wood left inside the weapon, perhaps because hardened pitch had made the timbers more difficult to remove from the ram's interior than simply cutting back the core blocks.

generation models "finished," I am now much more satisfied with their general appearance and faithfulness to their socket's nuances.[11]

Warship bows from warship rams.

The next logical step involves proceeding from the rams to the ships that originally carried them. Of course we cannot expect to reconstruct the entire ship from just the ram, nevertheless we can design on computer a generalized bow structure to fit inside our 3D ram models. This is because the sockets' uncarved cores preserve in outline the timbers that were originally inside each weapon. For guidance, we can follow the similarly shaped Athlit ram, whose bow timbers enabled J. R. Steffy to theorize a design (see Figure 9).[12] We might also build on John Coates's design of the trireme replica *Olympias,* as shown in Figure 10.

We can gain a general sense of the ship classes represented by our models by considering their relative sizes on the Nikopolis monument, which displays a selection of rams from a fleet known to include ship classes from "ones" to "tens." According to Strabo 7.7.6, after the war's conclusion, Augustus dedicated a "*dekanaian akrothinion*" or ten ship dedication resulting from his first pick of the spoils taken from the enemy. He placed the 10 ships in a naval yard across the straights from Nikopolis on Cape Actium and included in his selection a warship from each of the different classes that fought in Antony's fleet, from a "one" to a "ten." Because we thus know the limits of the classes available to Augustus for his Victory Monument, and because the Nikopolis monument preserves physical evidence from a range of different warship sizes,

[11] We must still refine the precise sizes and shapes of the different ramming heads, for example.

[12] When the ram was found, 16 different timbers were preserved inside its hollow casting. For Steffy's description of the preserved timbers and design of the bow just behind the preserved sections of the ram, see Casson and Steffy 1991, 6-39.

something you can actually see when you compare the sockets side by side, I have argued elsewhere that we have here the bow dimensions of "fives," "sixes," "sevens," "eights," "nines," and "tens."[13] Using the rams created from these sockets, we can now recreate the bows for this range of sizes, at least on computer. When this has been done successfully, our inquiry will be able to follow yet another path.

Finite Element Analysis (FEA), RAM^{3D}, and Ram Studies.

Finite Element Analysis (FEA) involves stressing a computer model of a material or design that is then analyzed for specific results. In this way, modern designers can test their designs before they are mass produced. Once we have created our warship bow models, I propose that we employ FEA to help us carry out controlled crash tests. FEA would allow us to account for the properties of the bronze alloy making up the ram, the species and grain direction of the wooden timbers in the ship's bow structure, and the speed, direction and mass of the object colliding with it on a surface of water. Although the calculations will certainly be complicated, there currently exists commercial software for FEA that should allow mechanical engineers to model the various elements necessary to simulate different kinds of battle collisions. Because of the complexities involved, replicating these battle scenarios must be a joint effort, involving naval architects, wood scientists, mechanical engineers and naval historians.

In order to explain our project and its goals to potential experts who might help us conduct this research, I am building a web site called RAM^{3D} (http://aist.usf.edu/ram3d). I hope

[13] See further Murray and Petsas 1989, 99-100 and 113-14. The full evidence has yet to be digested. Three partially preserved sockets recently uncovered at the eastern end of the wall (sockets Χ, Ψ, and Ω) as well as some socket blocks recovered from the hillside suggest that even more sizes may eventually be identified. For an illustration showing these size differences, see Murray 2007, II: 334, Fig. 3 and 2012, 41, Fig. 2.6.

that the site will also prove useful as a focal point for the exchange of data between scholars engaged in the study of warship rams. To this end, I intend to include 3D models of our Actian rams plus a full description of the methodology used to create them. I will also include 3D models of authentic rams, 3D models of large sculpted rams from ancient monuments (like the triumphal arch at Orange mentioned in the Introduction), and photographs of ancient warship representations (painted, modeled, sculpted, and inscribed).

Rams (*emboloi*) as a class of artifact are becoming more plentiful with each year that passes. Since 2005, 10 new warship rams have been found off Sicily's western coast by the RPM Nautical Foundation and Sicily's Soprintendenza del Mare. These new rams have been found on the seafloor beneath the site of an ancient naval battle fought between Rome and Carthage in 241 BC. The battle, traditionally called the Battle of the Aegates Islands, concluded the First Punic War and marked Rome's emergence as a dominant naval power in the western Mediterranean.[14] In brief, what happened was this: Carthage had dispatched a fleet to bring supplies to a besieged force on Mount Eryx (modern Erice) near ancient Drepanum (Trapani), and when this fleet approached the Aegates (Egadi) Islands, the Roman fleet successfully blocked its passage. The ships from Carthage were heavily loaded, the sea was rough, and the results are seen in the scatter of amphoras, helmets and warship rams still lying on the sea floor. Although recorded as an overwhelming Roman victory, evidence from the battle zone makes it clear that both sides lost ships, while the damaged rams and scattered helmets inform us that the ramming attacks were violent and deadly.[15]

[14] See Polyb. 1.60-61 and Diod. 24.11.1 for the best battle accounts.

[15] See Tusa and Royal 2012 for a preliminary report of the battle landscape that has been found.

Many areas remain unsearched. Rams are everywhere, so the odds are good that more will be found in the years to come. Thus far, all the new rams are relatively small, that is, significantly smaller than the Athlit ram, which I have classed elsewhere as coming from a Ptolemaic "four" or *tetrērēs.*[16] Since Polybius implies that "fives" or *pentēreis* made up a large proportion of the Roman fleet during the First Punic War, I remain hopeful that one or more of the larger rams will eventually be found.[17] Whether this occurs or not, we still have a growing body of artifactual evidence that should reveal much about the physical workings of ancient warship bows—at precisely the place where the ship delivered and absorbed the forces of the ramming collisions.

When you add to the Egadi rams the four rams recovered elsewhere (the Acqualadroni, Bremerhaven, Piraeus and Athlit rams) and our models from Actium, we now possess an impressive range of weapons for testing in different battle scenarios.[18] My hope is that such testing will teach us about the physical reality of ancient naval warfare during the Hellenistic and Roman periods. I also hope that our involvement of engineers and other scientists will produce new ways of looking at the evidence and mirror in a small way what happened with the

[16] For the Egadi rams, see Tusa and Royal 2012, 39-42; for the classification of the Athlit ram as a "four," see Murray 2012, 59-65.

[17] See Polyb. 1.59.7-8; in like manner, when Polybius sums up the devastating losses during the First Punic War (1.63.4-9), his fleet and casualty totals include only *pentēreis* or "fives."

[18] A brief discussion of authentic waterline rams known up to June 2011 (with references) can be found in Murray 2012, 48-52; more information can be found in Tusa & Royal 2012, 12-25 (for the Egadi 1-7 rams), and in Buccellato & Tusa, forthcoming (for the Acqualadroni ram).

construction and testing of the trireme replica *Olympias*. By this, I mean the fertile interaction between humanists and scientists reflected so clearly in that project's various reports.[19]

Conclusion.

I suspected years ago when I first saw the sockets at Augustus' Victory Monument that this site was important for the study of ancient warships. Still, I had no way of knowing just how important it would become until we produced our 3D models and began to reconstruct the rams that were originally displayed here. Thanks to 3D visualization techniques and other kinds of computer analysis, we are now poised to learn much more. When I first came to Nikopolis in 1978, the Victory Monument lay open and unprotected. It remained that way until the 1990s when Drs. Zachos and Douzougli, along with their colleagues—many of you who are here today—began a systematic program of study at and around Nikopolis. Now, the Victory Monument is protected within a fence, the thorns that once choked its blocks have been replaced by grass, and the site is properly conserved and managed by responsible officials. The monument has been excavated, the finds subjected to careful analysis, the preliminary results have been published in a separate monograph, and a fuller publication is in preparation.[20] The fact that we are here today to discuss this important site and share with one another our results is a direct result of the life's work of Konstantinos Zachos and Angelika Douzougli. I am grateful to them

[19] For a listing of the various reports and papers, see Rankov 2012, 1 and 9. A few chapter titles from this volume, which represents the project's "Final Report," demonstrate the kinds of research that embody this multidisciplinary interaction: "Human Mechanical Power Sustainable in Rowing Ships for Long Periods of Time" (161-64); "Paleo-bioenergetics: clues to the maximum sustainable speed of a trireme under oar" (165-68); "Trireme Life Span and Leakage: a wood technologist's perspective" (185-202); and "Collision Damage in Triremes" (214-24).

[20] See Zachos 2001 (in Greek) and Zachos 2003 for an English translation.

both for allowing me to join their efforts and I hope that my remarks in some small way honor their considerable accomplishments.

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William M. Murray

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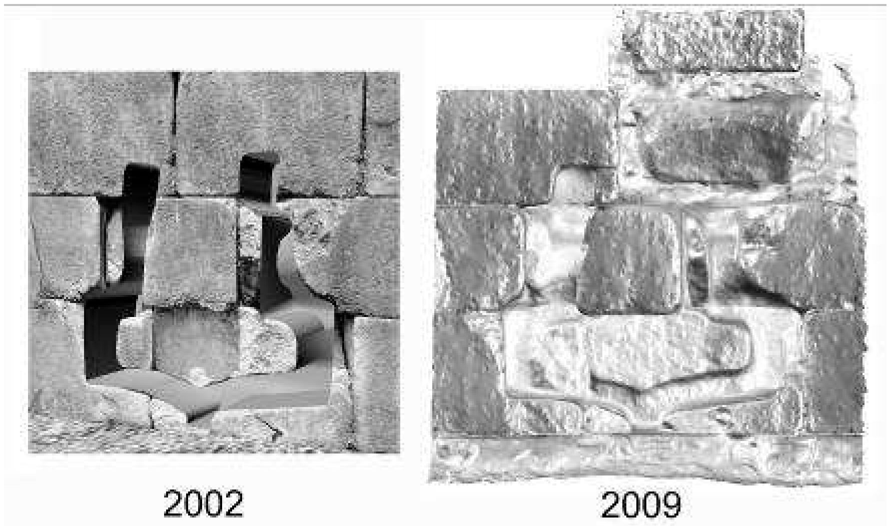
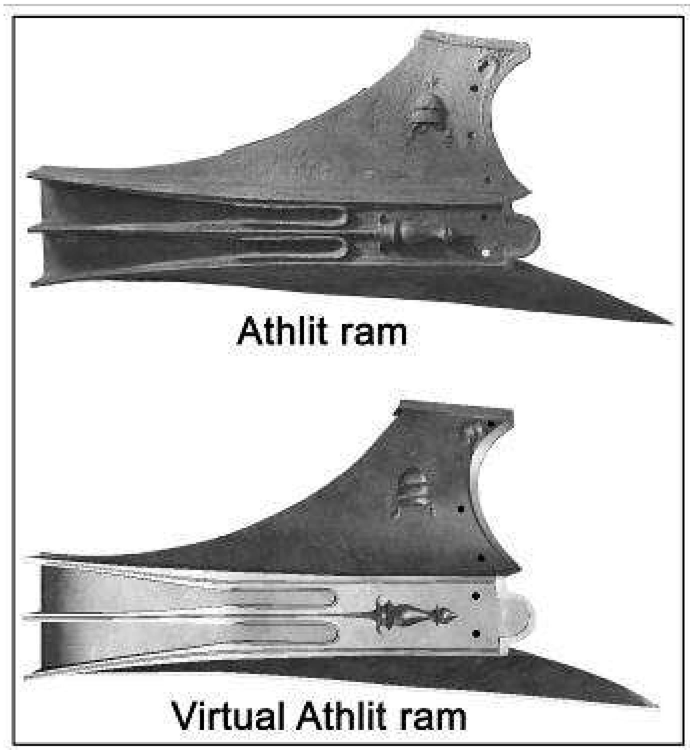


Figure 1



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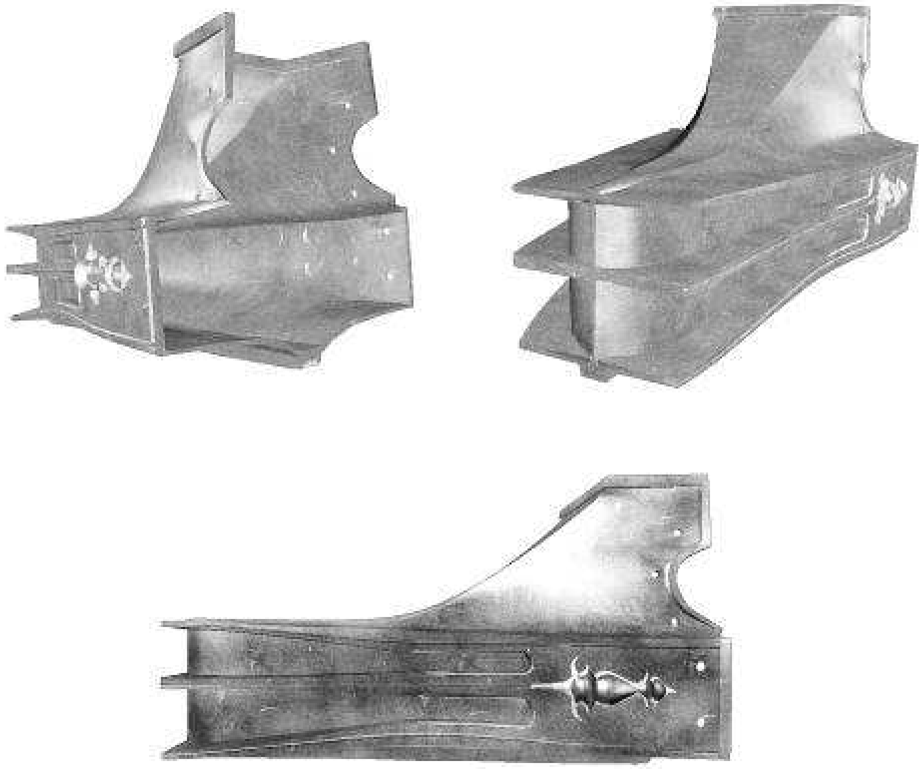
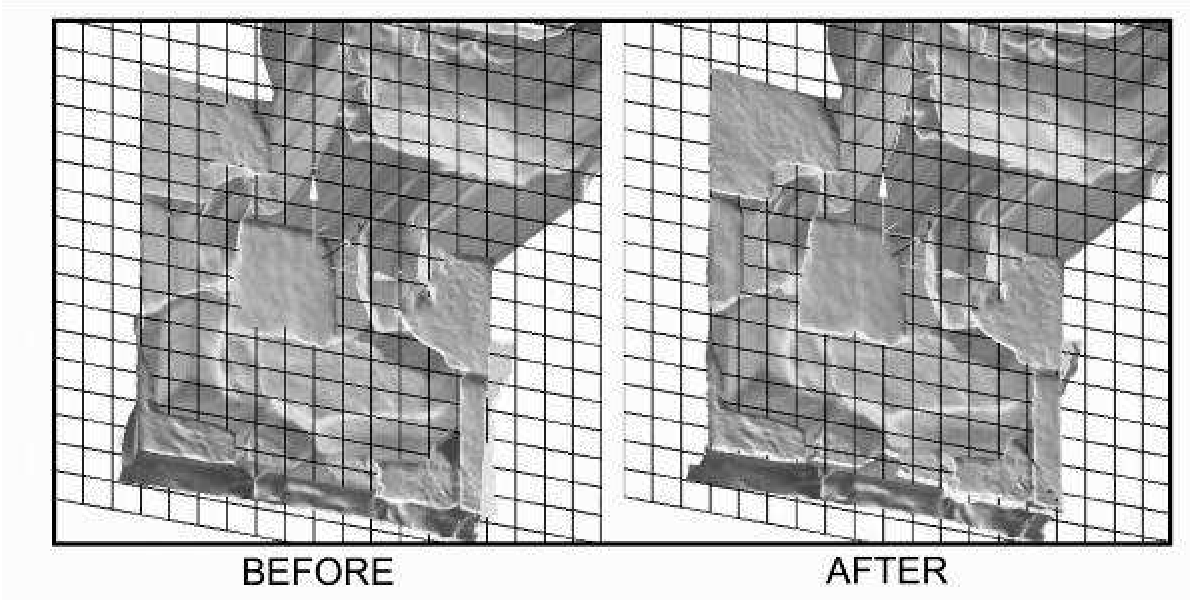


Figure 3



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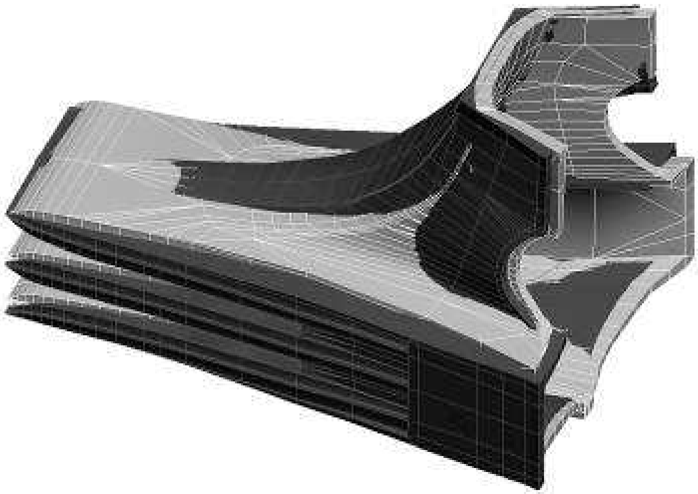

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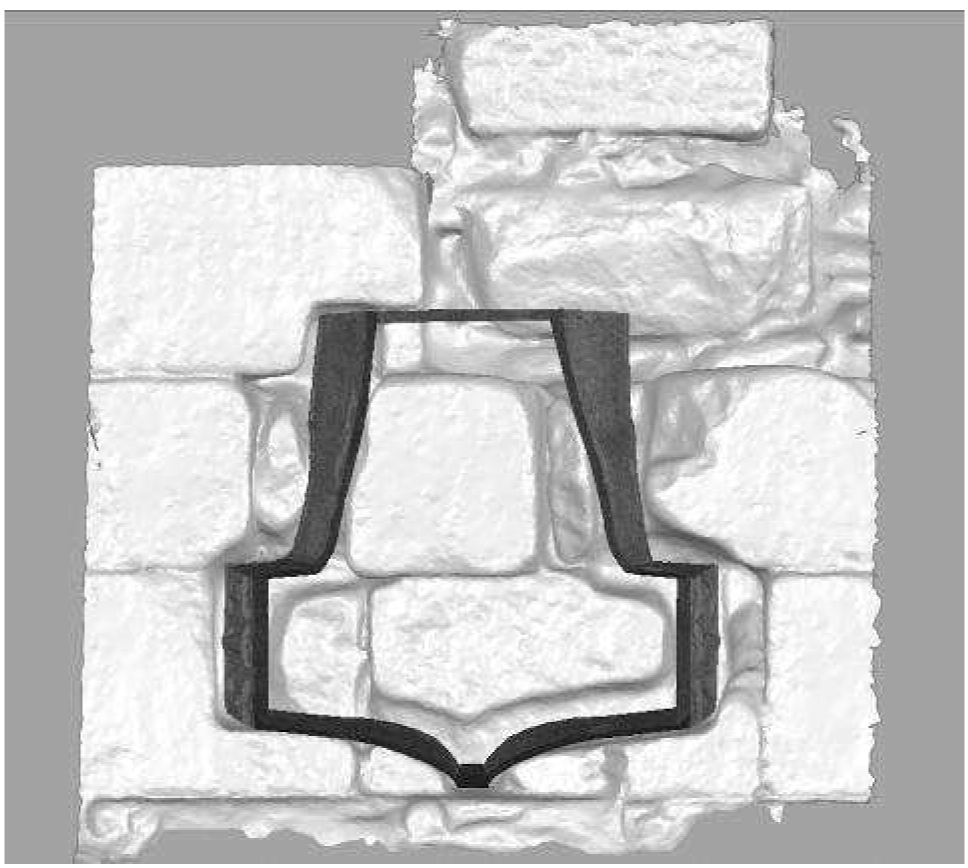

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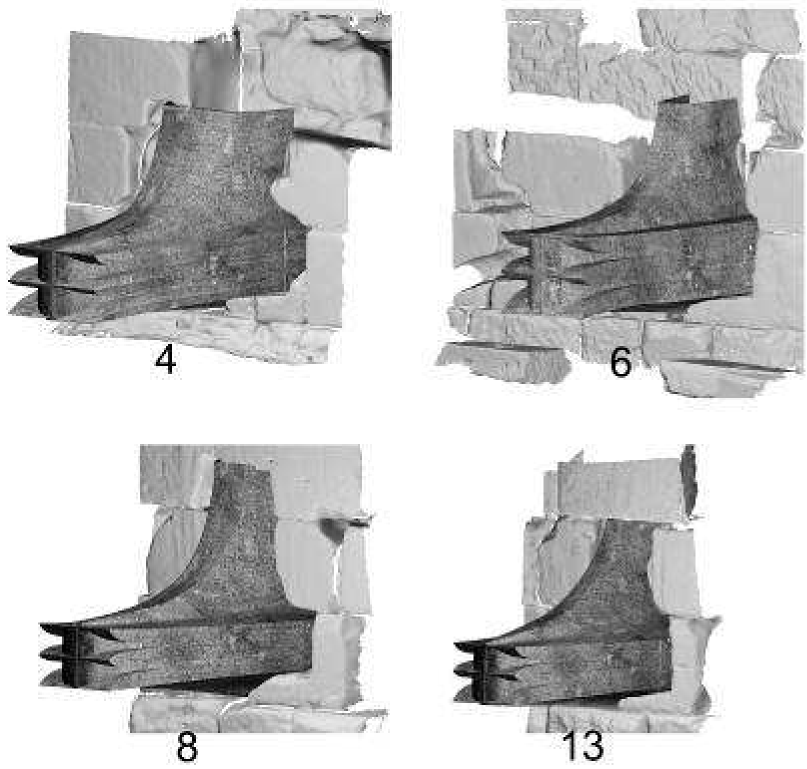

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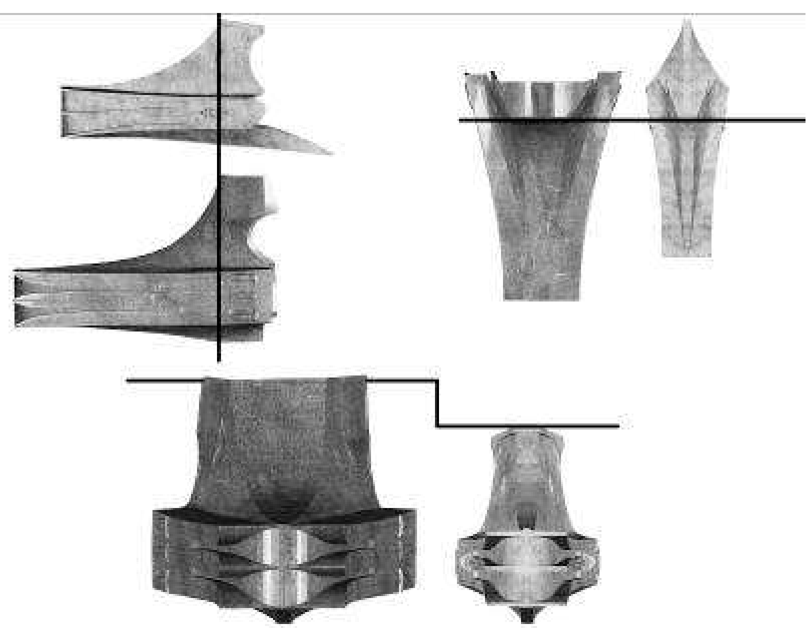

Figure 8

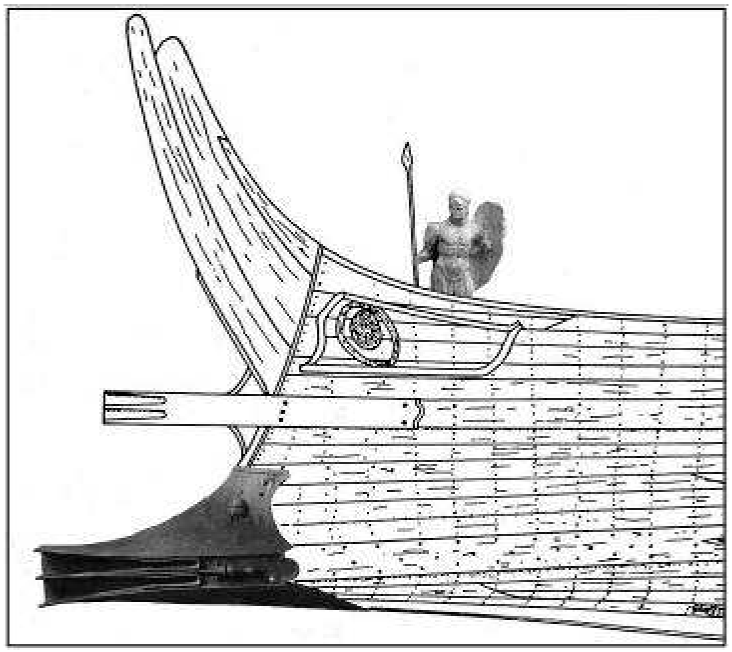

Figure 9

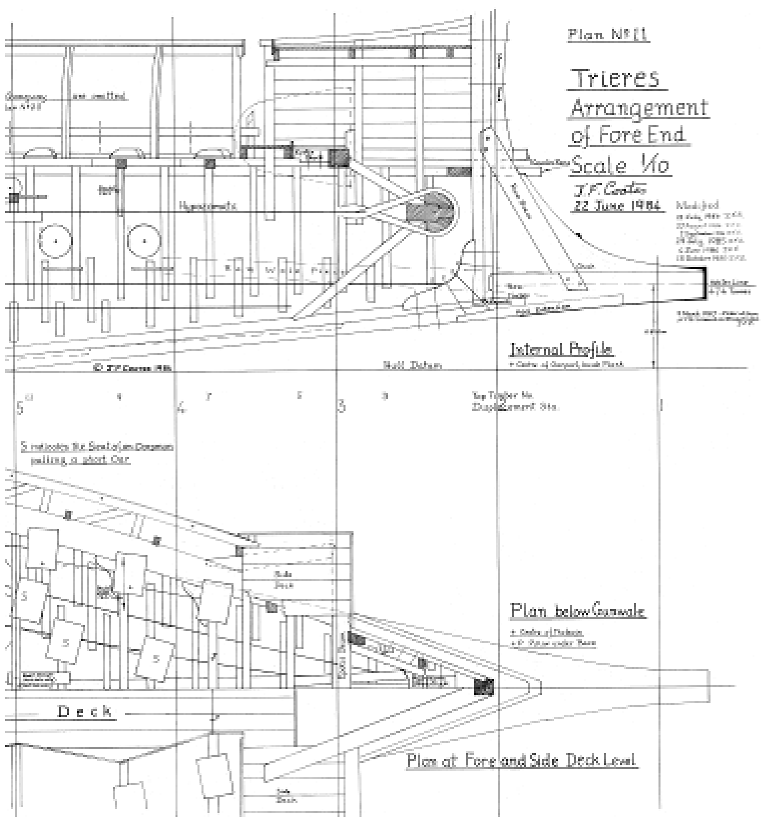

Figure 10