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a cura di

Stefano de Martino, Massimiliano Marazzi, Lucio Milano

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THE APPLICATION OF HIGH-RESOLUTION 3D IMAGING TECHNIQUES TO THE STUDY OF THE ATHLIT RAM

Asaf Oron – Leopoldo Repola

INTRODUCTION

The corpus of naval ram finds, and their research has increased dramatically in recent years in a large part through the work of Prof. Sebastiano Tusa and his team off the Sicilian coast (Tusa and Royal 2012; Adams *et al*. 2013; Buccellato - Tusa 2013; Prag 2014). This reality along with advances in analytical and imaging techniques brings with it a renewed interest in further analysis of the Athlit ram – an intact early 2nd century BC naval ram – and its timbers.

Consequently in 2017 through the generous support of the Honor Frost Foundation a new study of the Athlit ram was launched at its place of display at the National Maritime Museum Haifa, Israel.

Building upon a previous study of the ram (Oron 2006) the new study was designed to provide further information on the origin of the ram, the nature and chronology of its repairs and the spatial interrelations between the ram bronze cast and its bow timbers found within it. The study applied high resolution imaging and 3D recording techniques, not available during previous studies of the ram with further elemental and metallurgical analyses and lead isotope studies.

The results of this on-going study are currently being interpreted and prepared for publication. Meanwhile we wish to share the methodology and tools used for the high-resolution 3D imaging and surveying of the ram along with some preliminary observations. We believe that this information may be useful for those involved with the recording and interpretation of naval rams as well as other portable cultural heritage remains.

The Egadi rams along with the Athlit ram form the largest collection of naval rams derived from a known provenance. As such they generate great interest and hold much potential for comparative studies. A collaborative research project in this direction has been at the heart of an ongoing dialog with Prof. Sebastiano Tusa before his tragic death.

We hope that the current research will serve as a steppingstone towards this collaborative effort in Prof. Tusa's memory.

THE ATHLIT RAM BACKGROUND AND RESEARCH

The Athlit ram was discovered in 1980 in shallow water off the Carmel coast, south of Haifa, Israel. Measuring 2.26 m long, 0.95 m high and weighing 465 kg, it is by far the largest naval ram ever found (Fig.1). The intact bronze ram preserved a portion of the wooden hull of the galley from which it became detached in antiquity (Fig. 2). These wooden remains represent the only extant physical hull remains of a classical and Hellenistic galley. Based on stylistic, iconographic and dendrochronological considerations, the Athlit ram has been dated to the first half of the 2nd century BCE (Murray 1991).

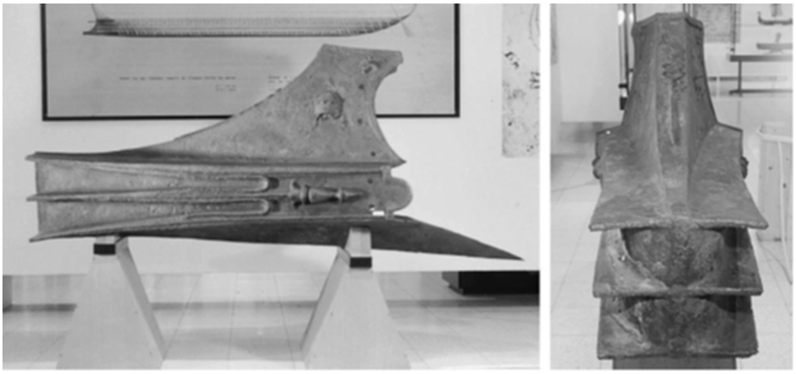

Fig. 1. The Athlit ram on display at the National Maritime Museum, Haifa, Israel. (Photograph by A. Oron)

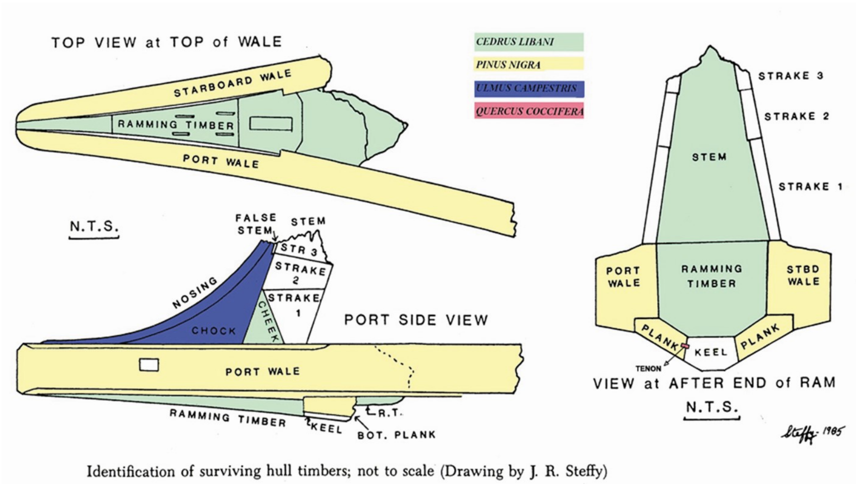

Fig. 2. The Athlit ram hull timbers arrangement and tree species (From Liphschitz and Pulak 2008, with permission from the authors)

The combination of the cast bronze ram and the remains of its hull comprise a unique assemblage and provide a rare opportunity to study the production process of naval rams within the context of the galleys on which they were mounted.

Previous technical studies of the ram casting (Oron 2006, 2001) showed that the ram was manufactured by the lost wax technique and not by the sand-casting method as previously proposed (Eisenberg 1991: 40-50). The former method was adjusted to facilitate a close fit between the cast ram and the bow timbers it was to be placed over. It was also noticed that the ram casting had been extensively repaired. Examination and analysis of some of these repairs (Oron 2006: 67, table 2) showed that they carried the hallmark of Classical and Hellenistic bronze craftsmanship closely linked with the use of the lost wax casting technique for the manufacture of small and large bronzes.

Studies of the ram timbers – carefully removed from the ram and conserved soon after its recovery (Steffy 1983, 1991: 6-39, 1994; 59-62; Liphschitz – Pulak 2008) – provided important insights into the complexity of the bow timbers on which the ram was mounted.

All together these studies showed that the ram was cast as a single unit most likely to fulfill the physical requirements i.e. to deliver a crashing blow to an enemy vessel. This contrasts with most other classical and Hellenistic large bronzes that were normally assembled from separately cast units. The bow timbers found within the ram were carefully selected and intricately crafted to withstand the immense impact forces during a ramming action and to dissipate them throughout the attacking vessel. The close match between the ram timbers and the bronze cast suggested that the ram was produced specifically for the bow with which it was found. This in turn reflects a close collaboration between bronze founders and the shipwrights suggesting that naval rams were most likely manufactured in close vicinity to the naval shipyards.

THREE-DIMENSIONAL SURVEYING AND RECORDING

The mounting of naval rams on the bows of Classical and Hellenistic warships and their use as impact weapons in battle dictated some adaptations in ship construction details. These were aimed at enhancing their strength and likely also to compensate for changes in their hydro dynamics and load distribution.

The low survival rates of hulls of Classical and Hellenistic warships in the archaeological record leaves much of the information related to these naval engineering issues unknown. The discovery of the Athlit ram along with its bow timbers presented a rare opportunity to gain a glimpse into the construction details of classical and Hellenistic warships and their rams.

Steffy's analysis of the bow timbers found within the Athlit ram revealed a highly complex carpentry work including a unique wooden element which he termed *ramming timber*. It was designed to integrate the key structural elements of the hull i.e. the keel, wales and stem thus dissipating the crushing blow of a ramming impact more evenly throughout the hull. The ram itself was carefully designed to fit intimately onto its bow and to inflict maximum damage to an enemy ship while staying intact.

In order to record the ram and its timbers after their recovery and to conserve them the massive bronze\wood assemblage had to be taken apart. This highly challenging process was caried out meticulously by Steffy and his collogues from the Israeli Antiquity Authority and Haifa university. The investigation and recording of the timbers and the bronze ram by Steffy was based on the methodologies available at the time including scale drawings, photography, and hand-built scale models.

The advance of 3D surveying tools and computer imaging techniques provides new possibilities for the ram research based on high resolution three dimensional numerical models. These in turn can be used for an in depth accurate spatial analysis of the ram and its timbers that could not be achieved before.

The application of 3D recording tools to the study of the Athlit ram described here was aimed at generating a complete inside-out record of the Athlit ram bronze cast and its bow timbers. As well as a set of numeric models to be used as a research tool aimed at providing new information on the ram its timbers and the spatial interrelations between the two.

The digitizing procedures of the ram bronze cast was carried out at its display hall at the National Maritime Museum. The timbers were scanned in their storeroom at the museum.

The point clouds for the different models were generated using two 3D digitizing systems: a structured light scanner (*Artec Eva*) and a photogrammetric scanner (*Sony HDR-AS200VR* camera).

The use of the *Artec Eva* instrument provided a resolution of 0.2 millimeters in the acquisition phase and made it possible to record the textures of the bronze cast and the hull timbers (Fig. 3). With this instrument all external surfaces and part of the internal ones were surveyed through 26 acquisitions.

Fig. 3 *a,b*. Using the *Artec Eva* instrument
during the 3D survey of the ram (*a*) and its timbers (*b*)

The photogrammetric acquisition procedures[1] were carried out with the small *Sony HDR-AS200VR* camera. This camera was mounted on a pole to reach some of the narrower and less accessible parts of the ram's cavity. All in all the technique generated a model of some 23,7 million polygons covering the ram exterior and interior surfaces with a resolution of about 0.2 millimeters.

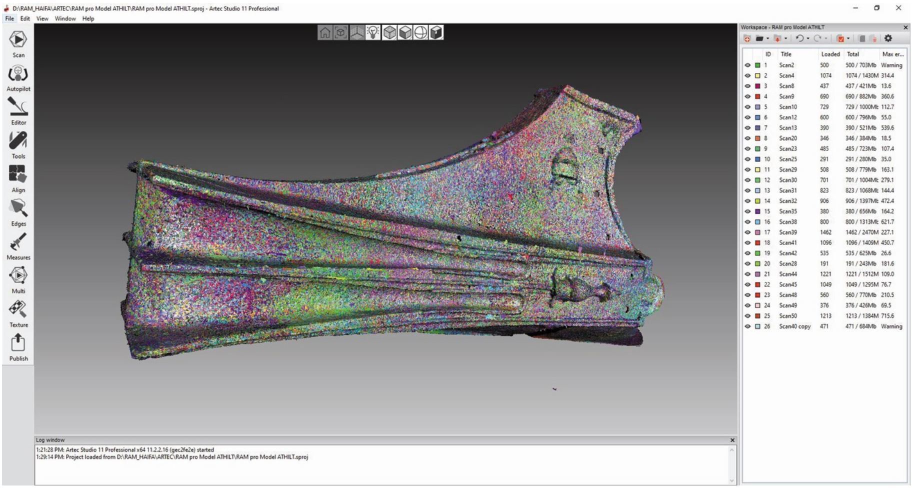

Fig. 4. Aligned point clouds of the ram

DATA PROCESSING

The various point clouds, produced through the 26 acquisition sequences, were aligned and merged into a single model with *Artec Studio* software (Fig. 4). They were then imported into *Geomagic* software and manually cleaned from reverberation points and noise followed by filtering using the *select outliers* command. The finished model was reproduced in three copies at different resolutions. A similar procedure was performed for the clouds of the four timbers (Fig. 5). The images produced by the photogrammetric survey were processed through *AgiSoft's Photoscan* software and filtered from noise using Geomegic software.

The survey of the ram produced two separate models, an internal and external surface. These were than aligned and brought to full scale using five

[1] The photogrammetric survey and first image processing activities were carried out by Nicola Scotto di Carlo.

scale bars that were positioned around the ram. Starting from the full point cloud three mesh models were produced, with a resolution of 22, 14 and 6 million polygons (Fig. 6).

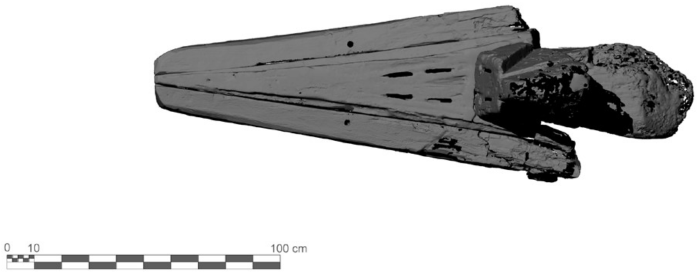

Fig. 5. Polygon models of the timbers

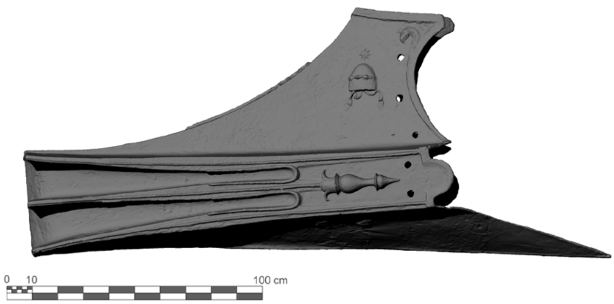

Fig. 6. View of the 6 million polygon model

Three-dimensional analysis

The high-resolution model enabled to produce a set of numeric sub models and sections of the bronze cast and the timbers. These allowed to explore issues related to the symmetry of the ram and its decorations through visual and numeric evaluation of shapes, sizes and alignment of different elements. To do so models were explored through two modes of representation: one produced on a single plane on which all the elements have been distributed in a sort of orthogonal projection (Fig. 7) the other performed in space through semi-automatic alignment procedures of the corresponding parts in order to compare the shapes, sizes and correspondences of repeating elements (Fig. 8).

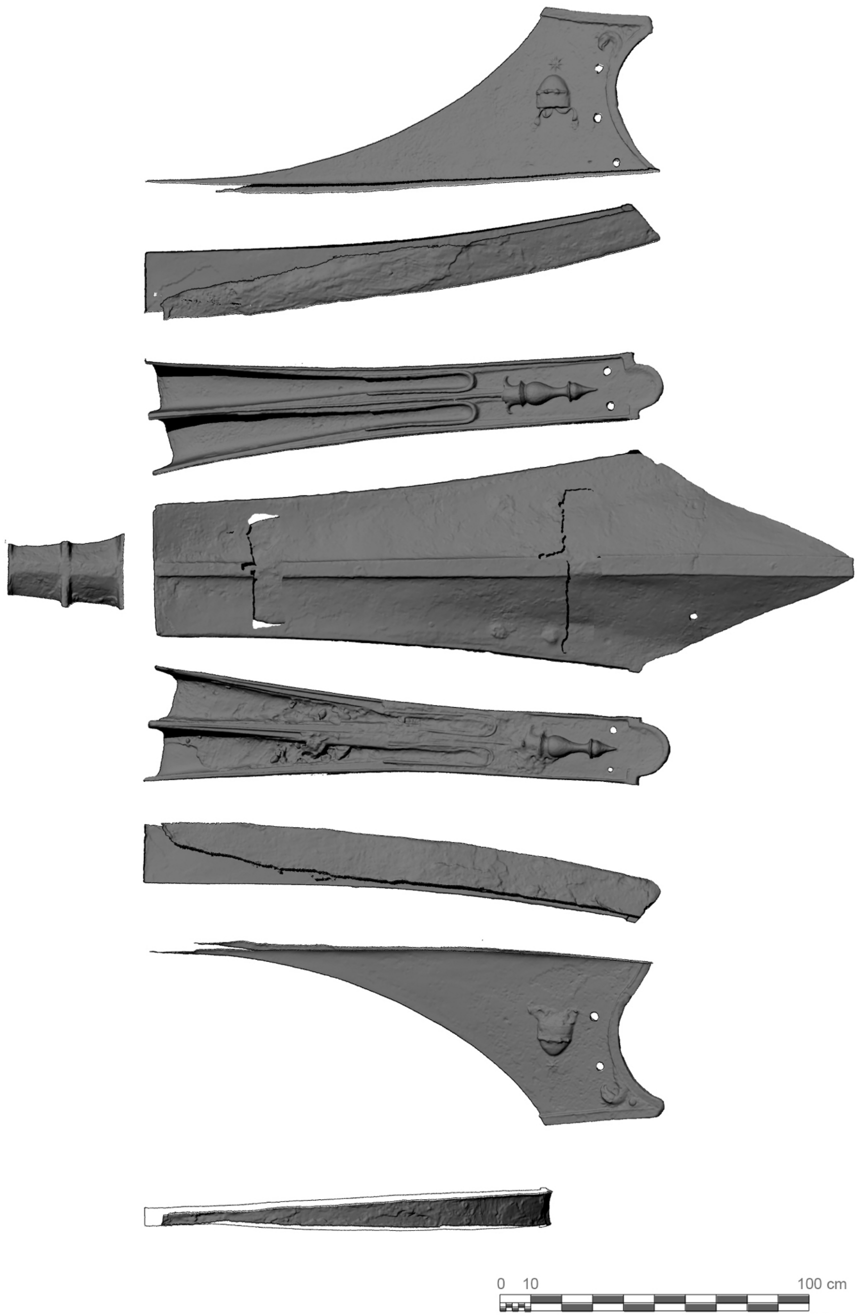

Fig. 7. Orthophoto of the exploded model

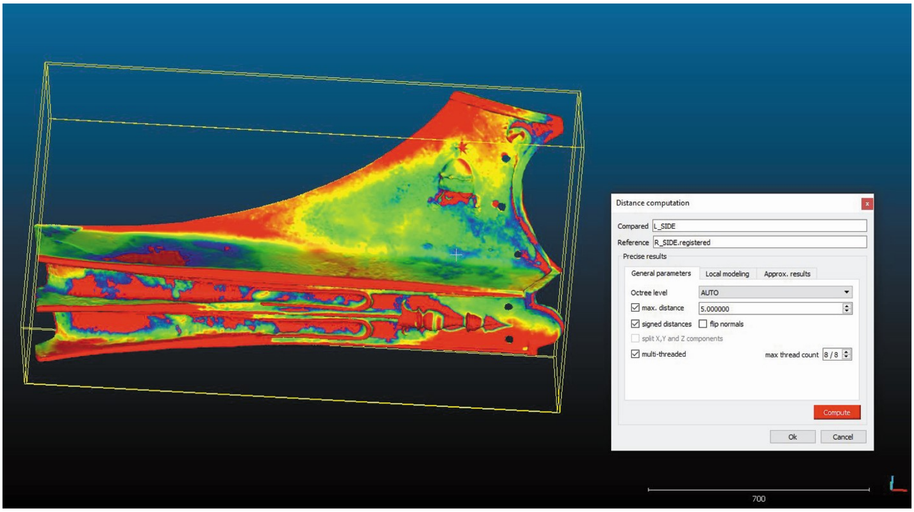

Fig. 8. Comparison of the starboard and port side of the ram
showing the geometric differences between the two volumes:
red - greater than 5 mm, green -close to 2 mm, blue- 0 mm

The model of the ram interior surface also made it possible to examine some of the less accessible areas of the ram and to record more accurately production marks and other features identified in this area during its previous study (Fig. 9).

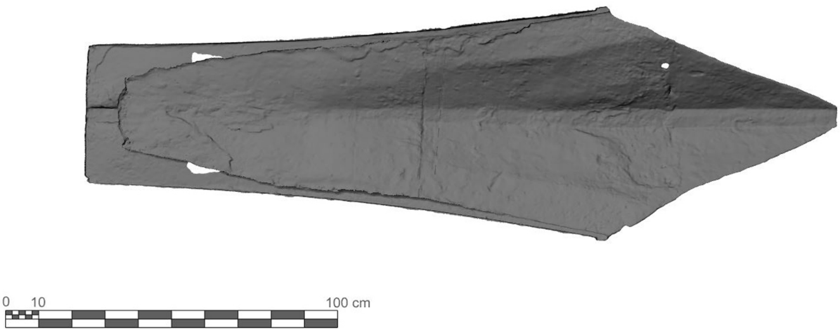

Fig. 9. View of the internal surface of the bottom plate
showing a perpendicular 'seam line' like feature

Examination of the bottom plate and the comparison of the geometry of ram starboard and port side shows variations in symmetry and allows to better quantify them using the numeric models. For example, the central axis of the bottom plate is not perpendicular to the ramming head instead it is off by 1.18° angle (Fig. 10). It is also possible to notice a substantial correspondence between the lateral curvatures of the sides plate, which differ in the central part by about 2.7 millimeters and length wise by 18.3 millimeters (see fig. 10). These variations are considered minimal and may support the use of a set form to shape parts of the initial wax model. By contrast the corresponding lateral contours of the tail piece vary greatly from starboard to port side. This variation stem from the repair of the entire tail piece, noted in previous studies, which may have been conducted at a later stage of the rams life. A comparison of the models in points of the cowls verified in the CloudeCompare v2.9.1 software, aligned through the fine registration command and compared by calculating a double parameter of *Max. Distance* set at 3 and 5 millimeters (Figures 11-12) shows a strong correspondence of surface curvatures, with millimetric average deviations also at this part of the ram.

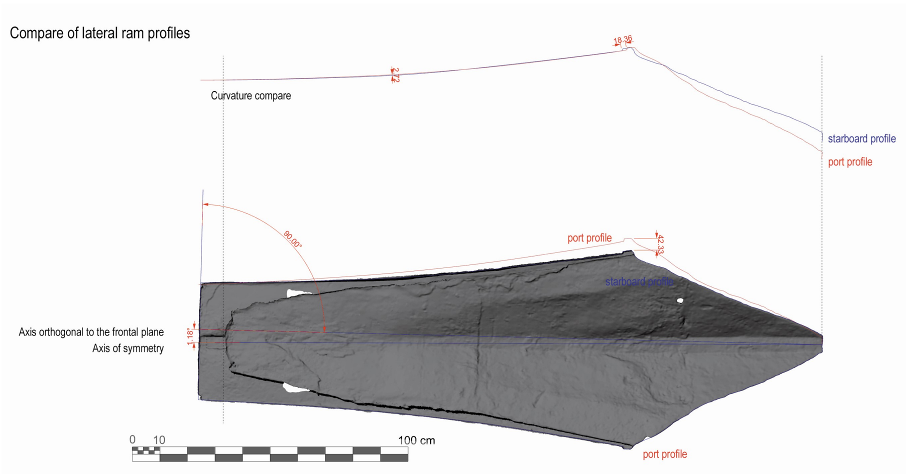

Fig. 10. Variations in symmetry along the *bottom plate* and between the ram's starboard and port *side plates* and the *tail*

Foe the study of the hull timbers their separate models were assembled using their general geometries and the fasteners holes. The latter were drawn directly on the mesh to produce a spatial representation of all the fastener holes and allowed more correct alignment of the timbers with relation to one another (Fig. 13).

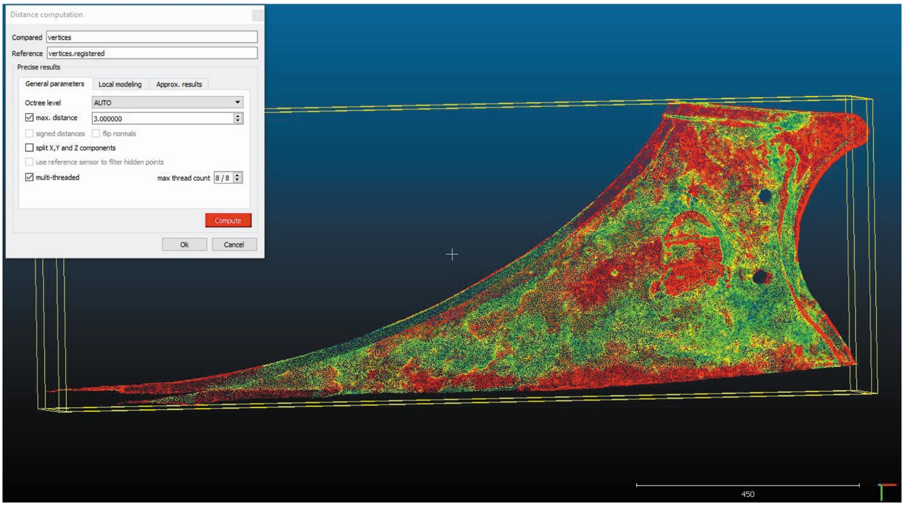

Fig. 11. Comparison of the cowl surfaces using the parameter of *Max. Distance* set at 3 millimeters

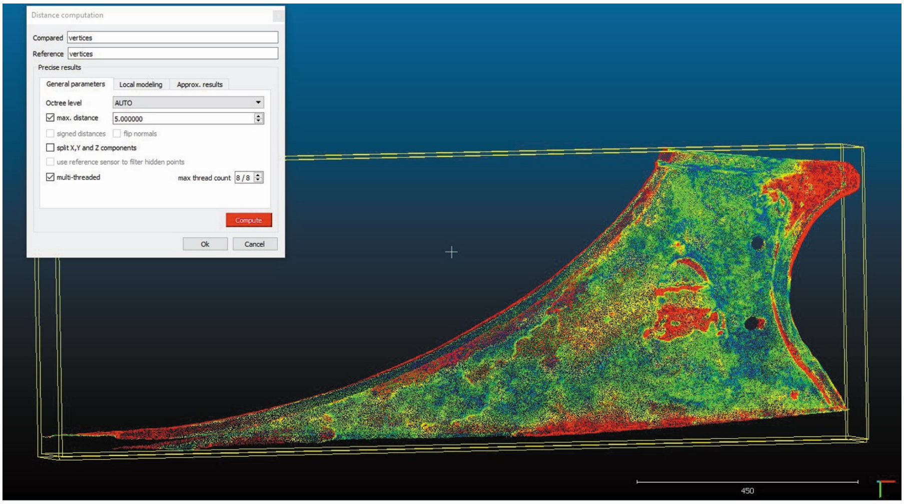

Fig. 12. Comparison of the cowl surfaces using the parameter of *Max. Distance* set at 5 millimeters

Once the timbers were reassembled, they were re-introduced into the ram cavity model. To ensure maximum accuracy and the best possible fit *Rhinoceros 5* software was used. It helped to keep the position of the timbers locked. The models were oriented according to the x, y, z axes of the virtual reference system; then only the internal surface of the ram was imported and positioned near the timbers; therefore, movements and rotations of the ram surface along and around the axes of the reference system were carried out, thus managing to parametrically control the movements. The assembly procedure was carried out in such a way as to make the surfaces match as best as possible and avoid intersections between wood and bronze (Fig. 14).

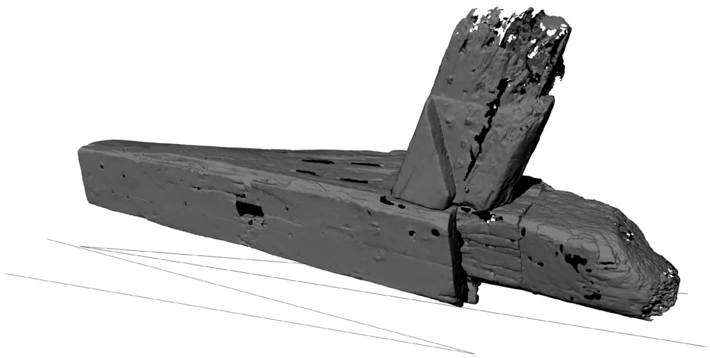

Fig. 13. Alignment of the timbers through their fastener holes

Fig. 14. The positioning of the timbers in the Ram's cavity

This virtual remounting of the Athlit ram onto its hull timbers allowed for the first time a three-dimensional visualization of the spatial relations between the ram and its bow timbers. It highlights once again the intimates match between the ram and its bow timbers supporting Steffy's initial assumption that the bronze ram was constructed for a specific bow (Fig. 15). This tight fit is best demonstrated by cross sectional view of the ram and timbers (Fig. 16). The cross sections correlate well with Steffy's initial study of the ram and provide accurate numerical information on the variations in the wall thickness of the bronze cast. It shows the irregularities in the cast wall thickness and demonstrates how it varies throughout the cast with the greatest thickness seen at the ramming head.

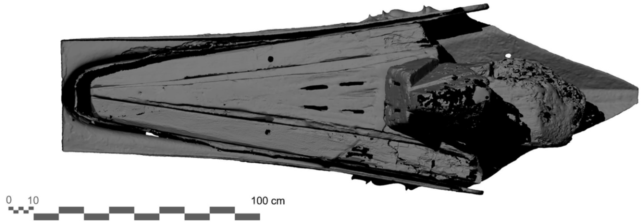

Fig. 15. Top view of the bow timbers within the bronze cast

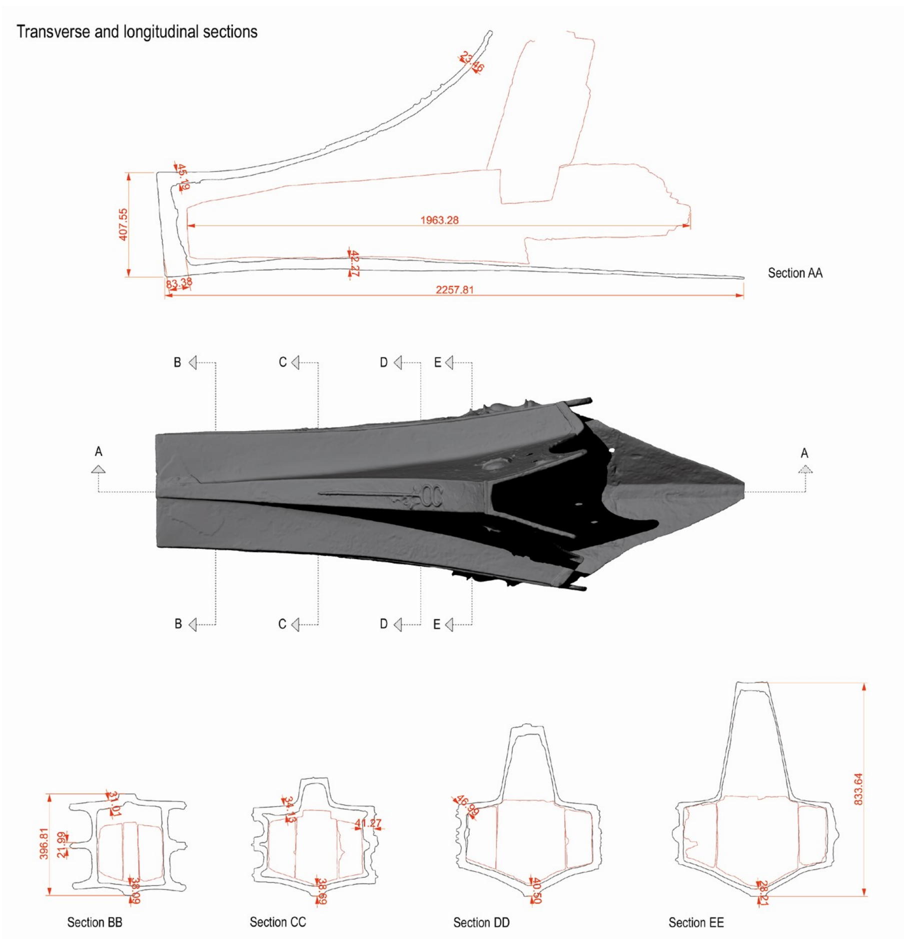

Fig. 16. Transverse and longitudinal sections of ram and timbers models

CONCLUSIONS

The application of high-resolution 3D imaging techniques to the study of the Athlit ram adds new dimensions to its study and highlights the importance of these tools to the overall filed of naval ram research.

The high-resolution models created in this study constitute a long term highly detailed and easily accessible numerical record of the ram and its timbers. The computer-based merging of the ram with its timbers allows to further investigate their spatial arrangement and to verify exiting hypotheses adding new information related to their production and geometric interrelations.

It is anticipated that as the analysis of the models progresses new details will immerge related to the ram symmetry, its casting method, and the production of its surface decorations. Finally, it is hoped that the models generated through this work will allow to venture into new directions of research such as simulations of ram hydrodynamics and impact analysis.

Author Contribution

Introduction: A.O. and L.R.; *The Athlit Ram background and research:* A.O.; *Three-dimensional surveying and recording:* L.R. and A.O; *Data processing*: L.R.; *Three-dimensional data analysis:* L.R.; *Conclusion:* A.O. and L.R.

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REFERENCES

Adams 2013 — J.R. ADAMS – A. ANTONIADOU – C.O. HUNT – P. BENNETT – I.W. CROUDACE – R.N. TAYLOR – R.B. PEARCE – G.P. EARL – N.C. FLEMMING – J. MOGGERIDGE – T. WHITESIDE, "The Belgammel Ram, a Hellenistic-Roman Bronze Proembolion Found off the Coast of Libya: test analysis of function, date and metallurgy, with a digital reference archive", *International Journal of Nautical Archaeology* 42(1), 60-75.

Buccellato – Tusa 2013 — C.A. BUCCELLATO – S. TUSA, "The Acqualadroni Ram Recovered Near the Strait of Messina, Sicily: dimensions, timbers, iconography and historical context", *International Journal of Nautical Archaeology* 42(1), 76-86.

Casson 1991 — L. CASSON – J.R. STEFFY (eds.), *The Athlit Ram*, Texas A&M University Press.

Eisenberg 1991 — S. EISENBERG, "Metallurgical analysis of the ram", in L. CASSON – J.R. STEFFY (eds.), *The Athlit Ram*, Texas A&M University Press, College Station, TX, 40-50.

Liphschitz – Pulak (2008) — N. LIPHSCHITZ – C. PULAK, "The Athlit Ram timbers re-examined: tree species identification and possible construction site of the galley", in H. TZALAS (ed.), *Tropis 10th International Symposium on Ship Construction in Antiquity* (2008) Hydra, Greece; Hellenic Institute for the Preservation of Nautical Tradition, Athens.

Murray 1991 — W.M. MURRAY, "The provenience and date: The evidence of the symbols", in L. CASSON – J.R. STEFFY (eds.), *The Athlit Ram*, Texas A&M University Press, College Station, TX, 51-66.

Oron 2006 — A. ORON, "The Athlit ram bronze casting reconsidered: scientific and technical re-examination", *Journal of archaeological science* 33, 63-76.

Oron 2001 — A. ORON, *The Athlit ram: Classical and Hellenistic bronze casting technology* (MA Thesis A&M University).

Prag 2014	J.R. PRAG, "Bronze rostra from the Egadi Islands off NW Sicily: the Latin inscriptions", *Journal of Roman Archaeology* 27, 33-59.
Steffy 1983	J.R. STEFFY, "The Athlit Ram: A preliminary investigation of its structure", *Mariner's Mirror* 69, 229-246.
——— 1991	J.R. STEFFY, "The ram and bow timbers: a structural interpretation", in L. CASSON – J.R. STEFFY (eds.), *The Athlit Ram*, Texas A&M University Press, College Station, TX, 6-39.
——— 1994	J.R. STEFFY, *Wooden ship building and the interpretation of shipwrecks*, Texas A&M University Press.
Tusa – Royal 2012	S. TUSA – J. ROYAL, "The landscape of the naval battle at the Egadi Islands (241 BC)", *Journal of Roman Archaeology* 25, 7-48.