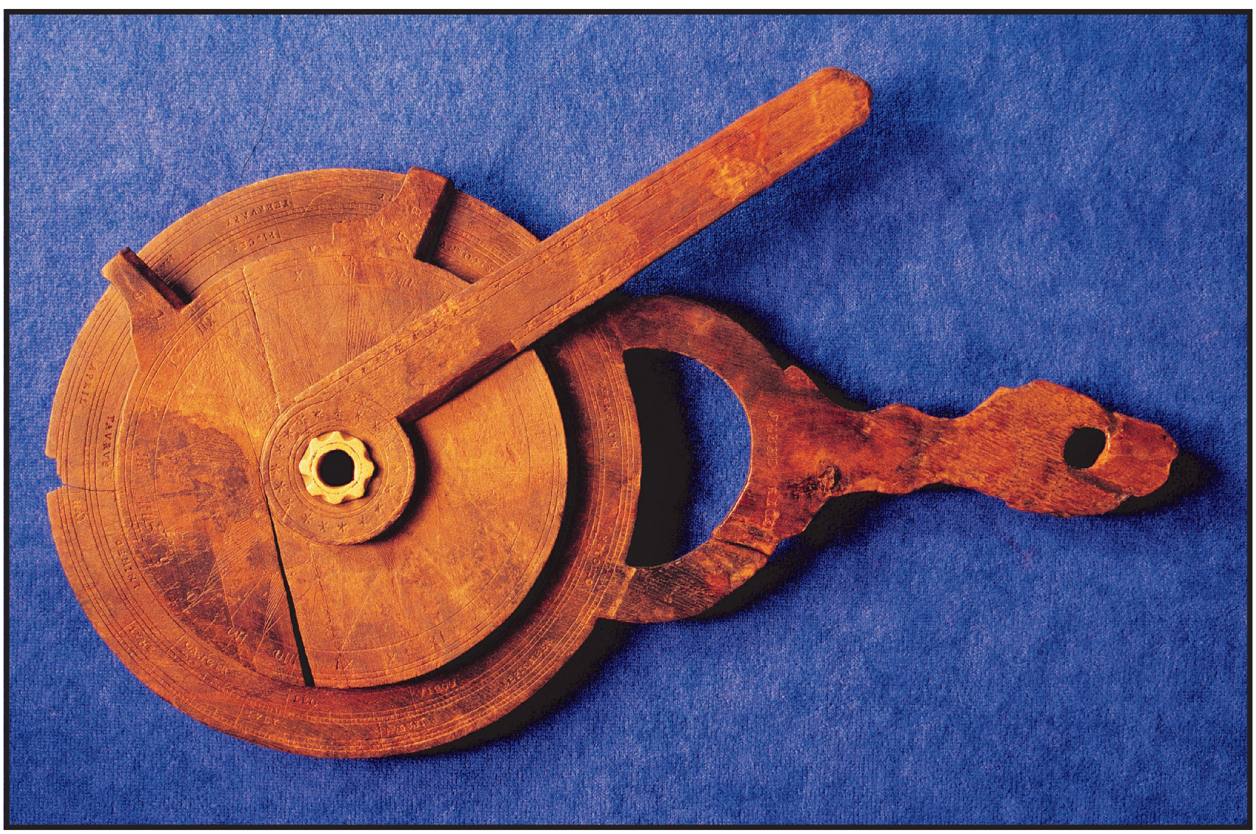
TEXAS A&M UNIVERSITY

# CMAC

Center for Maritime Archaeology & Conservation

# News & Reports

Spring 2010 Volume 2 No. 1



# CMAC News & Reports

Volume 2 No. 1 Spring 2010

## Contents



**On the cover:** A boxwood and brass nocturnal recovered from the *La Belle* shipwreck.



The Center for Maritime Archaeology and Conservation (CMAC) is based at Texas A&M University in College Station, Texas. Working in partnership with the Anthropology Department's Nautical Archaeology Program, the non-profit Institute for Nautical Archaeology, and other research institutions, CMAC strives to be in the forefront of maritime archaeological research around the world. The opinions expressed in *CMAC News & Reports* are those of the authors and do not necessarily reflect the views of the Center, or Texas A&M University.

Editor: Megan H. Smith

# Numerical Models and the Dynamic Interpretation and Reconstruction of Medieval and Early Modern Shipwrecks

Filipe Castro *(Texas A&M University),*
Nuno Fonseca and Tomás Vacas *(Instituto Superior Técnico, Lisbon Technical University),*
Albrecht Sauer *(Deutsches Schiffahrtsmuseum)*

From March 8 to 13, 2009, the Ship Reconstruction Laboratory at Texas A&M University hosted a workshop on the role of numerical models in the interpretation and reconstruction of late medieval and early modern shipwrecks. The objective of this workshop was to foster and contribute to interdisciplinary and international cooperation between engineers, archaeologists and historians. Such cooperation aims for a more complex and system-oriented understanding and interpretation of historic traditions of shipbuilding, seamanship, and navigation.

Following the example of the Bremen Cog computer reconstruction and testing, in 2005 the Ship Lab initiated a joint project with the Secção Autónoma de Engenharia Naval (SAEN) of Instituto Superior Técnico (IST) at the Technical University of Lisbon (Grant FCT No. PTDC/HCT/67337/2006). This partnership was formed for the purposes of reconstructing and testing the Pepper Wreck, tentatively identified as the India nau *Nossa Senhora dos Mártires*, lost at São Julião da Barra, Oeiras, Portugal, on the 14 or 15 of September 1606. A virtual model was also developed at Texas A&M University's Department of Visualization Sciences. The computer model allowed the team to better

**Figure 1: The Bremen Cog. Photo courtesy Albrecht Sauer.**



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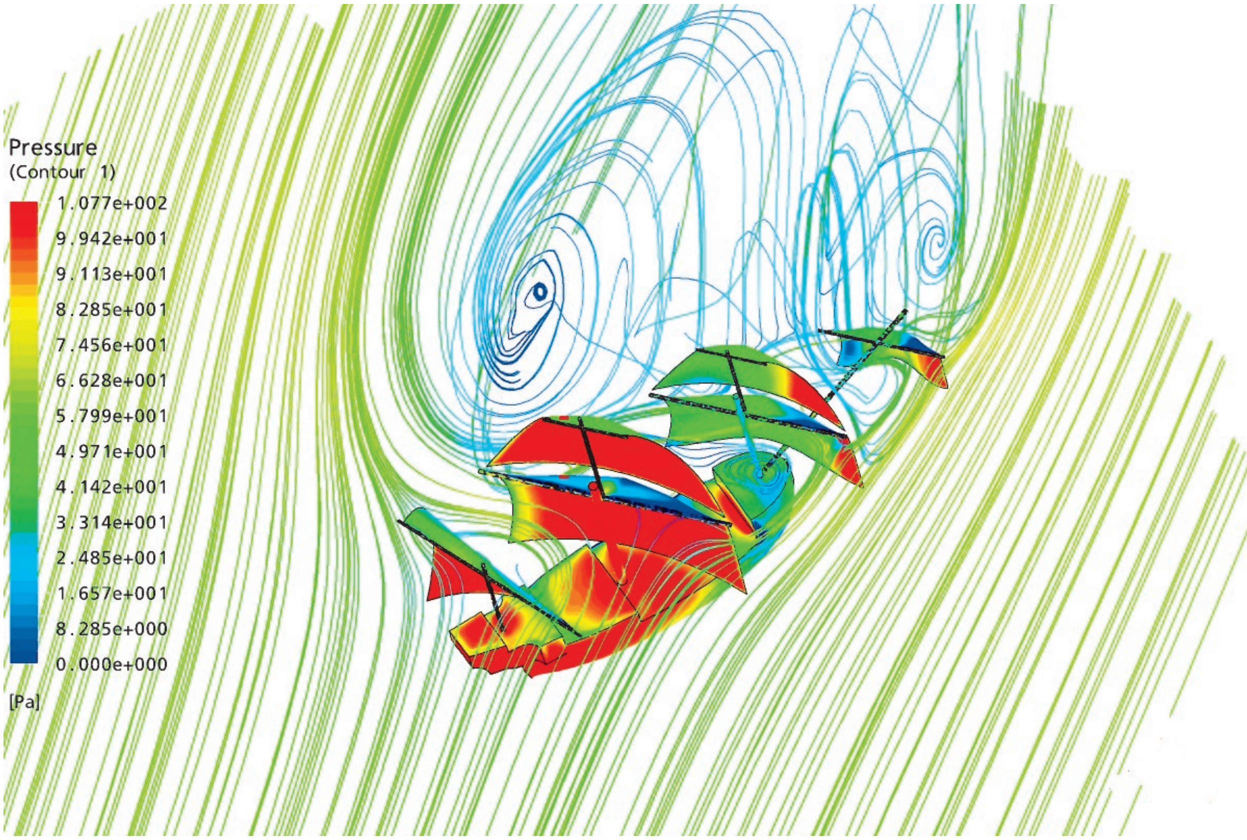


**Figure 2: A virtual model of the Pepper Wreck under sail.**

understand the interior spaces of such a ship and to hypothesize a plausible cargo arrangement.

The challenges and questions raised at all stages of the reconstruction of the Pepper Wreck suggest a more system-oriented approach to its study, relying on other similar experiments. The Bremen Cog study came to mind as a model of a thorough and highly successful multidisciplinary approach to the reconstruction and understanding of the archaeological remains of a late medieval ship. Throughout history, each ship represented a particular solution to a wide range of closely intertwined problems, and the reconstruction of old ships from fragmentary archaeological remains requires a multidisciplinary approach.

The sessions of this workshop, which we hope will be the first of a long series, were organized to present, compare, and discuss, the methods and tools used in the reconstruction of the Bremen Cog – preserved in the German Maritime Museum at Bremerhaven – and the Pepper Wreck. Computer models and numerical simulations were especially emphasized, but physical models also had a part in the discourse. The discussions generated numerous new ideas for the ongoing projects, successfully showing the value of an interdisciplinary and international approach. The collaborations fostered by the workshop led to an enrichment of the respective investigations and opened new perspectives for future experiments. The painstaking preparation of a numerical reconstruction of the Pepper Wreck and its sailing performance profited from the experiences acquired during the reconstruction of the Bremen Cog and the various model experiments carried out by the German Maritime Museum in cooperation with the Universities of Hamburg, Kiel, and Berlin (Germany).

Likewise, current research into seamanship and navigation at the German Maritime Museum profited from examination of the sailing properties of the Pepper Wreck, concluded from the calculations carried out by the Technical University of Lisbon and the Center for Maritime Archaeology and Conservation. In view of the promising results of this workshop it was agreed

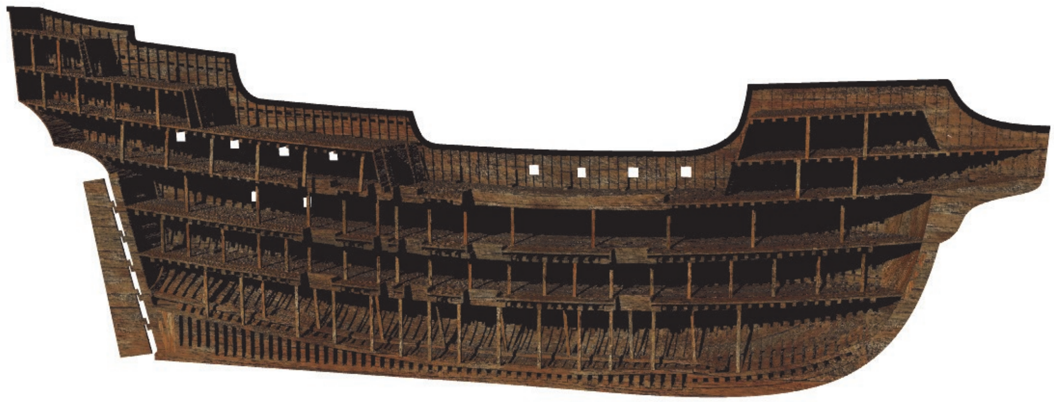

**Figure 3: A virtual reconstruction of the Pepper Wreck.**

that the organizers will stay in close contact and continue the exchange of data and discussions.

Given the complex international ties that fostered the development of shipbuilding in Europe in the late medieval and early modern periods, this collaboration will be broadened to include other institutions. Our intention is to achieve a better understanding of present and future nautical archaeology-related finds, and also investigate and compare specific possible achievements and limitations of numerical and physical models in experimental archaeology. On the basis of the work done in the current workshop, the organizing group expects to create synergistic relationships which contribute to the general understanding of the historic development of the sailing properties of seagoing vessels.

The results of this workshop will be discussed at the Annual Meeting of the Society for Historical Archaeology (SHA) to be held in Florida in January of 2010. They will be published as a series of reflections and analyses of the utility of numerical and physical models in experimental archaeology. A wider discussion is planned for the Annual Meeting of the Society for Historical Archaeology (SHA) to be held in Austin, Texas, in January of 2011.

**Acknowledgements**
The participants wish to thank the sponsors that generously made this workshop possible: the Luso-American Foundation (Lisbon), Deutsche Forschungsgemeinschaft (German Association for Research, Bonn) and CMAC (Center for Maritime Archaeology & Conservation, College Station).

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# Excavation of a Shipwrecked Marble Column

Deborah N. Carlson, Ph.D. *(Texas A&M University)*

Since 2005, an international team of archaeologists and students from the Nautical Archaeology Program (NAP) at Texas A&M University has been excavating an ancient ship wrecked off the Aegean coast of Turkey at Kızılburun, probably in the early first century B.C. This ship, discovered on a 1993 survey directed by Dr. Cemal Pulak, was a stone carrier transporting components of a single monumental marble column: eight enormous drums, each about 1.5 meters (5 ft.) in diameter and weighing around seven tons, topped by a capital of the Doric order. The Kızılburun excavation project has been made possible by the directors and staff of the Institute of Nautical Archaeology (INA), Texas A&M University, the Center for Maritime Archaeology and Conservation (CMAC), the National Geographic Society, the Samuel H. Kress Foundation, and Spiegel Television.

Isotopic data indicate that the marble drums originated on the island of Proconnesos in the Sea of Marmara. This is intriguing because – like many ancient marble sources – nearly all of the marble exported from Proconnesos before the 4th century AD was utilized locally or regionally (at sites like Troy and Pergamum), but Kızılburun lies well to the south of this region. Furthermore, the large size of the Kızılburun drums and capital rule out inclusion in a portico or theater façade—this column had been quarried for nothing smaller than a temple. Finally, the presence of a Doric column on board a shipwreck of the first century B.C. is remarkable because Doric architecture on a monumental scale was practically obsolete by this time.

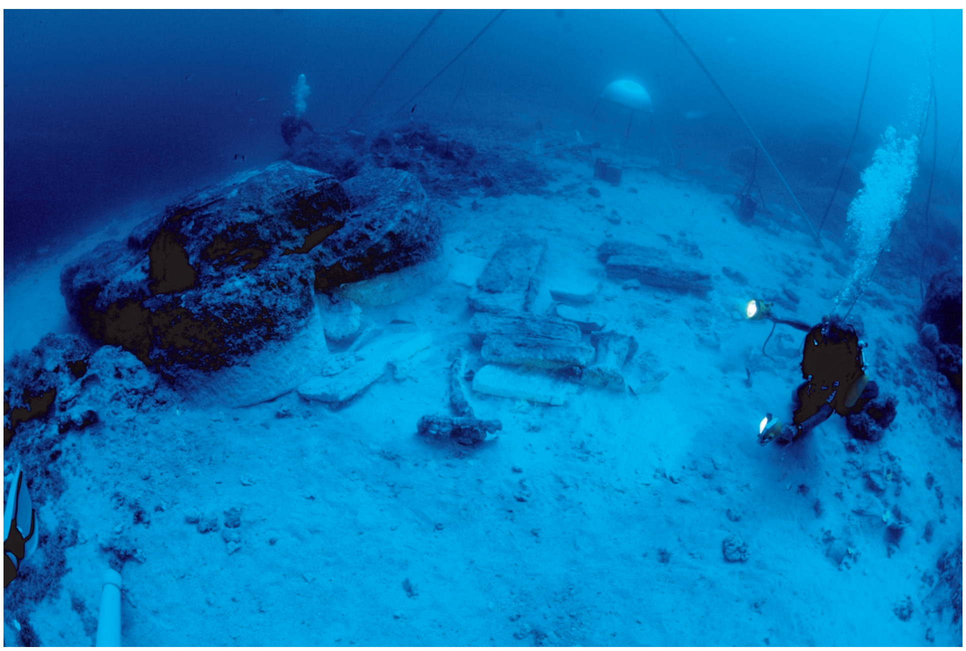

**Figure 1: INA photographer Don Frey illuminates portions of the Kizilburun shipwreck's secondary marble cargo. Photo by D. Carlson.**


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**Figure 2: Ken Trethewey excavates a trench in the upslope area of the excavation. Photo courtesy D. Carlson.**

From the beginning, the research goals of this excavation have been twofold: (1) to identify the intended destination of the Doric column and the ship's associated secondary cargo of newly-quarried marble basins, blocks, and gravestones, and (2) to uncover and study any remaining wooden hull remains in order to gain insight into the vessel's construction and determine whether or not this ship was a purpose-built stone carrier of the type the Romans called a navis lapidaria.

After three seasons of excavation (2005-2007) and one non-diving study season (2008), the Kızılburun team has made terrific progress on both fronts. Efforts to pinpoint the column's intended destination have shown that the unfinished drums from Kızılburun are consistently and proportionally similar to finished column drums at the nearby Temple of Apollo at Claros. Construction of the Apollo temple probably began around 300 B.C., but was still unfinished 500 years later, meaning it was underway at the time the marble cargo sank at Kızılburun. This shipwreck, then, is poised to provide historical information that few ancient shipwrecks ever do: namely, the starting point, final voyage and ultimate destination of a column lost at sea.

In 2006 and 2007, we moved the column capital and all eight of the 7-ton marble column drums to a different location on the seabed about 30 meters (100 ft.) away from the wreck site. Working at a depth of 45 meters (150 ft.), we rigged each drum with three Lift-All lifting slings arranged in a triple choker hitch and attached the slings to four 1814kg (4000 lb.) Subsalve lift balloons. As each drum was raised off of the shipwreck, it was possible to see fragmentary timbers of ash and black pine, badly broken and distorted after more than 2,000 years under water. We aim to return to Kızılburun in 2009 – for what is expected to be the final season of excavation – to complete the recording and recovery of any remaining timbers, in an effort to determine whether this ancient ship was in fact a purpose-built stone carrier.

# The Danaos Project, 2007-2008

Shelley Wachsmann, Ph.D. *(Texas A&M University)*

In antiquity an important blue-water sea route stretched from Crete to Egypt. The earliest evidence for this passage comes from scenes of foreigners bringing gifts and tribute in the Theban tombs of Egyptian nobles during the XVIIIth Dynasty (15th century B.C.). Among those appearing in these tombs are intrepid Aegean seafarers—shown bringing high-status objects—whom the Egyptians claimed came from "Keftiu" or "the Isles in the Midst of the Sea." These figures can be identified as representatives of Minoan culture, which evolved on Crete during the second millennium B.C.

The French scholar Jean Vercoutter demonstrated that the Egyptians considered these Keftiu as "westerners," indicating that they perceived of them as arriving from the west, across the direct, blue-water route from Crete. This makes meteorological sense also, as the windrose in the eastern Mediterranean during the summer sailing season blows from the northwest, making this a relatively easy sail. Homer gives the first literary reference to this route, describing it as a five-day voyage (Od. 14.252-258, 17.246). After an apparent hiatus during the early first millennium ancient authors indicate that this was a heavily traveled route.

**Figure 1: The Max Rover Remote Operated Vehicle (ROV) is deployed to sight check anomalies. Photo by D. Griffin. Courtesy Danaos Project.**




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**Figure 2: The Danaos 2008 science team displays the American, Greek, and Texas A&M University flags. Courtesy Danaos Project.**

Crete stretches for 260 kilometers (160 mi.) across the western side of the Aegean Sea, barring access to the Mediterranean Sea and forcing shipping around it and its southern coast was an important route for Roman grain ships heading back to Italy from Egypt, as the island's lee protected them from northwesterlies. A plot of these passages points to the Kassian Strait, which borders Crete to the east, was a vital intersection of these two ancient sea highways and, therefore, of particular interest from a historical and nautical archaeological perspective.

The Danaos Project, which takes its name from the Greek mythological figure connected to navigation, seafaring and movement between Crete and Egypt, is a deep-water multidisciplinary survey of these ancient sea routes. It is a collaborative effort of the Institute of Nautical Archaeology (INA) at Texas A&M University, the Hellenic Centre for Marine Research (HCMR) and the Hellenic Institute for the Ancient and Medieval Alexandrian Studies (HIAMAS). The survey is carried out on HCMR's 62-meter long research vessel the R/V *Aegaeo*, employing swath bathymetry (multi-beam) to map the topography, sidescan sonar to locate targets: a remote operated vehicle (ROV) and a two-man submersible are used to sight-check promising anomalies (Fig. 1).

During the 2007 and 2008 seasons we examined an unnamed plateau in international waters southwest of Ierapetra, Crete, near Gaidhouronísi (Chrysi) island. We chose this area because it is relatively flat, allowing for sidescan sonar survey, and has an estimated sedimentation of only 10 centimeters (4 in.)/millennium. The area varies in depth from 400 to 800 meters (1300-2600 ft.) and lies between the Pliny and Ptolemy Trenches. We have now mapped over 2000 kilometers$^2$ (772 mi.$^2$) with swath bathymetry, covered 155 kilometers$^2$ (60 mi.$^2$) with sidescan sonar and have recorded 550 kilometers (342 mi.) of track line.

We located hundreds of anomalies of which we selected 32 for sight inspection. None of these proved to be shipwrecks, however, in the course of these surveys we recorded 42 artifacts. Most of these were amphoras (two handled storage jars used for shipping) dating from the Classical period to Late Antiquity (Fig. 2). One anomaly proved to be a World War II airplane that has been tentatively identified as a Focke-Wolf (FW-190), perhaps lost during the Battle of Crete. Of particular interest was a series of Byzantine-period amphoras, found in pairs or triads on the sea bottom and lying roughly in a northwest-southeast line. This represents the archaeological results of a ship in distress tossing out its cargo (see, for example, Jonah 1: 4; Acts 27: 18). We carried out visual searches at either end of this line and, while we located additional amphoras, no remains of the ship were found. Apparently it either succeeded in escaping the peril or sank farther off.

We are grateful to the MacDonald Foundation for its generous support of the Danaos Project.

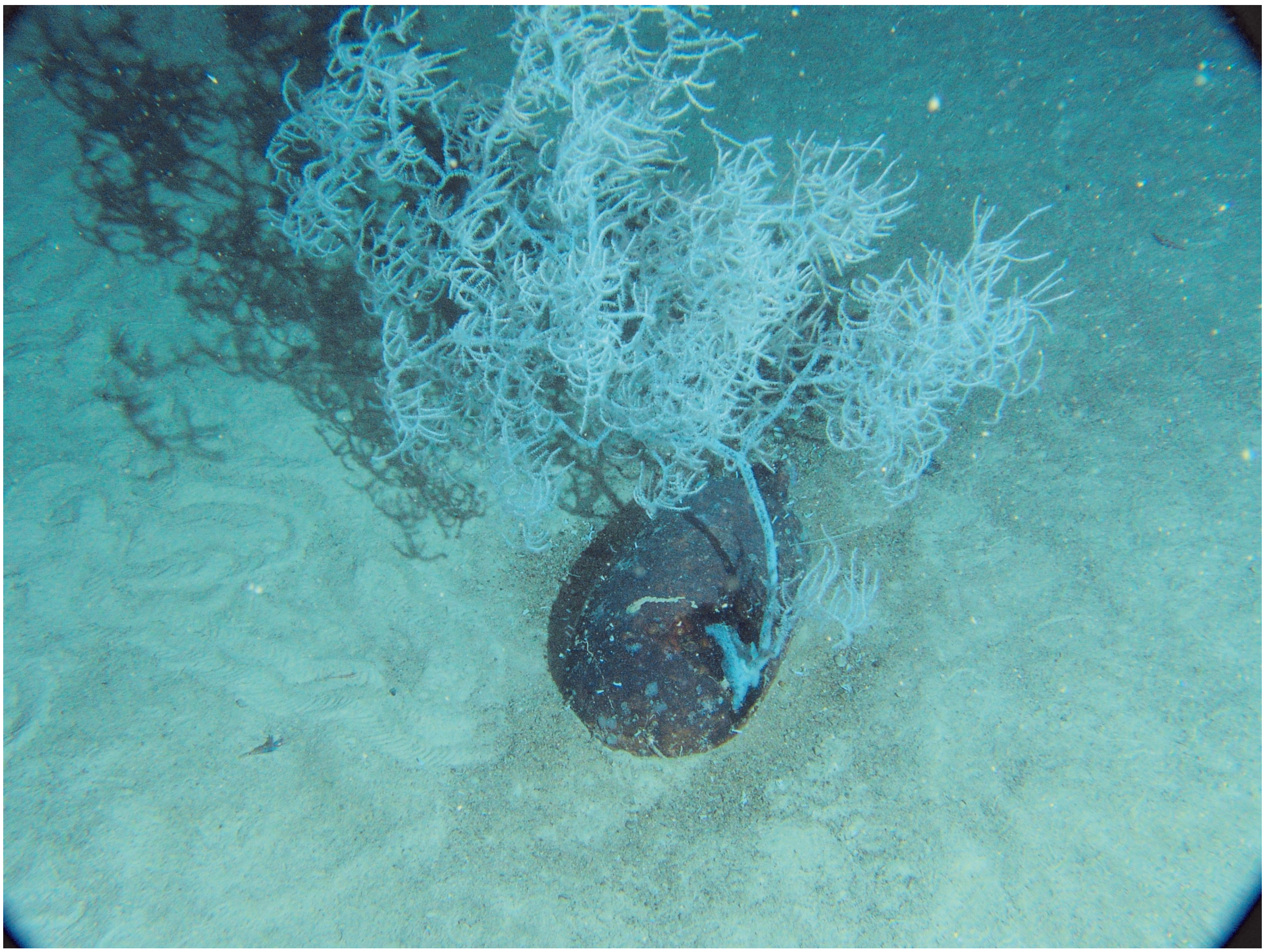

**Figure 3: Byzantine period amphora at 510 meters. Photo by D. Griffin. Courtesy Danaos Project.**

# *Vasa* comes to CMAC

Glenn P. Grieco *(Texas A&M University)*

In order to fully understand an artifact, it is necessary to understand its intended function. This is particularly true of the elements of rigging aboard a sailing vessel. Hands on experience is the best way to gain an understanding of how to rig a ship, however, very few people are afforded the opportunity to work aboard a full size sailing vessel. One solution is to provide a functional large scale model for instructional purposes.

A recent collaboration between CMAC's Ship Model Laboratory, Olof Pipping, and Dr. Fred Hocker has provided Texas A&M Nautical Archaeology Program student with a valuable tool for this purpose. An experienced sailor and ship model builder, Pipping has extensive knowledge of historic sailing rigs and his expertise has been invaluable in the reconstruction of the rig of the famed Swedish warship *Vasa*. Pipping will be a key contributor to the upcoming second volume of the *Vasa* final publication series. Hocker, formerly an associate professor in the Nautical Archaeology Program at Texas A&M University, has been the Director of Research at The *Vasa* Museum since 2003 and has been responsible for the documentation and publication of all finds associated with the vessel.

**Figure 1: The author shaping the main yard of the *Vasa* rigging model . Photo by C. Wayne Smith.**





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The 49 meter (160-ft.), 1200-ton *Vasa* was the flagship of the Swedish fleet. On its maiden voyage on August 10, 1628 the ship heeled over and sank in the cold water of Stockholm's harbor. Over 300 years later, the hull was recovered with much of its structure intact. The bowsprit, fore, and main masts were recovered along with many associated rigging elements, providing a unique look at 17th century Swedish sailing rigs and seamanship in this period, and the focal point of Pipping's research on 17th century rigging.

In March and April of 2009 the CMAC Ship Model Laboratory built a one tenth scale model of *Vasa's* rigging from plans that Pipping adapted from the actual rig of the *Vasa*. The model included the deck, mainmast and main topmast, lower foremast and mizzen, bowsprit and associated bitts and blocks. The masts and spars of the model were constructed in the Ship Model Laboratory by the author, with the assistance of Jim Jobling and Chris Atkinson of the Conservation Research Laboratory. The main sail, topsail and rigging were prepared ahead of time by Pipping and loaned for the presentation. The model was designed to allow many of the functions that would have actually been performed with the mainmast, topmast, main and topsail aboard the actual vessel.

In a three-hour presentation, Pipping and Hocker used the model to demonstrate to the students of Dr. Kevin Crisman's graduate seminar, Outfitting and Sailing the Wooden Ship, the many intricate steps involved in rigging and sailing an early naval vessel. These included raising the topmast and mainmast caps, swaying and positioning the yards, and unfurling and setting the sails. With the assistance of the students and guests, the sails were then manipulated to perform a number of sailing manouevers that were typically performed (if only briefly) on the original vessel. Pipping

**Figure 2: Rigging expert Olof Pipping secures the tie to *Vasa*'s main topsail yard. Photo by C. Wayne Smith.**

 

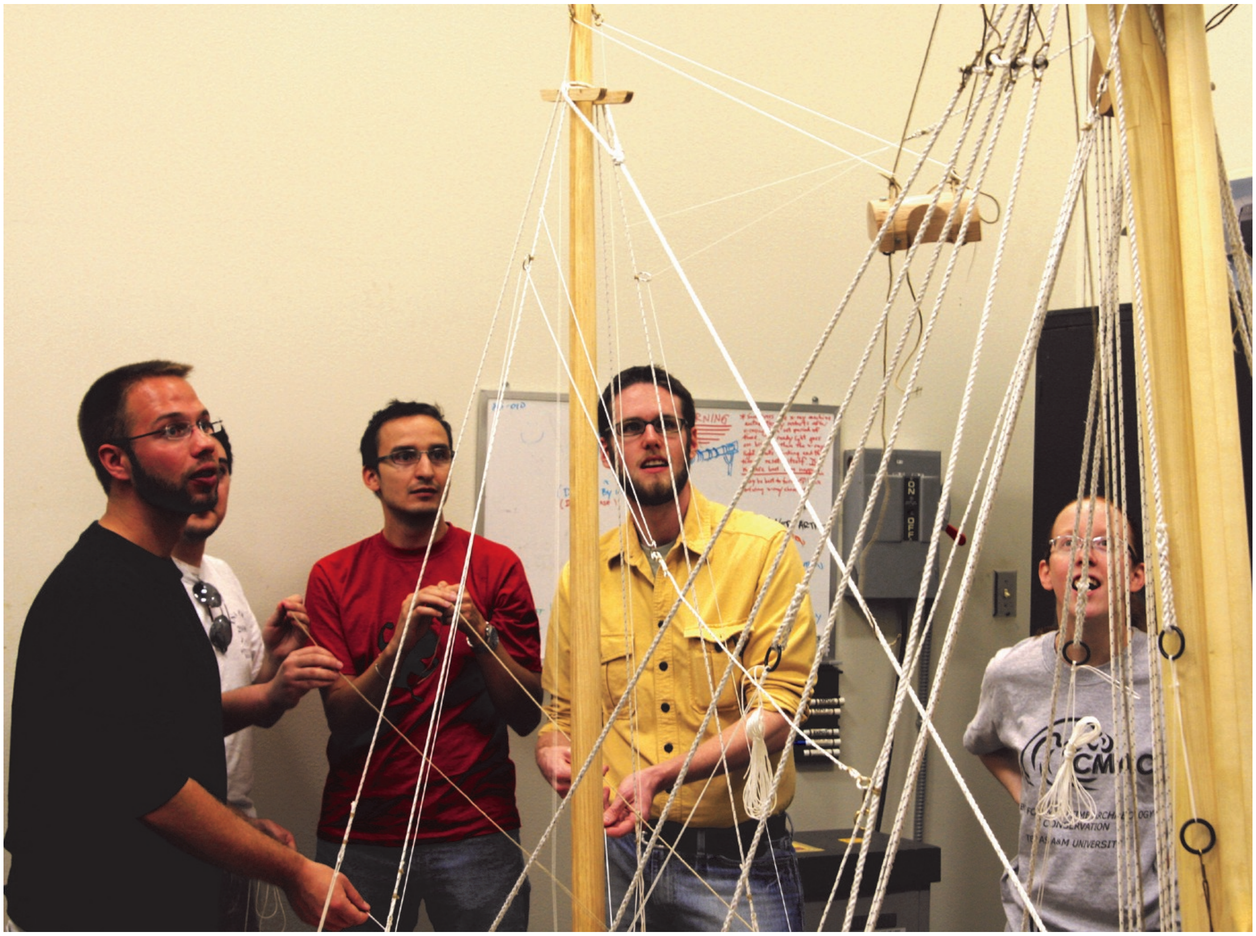


**Figure 3: Carefully coordinating their efforts, Nautical Archaeology Program graduate students gently lift the mast cap into position. Photo by Ryan Lee.**

and Hocker not only provided valuable insight into the construction and function of the rig but also contributed interesting historical and anecdotal information about the officers and crew who sailed *Vasa* during its short, tragic career. For participants in the rig demonstration the three hours available to us were all too short but, it is clear that we have only begun to realize the model's potential.

Thanks to Pipping's ingenious design, the model will no doubt continue to provide Nautical Archaeology Graduate Program students with insights into the complexity of early square rigs and the complex processes associated with a sailing vessel like *Vasa*. The model's sails and rigging have been returned to Mr. Pipping in Sweden, but The Ship Model Laboratory first replicated the rig so that the model can be used in the future for familliarizing Texas A&M students with the techniques and artifacts associated with wooden sailing ships.

# Conservation of a Composite Navigational Device

Helen Dewolf, Ph.D. *(Conservation Research Laboratory)*

Conservation of a composite artifact can be very complex. This is especially true of artifacts excavated from inundated sites. A boxwood and brass nocturnal was recovered from *La Belle* as part of the La Salle Shipwreck Project excavations undertaken by the Texas Historical Commission (THC) in 1996-1997. The artifact itself was almost intact with just the tips of the indicator arm and the handle in a compromised condition. Iron corrosion products had 'bled' not only onto the surface of the navigational instrument, but also between the rotating dials that made the nocturnal functional. This bleed of corrosion products, waterborne minerals, and sea-life distorted and distended the dials so they were no longer flat and straight.

Unlike many European instrument makers, who used brass for this type of navigational instrument, the English used boxwood. English craftsmen for centuries preferred to use this material for making navigational instruments because the wood had a smooth, dense, straight grain that 'moved' very little and was reasonably easy to incise, carve, and stamp. Boxwood was comparatively less expensive to work with than

**Figure 1: The nocturnal before conservation treatment. Photo courtesy Helen Dewolf.**



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**Figure 2: The nocturnal after treatment. Photo courtesy Helen DeWolf.**

brass. This wooden instrument was the ideal candidate for using the passivation polymer treatment developed by the CMAC Archaeological Preservation Research Lab at Texas A&M University (TAMU).

This technology was specifically developed to stabilize and conserve organic materials from inundated sites. We were certain that the polymer treatment would conserve the wood and yet have no adverse effects on the metal components of the artifact. This is especially useful if the artifact cannot be disassembled prior to conservation treatments. Even after treatment the chemistry employed would not have an adverse affect on the metal components once they were reassembled. The treatment would also assist in the mechanical removal of the thin layer of concretion covering a great deal of the artifact surface, particularly the concretion found in the grooves of incised lines and letters.

Over a period of several weeks the author systematically mechanically removed and chemically softened the majority of the overlying gross encrustation bleed from the surfaces and from between the pointer and dials of the nocturnal. This had to be done in order to effectively allow the removal of chlorides from the wood and then allow for the dehydration and subsequently the passivation polymer treatment of the wooden artifact. The instrument underwent some minimal chemical cleaning by immersion in 10% Hydrochloric acid ($HCl$)/water solution to soften and or remove some of the calcareous component of the concretion in the grooves and on the surface of the wood. The artifact was gently brushed with a soft toothbrush to remove this softened material. It was then placed in deionized water baths to rinse out the $HCl$ from the artifact.

Through a successive series of fresh and deionized water baths the chlorides were removed from the artifact. After cleaning, the nocturnal went through a series of baths to replace the water within the cells of the wood with an organic solvent. This process was performed through a series of baths of increasing increments (25%) of ethanol in water, ethanol, ethanol and acetone and then acetone removing the water from the artifact. Once the artifact had become acclimatized to the 100% acetone bath it was placed 'wet' into a bath of silicone oil and crosslinker (methyltrimethoxysilane) and allowed the exchange of silicone oil solution for the acetone. The acetone has become the 'highway' for the passivation polymer solution to penetrate into the cells of the wood. When it was felt that the polymer solution penetration was complete the artifact was removed and allowed to drain. As the device drained, it was noted that not all of the concretion had been removed from the incised lines and letters on the dials and pointer of the instrument. After some superficial washing of the artifact using the crosslinker (MTMS) the remaining concretion was obvious and easier to remove.

The polymer appeared to have created a minute separation between the wood surface and the layer of concretion. Using a very fine hypodermic needle, very pointed scalpel blade and binocular microscope the majority of the residual concretion in the grooves and incised lines was lifted out and off the surface. It was noted that some of the calcareous material was in places still well entrenched in the grain of the wood and the instrument was placed in a bath of 10% HCl/ water solution for up to 30 minutes to soften the fine layer of concretion. The artifact was brushed

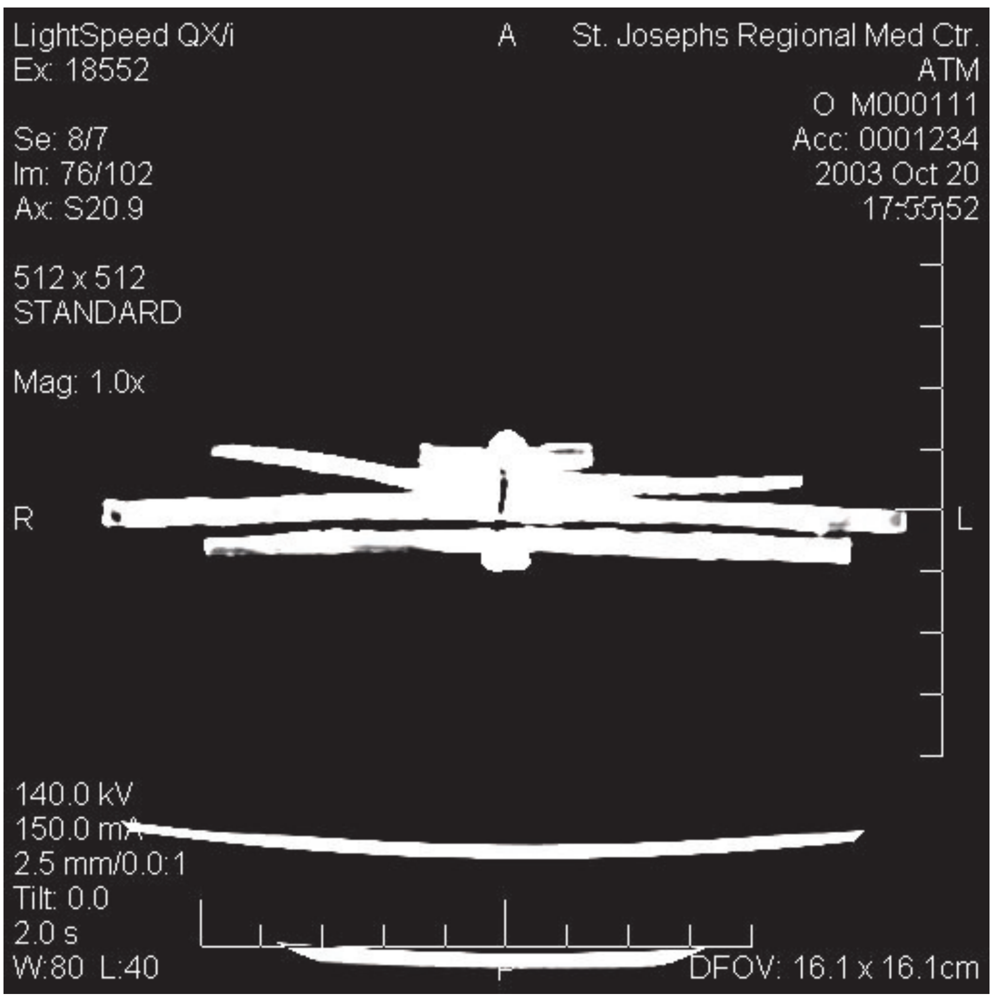


**Figure 2: A digital CT scan of the nocturnal. Courtesy St. Joseph's Regional Medical Center.**

again with a soft toothbrush and rinsed in deionized water several times. The mechanical and chemical cleanings were repeated several times until it was determined that any minimally remaining concretion could not be removed without causing more damage than leaving it in place. The remaining concretion is, for the most part, not visible to the casual observer. This painstaking procedure took several weeks with a very successful result. Not only were the letters revealed, but they turned out to show an instrument made specifically for the owner, with the names of the constellations in the vernacular of the pilot who used the instrument.

Although the brass sleeve and bushings tying the dials and pointer together could not be removed there was very little corrosion visible on the surface and virtually none evident in the area where the individual cupreous components interacted. Very fine beading needles and strips of Mylar were used to remove any corrosion from the spaces between the components and allowed for some movement of the components. This mechanical cleaning was done prior to the artifact undergoing dehydration. Once the artifact underwent silicone oil/crosslinker treatment and the wood was cleaned of excess polymer and any corrosion that may have occurred during dehydration, a thin layer of the polymer was reapplied to the cupreous sleeve and bushings. This formed a physical barrier on the surface of the brass, reducing the possibility of corrosion for a considerable period of time.

Once the mechanical and chemical cleaning pre and post conservation were completed the artifact was placed in a reseal-able plastic bag with a small aluminum testing dish containing 5 ml of catalyst - DiButylTin DiaAcetate (DBTDA). This catalyst locks the polymer chains which have bonded to the cell walls of the wood and on the surface of the metal components of the artifact. The catalyst, which has a working time of 24 hours, was changed out daily for 10 days to complete the conservation treatment of the nocturnal. It was fully photographed by CRL photographer Jon Swanson to complete the conservation documentation.

The artifact was then subjected to intense scrutiny by several researchers. Through the generosity of the late Dr. R. Bonichson, it was taken to the TAMU Center for the Study of First Americans (CSFA) to be photographed using the microscope photography facilities to identify and document areas where the lettering on the surface of the instrument was so faint it was very difficult to see with the naked eye. As part of a digital imaging class and the CMAC Wilder Digital Imaging Laboratory research, Dr. C. Wayne Smith took the artifact to the local St. Joseph's Hospital imaging department for CT scans. Finally, Nautical Archaeology masters student Lois Swanick and TAMU Department of Physics Professor Don Carona studied the instrument as an element of her thesis research on navigational instruments. Once the research was completed this unique and important artifact was delivered to the Texas Maritime Museum in Rockport, Texas as contracted by the CRL and the THC. The conservation of the artifacts was primarily funded by the THC and supported by Texas A&M University.

# Recording Artifacts Using Three-Dimensional Scanning

C. Wayne Smith, Ph.D. *(Texas A&M University)*
Ryan C. Lee *(Texas A&M University)*

Three-dimensional scanning and rapid prototyping were once considered improbable technologies of the fictional future universe of *Star Trek;* they are now becoming increasingly used by archaeologists and conservators in the study and preservation of our past. Like a number of other tools archaeologists use, three-dimensional scanners were not developed primarily for archaeology. They are mainly used for reverse-engineering manufactured products, and to refine ergonomic designs for consumer products, including cell phones, office chairs, automobile interiors, and even handles for surgical instruments. The design of virtually everything manufactured today is the product of three-dimensional scanning and computer-aided design.

It should not be surprising that engineering tools designed for manufacturing and reverse engineering have proven useful for archaeological conservation. When conservators first analyze an artifact, they seek to read the story that is unique to that specific item. Tool marks, use-wear patterns, and basic methods of construction are all essential information that conservators hope to understand in addition to the materials and methods used by the original artisan to create the

**Figure 1: One of the *USS Shark* cannons with its concretion intact. In the background are two larger cannon in a more advanced state of conservation. Photo by C. Wayne Smith.**



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artifact. These aspects of an artifact reflect cultural and technological preferences and have an effect on the degradation of the object once it enters the archaeological environment. For instance, cast iron components of an artifact will not deteriorate at the same rate as components made of wrought iron or cold rolled steel.

As important as it is for the conservator to understand manufacturing techniques in order to conserve artifacts more effectively, it is equally important for a museum curator to use the same information to create engaging and informative museum displays. Such is the case with two iron carronades that were recently sent for conservation at the Conservation Research Laboratory (CRL) at Texas A&M University.

As part of the conservation process, CRL's Jim Jobling requested that these two 18-pounder cast iron carronades recovered from the wreck of USS *Shark* (1821) at Arch Cape, Oregon, be three-dimensionally scanned as part of their documentation process (Figure 1). Iron objects recovered from marine environments are typically covered with a thick layer of concreted material that forms as the iron corrodes and combines with sediments, minerals, and other organic materials. For conservators, thick concretions on an artifact are generally a blessing. As the concretion forms, fine surface details of an artifact, such as makers' marks, patent information, and oven owners' inscriptions may be preserved. Without the formation of a concretion layer, these details are lost.

While scanning the exterior surfaces of a large concretion does not record information about the inner surfaces, the information captured is

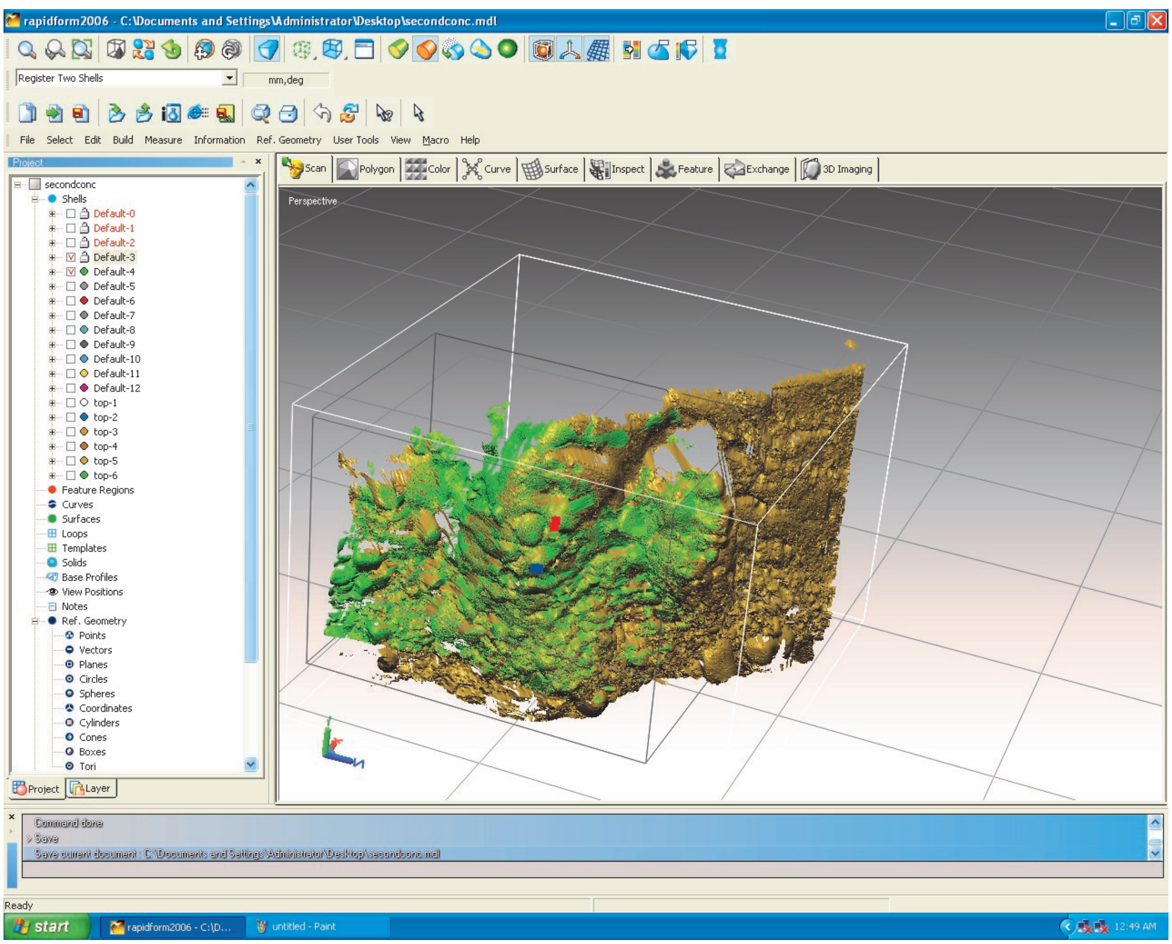


**Figure 2: One section of the surface scan of a cannon. Several scan sections can be fitted together to create a virtual three-dimensional model.**

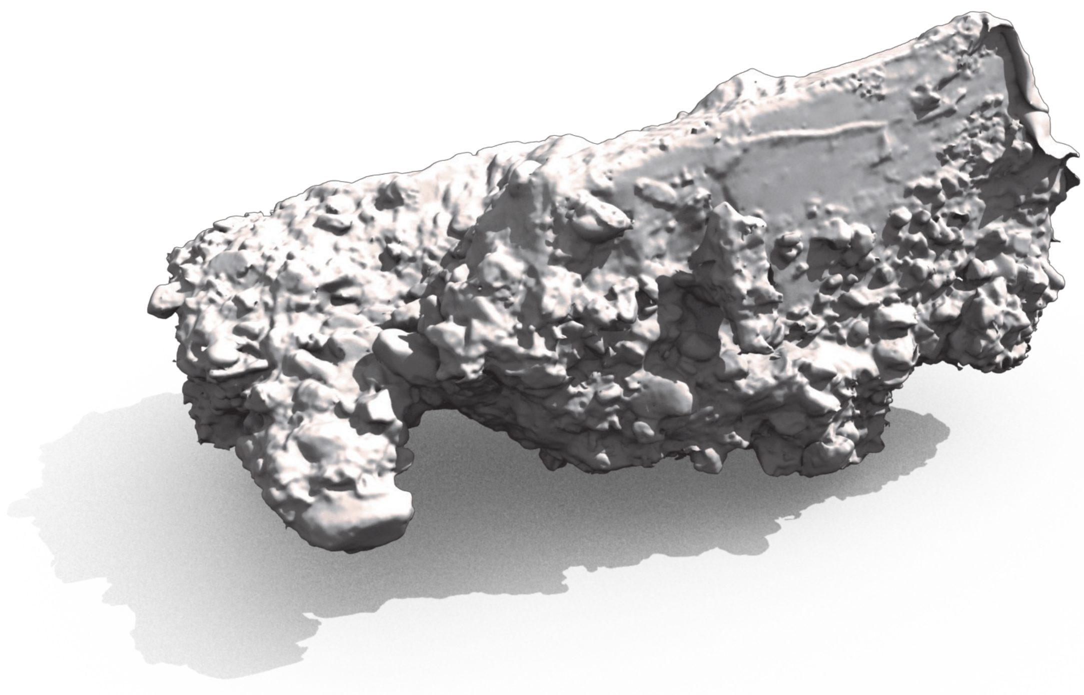

**Figure 3: Final mesh rendered in Blender, a free 3D graphics program.**

important for determining degradation processes as evidenced by the density and thickness of deposited concretion. This same information forms the foundation upon which conservation and illustration efforts will be based. Furthermore, the act of conserving the carronade for display results in the destruction of the concretion; scanning it first allows for a replica to be created from the digital data.

Artifact replication does not rely on digital technology like three-dimensional scanners. Mold making and replication predate professional archaeologists by thousands of years. In many ways, creating a physical mold and casting a replica based on the mold has many benefits over digitally scanning an artifact. The resolution of an analogue copy is typically higher than a digital one, for example. However, there are several disadvantages to the old method. For one, creating a mold requires the mold compound to be in physical contact with the object, which can potentially damage fragile objects. Further, creating multiple copies is a slow process, and replicating large objects is very labor intensive and expensive.

The three dimensional scanner used to scan the carronade concretions is a Konica Minolta Vivid 910 non-contact digitizer owned by the Wilder Three Dimensional Imaging Laboratory. During operation, the scanner employs a Class 2 laser and a sensor to record the distance between the scanner and the object, similar to the laser range finder in a total station. A galvanometer-driven mirror precisely deflects the beam to sweep back and forth across the object, recording up to 300,000 points in the 1.5 seconds it takes to complete a scan. At the same time, a low-resolution digital camera in the scanner photographs the object. The scanner then meshes the color data from the camera to the point cloud captured by the laser for each scan.

Figure 2 is an example of one portion of the scanned exterior surface of one carronade and parts of its carriage. The scanner has a limited field of view, and thus either the object or the scanner must be repositioned several times in order to scan the object completely. For smaller objects, this is usually accomplished by setting the

**Figure 4: Ryan Lee inspecting the results of scanning engineering models. Photo by C. Wayne Smith.**

artifact on a turntable and rotating the turntable between each scan, but it proved much easier to move the scanner and computer when recording the concretions. After capturing as much data as possible in its initial position, the concretion had to be carefully turned over to scan the bottom.

Since the Vivid 910 scanner uses a visible-light laser to capture distance information, the scanner can only record the portions of the artifact's surface that it can 'see.' Thus, any overlapping geometry caused by the rough, rocky nature of the concretion surface was obscured in any one individual scan. Moving the scanner and capturing the same area from a different angle resolved some of this problem. Due to the large size and complicated surface, it required approximately 22 scans to get full coverage of each concretion.

In order to align the scans together, each pass must overlap another enough to place virtual reference markers within the software (Rapidform 2006), which tells the program how to align the data. Once at least three of these marks are placed per scan pair, Rapidform attempts to move and rotate the scans so that the scanned geometry around the reference points matches up, and evaluates its own success on a five-point scale. If the results are not good, the user can further refine the alignment until the result is acceptable. Aligning such a large number of scans is a lengthy process complicated by the tendency of the program to crash at unexpected and unfortunate times. In the future, the more powerful computer and newer software package (Geomagic Studio 11) that CMAC purchased should rectify this problem.

Once all 22 scans aligned in the program, they had to be joined together into a seamless enclosed polygonal mesh. The software analyzes and optimizes overlapping data and fills in holes based on the curvature of the surrounding geometry in order to create a polygon mesh that can be exported to other CAD programs for visualization or rapid prototyping. These files can be used to create full-sized replicas from computer numerical control (CNC) mills or smaller copies on three-dimensional printers, such as the Wilder Lab's Z Corp z310 printer. Figure 3 represents the model exported to and rendered in Blender, an open-source modeling and animation program.

Recently, Ryan Lee and Dr. Wayne Smith also assisted two engineering students by scanning working models of technologies that may someday be used by aerospace companies. Figure 4 shows Ryan Lee inspecting the results of the engineering model scans. Despite the reflective nature of the materials being scanned, the scanner performed well in the climate controlled engineering laboratory. By contrast, the scanner's performance declined steadily throughout the day while scanning the concretions in the open bay at the Conservation Research Lab as the relative humidity climbed well past the scanner's 65% optimal limit.

Although the engineering-oriented result of scanning functional models of aerospace equipment is different from the conservation-minded recording of the nineteenth century carronades, the technologies for acquiring and representing the data are the same. In the case of aerospace engineering, knowledgeable people must assess design factors that contribute to metal fatigue and unusual stresses and flaws in the general design that may not be apparent until material testing is completed. In the case of the carronades, conservators will first assess the concretions, which may tell them something about the materials encased within. They will then carefully remove the concretion and evaluate the physical condition of the wooden carriage components and the general state of the barrel of the gun, including any fine details that may be preserved. For preserving important historic artifacts or testing space-age technologies, modern recording processes generate quality images that invite scientific scrutiny and excite the imaginations of museumgoers.

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