The Model Reconstruction and Presentation of the *Indigo* Wreck, Alexandria, Virginia

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Introduction

This paper documents the reconstruction and modeling of the remains of a vessel excavated in Alexandria, Virginia, nicknamed the *Indigo* wreck. Discovered and excavated in 2015 and 2016, the timbers comprise a significant portion of the starboard side of a medium-sized sailing vessel. After cleaning and cataloging, the timbers were transferred to the Center for Maritime Archaeology and Conservation at Texas A&M University for conservation. Prior to conservation, each timber was thoroughly scanned with the Faro 3-D scanner to create a digital representation of the remains. Each timber was then 3-D printed using the Lulzbot Taz 3-D printer and the Zortrax m200 printer. The goal of this project was to establish and document a method of representing the vessel's original shape, incorporating the 3-D printed models of the original timbers.

Without knowing the actual identity of the vessel, having a drawing or draft, or having an entire side of the vessel preserved, it is impossible to create a set of lines with 100% certainty; however, it is possible to create a believable shape that incorporates the specifications, structures, and construction techniques of the surviving remains and represents the possible appearance of the original vessel. This analysis will provide one possible representation of what the *Indigo* vessel may have looked like using models of the original timbers and comparisons to the geometry of contemporary vessels.

Timber Remains

The remains of the vessel comprise a significant portion of the forward starboard underwater section of the hull, which represents the backbone of the vessel. The remains included two sections of the keel: the forefoot of the keel, including the lower part of the stem, and the forward deadwood. In addition, a significant but badly eroded section of a false keel was also recovered. The starboard arms of 23 frames have survived, including eight of the forward-most nine frames still fastened to the keel with iron bolts. In addition, most of the associated first and second futtocks have survived to slightly past the turn of the bilge. In a number of locations, these timbers are fastened to each other or to adjacent floors with iron drifts. The floors of the vessel have been intentionally chopped through just above the keel. Large sections of eight strakes of outer hull planking were well preserved, as were parts of five ceiling strakes. The planking is fastened to the frames with wooden treenails.

Except for portions of the floors that cross the keel and part of the garboard strake, little remains of the port side of the vessel. The keelson, stern deadwood, and sternpost and associated part of the keel are also missing.

There were two unusual timbers associated with the remains. First, there is a chock of wood under the fifth frame from the bow supporting the floor on the keel. This timber has been bolted through and appears to be part of the original construction of the vessel. Secondly, in the bow, there is an unusual long timber nailed to the starboard side of the keel and forefoot. The purpose of this timber is unknown, but it may have been used to reinforce wear in this area as the vessel aged. Although neither of these timbers affected the overall shape of the vessel, they may provide details of the quality of construction and use of the vessel.

Reassembly of model timbers

Prior to the assembly of the 3-D printed timbers, Dr. Chris Dostal reassembled the scanned 3-D images of the original timbers into a virtual model of the vessel. From these images, he was able to extract a preliminary set of lines (Figure 1). These lines, in combination with a plan view of the reassembled timbers, were used to build a jig to position the model timbers as they were assembled. Before the model timbers could be assembled, they were inspected and cleaned of any burrs or other artifacts of the 3D printing process. Voids or problems with the texture of the printed timbers were filled in with Milliput, a two-part epoxy putty. The capacity of the 3D printer limited the size of the printed timber to 12" x 12" on the Lulzbot and 9" x 9" on the Zortrax. Timbers that were larger than this, such as the keel, had to be printed in sections and then spliced using Milliput to hide the seams. Once all of the parts were prepared, assembly could commence.

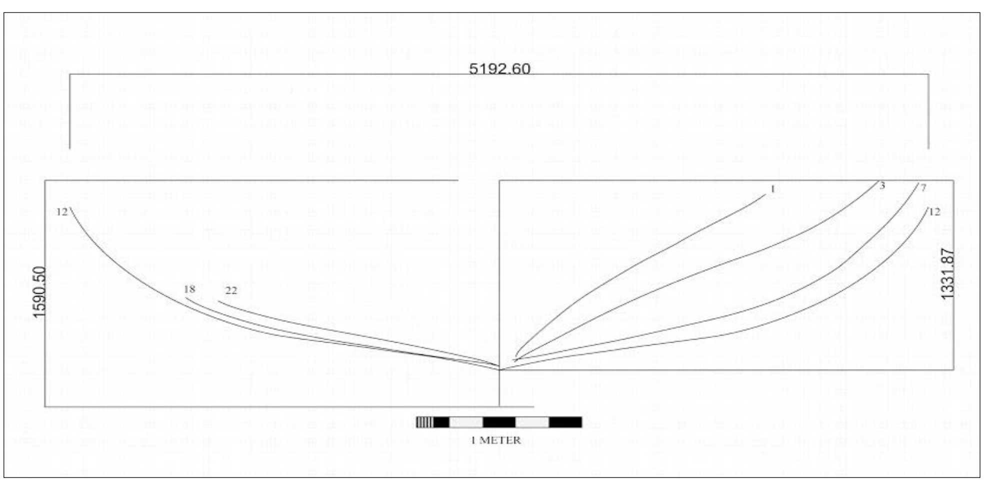

Figure 1: Reconstructed lines taken from the *Indigo* wreck (Drawing by Chris Dostal)

The plan view of the timbers was fastened to a suitably sized board in order to provide a footprint for the model. Over this, three longitudinal rails representing the buttock lines from the preliminary set of lines were fastened at the appropriate distance from the side of the keel. These rails provided a bed on which to erect the frames (Figures 2 and 3). Proper boatbuilding practice would have required the top of the keel to be level where it met the frames. For the model, this necessitated spacers under the keel to bring the upper surface to level. These spacers give a good indication of how badly the bottom of the keel had been eroded before the hull was deposited at the site. The vessel had a false keel over two inches thick that was completely worn away by the end of the timber.

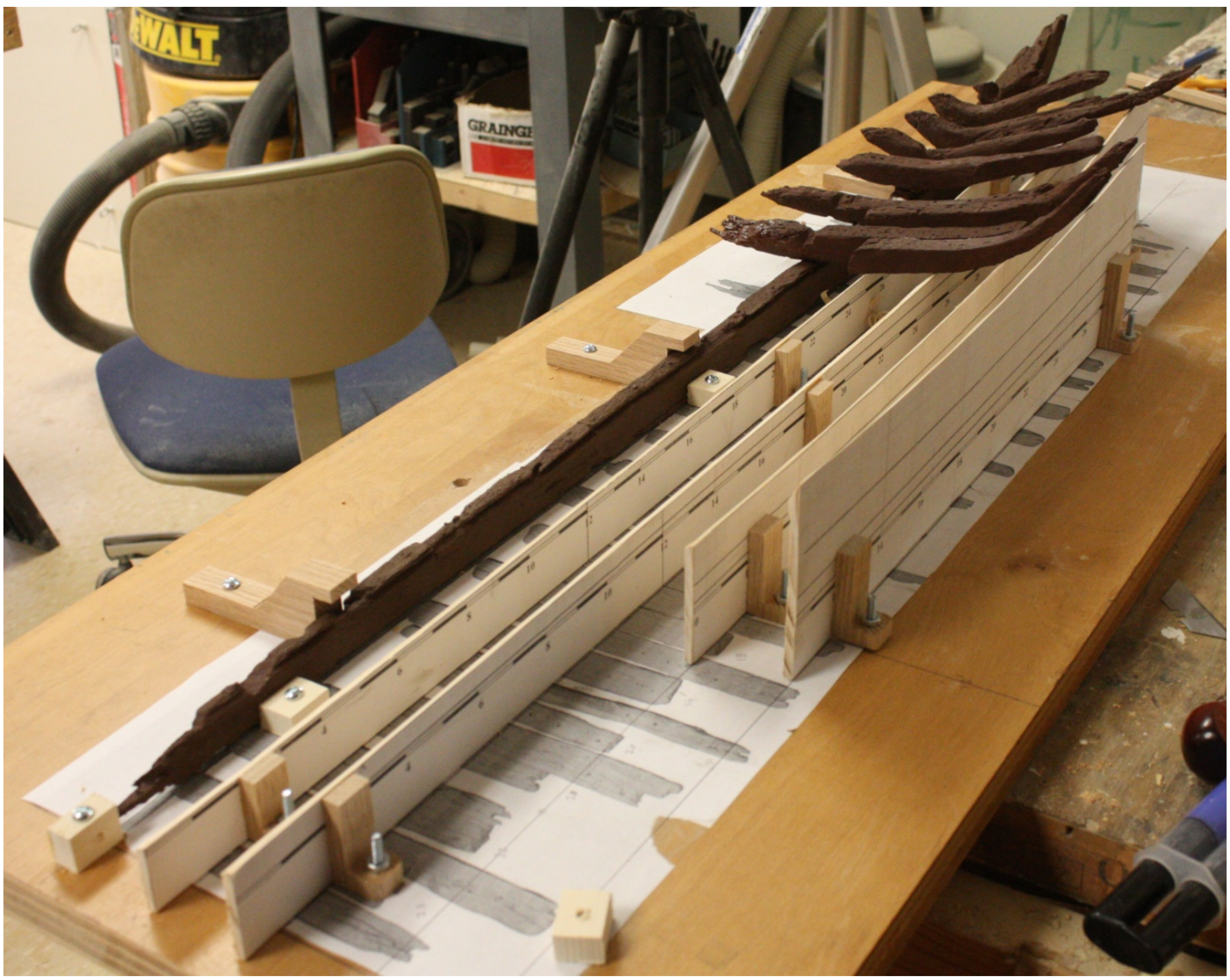

Figure 2: Futtocks supported on rails representing the reconstructed lines (Photo by Glenn Grieco)

Figure 3: Positioning the frames on the building jig (Photo by Glenn Grieco)

With the keel in place, the assembly of the floors and futtocks were fairly straightforward using Dostal's digital reconstruction. After the original vessel was framed, the outer faces of the frames were adzed flat to accept each strake of planking. The edges of these flats could be lined up on each frame to guide the positioning of the timbers. Trunnel holes were spaced fairly regularly and could be lined up with holes in the planking to further guide the assembly. The fastening of the timbers was with $^{1}/_{16}$ inch brass wire and two-part epoxy cement. The malleable brass wire would later allow for manipulation of the timbers as an assembly.

With the keel and frames assembled, it was now necessary to make adjustments to position and angle of the individual timbers. The shimming of the bottom of the keel made a slight difference in the rising of the frames, and this was adjusted by shimming points along the rails representing the buttock lines.

Once the hull remains were fair, it was time to move on to the outer hull planking. This posed a slight problem because the timbers could not be removed from their cradle without disturbing the shape of the hull. It would be necessary to make the hull more rigid before removing it from its base. In order to establish the necessary rigidity, a sheet of heavy aluminum foil was placed over the inner face of all the frame timbers. Cotton swabs were used to push the foil into every contour of the timbers. Over this surface, a layer of expanding foam insulation was applied. This foam becomes rigid as it dries and provides support for the timbers. To increase the rigidity, two wooden splines ¾ inch square and the length of model were set into the foam. After the initial application of foam hardened, a second layer was applied (Figure 4).

Figure 4 Completed frame model covered in Aluminum foil and rigid expanding foam. (Photo by Glenn Grieco)

Installing planking

With the hardened foam now providing a solid support for the frames, the entire model was inverted, presenting a fair surface to plank. In order to allow the 3D printed planking to bend to the contours of the framing, it was printed with a much more flexible plastic. The rubbery nature of the planking, however, prevented the use of epoxy for fastening the planks to the more rigid frames. After experimenting with several adhesives, It was determined that ShoeGoo was the most effective for attaching the planking. To install the planking, the proper location of each plank was determined using the location of trunnel holes. Once the plank was properly positioned and held in place by several clamps, each trunnel hole was cleaned out with a drill bit and a temporary wooden peg was inserted. The strakes were fitted starting with the garboard adjacent to the keel and working out. Once two complete strakes were fit, the inner strake was glued and permanently fastened with trunnels. With each consecutive strake positioned, the previous strake would be permanently fastened. This sequence guaranteed that a small error in one plank would not throw off all the remaining planks.

With the outer planking firmly attached to the frames, the entire assembly was surprisingly rigid and held its shape well. Once again, the entire model was inverted and returned to the original building jig with the rails representing the buttock lines removed. In their place, several lateral wedges were used to support the model at the proper angle. With the model secure, the remaining fragments of futtocks were positioned and the ceiling planks were attached in the same method as the outer planking.

During the construction of the framing, the timbers were painted prior to assembly with acrylic paint, avoiding surfaces that would be glued. This assured that areas not accessible after construction would be properly finished. With the completion of the hull framing, the entire model was given a final coat of acrylic paint.

Reconstructing the lines

With the reconstructed lines confirmed by the shape of the 3D model, the next step was to determine the frame locations. It was determined that the frames were erected on 20-inch centers. With floors timbers averaging 11 inches sided and a sided dimension of approximately 9 inches for the first futtocks, the framing provided a solid wall of timber up to the turn of the bilge. This was further confirmation that the vessel was designed with the 20-inch spacing.

The midship frame of a vessel is always placed at the maximum beam of the vessel. Analysis of the reconstructed lines indicated that the maximum beam coincided with floor number 12, approximately 21 feet aft of the forward end of the keel. Projecting the curve of the stem forward provides a length of stem to midships of approximately 26 feet. Unfortunately, a large section of the stern of the vessel is missing. The stern knee can tell us much about the shape of the stern, but in these remains, it is completely missing. We do, however, have the remains of a scarf in the keel. Although not always the case, it is good practice to construct the keel from two approximately equal length timbers. If we estimate that the scarf lies approximately midway along the keel, we get a keel length of approximately 58 feet. The last remaining floor we have from the remains does not show significant rise, which indicates that it is still some distance from the stern knee and stern post, suggesting that a significant portion of the keel is missing. With so much of the stern missing, it was necessary to create several sets of lines using different keel lengths to find a feasible length that agrees with both the frame spacing and the existing curvatures.

A good representation of the midship frame is also necessary to determine the lines of a vessel. Although we do not have a complete midship frame, we have a large portion of frame 12 to just past the turn of the bilge. Experimenting with different arcs, it was determined that the maximum beam could be no larger than 20 feet or less than 17 feet. The most appropriate curve gave a maximum beam of about 18 ½ feet. The heavy framing and relatively flat floors suggest a deep hold, possibly indicating a merchant vessel.

After several iterations of lines were created in AutoCAD, a suitable plan that fit both the frame spacing and the shape of the existing remains provided a preliminary outline of the vessel, which was compared to specific ship types of the period. It was determined that the vessel was similar in size and form to a Brig or large sloop. The reconstructed lines from the remains were then compared to numerous contemporary drafts of similar-sized vessels. Eventually, one draft that seemed to fit the reconstructed lines, overall dimensions, and midship frame location was located.

Although there is no way to compare the shape of the vessel above the waterline to the remains of the *Indigo* hull, the shape of the hull below the waterline of Brig #38 of Plate XXVI in F. H. Chapman's *Architectura Navalis Mercatoria 1768* fits very precisely with the lines of the *Indigo* remains. Most likely, the upper works of this vessel differed from the *Indigo* remains. For that reason, the reconstruction has been given a very generic shape above the 10-foot waterline. Below the waterline, however, the lines are almost identical and provide support for the overall length of the vessel. The reconstructed set of lines for the Indigo timbers is shown in Figure 6.

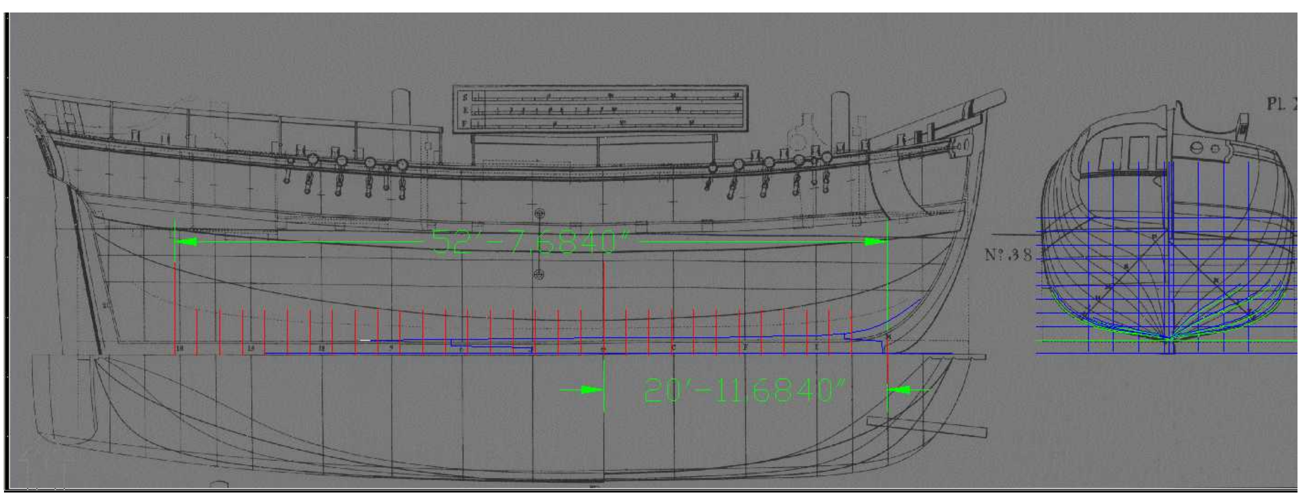

Figure 5: Comparing the reconstructed lines to the shape of a 18th Century Brig.

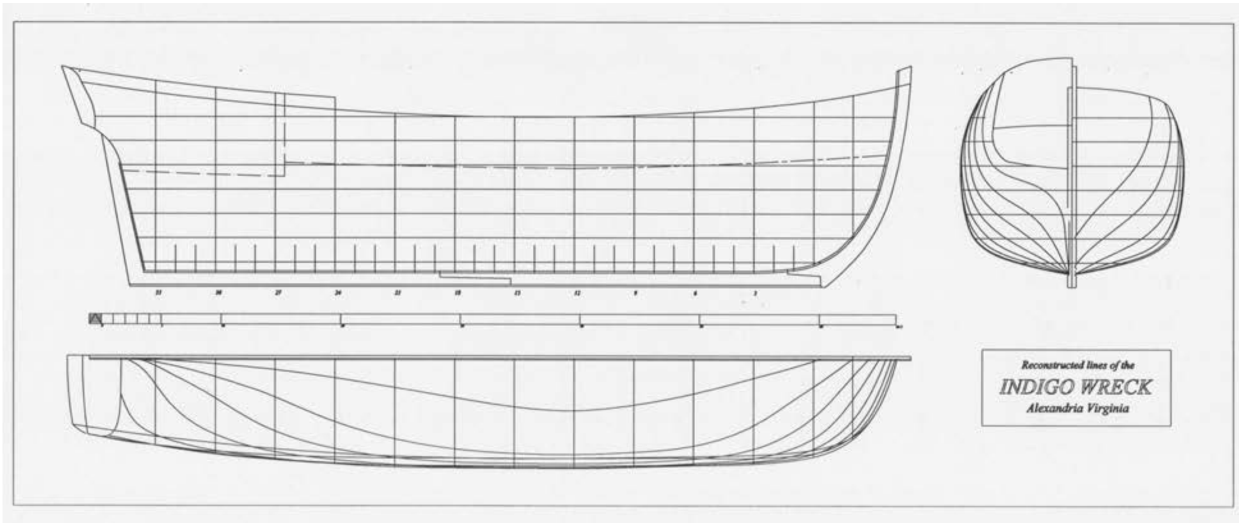

Figure 6: Reconstructed lines for the *Indigo* wreck. Drawing by Glenn Grieco

Building the wireframe

A wireframe is a very efficient way to represent the possible original lines of the vessel. Inspiration was taken from the *Serce Limani* reconstruction in the Bodrum Museum of Underwater Archaeology in Bodrum, Turkey, and the *Skuldelev* reconstructions in the Roskilde Viking Ship Museum in Roskilde, Denmark. It was decided, however, that too many lines would obscure the view of the original timbers without providing a significantly better idea of the shape than could be represented by just the sections. The sections included in the wireframe represent the midship frame, six sections aft at five-foot intervals, five sections forward at five-foot intervals, and an additional section in the bow, two and one half feet forward of the fifth section. Longitudinal support for the sections was provided by a single waterline running from the stem to the transom at the height of the 10-foot waterline and the sheer lines at the top of the sections.

The material used for the wireframe is 1/8 inch square section low carbon steel rod. Each section represents the shape of the hull inside the hull planking and the possible height of the main deck. Each section was formed using a bending jig (Figure 7) to carefully work the wire into the shape of each section. The location of the deck was determined and an arc representing the deck curvature was carefully half-lapped and silver soldered to the section. Each completed section was spray painted with sand colored Rust-Oleum gloss protective enamel paint.

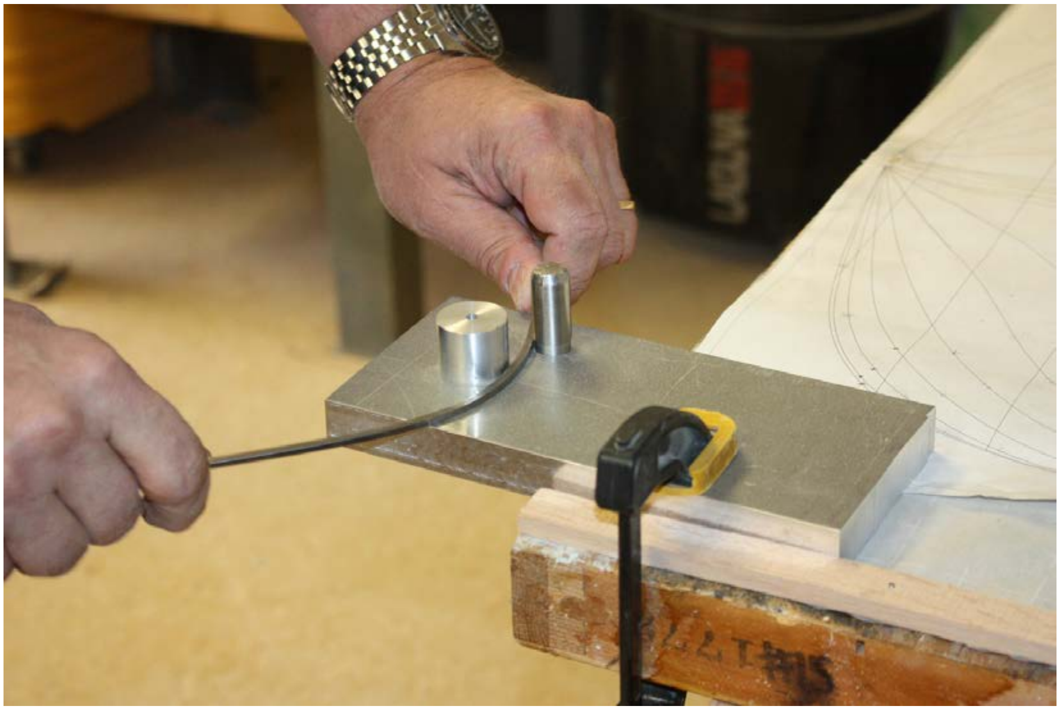

Figure 7: Using the bending jig to form one of the *Indigo's* frame sections (Photo by Glenn Grieco)

With the keel firmly attached to the display base and the starboard side of the hull firmly buttressed at the proper angle, construction of the wireframe could commence. A mock-up of the missing sections of the keel and stem and a reconstruction of a possible sternpost and transom were constructed of red oak and firmly attached to the model. These would provide much of the vertical support to the finished wireframe. The sections were then attached to the keel and, wherever possible, to the inside of the hull planking. Simple brass staples were used to fasten the sections to the oak section of the reconstructed keel; however, these staples would not be sufficient to fasten the steel wire to the plastic in the 3D printed frames. The hollow structure of the 3D printed timber was insufficient to secure the fasteners in place. Four-pronged brass staples (Figure 8) had to be machined to provide a strong connection between the plastic and the steel rod. Heated to the melting point of the plastic, the four prongs easily penetrated the keel and once cooled, fastened themselves securely inside the part. Once all of the sections were erected, the two wires representing the 10-foot waterline were shaped and firmly silver soldered to the sections. Finally, the wires representing the sheer of the vessel were formed and soldered in place. A final clean-up and coat of Rust-Oleum completed the model.

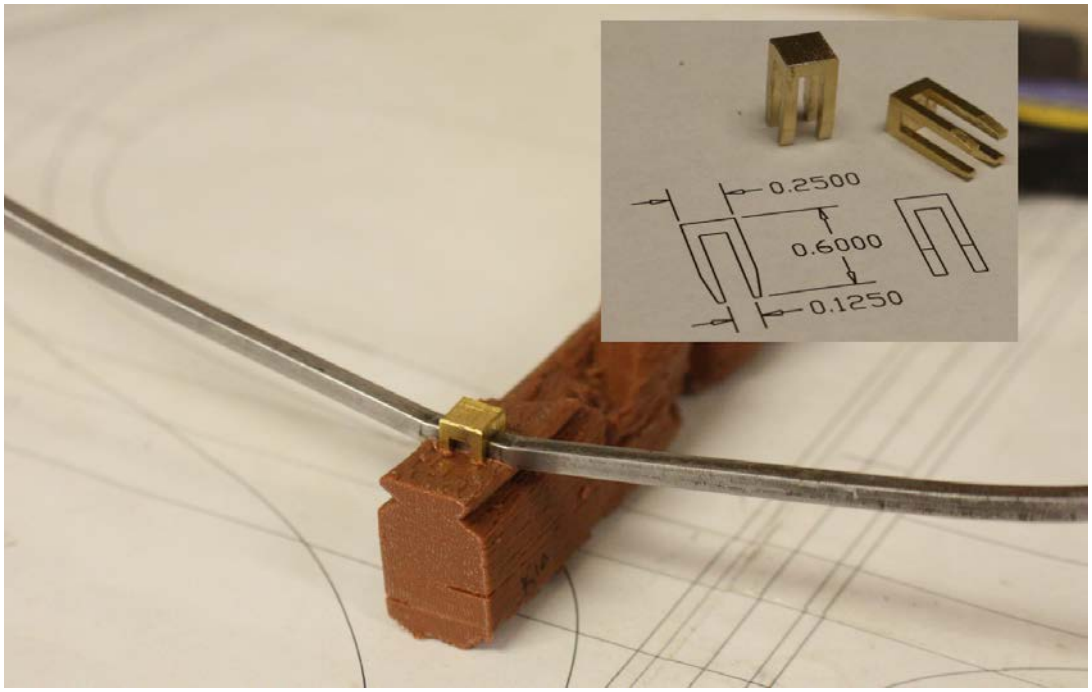

Figure 8: Custom staples used to join *Indigo's* frame sections to the 3D printed keel (Photo by Glenn Grieco)

Analysis

The purpose of this undertaking was twofold. First, to create a reasonable reconstruction of how the *Indigo* vessel may have appeared before she was broken up and deposited at the site where she was discovered and, secondly, to come up with a method of displaying a scale model of her remains in a way that would allow us to propose an idea of her possible original appearance.

The dimensions of the reconstructed timbers from the *Indigo* wreck are consistent with a vessel with a length of keel of about 58 feet (17.7 meters) and a beam of approximately 18 ½ feet (5.6 meters). This would give an overall length of hull of around 70 feet (21.3 meters form stem to transom). Determining the rig of the vessel would be very difficult without the remains of maststeps or evidence of their possible locations. Often, it is possible to get this information from a keelson, but this timber was also missing from the wreck. The reconstructed dimensions do seem appropriate for a large sloop or medium-sized brig.

Determining the possible use of the vessel would also be difficult without more evidence. The framing pattern is one that is seen in both naval and merchant vessels in the 18th century. Perhaps the extensive wear on the keel suggests a long, hard, career as a merchant vessel; however, this wear could also be the result of an unused and abandoned vessel slowly grinding its keel away where it was moored. The relatively flat floors and full shape of the hull provide a voluminous vessel that would have been well suited for carrying cargo and might be a good indication that the *Indigo* wreck was a merchantman.

For close to two decades, the CMAC Ship Model Lab has produced traditional plank-on-frame ship models and wooden research models. The *Indigo* wreck is the first model built in cooperation with the Analytical Archaeology Laboratory using state of the art 3D scanning and printing technologies. There will always be a place for the traditional models in nautical archaeology; however, the accuracy and detail of the 3D printed timbers have added a new dimension to the representation of archaeological resources. Along with the advantages of this technology come new challenges which became apparent while attempting to assemble the plastic and metal components of the *Indigo* model. Through trial and error, methods were established to utilize the new materials to their highest potential and provide guidance for future models.

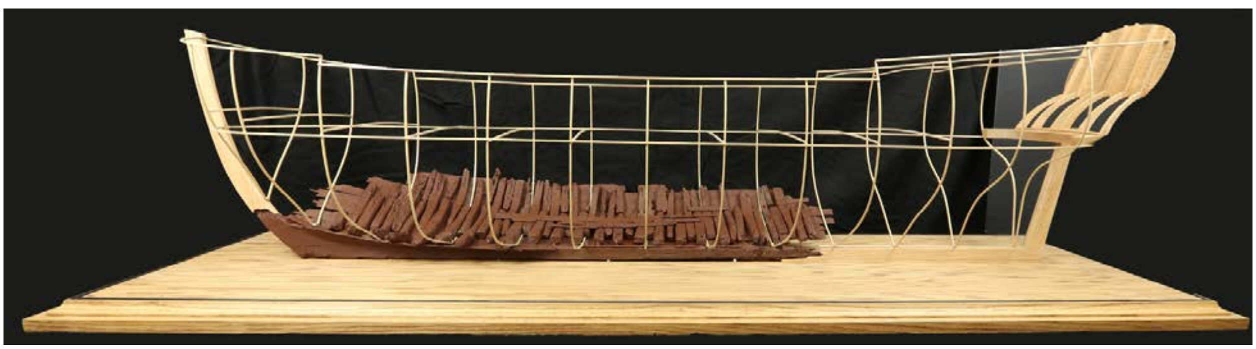

Figure 9: Side view of completed *Indigo* model (Photo by Glenn Grieco)

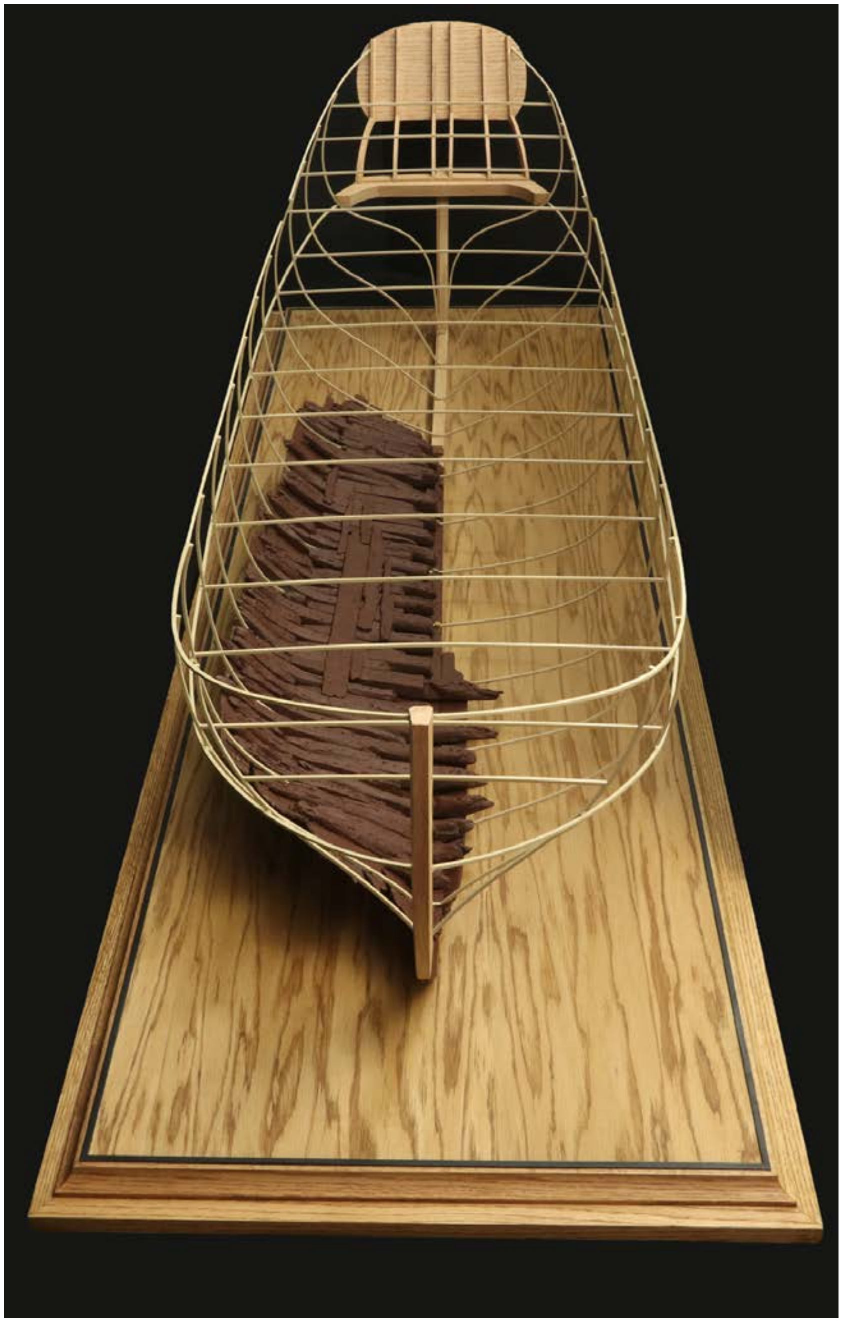

Figure 10: Bow view of completed *Indigo* model (Photo by Glenn Grieco)