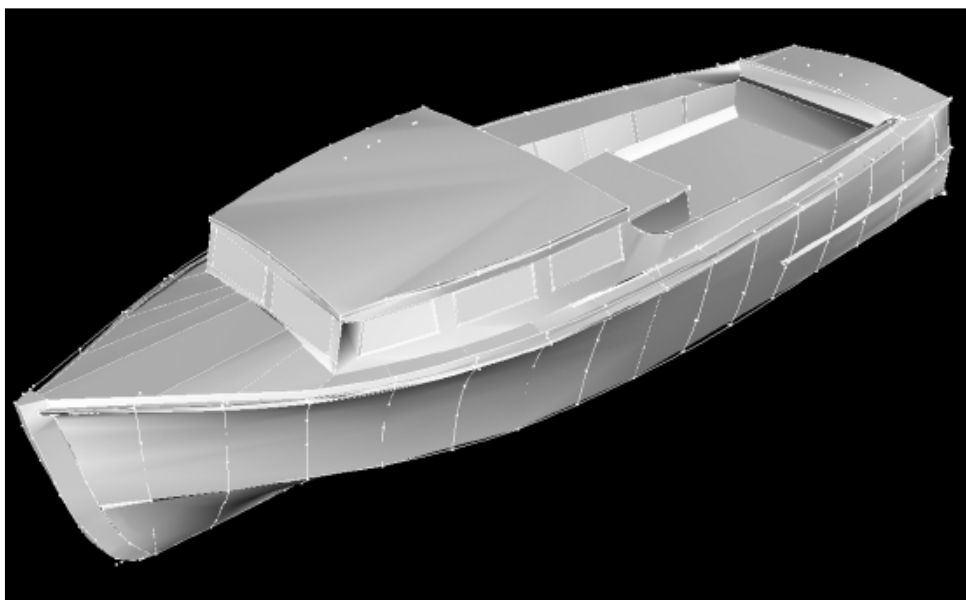


# Virtual Modeling and 3D Photogrammetry for Maritime Heritage: *Exercises in EOS PhotoModeler Pro 5.0*



Nathan Richards, Sami Seeb, Brian Diveley, and Michelle Liss

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Program in Maritime Studies  
East Carolina University  
Greenville, North Carolina

*... Integrating hands-on experience  
with interdisciplinary studies*



2006



Research Report No. 18

Virtual Modeling  
and 3D Photogrammetry  
for Maritime Heritage:  
**Exercises in EOS *PhotoModeler Pro 5.0***

Nathan Richards, Sami Seeb, Brian Diveley, and Michelle Liss

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Cover: Shaded photo-model of NCHH0025 (Brian Diveley, 2005)



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# Abstract

In the fall of 2005, students enrolled in the class HIST 5005 (*Special Topics*): *Deep Water and Advanced Methods for Maritime Archaeology* were engaged in the production of a virtual model of a maritime heritage subject with the use of the EOS program *PhotoModeler Pro* version 5. In two cases, students created the virtual models from pre-existing physical ship models built from historical records and archaeological observation, and in one case, a participant recorded data from an historic preservation study undertaken on historic North Carolina watercraft. In addition to the production of these highly accurate three-dimensional virtual replicas, contributors produced a report on each project. In this publication, the authors have combined and presented the processes and experiences of modeling, and the finished product. The process and experience of the first-time modelers demonstrates not only the potential of this software for use in relation to the depiction of maritime heritage resources, but also as a tool to strengthen skills development in the areas of survey conceptualization and planning.

# Acknowledgements

While tangential to the HIST 5005 class, and this report, the authors gratefully acknowledge support for the Currituck Project through the National Park Service HABS/HAER Sally Kress Tompkins Fellowship and the North Carolina Maritime Museum. We would also wish to acknowledge the assistance and encouragement received from a number of different fronts, without which one aspect of this project would not have been possible. Dr. Paul Fontenoy, Curator of Maritime Research at the North Carolina Maritime Museum, contributed numerous hours of fieldwork and considerable support for attaining software and field recording equipment. Todd Croteau, of the National Park Service HABS/HAER office, donated the use of a total station to record vessels and his subsequent understanding of transitioning these vessels to a three-dimensional record. Thanks also to Dr. Lawrence Babits, Director of the Program for Maritime Studies, and the assistance of faculty at East Carolina University, that allowed this project to be examined from another perspective. We extend a special note to Wilson and Barbara Snowden of Currituck, who not only extended the use of their home as a base of operations for the 2005 field season, but also moved vessels, arranged interviews, and proved to be a general encyclopedia of expertise for vernacular watercraft of the region. Final thanks go to Jeremy Eamick and Dr. Bradley Rodgers for assistance with proofreading.



# Introduction

In fall 2005, Faculty offered a course entitled HIST 5005: *Deep Water and Advanced Survey Methods for Underwater Archaeology* for the first time as a special topic in the Program in Maritime Studies (Department of History), at East Carolina University. Dr. Nathan Richards (course designer) taught the class as an extension to a program mainstay, HIST 6820 *Research Methods in Nautical Archaeology* to students undertaking the MA in Maritime History and Nautical Archaeology, and the PhD in Coastal Resources Management. The material covered aspects of technologically focused and computer-dependent maritime archaeology methods, including remote sensing techniques, remotely operated vehicles and numerous software packages. Class assessment revolved predominantly around explorations of emerging technological options in the area of maritime heritage, as well as the preparation of a three-dimensional photogrammetric model of a maritime object of the student's choosing. Participants created a report outlining his or her experience of the process, and their assessment of the finished product. The software used for the production of these was EOS *PhotoModeler Pro* (version 5.0).

*PhotoModeler* is a Windows program that allows a user to extract measurements and three-dimensional models from photographs. The user begins the process by importing photos from a calibrated camera. From these photos, the program essentially triangulates by measuring rays from the camera to points on the site, feature, or object. Images containing multiple views of the same points allow the program to calculate angles and therefore complete the necessary geometry to create a model of the photographed image (Green et al. 2002: 283-284). The software user references the photos to one another by making marks on the photographs which tag and trace specific identifying features of interest that appear on one or more photograph. In other words, *PhotoModeler Pro* allows a user, "to derive three-dimensional point coordinates, vector angle, area or volume information of an object from standard photography" (Franke 1991: 1).

*PhotoModeler* is useful for maritime and underwater archaeology, and, though published work is limited, more archaeologists are embracing the software as an important tool with significant potential to aid in site surveying and analysis. Franke (1999) produced early work done in underwater archaeology with *PhotoModeler*. In his investigation, he created a three-dimensional model of the J3 submarine wreck in Victoria, Australia. The submarine site is semi-submerged, forcing Franke to limit modeling to the parts of the wreck above the waterline. The result was a three-dimensional site plan of the J3 submarine viewable from any angle. Franke conducted analysis by comparing the model to actual historical photographs of the submarine. Another instance of archaeological use of *PhotoModeler* was on the fifth century BC shipwreck at Tektas Burnu (Green et al. 2002).

Photogrammetry provided a resolution to the problem of conducting diving archaeological investigations, which must be limited because of the depth of the site. Using control points put directly onto artifacts surrounded by a control grid enabled archaeologists to map artifacts in three dimensions which were otherwise difficult or impossible to map.

The photo modeling product provides a tool for archaeologists to conduct analysis that might otherwise be restricted or impossible. Precise measurements and three-dimensional models allow archaeologists an additional approach to analytical work on sites. In circumstances where time or access to a site is limited, photo modeling provides a means to spend a short time capturing the site digitally so that the researcher can create maps and drawings later. Photo modeling might also help with post-fieldwork analysis, highlighting specific features or characteristics that might not have been readily apparent in the field. In addition, *PhotoModeler* software has an innately predictive character, allowing the user to estimate features that might have been unclear or unnoticed in the field with a high level of accuracy. Additionally, photo modeling allows the user to create and view aspects of a site or feature that they could not see while at the site.

By the end of the fall, 2005 semester, the students had produced three highly-accurate digital photo-models. In one case, this was of an historic small craft, reconstructed from photographs taken by a student during a stint of fieldwork for the National Parks Service in the summer of 2005. In two other cases, participants constructed photogrammetric replicas from ship models built by faculty and students during Dr. Bradley Rodgers' class HIST 6810: *History of Marine Architecture and Ship Construction*. These two models were very different. One, constructed in 2003 by ECU MA Students Evguenia Anichtenko, Jake Betz, Jeff Bowdoin, Matt Brenkle, Clint Ethridge, Calvin Mires, Dave Nelson, Jason Rogers, and Travis Snyder emerged from the ship plans of the British Frigate HMS *Alert*. The other was the product of ECU archaeological inspections of the wreck of the paddle-steamer *Montana* (model by Dr. Bradley A. Rodgers). Together, these three photo-models represent the process and progress of students learning about not only the strengths and limitations of photogrammetry, but also about photography, survey, and geometry. The hundreds of hours spent in learning about the program, photographing their subjects, processing photographs, and fine-tuning their models was an invaluable experience, with lessons that can be extended not only to the creation of future photogrammetric models with EOS *PhotoModeler Pro* software, but also when creating two-dimensional photo-mosaics. The lessons also invariably influence the development of conceptual skills in general survey planning and execution.

This report is a re-configured, re-contextualized, and expanded amalgam of the three reports submitted in fall 2005 (see Diveley 2005; Liss 2005, Seeb 2005). What follows is a synopsis of the *PhotoModeler* work flow model common to each of the participants in the experimentation with the software (Chapter 2), followed by a detailed description of each of the photo-models created throughout the semester (Chapters 3-5). While the photo-models described in detail in this report are not without error, they represent an astonishing learning curve that demonstrates that the *PhotoModeler Pro 5* software has much potential, and can produce

impressive results. Indeed, all of the authors agree that *Photodeler* is an amazing tool – and that with further experience and experimentation the few minor problems noticed are likely fixable. In particular, had our hardware capabilities included the most up-to-date processors, graphics cards, and expanded memory, we feel that the finished product would represent an even more accurate and fault-free product.





## Methodology and Work Flow

All photo modeling projects follow a basic pattern of steps necessary for producing a three-dimensional model. The steps, outlined by Franke (1999: 2) and the *PhotoModeler* user manual (EOS Systems Inc. 2004), delineate the work flow:

### 1. Plan proposal

- Assessment of objectives, budget, and scheduling.
- Acquisition of metric compatible cameras.

### 2. Suitability of *PhotoModeler Pro 5.0*

- Evaluation of proposal in relation to the *PhotoModeler* software.
- Determination of whether coded targets should be used in the project. If so, estimation of target size based on size of the subject and camera resolution (EOS Systems Inc. 2004:444).
- Where targets are not utilized, points should be marked on flat surfaces that have no visible reference marks (for example, where there is a need to record flare and dead-rise of watercraft).
- Metric compatible cameras should be calibrated using focal lengths suitable to the project needs. Calibration of the camera should be completed at earliest convenience before survey is to commence.

### 3. Photographing the object

- Targets should be placed on the object or site where necessary. Target distribution varies depending on the size and scale of the object/site being recorded. Larger sites will require more reference points than smaller ones, although features should be recorded in greatest detail possible.
- Scales are referenced in photographs to verify accuracy of measurements taken on-site. Duplicate photographs should be considered.
- Conditions and shutter speed are important in acquiring the highest depth of field possible. On larger sites and at angles greater than 90°, reference points can be difficult to distinguish if blurry. By increasing aperture/decreasing shutter speed of the camera, the photograph will have better focal accuracy. However, if extending shutter speed at or below 1/60 second, a tripod should be used.
- Depending on the type of vessel, camera stations should be orientated at as close to 90° angle to one another as possible. Smaller angles will generate an incorrect position for the three-dimensional point (EOS Systems Inc. 2004:69). Similar attention to horizontal and

vertical separation should be given to photographing targets when possible (EOS Systems Inc. 2004:71).

- Photographs should only be taken from calibrated focal lengths. When using different calibrated focal lengths, field notebooks should be kept logging changes.

#### **4. Transfer photographs to *PhotoModeler Pro 5***

- Photographs taken in digital format can be transferred to *PhotoModeler Pro* using direct link cables.
- Printed photographs should be scanned and imported into *PhotoModeler*.
- Camera calibration, when necessary should be set to specific photographs used in a *PhotoModeler* project.

#### **5. Data processing**

- Use of targets allows the user to automatically reference given points taken on a project. This process inherently decreases the amount of processing time to reference points.
- When use of targets is not mandated, or possible, manual reference using a mouse to trace and tag individual points in a project is necessary. Although this process is labor intensive and often complicated, the system can be used to recreate objects without previous consideration of the photogrammetric process.
- Excess data should be tagged if possible to increase accuracy in a project. Data not used in referencing points or from non-orientated photographs can be removed after each vessel is completed.

#### **6. Structuring the model**

- Similar to step five, referencing using additional points, lines and surfaces allows greater visualization of the three dimensional object.

#### **7. Representation**

- Structured models can be visualized and measurements taken using the 3D viewer. Three-dimensional inspection of the model, layered with photographic textures, can be used for additional analysis.

#### **8. Data export**

- Surfaced data can be exported to *SurfaceWorks* or other three-dimensional viewing and manipulation programs such as *Cosmo Player*. Architectural line drawings and ship curves are derived based on three-dimensional data collected in this process.
- $x$ ,  $y$ , and  $z$  points can also be exported to Computer Aided Design (CAD) software packages or applicable software application.

# The Watercraft of Currituck County, North Carolina

## Introduction

This chapter describes the use of survey techniques in recording traditional watercraft off the Outer Banks of North Carolina, and the subsequent use of documentation to re-create a three-dimensional photogrammetric model of these vessels without the use of expensive hardware. Technological advances and new methods of application have seen the development of improved photogrammetric methods to record cultural heritage. The evolution of these tools and their application to terrestrial and maritime archaeological environments has expanded significantly with each new version of software released.

A grant supported by the National Park Service's historic preservation effort, the Historic American Buildings Survey/Historic American Engineering Record (HABS/HAER), and the North Carolina Maritime Museum in Beaufort, North Carolina initiated the preliminary survey of North Carolina Outer Banks watercraft. Parameters of the project included historic documentation, photographic recording, and two-dimensional/three-dimensional representations of project data using *SurfaceWorks 5.0*. Funding for the project specifically provided for personnel, software, and hardware use, specifically that of a Sokkia total station for the duration of the two month survey.

Although costs incurred throughout this project were justified in the survey proposal, recording vessels of this type, specifically using *PhotoModeler* to record three-dimensional spatial location, could obviate the use of expensive equipment such as the total station. This chapter intends to discuss the inherent advantages and disadvantages of using *PhotoModeler Pro 5* as a viable means to record watercraft.

## Project History

As per the parameters of the project, the survey had three separate components. The first included historic documentation of each vessel in the Currituck survey, regional background, vessel history, and builder and owner information when possible. The second component consisted of low resolution and high resolution photographic documentation of each vessel in accordance with archival standards and guidelines for national archive submission. The third aspect of this project involved the software *SurfaceWorks 5.0* and included the use of a Sokkia total station to record two-dimensional and three-dimensional features of each vessel in the survey.

A Sokkia total station collected initial project data ( $x$ ,  $y$ , and  $z$  values) along stations noted on the hull surface. Stations consisted of various points to record hull flare and dead-rise as well as specific design and construction features such as combing, rub-rail, keel, keelson, shoe, transom, beam, shaft, rudder, prop, and various deck-side components. These points were later transferred to *SurfaceWorks 5.0*, a program that allows users to re-create three-dimensional drawings based on the series of points taken in each project. *SurfaceWorks* recreations can be easily converted to architectural line drawings based on points recorded on the vessel. While this chapter does not address the specific benefits of using *SurfaceWorks*, the application of *PhotoModeler* to this software will be addressed later.

Of the 32 vessels in the Currituck survey project, NCHH0025 became the representative model for this photo-modeling project. As mentioned above, photographic consideration was given based on the parameters of the project, which consisted of recording individual features of each vessel. However, because over 280 photographs were taken at a resolution of 7.1 mega-pixels, there was a high probability that there would be a greater diversity of photographic options available in the photogrammetric process. While technically only one photograph is necessary to create a photo-model of a vessel of this type, with pronounced dead-rise and flare of the hull sections, additional photographs were considered necessary to include sections not in focus or not visible.

Vessel NCHH0025 is currently catalogued with the North Carolina historic vessel registry database at the Maritime Museum in Beaufort, North Carolina (NC HABS/HAER Database). Built by Burbel Beasley in 1958, vessel NCHH0025 is one of few surviving personal and recreational watercraft specific to regions of North Carolina and southern Virginia. Beasley, an engineer at the Ford Plant in Virginia, built the vessel on commission to Ranier Collins, of Currituck, NC (Wilson Sowden 2005, pers. comm.).

Collins later used NCHH0025 as a transport carrier that brought workers from Church Island to Corolla and back. In 1964, Collins transferred vessel registration to the Whalehead Club, and it again changed hands in 1966 when the club sold the vessel to Atlantic Research, which was engaged in testing rocket fuel and space rockets off the islands of the Outer Banks of North Carolina (North Carolina Department of Fish and Game (NCDFG) 1964, 1966). Atlantic Research again used vessel NCHH0025 to transport its employees to and from work sites. Local historians note that during this period, Collins helped install a jet engine into the boat, which supposedly broke up shortly after running into the marsh during a test run.

The vessel changed hands again in 1969, when Atlantic Research closed operations and transferred ownership to the grounds caretaker, Gene Austin (NCDFG 1969). Later in 1984, Austin sold NCHH0025 to Wilson Snowden, a local historian and maritime enthusiast in Currituck, who repaired the vessel and used it recreationally for several years before finally retiring the boat within a shed on his property (North Carolina Department of Fish and Game 1984). Figure 1 shows vessel NCHH0025 in 2005.



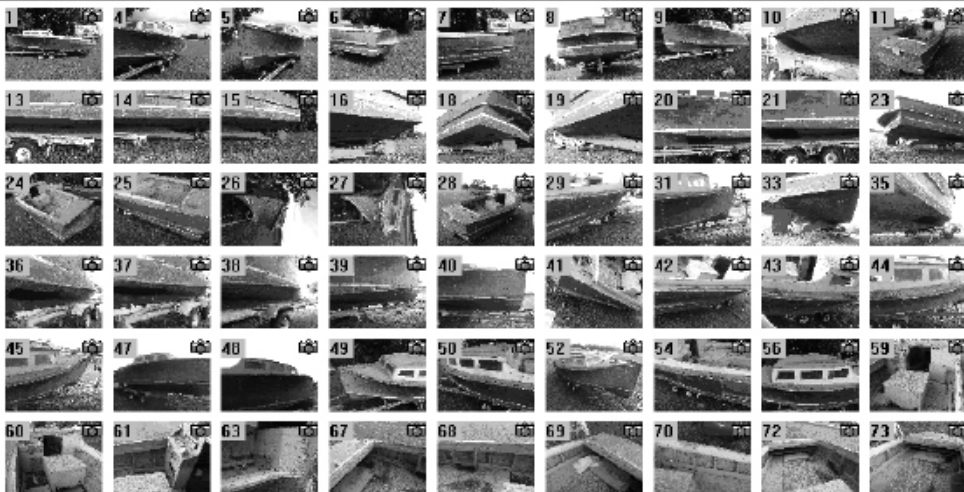
**Figure 1.** NCHH0025 with noted dead-rise and bow flair, Currituck, NC (Brian Diveley, 2005).

During the course of this project, NCHH0025 was identified for inclusion in the 2005 survey. Despite having been stored away for almost thirty years, the vessel was in remarkably good shape. Some noted sagging and hogging was documented, but overall conditions were very good given the period in storage. After project participants removed the vessel from its storage facility, they took photographs and total station points on the vessel. Additional line drawings were made to record construction features, including the pronounced dead-rise in the transom and extreme flare in the bow section. Beasley is noted for this type of vessel construction.

In applying a *PhotoModeler* project to the selected photographs taken in the Currituck survey, several assumptions had to be made. First, the edge tool was used to estimate potential points located along pronounced curves and on photographs with limited focal integrity. Initial tests processed with high error residuals. Edged points proved to be highly inaccurate and increased the number of overall processing iterations well beyond acceptable limitations. Summarily edged points were removed and project error returned to normal levels.

Second, photographs taken in the previous survey were not shot with a photo-model in mind and failed to meet the requirements noted in step 3 of the workflow outline. Although some photographs were oriented at 90° angles, they failed to have good horizontal or vertical separation. Similarly, photos with good vertical or horizontal separation were oriented at acute angles and could not be used. Figure 2 displays a sample of oriented photographs in the project survey.

Last, because of the overall length of the vessel and the many curves located on each photo, points connecting vectorized lines could not be drawn in a single viewing panel. To solve this problem, lines were bisected according to the photographs in the set selection and treated as separate entities. This also proved problematic; by treating large curved lines separately, the vectorized curve displayed inaccurately.



**Figure 2.** Selection of photographs oriented in *PhotoModeler* project (Brian Diveley, 2005).

The project camera was a calibrated Olympus 7070W at 27 mm. Photographs were not calibrated at the time of the project and various focal lengths between 27 mm and 107 mm were used. One hundred and ninety digital quality photographs at 7.1 mega-pixels were taken in the course of two hours in August 2005. In late October, another 90 photographs were taken along the starboard side waterline which could be referenced to previous photos.

### Survey Quality

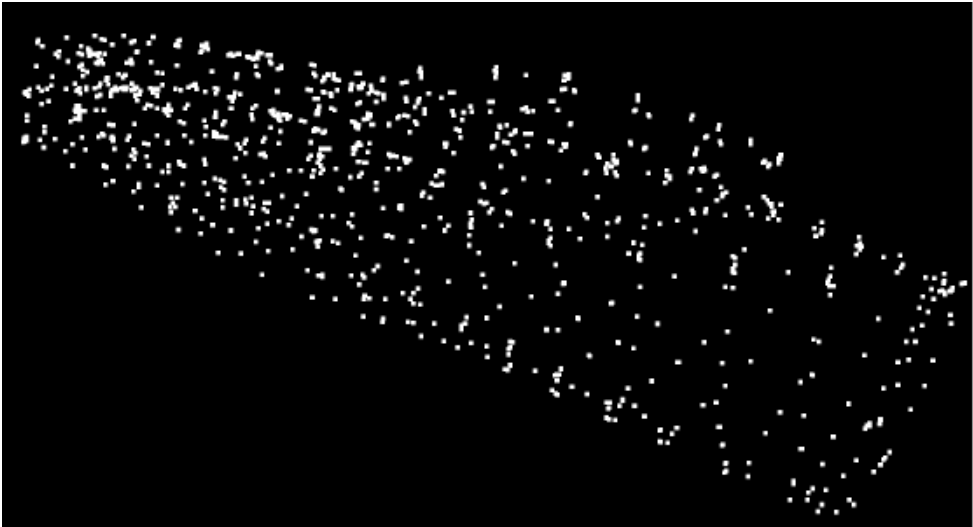
Photographs were analyzed for *PhotoModeler* compatibility at the beginning of the project. Of the 280 photographs, only 94 photos were processed at the default focal length of 28 mm. Because zoomed images employed various focal lengths of unknown origin, only the default 28 mm was calibrated for use. Likewise, many of the photographs were unintentionally oriented at angles close to 90° but did not have large overlapping sections for point acuity. To solve for this error, station marks for use with *SurfaceWorks* were utilized.

This process proved quite effective, and the series of grid points at approximate 1.5-foot radials along the hull of the vessel could be used. Point referencing was initiated from the portside bow and worked to the portside stern in overlapping sections that allowed a minimum of six overlapping points. Camera stations along the transom were tied to marks along the portside hull and allowed referencing to continue along the starboard transom. This process continued until it once again met the bow section along the starboard side.

The problem encountered with this method of referencing was that it allowed for increased error in processing point relationships as they continued around the vessel. Marginal initial errors increased proportionately the progressed to the origin point at the bow of the vessel. To eliminate distributed error, points were corrected after each processing phase was completed. Additional photographs

spanning the length of the vessel were added to the data collection and although these did not have high resolution and pinpoint accuracy, they allowed marked sections to be accurately related to one another.

Once the vessel exterior was marked, evaluation was possible. Detailed measurement of the bow at various points showed a marked deviation of 0.5 inches. With a low project distribution error of 1.4 pixels in a 7.1 mega-pixel image, additional points marking combing, rub-rail, and deck-side features were referenced. The point references used are illustrated in Figure 3.



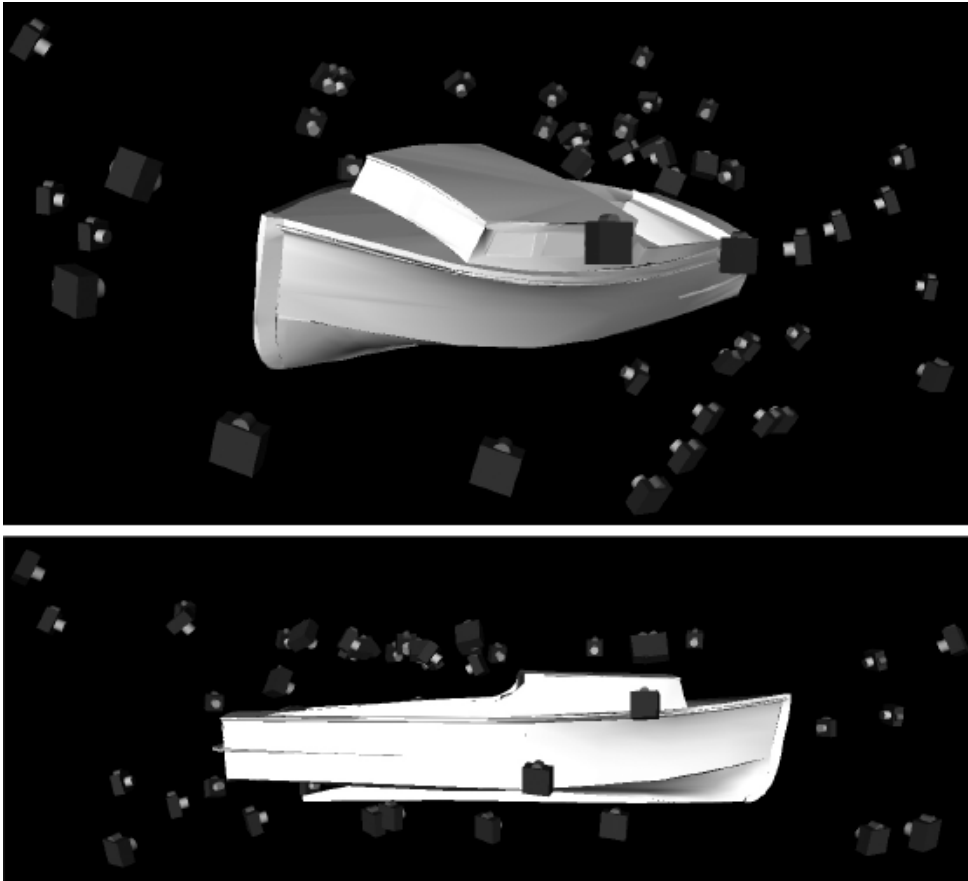
**Figure 3.** Point references on NCHH0025 from starboard bow (Brian Diveley, 2005).

Visibility along the underside of the vessel diminished significantly due to shading, vessel curves, perspective, and focus. To correct for missing reference points, the second photo set was imported into the project. In total, 54 qualified images were sufficient to model vessel NCHH0025. The points of view of these images, or camera stations, are noted in Figure 4.

### Survey Accuracy

With reference points in place, general orientation of the vessel can be established. The origin of the coordinate system was set with an  $x$ ,  $y$ , and  $z$  axis. The  $x$  axis was established along the port side length of the vessel from bow to stern. The  $y$  axis was assigned to the beam along the transom and the  $z$  axis was set at right angles to the deck. If incorporating a project into *SurfaceWorks*, orientation can be set up in either program. However, this setup in *SurfaceWorks* is significantly easier and recommended over *PhotoModeler's* rotation feature.

Model scale was established through camera calibration and was estimated by the overall point distribution over given photographs in a project. Measurements of the vessel are made directly through the measure tool in *PhotoModeler*. Overall vessel length through given points at the bow and stern measures 25.538' (7.78998 m)



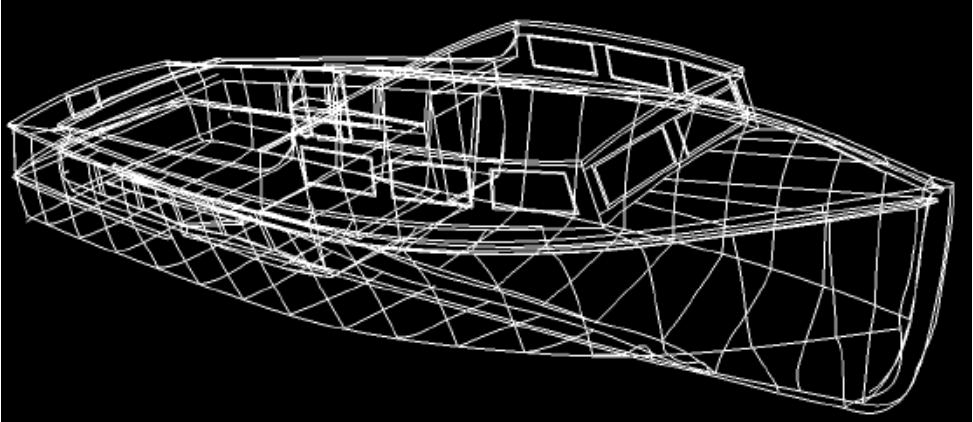
**Figure 4.** Location of camera stations adjacent to NCHH0025 (Brian Diveley, 2005).

by *PhotoModeler Pro* compared to an overall on-site measurement of 25'6" or 25.5' (7.7724m). Distributed error over the length of the vessel at 0.03-0.04 inches (0.762-1.016mm) was relatively comparable to that of a Sokkia total station.

In creating the survey model, over 2,453 points were marked throughout the project. Because many of these reference points were placed within photograph sections with poor focal acuity, many of these were discarded throughout the process. A total of 1052 three-dimensional points were used to solve general model dimensions.

From these reference points, line-work and dimensions were derived from given photographs in the project. Delineating line and surface space of an object is a time consuming process and should be considered when designing any project of this scale. Poor referencing will either not allow certain curves to be established, or will skew a line well beyond its natural shape. Therefore, accurate referencing will make creating line-work and surfacing considerably easier. Improving poor referencing required the import of additional photographs and referencing for correction purposes. Figure 5 illustrates the line and curve delineation for vessel NCHH0025.

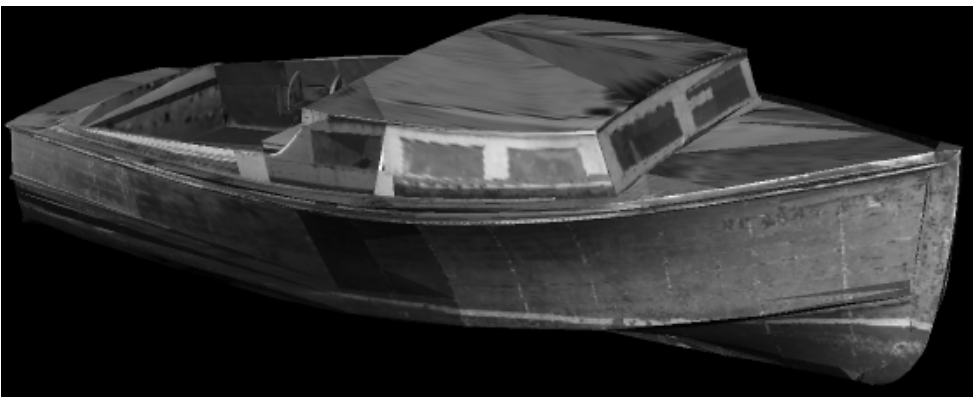




**Figure 5.** Line drawing of Beasley boat (Brian Diveley, 2005).

Surfacing using Non-Uniform Rational B-Splines (NURBS surfaces) is the final phase of modeling delineation. The advantage of station marks placed along the hull of the vessel allowed the hull surface to be accurately recorded. The progression of points to lines, and lines to surfaces relies upon accurate data, and projections off this point are discernable. Correcting irregular points and lines can be a difficult process, but in the creation of the curves of the ship lines, it is very important and requires the creation of an accurate model.

*PhotoModeler Pro* uses surfaces that contain the highest number of point references to overlay photographic information. Using photographs with low angle separation tend to “stretch” an image over the surface. This process can be corrected, but due to time constraints of this project, was not included in the overall correction. Likewise, surfaces created with low point reference default to  $x$ ,  $y$ , or  $z$  oriented photographic overlays. This became apparent in the cabin and on the deck surfaces of vessel NCHH0025, where few photographs were taken. Figure 6 shows vessel NCHH0025 with photographed surfaces.

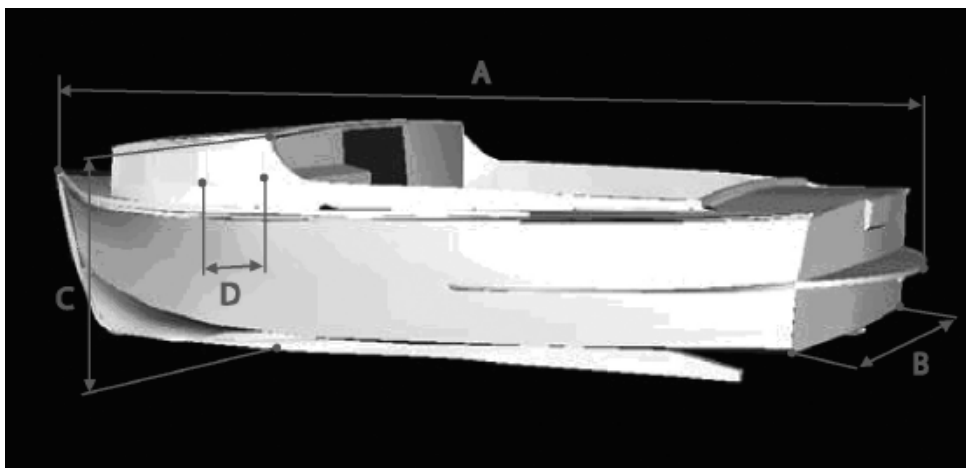


**Figure 6.** Surfaced textures with photographic overlay (Brian Diveley, 2005).

Project quality is directly associated with several components of the

*PhotoModeler* program which rely on quality of camera calibration, resolution of the camera, geometry of the camera positions, and the precision of user marks on photographic images (EOS Systems Inc. 2004:435). Accuracy measure of 1:5,000 or higher is assumed for a project of this size and is classified between average accuracy and highest accuracy. Estimates are based on 7.1 mega-pixel digital output, calibrated camera, between 20 and 90 degree angle separation of photos, 13 points per photo, 13-78% coverage, and naturally lit target set (EOS Systems Inc. 2004:438).

Measurement verification on four separate points along the project were checked against one another for correctness. Four measurements taken from eight separate points were used in this assessment. Demarcation of these points is as follows: Point A is located starting at the top portside bow and terminates at the central point located on the transom, Point B measures the transom bottom section from port to starboard, Point C is located mid-ship and measures the portside top cabin corner to the keelson located at station 9, Point D is a small measure of the portside aft cabin window along the bottom molding. Figure 7 illustrates the location of these points.



**Figure 7.** Location of line reference points on vessel NCHH0025 (Brian Diveley, 2005).

Table 1 shows the accuracy of these measurements based on field data collected in the project. Field measurements were taken using 30' tape measures and extension rods for areas that could not be directly measured due to vessel curvature. Items A, B, and D all showed a relatively small measure error against points taken on the *PhotoModeler* project. However, measurement C showed an elevated discrepancy compared to the other items in this verification. An explanation for this error, based on the accuracy of other measurements taken in this test, could be in the collection of field data. For this reason, *PhotoModeler* should also be considered an accuracy check against collected field data.

For reasons of photo coverage, the overall photo quality of this project was noted as poor while the overall total error was well within processing limitations. This mark is indicated by measure noted as iteration to error in pixel. The overall

error at the project's conclusion was 5: 1.559. With five processing iterations and a pixel error of 1.559, overall accuracy was considered good given the parameters of the project. Because a high quality digital camera was used in this process, and the majority of photographs processed were in close proximity to vessel NCHH0025, the overall point tightness and Root Mean Square were very low for a vessel this size.

Item	Tape Measure.	PhotoModeler Measure	Difference	%
A	25'6" or 25.5 ft.	25.538 ft.	0.038 ft.	0.15%
B	5'9" or 5.75 ft.	5.710 ft.	0.045 ft.	0.78%
C	6'4" or 6.38 ft.	6.158 ft.	0.222 ft.	3.60%
D	1'11" or 1.91 ft	1.924 ft.	0.014 ft.	0.73%

**Table 1.** Line accuracy measures.

Completed survey data at this point could then be exported to *SurfaceWorks 5.0*. This program is utilized for the visualization of three dimensional points, and, more importantly, for the marine architecture features it employs. Specifically of importance in this project is the tool creating line drawings from surfaced objects. Exported as dxf files, *SurfaceWorks* can process data collected in *PhotoModeler* without the need for expensive hardware.

The following relevant statistics apply to the Currituck *PhotoModeler* project:

Total No. of Photos Used For Processing	54		
Total No. of Points	2453		
Total No. of 3D Points used	1052		
3D Points Per Photo	Min. 13	Max. 146	Average 58
Photo Coverage (%)	13	78	51
Points on 2 Photos Only	590		
Average No. of Rays per 3d Point	2	10	3
Point Marking Residuals (Pixels)	Min. 0.001	Max. 3.357	
Point Marking Residuals (Pixels)	Min. RMS 0.001	Max. RMS 2.975	
Overall RMS (Pixels)	1.445		
Point Tightness (Feet)	Min. 1.1e-005	Max. 0.32	
Overall RMS Vector Length (Feet)	0.0486		
Vector Length (Feet)	Min. 0.0158	Max. 0.195	
Point Precision	Min.	Max.	
X	0.00812	0.146	
Y	0.00695	0.0849	
Z	0.00961	0.125	
Project Total Error as Indicated by Error Bar (Iterations : Error in Pixel)	5 : 1.559		

**Table 2.** Overall Currituck Survey Statistics

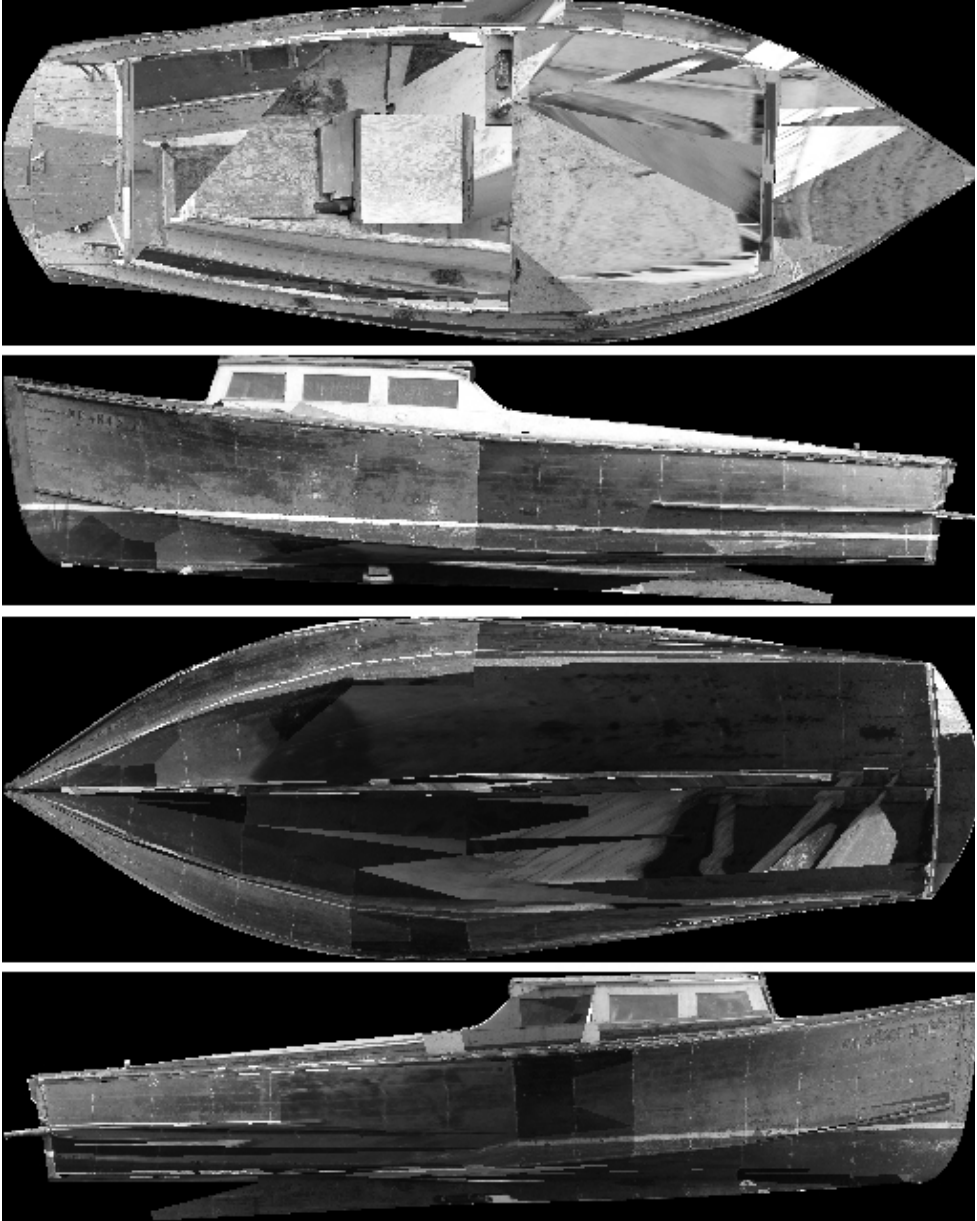
## Conclusions

Based on data presented in this project, use of *PhotoModeler Pro 5* presents new options for collecting field data, specifically in maritime heritage survey. In addition to being a useful method to evaluate field data collection, one of the most important features is the relative inexpensive cost compared to expensive hardware alternatives. Although this chapter does not recommend one method over another, it does present *PhotoModeler Pro 5* as a viable option for projects of this type and should be considered with small craft survey.

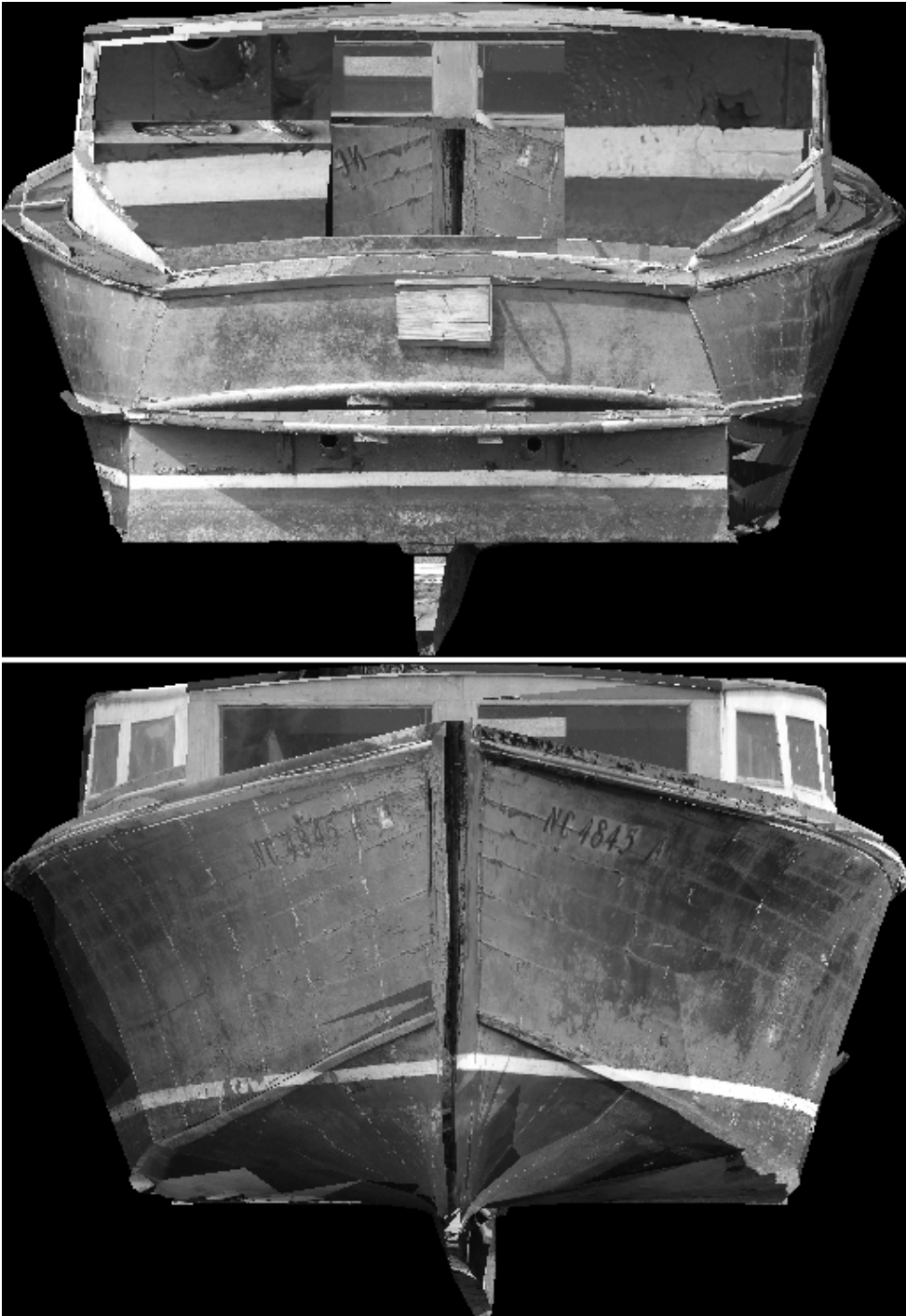
Yet there are definitive drawbacks to *PhotoModeler*, specifically in the amount of manual processing required and instruction necessary to become proficient in use of this software. Proficiency in the *PhotoModeler* environment are not required, but is especially useful when designing and solving problems inherent when processing data. Additionally, target marking and auto-reference features of *PhotoModeler* could alleviate much of the time required to process large projects of this size in future *PhotoModeler* projects. This method is practical in design, but its application still requires assessment.

*PhotoModeler* is also an efficient tool in the examination of field data and recording accuracy in a given project. This process allows measurements to be checked against one another and provides information about recorder accuracy in the field. Likewise, field measurements, as shown in this project, can be used to check *PhotoModeler* accuracy.

The final component examined in this project was *PhotoModeler's* orthophoto creation capability (Figures 8 and 9) and seamless integration with *SurfaceWorks 5*. Importing *PhotoModeler* data into *SurfaceWorks* allows users to construct marine architecture line drawings of archival quality in a relatively short period. This process is reliant on the use of auto-referencing techniques to decrease the amount of referencing time required in a project.



**Figure 8.** Digital ortho-photo of top, port, bottom, and starboard side view of vessel NCHH0025 (Brian Diveley, 2005).



**Figure 9.** Digital ortho-photo of transom and bow views of vessel NCHH0025 (Brian Diveley, 2005).

## Modeling HMS *Alert*

### Introduction

The objective of this project was to create a three-dimensional model of the stern portion of the HMS *Alert* ship model. The result of this project is going to be the eventual production of the models on the World Wide Web. This will allow viewers from all over the world to see the kinds of projects former and current students have completed. It will also serve as an advertisement to the capabilities of the Maritime Studies Program at East Carolina University (<http://www.ecu.edu/maritime/cou5005a.htm>).

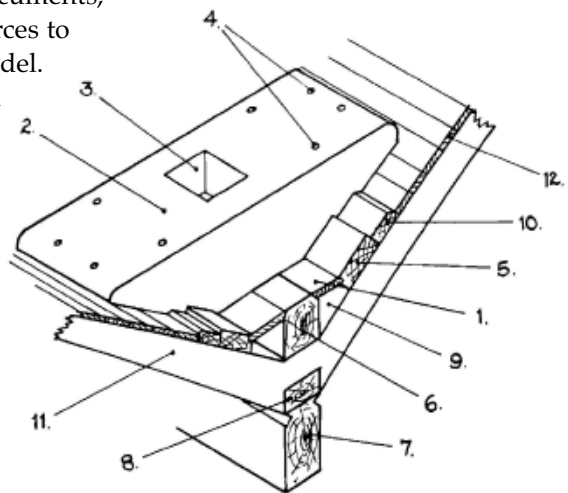
### Project History

The HMS *Alert* ship model was constructed for a project during the East Carolina University ship construction class of 2003. Every year the ship construction class builds models of historic shipwrecks to learn, hands on, how historic ships were erected. That year the entire class, consisting of Evguenia Anichtenko, Jake Betz, Jeff Boudoin, Matt Brenkle, Clint Ethridge, Calvin Mires, Dave Nelson, Jason Rogers, and Travis Snyder, worked on the construction of the three part HMS *Alert* model. The entire model consisted of a bow section, an amidships section, and a stern section. The three parts of the model were constructed using the same scale, so the separate sections could be fitted together to model the entire ship.

The class used historic documents, construction plans, and other sources to research the ship and build the model.

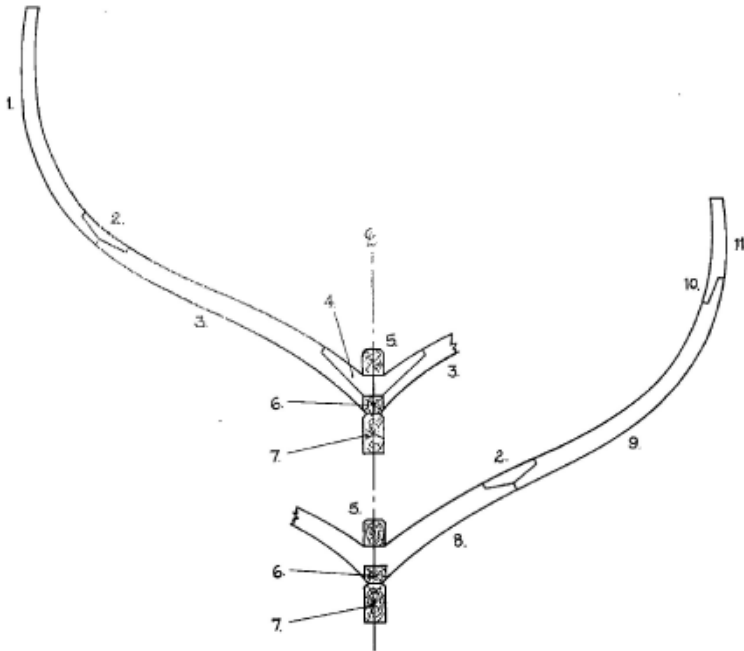
HMS *Alert* was a naval cutter from 1777 (Anichtenko et al. 2003).

Most likely, it was an advice vessel of the Royal Navy (Dr. Bradley Rodgers 2005, pers. comm.). Figure 10 illustrates an amidships cross-section highlighting the mast saddle and the elements of the ship's backbone.



**Figure 10.** Amidships cross-section (Anichtenko et al., 2003).

Figure 11 shows the detailed frame construction. From this construction drawing, one can see that the frames consisted of a floor and futtocks fastened together by scarf chocks.



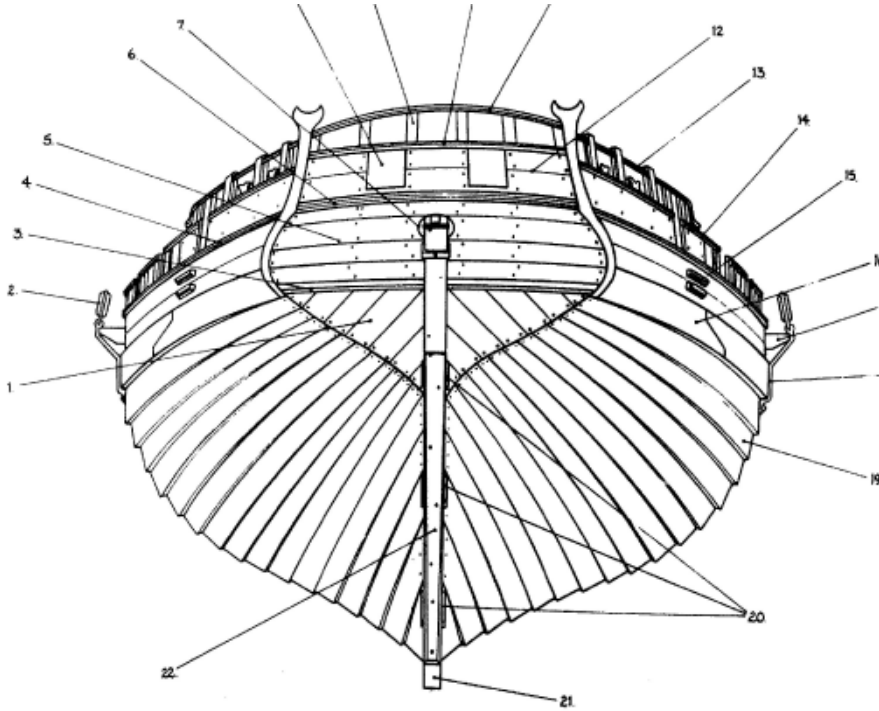
**Figure 11.** Detail of frame construction (Anichtenko et al. 2003).

Figure 12 shows the stern portion of the ship, including the exterior ship lines and outer planking. This plan drawing illustrates the curve of the ship, the wide beam, and the drastic tuck at the stern.

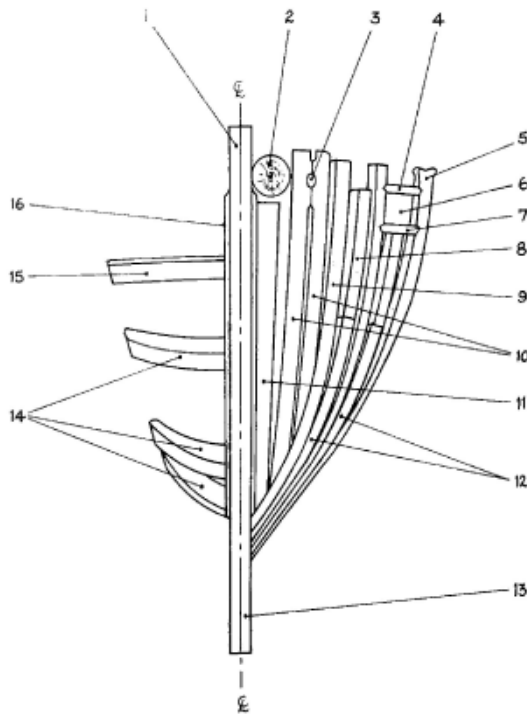
Figure 13 reveals the frames and outer planking of the bow section as the planking tucks into the stem-post. These ship plans were used by the ship construction class to aid in their construction of the HMS *Alert* model. These plans reveal typical ship construction details of the period, including the mast saddle, futtocks, high stern tuck, and a strong composite keel construction.

While the ship model was created in its entirety, albeit, in three sections, the scope of this photo model project only dealt with the stern section of the model. The camera used for the project was a digital Sony Cyber-Shot 5.0 mega-pixel. The camera was calibrated using the camera calibration sheet and camera calibration wizard within the *PhotoModeler* program. The calibration sheet was photographed from all four sides. The sheet remained stationary while the camera was moved. One portrait and one landscape photograph was taken from each side of the sheet, resulting in a total of eight pictures. The photographs were then downloaded directly from the camera into *PhotoModeler*. Using the camera calibration wizard resulted in a camera focal length of 8.061854 mm. The initial calibration photographs were taken using the standard “power-up” focus; therefore, all subsequent photographs were taken with the same focal length.



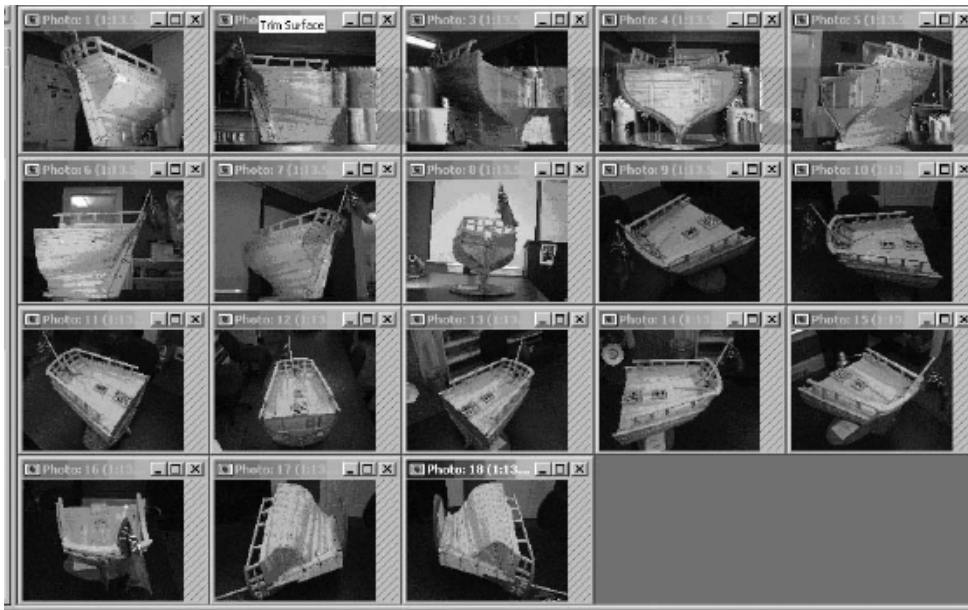


**Figure 12.** Exterior stern lines and outer hull planking (Anichtenko et al., 2003).



**Figure 13.** Bottom view, bow section frames and planking (Anichtenko et al., 2003).

Eighteen photographs were taken of the HMS *Alert* model; all of which were utilized for *PhotoModeler* imaging (Figure 14).



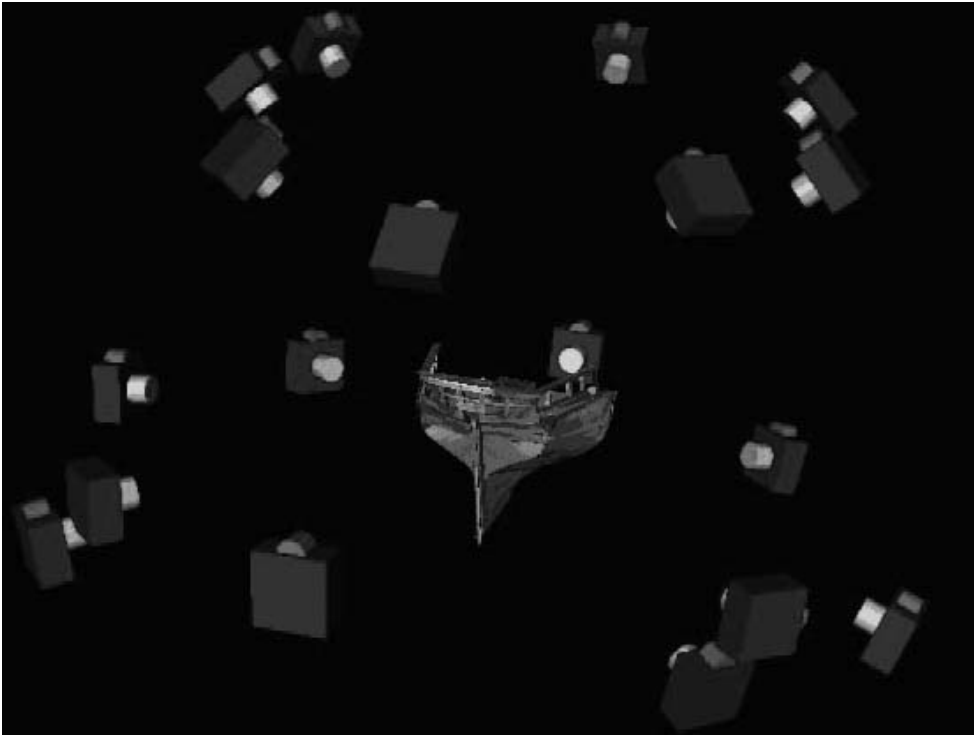
**Figure 14.** Tiles of photographs used for *PhotoModeler* rendition of HMS *Alert* (Michelle Liss, 2005).

The model had been built on a base for support; therefore, it was impossible to turn over and photograph from the bottom. To solve this problem, eight photographs were taken around the entire model 45° below the deck, looking up. Another eight photographs were taken 45° above the deck, looking down. To provide better references for the plank curvature, two additional photographs were needed. For this, the model was laid on its side and photographed along the length of each side (Figure 15). The photographs were planned to overlap so that most points were visible in at least three photographs. A photograph was taken at every corner/joint and every side/face of the model.

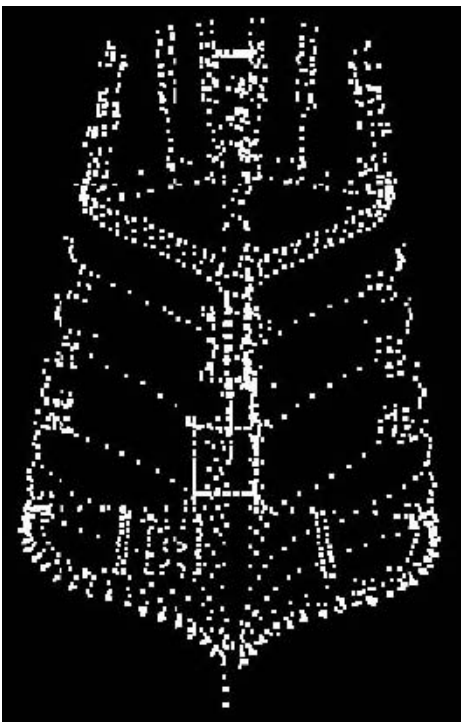
### Survey Quality

In his experience with the *PhotoModeler* process, Franke (1999:8) stated “The most important part of creating a 3D model in *PhotoModeler* is orienting the photographs by marking and referencing tie points between the photographs.” Two thousand and sixty-four three-dimensional points were used for creating the HMS *Alert* project by this method (Figure 16).

Franke (1999:8) continued, “The quality of this process determines the accuracy of dimensions derived from the linework created in the onfollowing step.” While not technically difficult, this is the part of the project that takes the most time. The points need to be marked and checked for accuracy and then referenced across several photographs. Franke (1999:8) concludes, “As unique and satisfying [as]



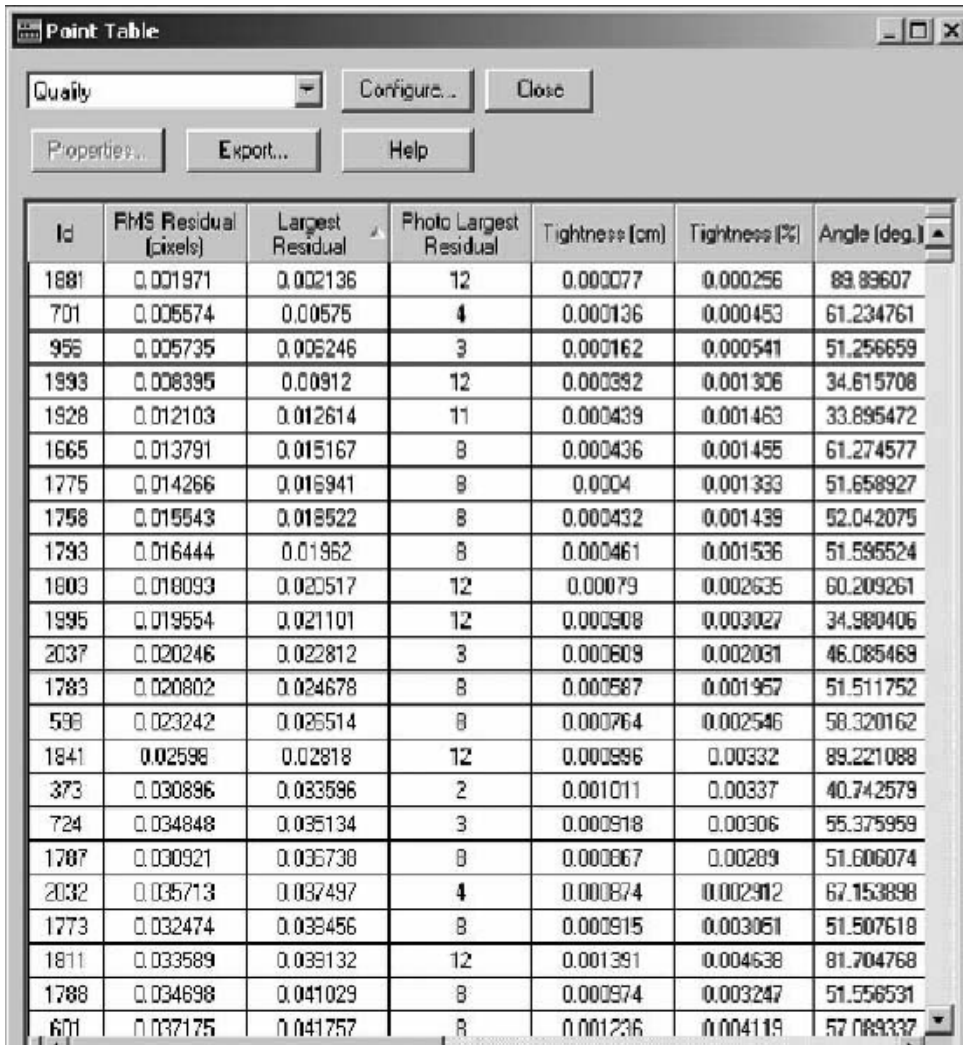
**Figure 15.** Camera stations of the 18 photographs revealing camera positions and angles (Michelle Liss, 2005).



**Figure 16.** Marked and referenced points on HMS *Alert* model (Michelle Liss, 2005).

*PhotoModeler* results can be, the amount of time that needs to be invested to reach that result can be considerable." Taking the initial photographs from appropriate angles, rendering quality images, can aid in the marking and referencing of points later.

Checking the accuracy of referenced points is essential to creating a true three-dimensional rendition. The point table is a handy tool used to calculate the precision of points (Figure 17).



Id	RMS Residual (pixels)	Largest Residual	Photo Largest Residual	Tightness (cm)	Tightness (%)	Angle (deg.)
1881	0.001971	0.002136	12	0.000077	0.000256	89.89607
701	0.005574	0.00575	4	0.000136	0.000453	61.234761
955	0.005735	0.005246	3	0.000162	0.000541	51.256659
1993	0.008395	0.00912	12	0.000392	0.001306	34.615708
1928	0.012103	0.012614	11	0.000439	0.001453	33.895472
1665	0.013791	0.015167	8	0.000436	0.001455	61.274577
1775	0.014266	0.016941	8	0.0004	0.001333	51.658927
1758	0.015543	0.018522	8	0.000432	0.001439	52.042075
1793	0.016444	0.01952	8	0.000461	0.001536	51.595524
1803	0.018093	0.020517	12	0.00079	0.002635	60.209261
1995	0.019554	0.021101	12	0.000908	0.003027	34.980406
2037	0.020246	0.022812	3	0.000609	0.002031	46.085469
1783	0.020802	0.024678	8	0.000587	0.001957	51.511752
598	0.023242	0.025514	8	0.000764	0.002546	58.320162
1841	0.02598	0.02818	12	0.000996	0.00332	89.221088
373	0.030896	0.033596	2	0.001011	0.00337	40.742579
724	0.034848	0.035134	3	0.000918	0.00306	55.375959
1707	0.030921	0.035738	8	0.000667	0.00289	51.606074
2032	0.035713	0.037497	4	0.000874	0.002912	67.153898
1773	0.032474	0.038456	8	0.000915	0.003051	51.507618
1811	0.033589	0.039132	12	0.001391	0.004638	81.704768
1788	0.034698	0.041029	8	0.000974	0.003247	51.556531
671	0.037175	0.041757	8	0.001236	0.004119	57.069337

**Figure 17.** Quality Point Table showing a selection of most accurate point from the HMS *Alert* project (Michelle Liss, 2005).

It shows the point number, the largest residual, the photo in which the largest residual exists, all photos containing the point, tightness, angle of points, and many other helpful features. By concentrating on the largest residual and photo of largest residual, one can adjust the point position until each point is within the reasonable error of less than 5.00 pixels (Figure 18).

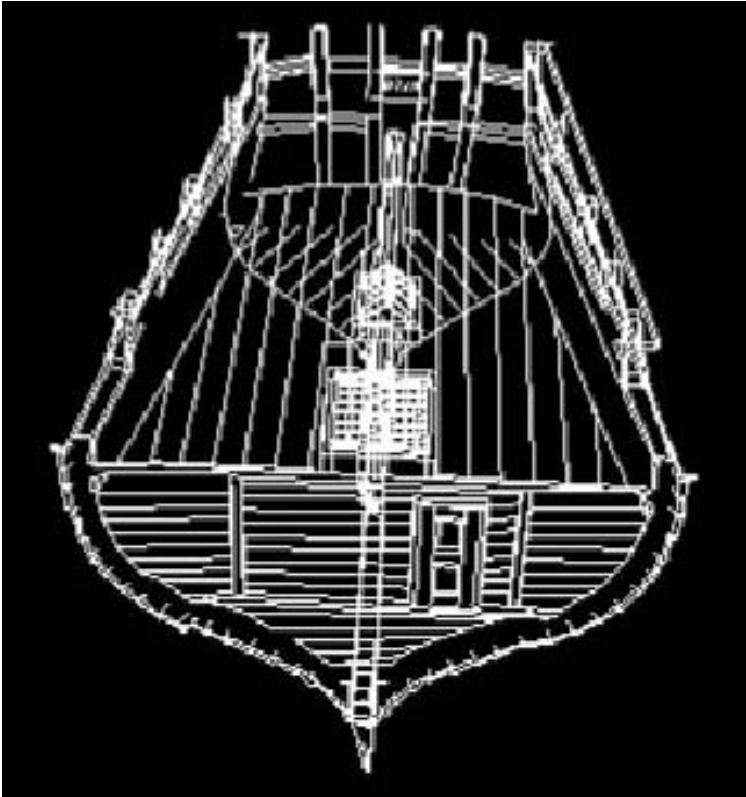
Id	RMS Residual (pixels)	Largest Residual	Photo Largest Residual	Tightness (cm)	Tightness (%)	Angle (deg.)
285	3.362095	4.986257	2	0.123574	0.411912	88.723517
550	3.588456	4.966572	2	0.136148	0.453828	79.526709
1973	3.731661	4.962706	10	0.157447	0.524825	89.226659
1222	3.561322	4.946333	6	0.056691	0.188971	86.557601
1219	3.939137	4.938235	7	0.11851	0.395035	87.821829
547	3.880695	4.918142	2	0.120526	0.401752	73.61427
496	4.11742	4.913132	4	0.144635	0.482118	59.992621
1682	3.787671	4.905365	3	0.117252	0.390839	87.179967
1046	3.671866	4.878798	6	0.105872	0.352907	85.60776
521	4.627627	4.856954	8	0.1513	0.504335	59.233288
491	2.778148	4.846497	2	0.123865	0.412884	77.489238
1073	3.032957	4.843755	5	0.08997	0.299901	84.432741
1049	2.96224	4.835088	6	0.115362	0.38454	87.290547
734	4.090441	4.829367	4	0.107462	0.358208	76.235805
1609	3.801971	4.798488	8	0.118243	0.394144	77.106875
860	3.119624	4.795408	4	0.123352	0.411174	87.537937
1600	3.608295	4.785039	1	0.1278	0.425999	76.62992
461	3.542504	4.771234	5	0.113322	0.377741	87.27307
705	4.30326	4.760739	5	0.058111	0.193705	68.750692
290	3.684333	4.750777	3	0.119684	0.398946	88.170352
415	3.629027	4.733543	4	0.109911	0.36537	72.329409
887	2.088075	4.73098	9	0.093239	0.310798	89.227235
1174	3.191151	4.714006	9	0.136714	0.455714	86.245331

**Figure 18.** Quality Point Table showing a selection of the least accurate points from the HMS *Alert* project (Michelle Liss, 2005).

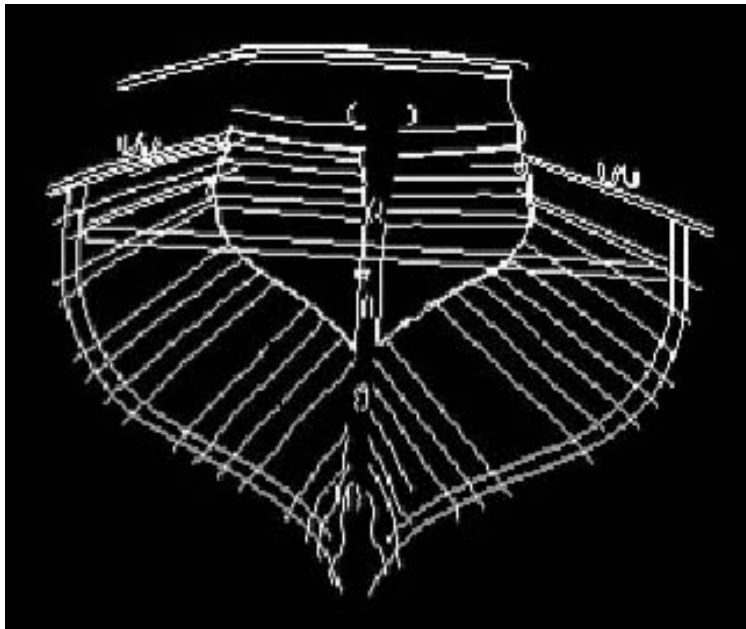
Once all of the points are in the correct positions, one can begin delineating the model by inserting lines and curves onto the photo-model. For flat or straight surfaces, simple lines can be used to connect points (Figure 19).

Lines connecting referenced points will be automatically rendered on all photographs containing the referenced points. Curved, rounded, or uneven areas can be modeled by customizing curves to fit the surface of the object (Figure 20).

Curves are “locked in” by anchoring the ends of the curve to a referenced point. The curve is modeled by plotting reference points along the surface. A sharp curve will result from placing the reference points close together. A shallower curve will result from placing the reference points further apart. Unlike lines, curves are not automatically generated across photographs. Corresponding curves must be modeled individually on each photograph. Once the curves are created



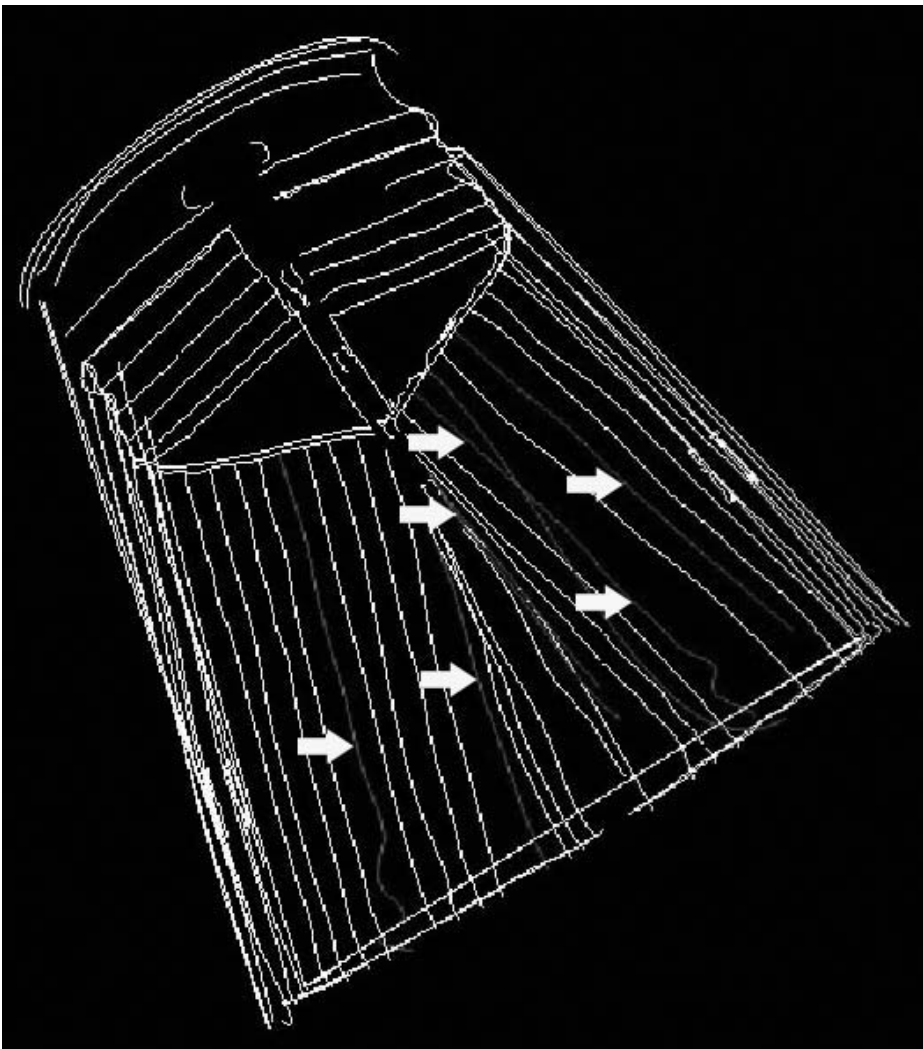
**Figure 19.** Rendition of lines in the 3D viewer (Michelle Liss, 2005)



**Figure 20.** Rendition of curves in the 3D viewer (Michelle Liss, 2005).

they must be referenced together so the program knows which curves correspond to each other.

The angles of the initial photographs are especially important when creating and referencing curves. If the angles of the photographs are not correct, the curves may be inaccurate, skewed, or completely absent in the 3D viewer. This became a problem with the HMS *Alert* project. Originally, the curves modeled on the port and starboard sides of the ship were referenced across three photographs. Even though the photographs were taken from wide angles, many of the curves failed to convert into the three-dimensional plane. A fourth photograph, with referenced curves, was then added to each side. With this fourth reference, the curves showed up in the three-dimensional rendition; however, many of them were skewed or inaccurate in length (Figure 21).



**Figure 21.** Display of errant curves (shaded lines shown with arrows) in the 3D viewer (Michelle Liss 2005).

The appearance of some of the curves was improved by making the curves planar or increasing the tightness of the curve. Other curves were worsened, or not affected at all, by this manipulation. All errant curves were rechecked for accuracy across the original photographs. Many manipulations were attempted to improve the form of the curves to no avail. With no solution in sight, some of the bad curves had to be eliminated from the project.

As a final step of completing the initial 3D rendition, cylinders were added to represent the flagpole and tiller. The edges of each cylinder had to be defined and referenced across three photographs (Figure 22).



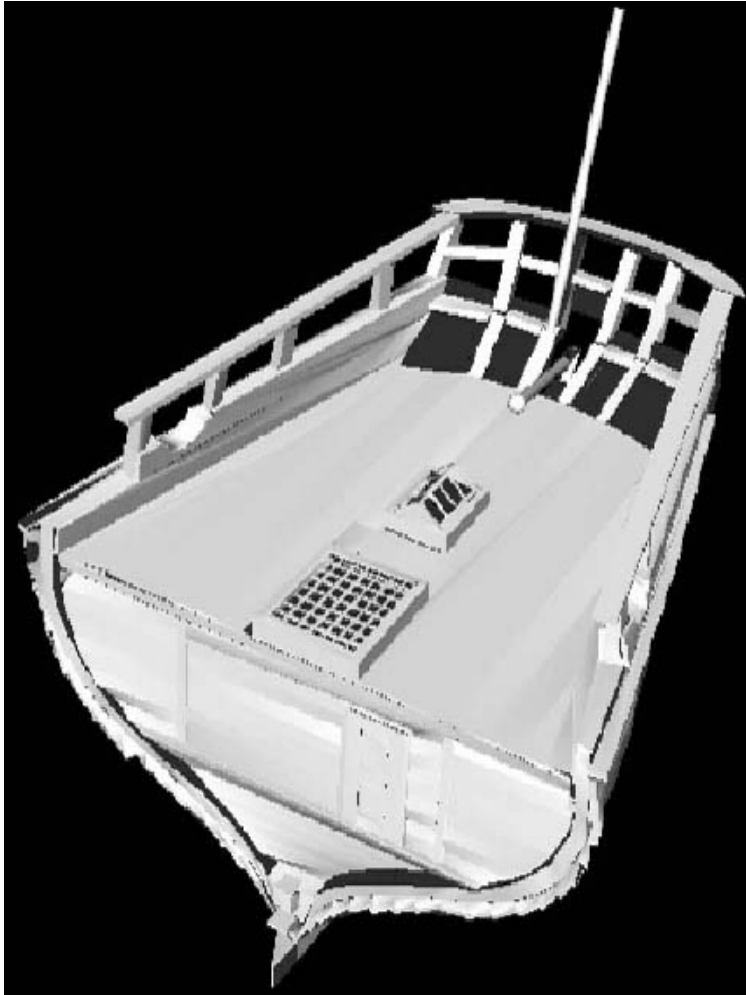
**Figure 22.** Rendition of flagpole and tiller cylinders as seen in the 3D viewer (Michelle Liss, 2005).

The knob at the end of the tiller was also modeled by defining the exterior curve and using the axis of revolution tool about the cylinder.

Once all of the points, lines, curves, and cylinders were displayed in the 3D viewer, creating a complete frame, the model was ready to be surfaced. In the process of surfacing the HMS *Alert* model, almost every surfacing tool was used, including path mode, loft mode, sweep mode, and axis of revolution mode. The process of surfacing reveals any small details that were missed during the delineation of surfaces. A shape had to be defined on all sides for a surface to be applied; therefore, all missed lines, curves, and points were easy to detect when surfacing. In this case, one had to return to the photographs to reference the needed area before surfacing could continue. The initial surfacing of HMS *Alert* was created using a shaded texture (Figures 23 and 24).

With simple shapes, the loft mode was used to surface between two lines or curves. On more complex shapes with many angles, the path mode had to be used to more precisely define the surface area. This often caused some distortion in the surface appearance because of the way the path mode distributes the surface image. In addition, the opposite sides of the surface had to be similar in dimension,





**Figure 23.** 3D rendition of HMS *Alert* model showing shaded textures (top view) (Michelle Liss, 2005).

or the resulting surface texture would be skewed. In the HMS *Alert* model, this distortion occurred on the plank ends. Initially, the interior edge of the plank ends was modeled as one long curve to show the curvature of the vessel, where the exterior edge of the plank ends was modeled as individual lines delineating the shape of each plank. This caused a problem when surfacing because an accurate surface could not be created between one short line and one long curve. To solve this problem, a “curve through points” was created on the exterior edge to match the length of the interior edge. The resulting surface was much more accurate.

After the shaded surfaces were added, the three-dimensional model was reprocessed to apply quality textures to the existing surfaces. During this process, *PhotoModeler* chooses textures from the original photographs to apply directly to the delineated surfaces on the three-dimensional model. The program automatically picks the textures that it thinks are the most accurate and superimposes them on the



**Figure 24.** 3D rendition of HMS *Alert* model showing shaded textures (rear view) (Michelle Liss, 2005).

model. The automatic textures are not always exactly the same as they appear in the photograph. The accuracy of the quality texture also depends on the manner in which the surface was initially modeled. Complicated surfaces that have many angles tend to be less accurate than those with fewer angles. On the HMS *Alert* model, these skewed surfaces can be seen on the rudder and top bulwark planks (Figures 25 and 26).

### **Survey Accuracy**

The goal of the HMS *Alert* model project was to create the most accurate three-dimensional model possible using the tools and capabilities of *PhotoModeler* software. In order to realize this goal, in addition to the already mentioned photographic referencing, the constraints of the project had to be defined. This was

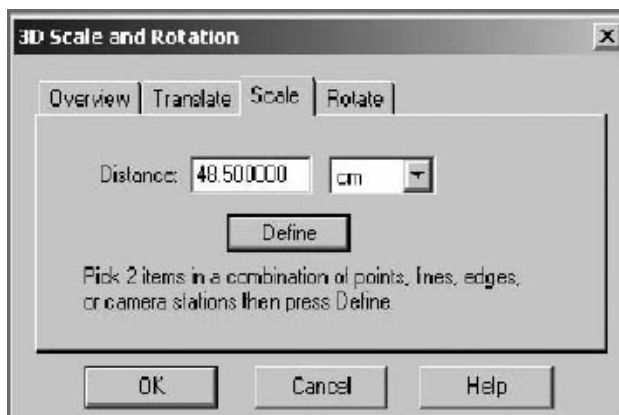
achieved through several tools within the *PhotoModeler* program. The user input approximate dimensions of the physical model into the program. The first step in this process was to take some measurements off the HMS *Alert* model. The scale of the three-dimensional model was defined by accessing the “3D Scale and Rotation” tool (Figure 27).



**Figure 25.** 3D rendition of HMS *Alert* model showing quality textures (rear view) (Michelle Liss, 2005).



**Figure 26.** 3D rendition of HMS *Alert* model showing quality textures (starboard view) (Michelle Liss, 2005).



**Figure 27.** Scale and Rotation box, showing the definition of the model scale (EOS Systems, 2005).

By selecting the “Scale” tab, one is able to define a distance between two points for use as the model scale. For this project, the distance used was the beam width from the most extreme points on the outer railings (points 1 and 669). On the physical model, this distance was 48.5 cm. The points were defined in the model and the distance entered into the box. This defined the overall scale for the model, from which all other measurements could be extrapolated. To test the true accuracy of this scale, other measurements were compared from the physical model and the three-dimensional model (Table 3).

Measurement Description	Distance on physical model (cm)	Distance on 3D model (cm)	Differences in measurements (cm)	Percentage of error
Width of beam from most extreme points on railings	48.50	48.50	0.00	0.00%
Length of keel, fore to aft	34.00	33.01	0.99	2.90%
Length from fore end of keel to aft end of rudder	39.00	38.52	0.48	1.20%
Central length from fore end of deck to outside edge of aft railing	49.50	49.98	-0.48	-1.00%
Width of “grate” feature on top of deck, port to starboard	9.00	8.89	0.11	1.20%
Length of pitched “cage” on top of deck, fore to aft	7.00	7.02	-0.02	-0.30%
Height from bottom of keel to top of deck	29.00	29.03	-0.03	-0.10%

**Table 3.** Comparison of scaled measurements from physical model to 3D model.

Measurements were taken on the three-dimensional rendition using the measurement tool. The program is able to calculate the distance between any two selected points once the proper scale is defined. Using the defined scale, the maximum measurement error between models was 2.9%.

The next step in manipulating the constraints was to define the axes for the three-dimensional model. This operation was completed by accessing the “3D Scale and Rotation” tool. The “Rotate” tab allows the user to define the  $x$ ,  $y$ , and  $z$  axis for the three-dimensional rendition (Figure 28).

Two points were selected to define each axis. The  $x$ -axis was defined as the beam of the ship from the most extreme points on the railings. The  $y$ -axis was defined along one of the deck planks from fore to aft. The  $z$ -axis was defined on the front of the ship from the bottom of the keel to the top of the deck. While the “Scale and Rotation” tool will let one define all three axes, it will only allow two to stay active at one time. Specifically defining the axes of the HMS *Alert* model resulted in a more accurate, appropriately oriented three-dimensional rendition (Figure 29).

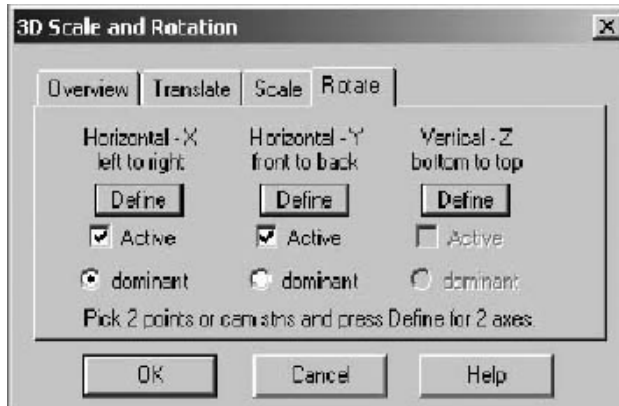


Figure 28. Scale and Rotation box showing axis definition options (EOS Systems, 2005)

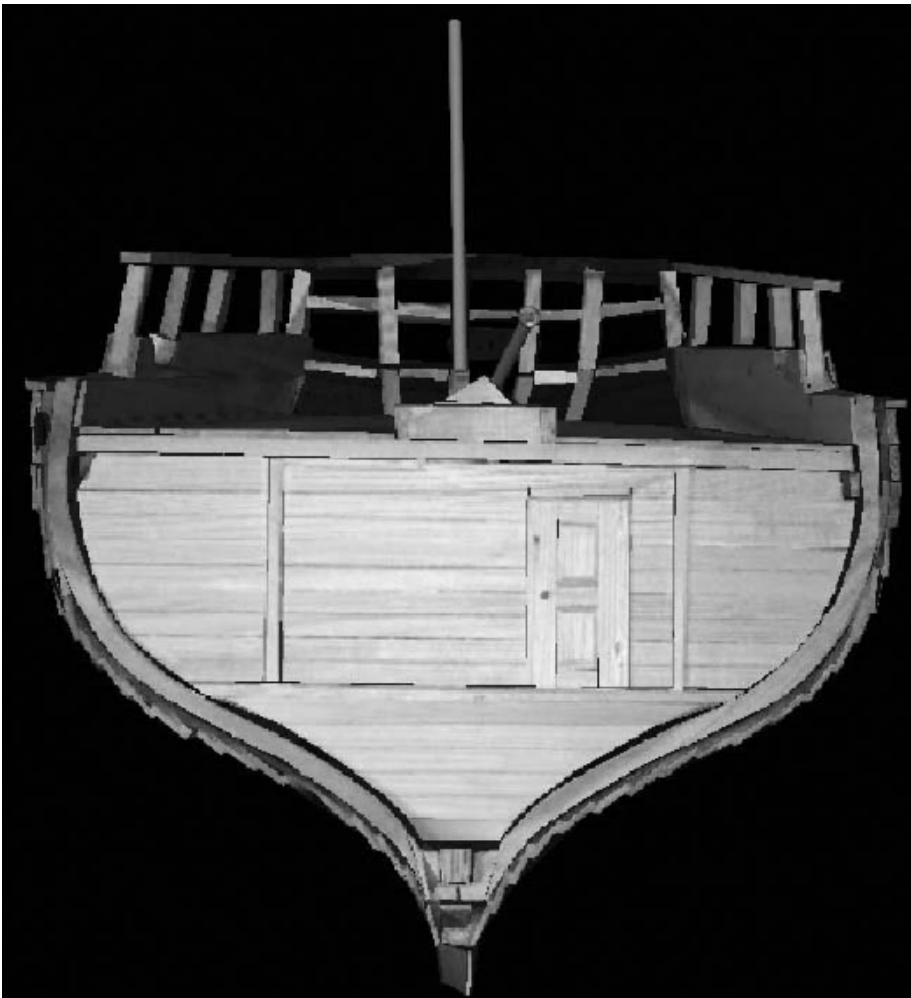
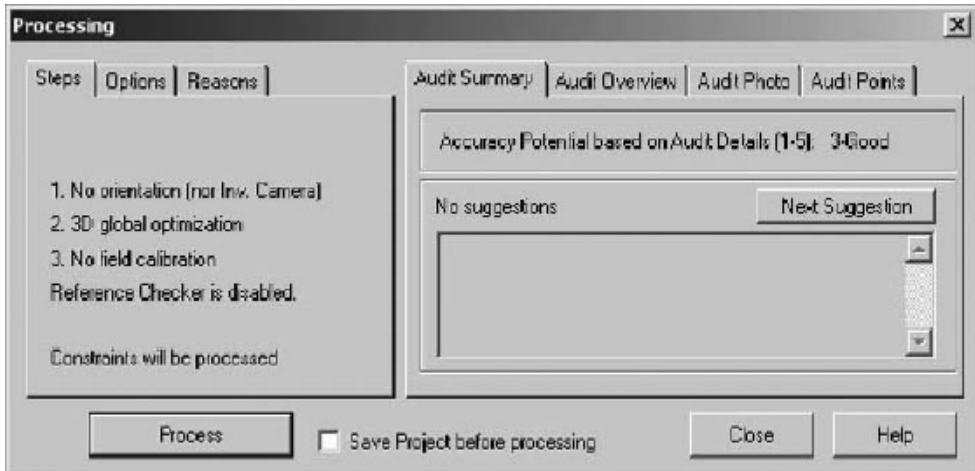


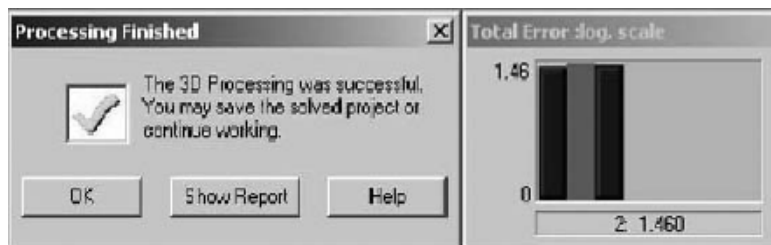
Figure 29. Final oriented scaled model of the HMS *Alert* (Michelle Liss, 2005).

Once the scale, axes, and orientation were defined, the project was processed for a final time. The *PhotoModeler* program uses a scale of 0 (bad) to 5 (very good) to indicate project quality. The final processing rendered a project quality of 3 (good), and offered no suggestions for improvement (Figure 30).



**Figure 30.** Summary of Results from Final Processing. (Michelle Liss, 2005).

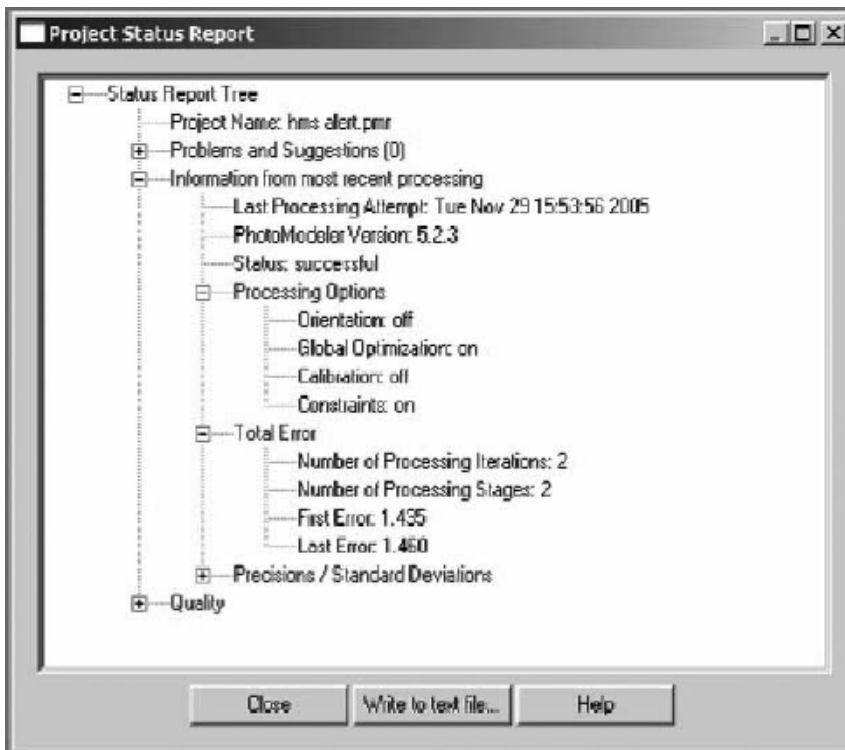
The calculated error in Figure 31 is used to assign a more precise numerical value to the error of the model.



**Figure 31.** Numerical Error Results from Final Processing (Michelle Liss, 2005).

In the above figure one can see several bars that represent the number of iterations that *PhotoModeler* used to solve the model. Through the course of his project, Franke (1999:10) discovers, "As the project converges, the Error Bars get smaller. Although the *PhotoModeler* manual does not explain what the value of this error stands for, it is assumed that it represents pixels, the absolute quality of that of course being highly dependant on localized scale." He concludes that, "... large final Error Bar values of more than nominally three do not seem to lead to acceptable results" (Franke 1999:11). The "Total Error :log.scale" from the HMS *Alert* project, as seen in Figure 31, is calculated at 2:1.460. This represents an acceptable error based on the defined scale. It also means that it only took *PhotoModeler* two iterations to solve the model. Finally, the report generated by

the final processing, represented in Figure 32, showed no problems or suggestions that needed to be addressed.



**Figure 32.** Project Status Report Box Resulting from Final Processing of the HMS *Alert* Model Project (EOS Systems, 2005).

## Conclusions

The precision and detail with which this model was created took countless hours and posed some challenges that were overcome. The resulting model exhibits high accuracy and a solid project solution. The newly scaled three-dimensional model of HMS *Alert* offers the physical model new life, and new visualization in a new dimension.

The *PhotoModeler* program has many applications in the field of maritime history and archaeology. As has been shown in this project, ship models, and on a larger scale full-size ships could be accurately modeled using this software. Artifacts and museum collections could be rendered in three-dimensional space for public viewing, theoretical manipulation, and research. The possibility of modeling entire archaeological sites is now very real.

The purpose of creating a three-dimensional model is to allow easy and all-around viewing of an object. The capabilities of *PhotoModeler* in combination with the Internet offer endless possibilities for the applications of these three-dimensional renditions.



# Modeling *Montana*

## Introduction

The objective of this project was to learn the *PhotoModeler Pro* software and gauge the feasibility of modeling archaeological work conducted at East Carolina University in the Program of Maritime Studies (PMS). The software could prove to be useful in a number of arenas, and an extension of the objective of this project was to determine the areas in which the software is applicable and its use warranted through actually performing the solving of a model. Specifically, this report describes the creation of a three-dimensional model of a wooden boat model of the vessel, *Montana*, using digital images imported into *PhotoModeler Pro*, version 5.0 software.

## Project History

*Montana* was a luxury steamer built near Pittsburgh, Pennsylvania over the winter of 1878-1879. The vessel measured 252 feet long by 48 feet and 8 inches in beam and carried 959 tons (Way 1983: 118, 330). Sanford B. Coulson built the luxurious vessel to operate on the Missouri River at a time when the mountain steamer, the smaller, lighter, more utilitarian vessels were typical of the Missouri River vessels. The elaborately decorated *Montana* mimicked the typical passenger vessels of the Mississippi River, averaging nearly double the cost and carrying about twice the load of the typical mountain steamers of the Missouri River (Corbin et al. 2004: 18-20).

In June 1884, carrying 500 tons of freight along with passengers and crew, *Montana's* Captain Massie attempted to maneuver the hulking vessel between the piers of the St. Charles Bridge in Missouri. As the vessel went under the bridge, it swung around, struck the third pier of the bridge, and limped to a spot near shore just below the bridge where it sank in twelve feet of water. One passenger reported that, as it passed under the bridge, the paddlewheel became caught in an eddy, rendering the vessel powerless in a strong current which forced the boat against the pier, breaking the hold of the vessel (Corbin et al. 2004: 23-25).

In February 2002, archaeologists from East Carolina University led a field school on behalf of the Missouri Department of Natural Resources State Historic Preservation office to document the site. The archaeology team conducted a Phase II pre-disturbance survey to document the site *in situ*. Additionally, field technicians conducted test excavations to reveal more detailed information for creating the site map (Corbin et al. 2004: 48, 50, 56). In the spring of 2005, students studying ship construction at East Carolina University built a model of *Montana*. The students had difficulty building the model because of limited knowledge on the construction specifics of the vessel. None of the students who built the model had seen the

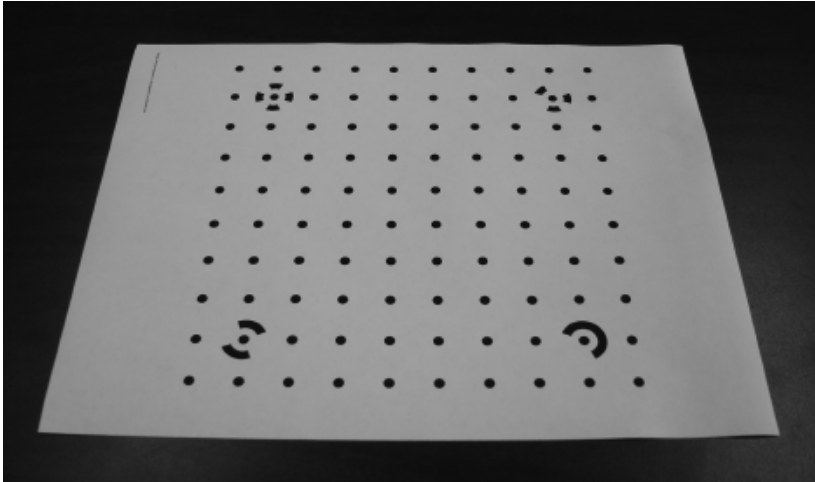
archaeological remains and had little more than the site map and drawings from which to gain dimensional and structural information about the vessel. The model builder conjectured many of the details resulting in a model of limited accuracy (McFadden et al. 2005).

Later that year, in the summer of 2005, one of the primary investigators of the archaeological project, Dr. Bradley Rodgers, attempted a second model, this time of the stern section, of *Montana* to fix distinct errors on the first model. The second *Montana* model, used in this *PhotoModeler* project, is a detailed and precise representation of the actual vessel. It clearly demonstrates key structural features such as the staggered half floor construction which allowed *Montana* the flexibility necessary given the dimensions of the vessel. The model also accurately depicts the engine trough and the cylinder timbers on which the engine operated. Under the cylinder timbers sit the pylons and tie rods which added support to the engine trough. In addition, it accurately displays the cocked hats that stiffened the sharp turn of the bilge. The model also demonstrates the bustle in the stern and the apron, a distinct design feature on *Montana* used to push water into the paddle wheel and rudders (Bradley A. Rodgers 2005, pers. comm.).

*PhotoModeler* has a distinct application within the *Montana* project. *PhotoModeler* could have been used on photographs from the archaeological site to create the site map, or could still be used on the photographs to verify the existing site map. Logistically, conditions at the *Montana* site create a difficult working environment and use of *PhotoModeler* might have alleviated some of the difficulties. Using the software might have simplified construction of wooden models. Students in the ship construction class mention the difficulties they had in determining specific details associated with constructing the model (McFadden et al. 2005) and using *PhotoModeler* on site plans, digitized drawings, digital photographs, and historic photographs might have aided in determining such construction information.

Regardless, using *PhotoModeler* will still aid in future analysis of *Montana*. The three-dimensional image allows for analysis of ship construction using a different tool than a wooden model or two-dimensional drawing. Additionally, using *PhotoModeler* to create a three-dimensional image highlighted some avoidable and unavoidable errors in the wooden model itself, such as the misalignment of outer hull planking and inconsistencies in timber measurements. Overlaying photographs and drawings onto the three-dimensional model can provide a further tool for analysis. Another use for *PhotoModeler* is to check archaeological work done in the field. The three-dimensional image can be more accurate than measurements coming from the field, depending upon circumstances in the field, and the model might be able to eradicate or minimize error from the field. Also, *PhotoModeler* could be used as a site management tool. Modeling over time could allow for analysis of site formation processes and could enable a manager to monitor major changes on a site, simply from photographs. *PhotoModeler* can serve many purposes for the *Montana* project and beyond.

The primary step in the modeling process was camera calibration. This is necessary for *PhotoModeler* to build a proper geometric relationship between points on photographs and points in three-dimensional space (EOS Systems Inc. 2004:50). To calibrate the camera, sixteen images were taken of a calibration sheet included

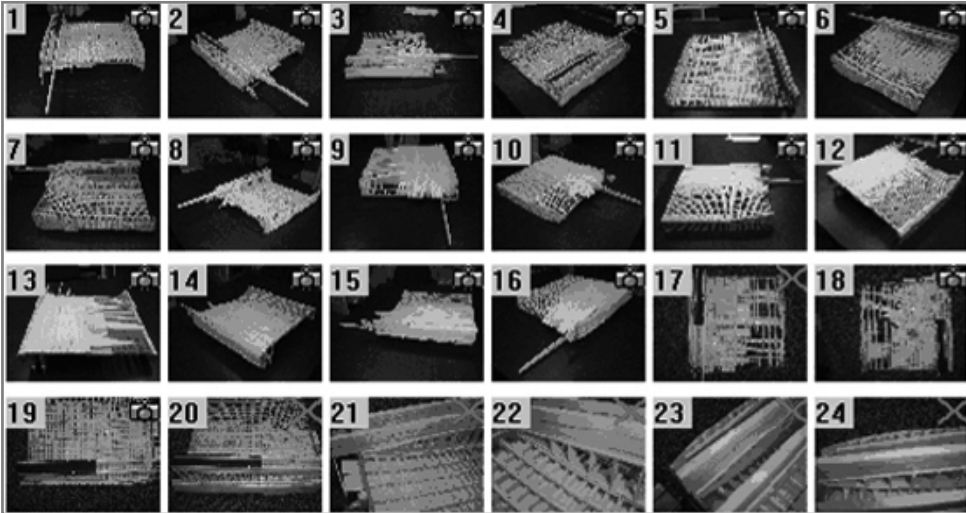


**Figure 33.** Example of Calibration Photograph (Sami Seeb, 2005).

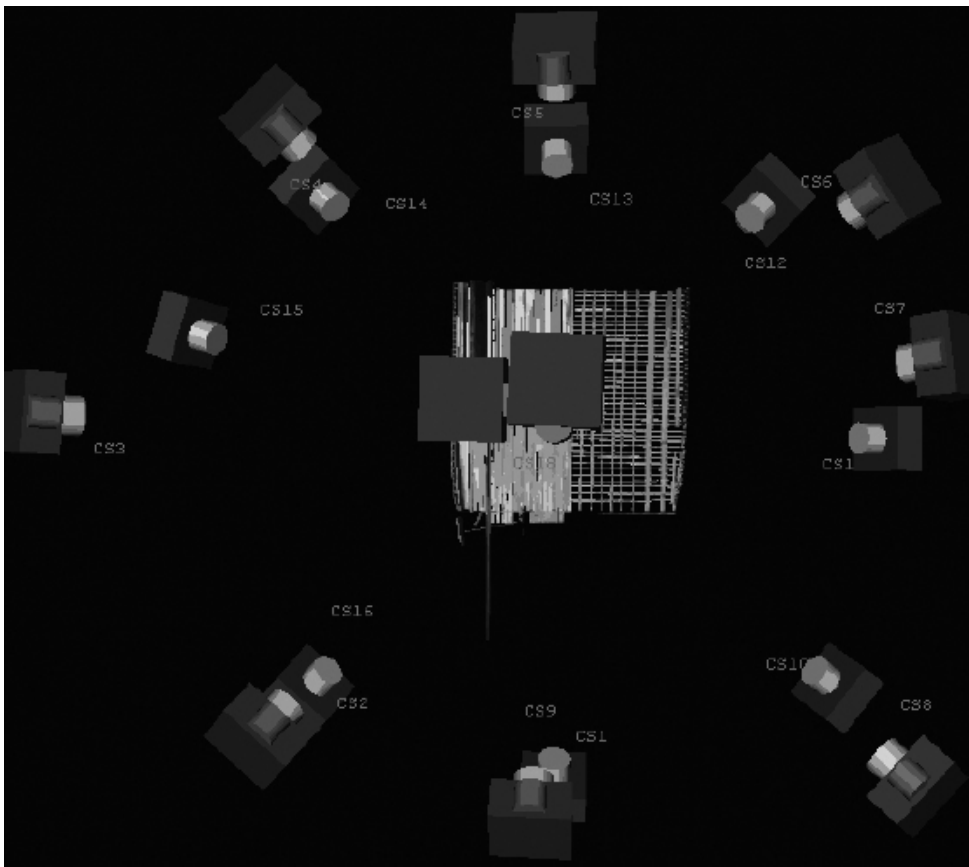
in the software (Figure 33). These images were put through the calibrator program within the software to ensure the program would produce accurate camera parameters. Initially, the calibration did not work. This was apparent because the calibration sheets have 100 possible points to reference, and nearly 120 points were referenced during the calibration process. When viewing the calibration photographs, it became apparent that because the sheet was on a spotted carpet when the photos were taken, the carpet interfered with the calibration. After removal of the error, new photos were taken and the camera re-calibrated.

After the camera was successfully calibrated, photos of the model itself were taken. Eight photographs were taken with the model upright at increments of forty-five degrees. The process was repeated with the model flipped upside down. Additional photographs, including two plan view images, were added as needed. Because each point, line, or curve that is to be modeled must appear on two or more photos, the selection of camera stations is extremely important. In planning the stations for this project, overlap of imagery was the greatest consideration, hence the sixteen angles from which the original photos were taken. Figure 34 shows all photos captured and imported for the project.

As the modeling progressed, specific areas that required a more focused view or needed better representation were re-photographed from a different angle or point of view. It became apparent that certain photos were more useful than others depending on the angle from which they were taken. Also, some photos remained unusable because they did not capture an appropriate angle or including them in the project increased error unnecessarily. Despite the relatively low total error of the final product, the accuracy potential predicted by the program remained low (2) because, as the software suggested, one or more points imaged on the photos were too close to each other, causing the station angles of the cameras to be too low. In viewing the station angles around the three-dimensional model (see Figure 35), the angles appear to be standard. It is interesting to note that the eight



**Figure 34:** Overview of the photos imported for the project. Six of the twenty-four photographs remained unused (Sami Seeb, 2005).

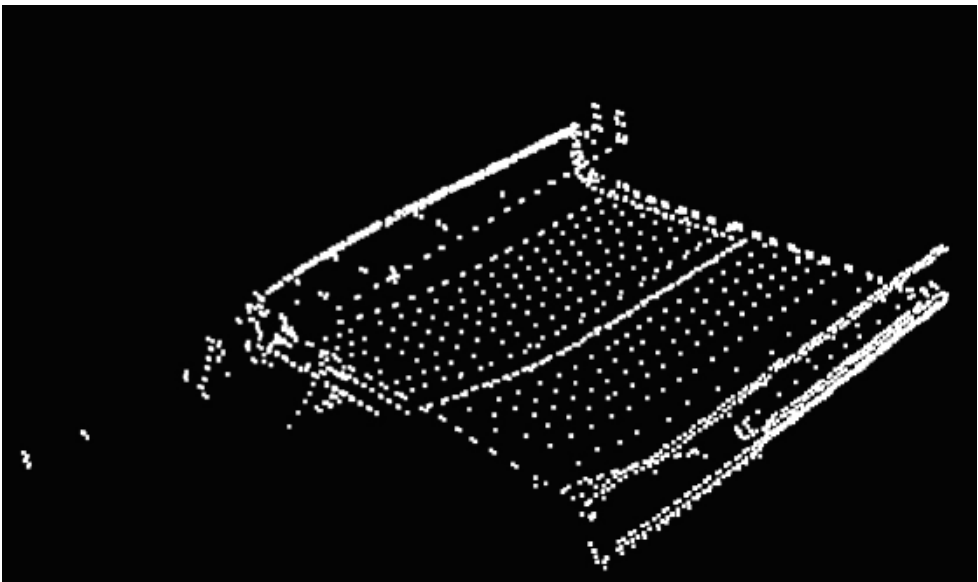


**Figure 35.** Camera station angles and the camera identifications (Sami Seeb, 2005).

stations used to capture the bottom of the model appear upside down, reflecting the fact that the model was flipped at the time those images were captured.

The most commonly occurring problem with photographs was pixelation. When trying to locate a very specific point, zooming in close on the photograph proved to be problematic because of resolution.

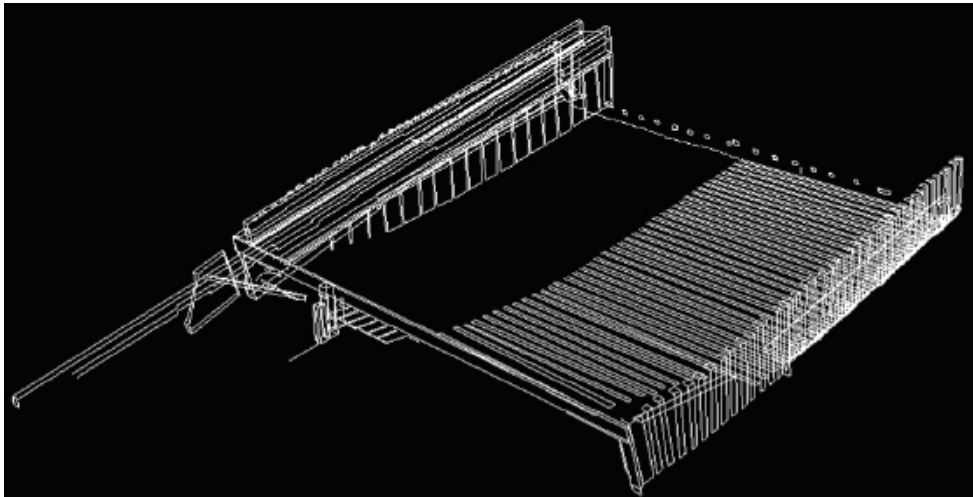
To start the project, the photographs had to be imported. Although *Photo-Modeler* suggested that only a few photos be imported and the rest added as needed, in this project, all photos were imported just after they were taken in two separate sessions. Initially, the primary sixteen photographs were imported, with the remaining eight photographs imported after they were taken once modeling was underway. The next step after importing photos was to begin selecting features and referencing them. Fasteners were selected and referenced first because they were easy to locate and pinpoint from a variety of angles. Many of the fasteners, which can be easily seen in all photos taken from the top (photos 1-8, 18, and 19) are referenced on at least seven different photographs. Referencing just a small number of fasteners on each photo helped the software orient the photographs to one another. After that was done, more points were referenced on more fasteners to increase accuracy. The epi-polar line, a referencing aid, helped speed up the referencing process by suggesting where a point should fall once a photograph was oriented. After referencing all possible fasteners, the more difficult features were referenced with points. Obvious timber corners and edges were marked and cross referenced on photos. Figure 36 shows all referenced points in the project.



**Figure 36.** Points referenced on completed three-dimensional model (Sami Seeb, 2005).

Once a considerable amount of points were selected and referenced, other features were marked. Lines were the first feature marked after points. Lines were

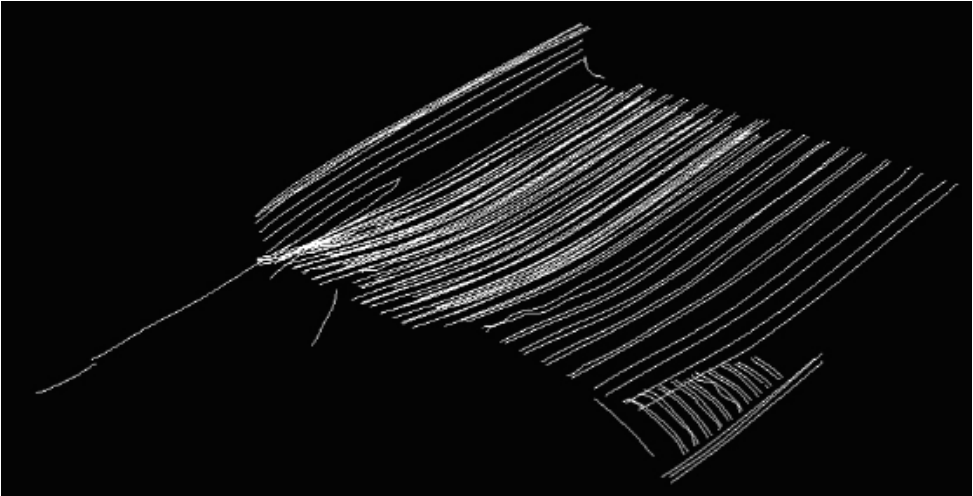
placed between any points that could be connected by a completely straight line. At times, lines were marked that did not necessarily correspond correctly with the visual image on the photograph, but did exist between two known points in space. This eliminated the problem of photographic perspective and enabled projection of important lines on the three-dimensional model that might not have been there otherwise. Figure 37 shows all the marked lines in the project.



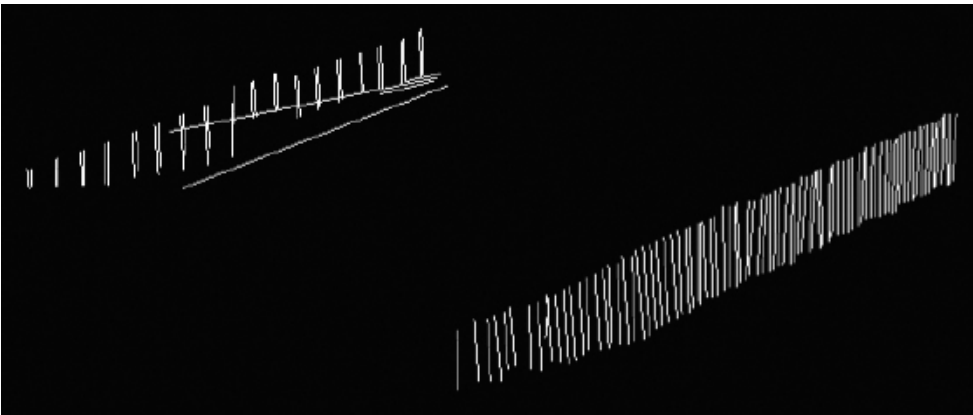
**Figure 37.** Lines referenced on completed three-dimensional model (Sami Seeb, 2005).

After the lines were marked, curves were added to the model. The wooden model distinctly depicts curves within the structure of the vessel; therefore, it was extremely important for the curves to be accurately represented on the three-dimensional model. Marking curves presented a more significant challenge than marking lines. Curves, in order to show up in the third dimension, must be extremely accurately marked and must be referenced from at least two dramatically different angles, in some instances as far apart as ninety degrees. On the three-dimensional *Montana* model, many curves appear to be straight from one angle, but are actually skewed when viewed from other angles. In some cases, curves could be straightened by dragging guide points along the curve, but that proved to be a difficult, time-consuming undertaking. In Figure 38, all curves marked in the project are visible.

The next addition to the model involved adding edges. The edge tool was used to mark a line under circumstances where two points cannot be connected or where distinct points cannot be seen in more than one photograph. An edge, an entirely unique entity, does not connect any points and the end points of an edge do not need to match when referenced across photographs (EOS Systems Inc. 2004: 472). The software is able to calculate the three-dimensional location of edges with global optimization, despite the fact that they do not necessarily correspond entirely. On the *Montana* model, edges were used to depict frames with obscured ends, obstructed cylinder pylons, and other obstructed timbers. Figure 39 shows the referenced edges on the model.

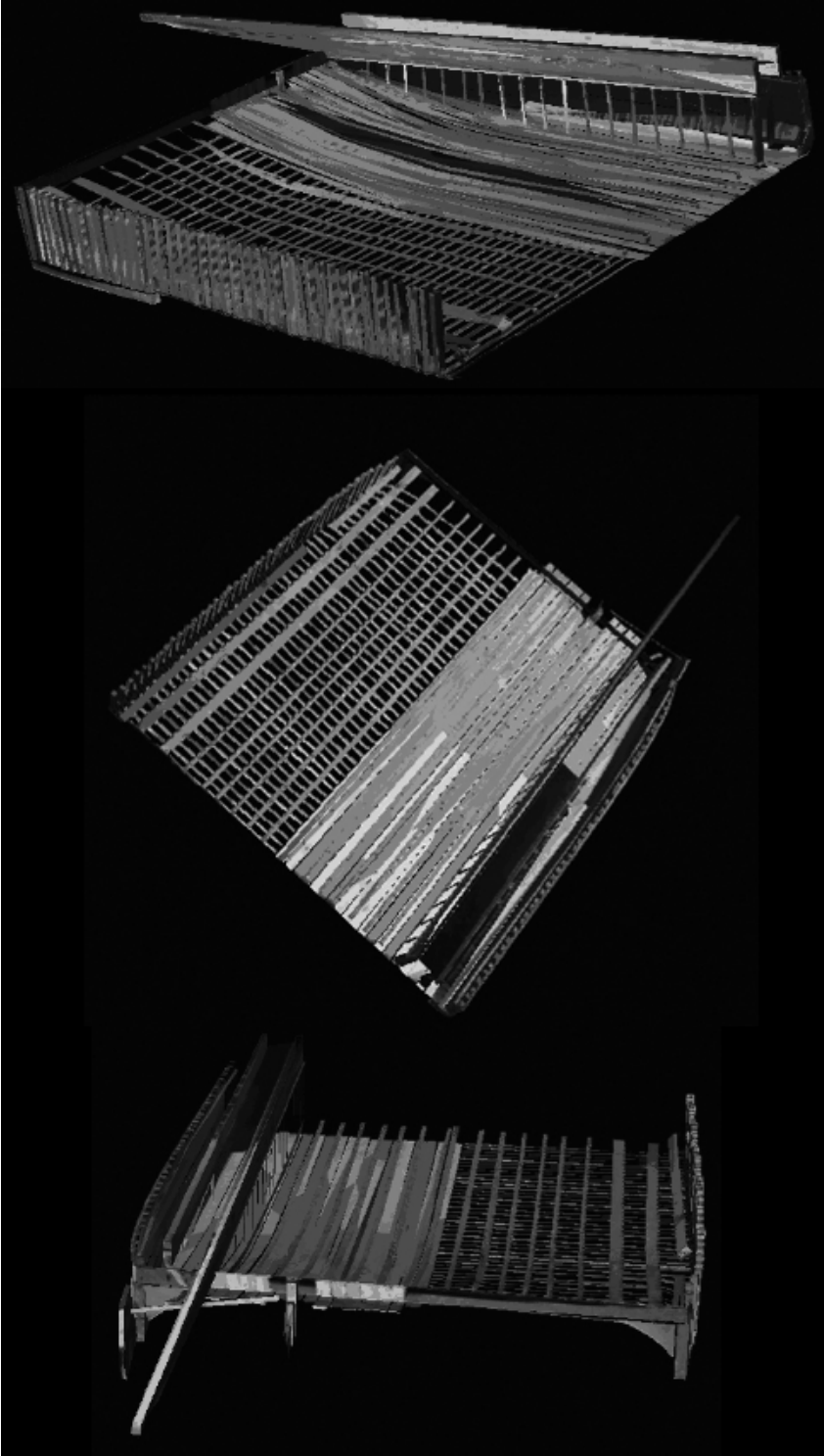


**Figure 38.** Curves referenced on completed three-dimensional model (Sami Seeb, 2005).



**Figure 39.** Edges referenced on completed three-dimensional model (Sami Seeb, 2005).

The final additions for creating the three-dimensional model included finishing the surfaces and adding quality textures taken from photographs. Surfaces were finished using both the three-dimensional model and on project photographs depending on which of the two afforded the best view of the particular surface. Surfacing proved to be an important final step because it served as a testing mechanism to examine the model for unfinished areas that might have otherwise gone un-noticed. Once the finished surfaces existed on the model, the software imported textures taken from the actual photographs. The textures, while in most circumstances did project the true surface for a feature, they also in certain instances, project the wrong surface on an area, the reflection of a surface on the wrong area, or an entirely different colored surface from the surface directly adjacent. In Figures 40, texture errors are visible throughout the project.

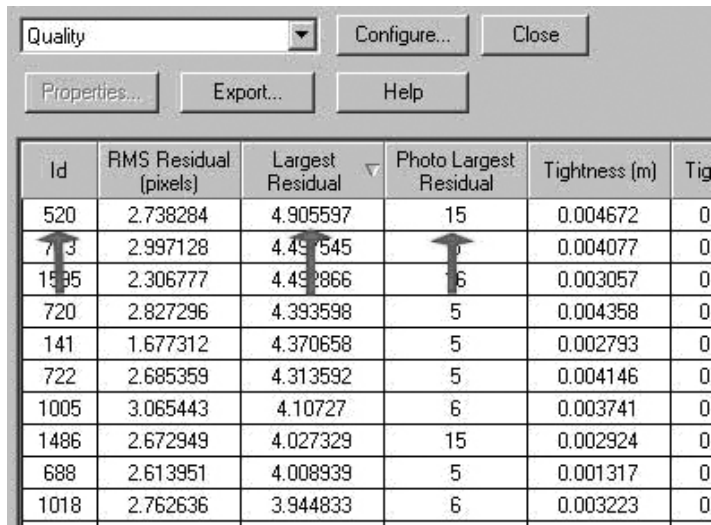


**Figure 40.** Surfaces and textures on completed three-dimensional model (Sami Seeb, 2005).



## Survey Quality

The quality of the process of marking and referencing similar features between photographs is the most important part of creating a three-dimensional model in *PhotoModeler* (Franke 1998: 8). Eighteen hundred and forty-five three-dimensional points were marked and referenced to solve the project. The lowest residual error for a point in the project 0.001682 (0.001624 pixels) while the highest measured 4.905597 (2.738284 pixels). Because points themselves are the most commonly used feature in solving the model, the quality of the points severely affect the accuracy of the other tools used to solve. When processing, the software will warn the user before the actual processing occurs if any points have a residual error of 5.0 or higher. Point qualities were analyzed in the point chart using the quality pull down menu (see Figure 41). With both the quality point chart open and the photo with the largest residual error for that point open, the point can be moved until its error is decreased to reasonable levels. Another way to decrease residual point error is to project points onto photos while referencing in order to provide a guide to place the point. Yet another way to increase accuracy in point marking is by quick referencing a point using the software's point location prediction capability to mark a point that cannot necessarily be seen on a photograph in order to force the three-dimensional projection of that point or related features.



Id	RMS Residual (pixels)	Largest Residual	Photo Largest Residual	Tightness (m)	Tig
520	2.738284	4.905597	15	0.004672	0
73	2.997128	4.497545	15	0.004077	0
1995	2.306777	4.492866	15	0.003057	0
720	2.827296	4.393598	5	0.004358	0
141	1.677312	4.370658	5	0.002793	0
722	2.685359	4.313592	5	0.004146	0
1005	3.065443	4.10727	6	0.003741	0
1486	2.672949	4.027329	15	0.002924	0
688	2.613951	4.008939	5	0.001317	0
1018	2.762636	3.944833	6	0.003223	0

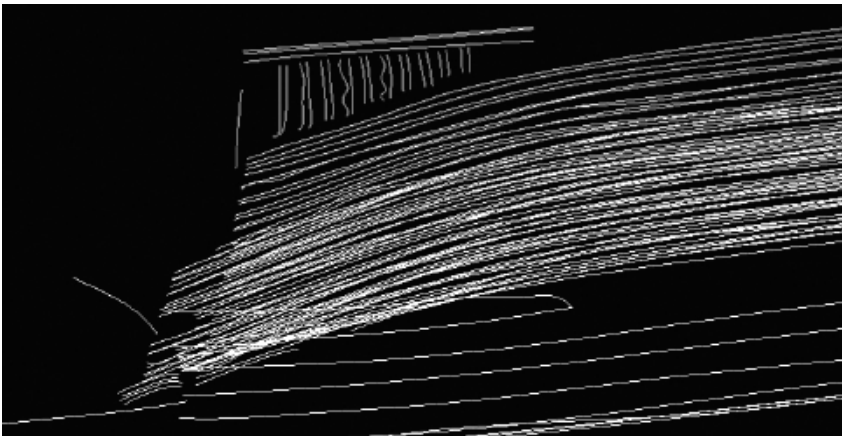
**Figure 41.** This point chart shows point 520 has the largest residual error in the project. The most error for the point exists on photo 15. The table provides the necessary information to fix the points with significant error (Sami Seeb, 2005).

One of the most common difficulties encountered with points was the “bad reference” label. When a point had a high RMS, it was labeled bad reference and forced inaccuracies in processing. Typically, in the *Montana* project, it appeared that bad references occurred when the software had difficulty referencing points across photos that were marked on the corners of features. For instance, the software could

not rectify a point marked at the corner of a frame viewed from the front of one image to the same point viewed on the side of another image. To solve this problem, some points were unreferenced while others were deleted entirely. In circumstances where it was necessary to show the point on both photos, two separate points represented on at least four photographs were marked at the same location.

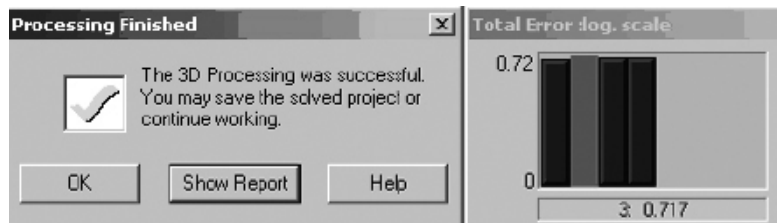
Line quality is of less concern than point quality because lines were usually added after points reached their most accurate position across photographs. Lines contributed significantly to the quality of the project numerically and aesthetically because they are so uniform throughout various photographs. The software is able to adjust lines based on the movement of the points they are attached to, therefore standardizing the referencing of lines throughout the entirety of the project. Quality can diminish, however, if lines are connected to improper points and subsequently referenced to one another. Another difficulty with lines arise when surfacing because it is difficult to discern lines on the three-dimensional model when there are many lines projected in a small area.

The curvature of various features of the model was extremely important and the sheer quantity of curves within the model influences the quality of the model, though not necessarily directly. The curve table indicates that 508 curves are drawn onto photographs within the project. However, 25 of those marked curves are not projected on the three-dimensional model. Some marked curves were not referenced across photos because doing so distorted the intended three-dimensional shape more than necessary. In other instances, the missing curves can be attributed to poor photo station angles capturing those curves. Of the curves that are projected, nearly all of them are slightly skewed when viewed from a given angle (see Figure 42). Several methods were used to increase curve quality on the model. Primarily, the curves that contained more points within them usually appeared straighter. Curves referenced over three or more photos project a markedly straighter line than those referenced on only two photos. Also, at times, selecting the planar box in the curve properties for an individual curve forced it into one plane, and therefore removed the skewed look of the curve.



**Figure 42.** Some noticeably bad curves on the underside of the model (Sami Seeb, 2005).

Processing the model frequently while choosing features and referencing them to one another also helps to increase quality as the model is being solved. Primarily, once oriented to one another, the software can help predict where a point or line might belong on a photograph. Additionally, processing compels the user to fix errors in quality throughout the creation of the model rather than after. While processing, the software goes through a number of iterations to determine the location of each point and edge in three-dimensional space and to limit the error (EOS Systems Inc. 2004: 237). If the number of iterations is high and the bar graph showing error is black, that is an indicator of a quality problem. Once iterations are finished, the program will supply a report which will make any necessary suggestions as well as display the total error of the project (see Figure 43).



**Figure 43.** The iterations and error log produced from processing (Sami Seeb, 2005).

The report and error log scale indicate that three iterations were made with a total error near 0.72. This error is a unit-less number representing accumulated error from a variety of residuals throughout the project (EOS Systems Inc. 2004: 249). The following values provide statistics for the quality of the project:

Photos: Total, Bad, Used	24	6	18
Total Number of 3D Points	1845		
3D Points per Photo: min, max, avg.	75	787	387
Photo Coverage (% area): min, max, avg.	32	76	53
Points on Two Photos Only: num, %	565	30	
Number of rays per 3D point: min, max, avg.	1	10	4
Angle Intersection (degrees): min, max, avg.	8	89	73
Point Tightness (meters): max, min	0.0047	2.1e-006	
Point Precisions:			
RMS Vector Length (m): total, max, min	0.000652	0.00293	0.000283
X (meters): max, min	0.00205	0.000151	
Y (meters): max, min	0.00226	0.000162	
Z (meters): max, min	0.00199	0.000168	

**Table 4.** Montana Project *PhotoModeler* Statistics.

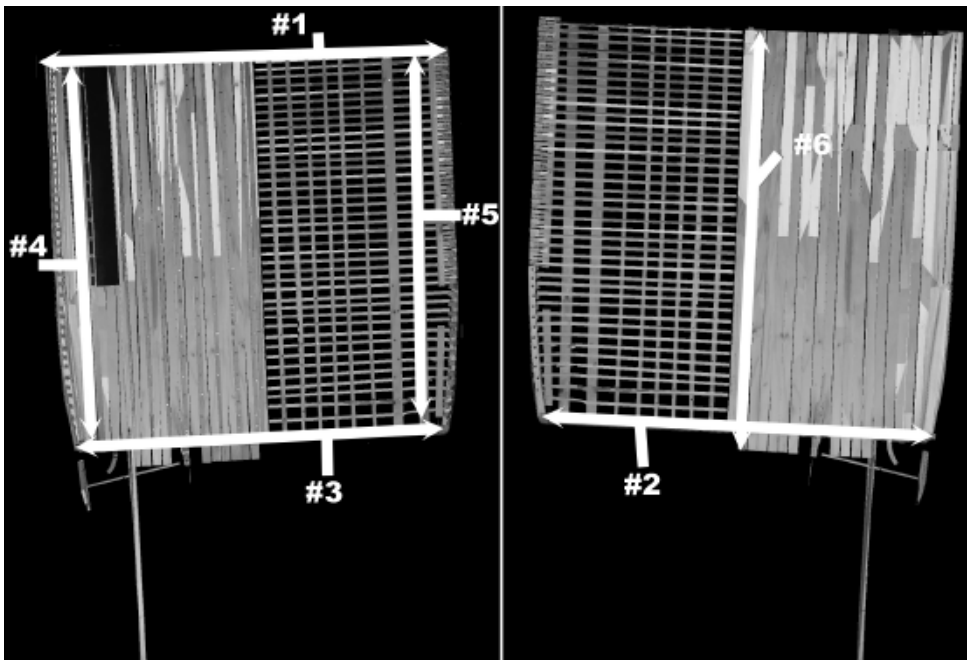
Some photos were not used in the project due to lack of time, or simply because they were not needed. The quality statistics indicate that the point precision is extremely high. All other information was listed as acceptable quality in the audit except the number of points on only two photos which is classified as “maybe” being acceptable in the point audit. Many of the points on only two photographs were limited by perspective. Given more time, those points could have been selected from the point table and, when possible, referenced on a third photograph.

## Survey Accuracy

Though the objective of the *Montana* project was to test the application of the software and equipment associated with the software, the project also aimed at creating the best possible product accuracy. Though more time would be necessary to complete the model in its entirety and with the most concise accuracy, an estimated 100-120 hours were spent on the model and the report.

Because the wooden model was available, and because a considerable amount of time was afforded to the project, many techniques were used to eliminate error and increase accuracy in the project: moving points with the assistance of the point table aided the precision in referencing points, straightening curves on photographs with the assistance of the projected curve tool helped eliminate some waviness, using the edge tool on undefined lines helped by eliminating guess work, deleting error ridden curves and points that were not necessary to render the model increased quality, and un-referencing bad reference to either re-reference them later or create more points in one area helped eliminate bad references from the project.


A scale was input into the model in order to calculate accuracy. Six measurements were taken on the *Montana* model to accurately capture major dimensions such as the length and width of the model, as well as several specifically notable features (see Figure 44).



**Figure 44:** Delineation of the measurements taken to check accuracy (Sami Seeb, 2005).


Measurement 1 from Figure 44 was measured on the wooden model and entered into the program software. Given that scale, measurements taken from the

wooden model were compared with measurements taken from the three-dimensional model to create the following table (Table 5):

Scale Used: 52.2 cm (distance)-measurement 1					
Wooden Model Measurement (cm)		PhotoModeler Result (cm)		Variance (cm) 	Error in %
# 1	n/a scale	# 1	n/a scale	n/a	
# 2	49.8	# 2	49.7	-0.1	0.2
# 3	48.6	# 3	48.2	-0.4	0.8
# 4	51.2	# 4	51.7	0.5	0.9
# 5	50.3	# 5	50.3	0.0	0.0
# 6	53.7	# 6	53.3	-0.4	0.7
					Average 0.52

**Table 5.** Resulting error with measurement 1 input as scale.

The results indicate that the average error is relatively low and the variance between measurements ranges from none to five millimeters, with measurement 1 used as the scale. This indicates that points used to take measurement 1 have high precision, therefore allowing the other measurements to reflect that tightness. Because measurement 4 had the largest percent error of the measurements in the set, it was plugged into the program as the scale and measurements were retaken on the three-dimensional model given the new scale. The results were slightly different from those with measurement 1 as the scale (see Table 6):

Scale Used: 51.2 cm (distance)-measurement 4					
Wooden Model Measurement (cm)		PhotoModeler Result (cm)		Variance (cm) 	Error in %
Meas 1	52.2	Meas 1	51.6	-0.6	1.1
Meas 2	49.8	Meas 2	49.2	-0.6	1.2
Meas 3	48.6	Meas 3	47.7	-0.9	1.8
Meas 4	n/a scale	Meas 4	n/a scale	n/a	n/a
Meas 5	50.3	Meas 5	49.7	-0.6	1.19
Meas 6	53.7	Meas 6	52.7	-1.0	1.86
					Average 1.57

**Table 6.** Resulting error with measurement 4 input as scale.

The resulting error was more than one percent higher given the change in scale from measurement 1 to measurement 4. The higher average error is likely a result of less precision in the points used to take measurement 4, as reflected in both error tables. This indicates, for various reasons, that measurement 4 has inherent error. Error in the project can be attributed to a number of sources including errors in measuring the wooden model, errors from marking points, errors in measured distances on the three-dimensional model, and inherent errors in the program itself. Given the error possible in creating such a project, the error accrued in the *Montana* project was low.

## Conclusions

*PhotoModeler* is a highly advanced and uniquely innovative tool for the field of archaeology and specifically maritime archaeology. The purpose of this project, to learn the *PhotoModeler Pro* software, was certainly achieved. The result is an accurate, detailed, three-dimensional model of a complex wooden boat model. Additionally, learning the software and analyzing its applicability in the field indicates that it can be used for a number of purposes including surveying and mapping, in-field and post-fieldwork analysis, error evaluation, site management, and post processing analysis and presentation (see Figure 45).



**Figure 45.** Two images showing the same perspective, one in the field and one on the three-dimensional model, demonstrating analysis prospects (Courtesy Maritime Studies Program, ECU © 2002)

Like any other computer software or archaeological tool, *PhotoModeler* does have its limitations. The software, when in use for long periods, seems to slow processing performance significantly. Additionally, on nearly five separate occasions, the software encountered error and shut down, causing loss of work. Potentially this was a consequence of hardware failure, not the software itself, but the authors were not capable of determining the actual cause of these shutdowns. It is highly likely that the lack of latest, high-end computer hardware with ample video-memory invariably contributed to these occurrences. Another limitation comes with photographs. It can be difficult to know ahead of time exactly what angles are needed and what, if any, specific detail photos are necessary. While this knowledge can certainly come from experience, if photographs are taken in the field and returning to the site to get additional images is not possible, the lack of photographs could significantly hamper a project. Another problem with photographs is the variation in lighting. This drastically affects overlaying quality textures on surfaces – creating distortions as can be seen in the *Montana* project (see Figure 46). In addition, reflections are noticeable on some projected surfaces. We acknowledge that this might be

a reflection of our place in the learning curve, and that with some minor methodological adjustment this problem may be easily fixed.



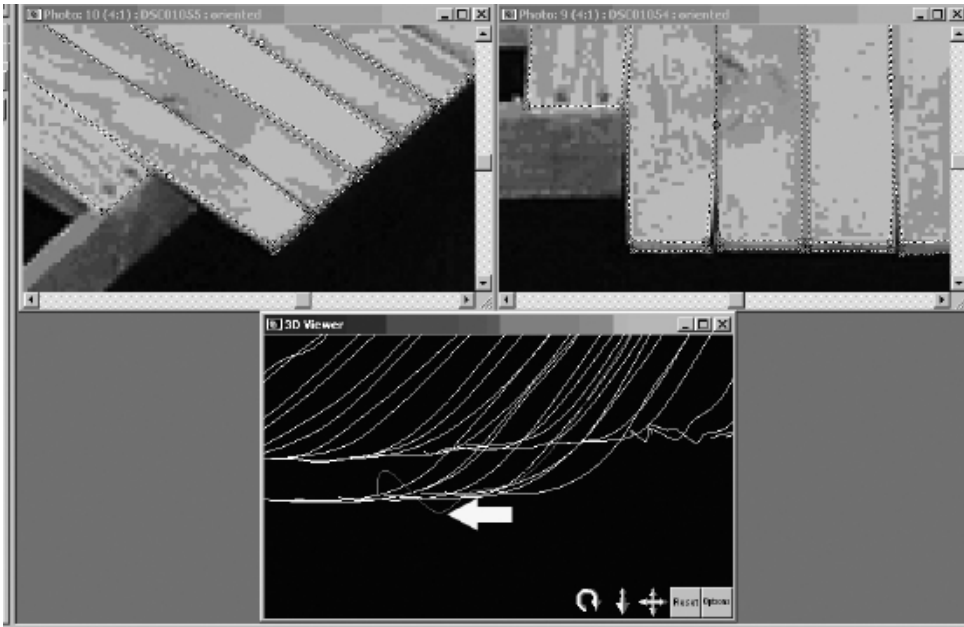
**Figure 46.** Texture distortions due to light surfaces on photographs (Sami Seeb, 2005).

Pixelation is another problem, which might be alleviated by using higher resolution photographs than those used in this project. A severe limitation in point marking is the inability for the program to recognize and reference a point on a common corner in two photographs (see Figure 47).



**Figure 47.** Three points deemed bad references because of the point of view of the photograph. The points mark the same corners, but the program, because of the photo angle, is unable to recognize that they correspond (Sami Seeb, 2005).

Another limitation is the necessity for perfection when drawing curves. Even if all drawn curves on the photographs look accurate, the three dimensional results might project a skewed curve. When skewed, curves are difficult to correct (see Figure 48).



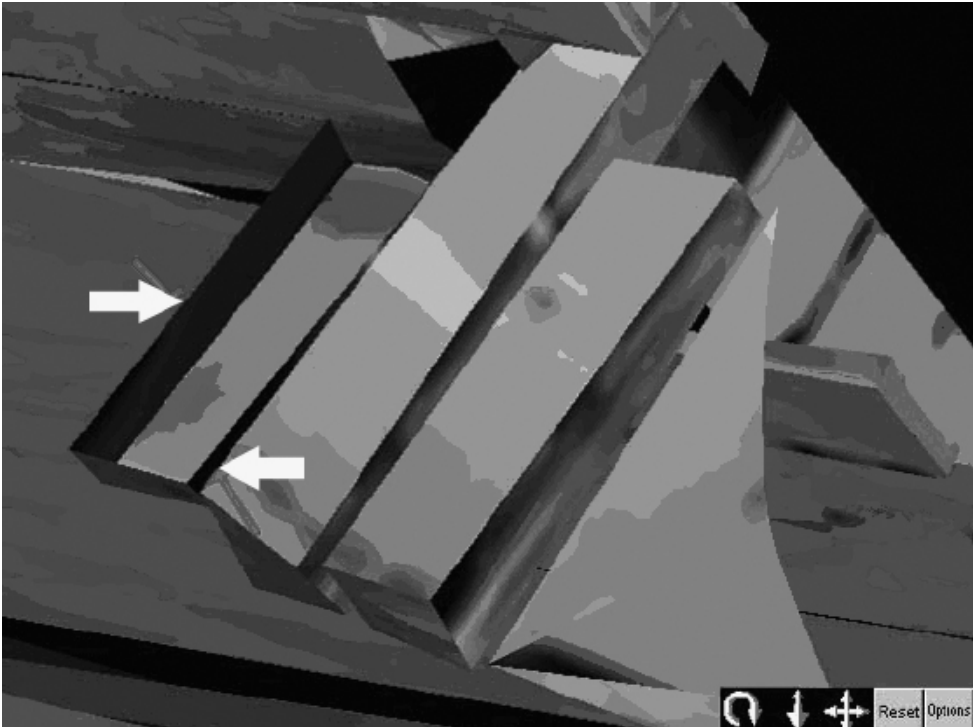
**Figure 48.** A three-dimensional image shows a skewed drawn curve on the photographs appears to be straight (Sami Seeb, 2005).

While it has limitations, the *PhotoModeler* software also has extremely practical features that greatly assist in solving a project. Primarily, although it makes the processing process significantly slower, the software alerts users to point error before processing a project. This eliminates the accumulation of error over a number of processing jobs and increases quality and accuracy in the points. In some instances, the alert is able to highlight altogether misreferenced points. Another helpful feature is the ability, once a photo is oriented, for the program to predict the general destination vicinity of a point. In addition, having the ability to draw lines between points on the three-dimensional viewer is extremely useful. In some cases, a line cannot be drawn on a photo or cannot be referenced between two photos, even though it does exist in space. Being able to draw it on the three-dimensional viewer solves the problem. Additionally, surfacing has some very helpful features. If a surface is known to exist between two projected lines or curves, but there is no delineation to create a surface at that point in three-dimensional space, the swath tool creates a surface based on where it should be in space (see Figure 49).

Another extremely helpful feature of surfacing is that both sites of a surface can project the texture. This was used to enhance the visual aesthetics of the *Montana* three-dimensional image. However, before conducting analysis on a model, all double sided surfaces should be located (in the surface table) because they could lead



to misinterpretations. For instance, in this project, only one surface is drawn on all the floors and planks, but both sides of the surface project a quality texture. It is important to recognize that those floors and planks do not represent the actual four-sided dimensions on the wooden model, just one of the four sides.



**Figure 49.** Two surfaces created using the swath tool. While it was known that the surfaces exist in space, it was not possible to draw lines to delineate the surfaces there (Sami Seeb, 2005).

Some features that seem possible, but are not integrated into the software would also ease the usability of the program. One such feature is a curve predictor. If a curve is referenced on at least two photos, even if it is not projected, it would be extremely helpful if the software could predict the location of the curve on a third photo. While drawing lines on the three-dimensional image is useful, it would be more helpful if, in addition, points, lines, and curves could be moved and changed on the three-dimensional image. Also, the three-dimensional wire image is difficult to see and interpret when completed because of the sheer mass of lines, curves, and edges. It would be useful if specifically chosen marks could be displayed while others could be excluded to study specific features on a model. Along the same lines, the ability to color code lines, curves, edges, and points would also aid in solving and analyzing a project.



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