THE DEVELOPMENT OF THE NAVAL TRUCK GUN CARRIAGE: HISTORY, ARCHAEOLOGY, AND DESIGN

By
Katrina Bunyard
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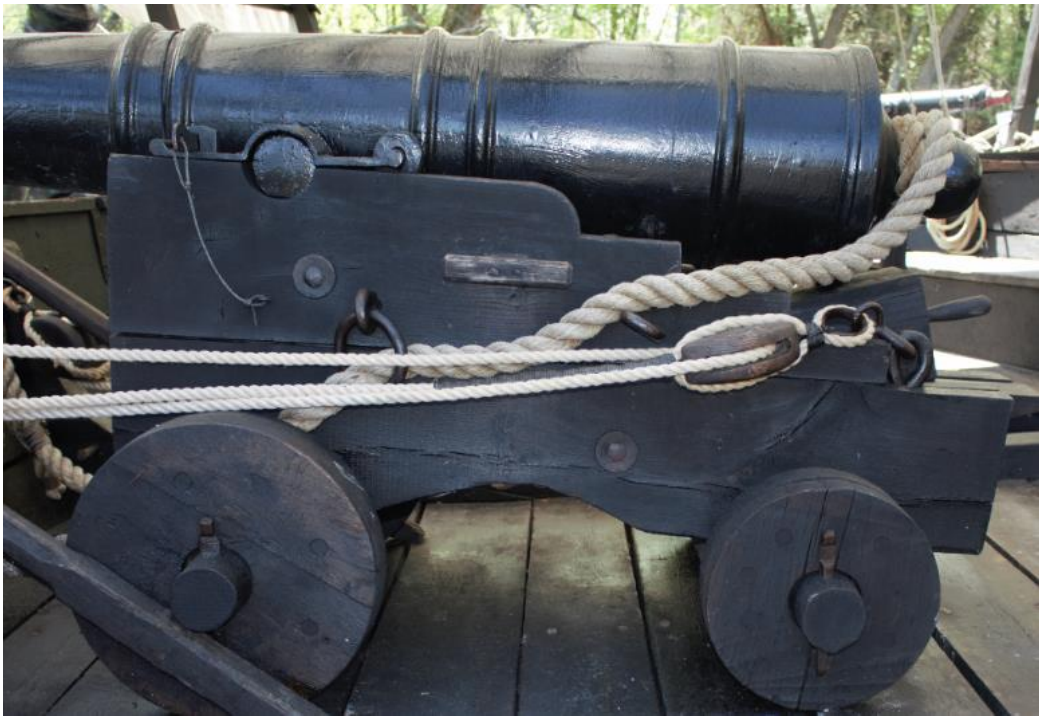
Director of Thesis: Dr. Donald Parkerson
Major Department: Program in Maritime Studies

Truck carriages represented the primary naval gun mounting of European and American navies throughout the Age of Sail. Developed during the early to mid-16th century, truck gun carriages were found upon armed ships for over three centuries. They allowed for gunners to control and aim their pieces, promoting the development of naval guns of increasing power. During the 19th century, the truck carriage became viewed as a stagnant medieval leftover that underwent little change. Some later scholars further propagated this belief.

This thesis seeks to examine the truck carriage's place in the development of modern western navies, evaluate the nature of its design and construction development, and explore its presence in the archaeological record. The truck carriage developed from the concerted efforts of artillerists across Europe, developed in sophistication in tandem with naval administrations, and played a role in shaping the living and working space aboard warships. Numerous archaeological sites contain the remains of several types of gun carriage, providing ample material for further study. Through the development of a gun carriage database, statistical testing was undertaken to explore the nature of design change over time. This database suggests that the truck carriage underwent non-linear change in several of its basic proportions over the course of its lifetime, likely adapting to changing capabilities of naval cannon and increased industrialization.

The Development of the Truck Gun Carriage: History, Archaeology, and Design



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Katrina Bunyard

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By
Katrina Bunyard

APPROVED BY:

DIRECTOR OF
THESIS: ______________________________
Donald Parkerson, Ph.D.

COMMITTEE MEMBER: ______________________________
Wade Dudley, Ph.D.

COMMITTEE MEMBER: ______________________________
Lynn Harris, Ph.D.

CHAIR OF THE DEPARTMENT
OF HISTORY: ______________________________
Christopher Oakley, Ph.D.

DEAN OF THE
GRADUATE SCHOOL: ______________________________
Paul J. Gemperline, Ph.D.

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LIST OF ABBREVIATIONS

LCMM	Lake Champlain Maritime Museum	6
VDHR	Virginia Department of Historic Resources	6
THC	Texas Historical Commission	6
ANOVA	Analysis of Variance	7
NPS	National Park Service	24
PEG	Polyethylene glycol	53
TSC	Trunnion Support Cheek	57
RSC	Rear Stepped Cheek	59

CHAPTER 1
INTRODUCTION

The study of gun carriage technology, particularly the truck carriage type, offers great opportunities for both archaeologists and historians to gain a better understanding of some lesser known aspects of naval ordnance development. A vital support technology, the gun carriage provided strong recoil control, which enabled the gun to grow powerful enough to become an effective weapon, harnessing forces which would otherwise destroy it (Robertson 1921:40). Carriages also increased the efficiency, accuracy, and manageability of the guns they mounted, which in turn led to their later predominance in sea battles (Tucker 1989:3). They became a common sight aboard armed European and American vessels for over three hundred years. The significance of gun carriage technology to the development of naval warfare cannot be contested. Several scholars, such as Robertson (1921), Moody (1952), Tucker (1989), Caruana (1994 and 1997), Broadwater (1996), Hildred (2011), Cederlund (2006), and Bruseth et al (2017) understand this significance and devote large sections of their works to the truck carriage.

Unfortunately, hostility towards the truck carriage, developed in the 19th century, colors some later scholarship. H. Garbett calls the truck based naval gun carriage an unchanged medieval relic (Garbett 1897). This perhaps led to the view that gun carriages were simple and uncomplicated machines (Eller 1976:16).

This thesis examines the history of the truck carriage, its origins, manufacture, design, and proportional relationships. It also consolidates previous historical and archaeological research. This research supported the development and analysis of a truck carriage database. This thesis seeks to understand the truck carriage’s role in naval administration, its construction, design, and shipboard use through by asking the following questions:

1. What are the origins of the truck carriage and how is it adopted by English, French, and Spanish navies?
2. What organizations or people are responsible for the design, manufacture and distribution of the truck carriage in the British and American navies?
3. What is the character of archaeological investigations conducted on gun carriages?
4. In general, how does the design and construction of the truck carriage vary over time?
    a. What are the significant proportional relationships?
    b. How do the proportions of physical examples of the truck carriage compare to artillery treatises?
5. What are future avenues of research into gun carriages?

A great deal of information exists on gun carriages and several studies devote some discussion to their general history and development. One of the earliest study dates to 1921, written by Frederick Leslie Robertson, as part of his work, *The Evolution of Naval Armament*. He devotes a sizeable chapter to carriage development and physical descriptions, citing important primary sources such as Muller and Congreve. He provides some general discussion on early carriage design, and offers some speculation on their origins, mainly from land-based models. Much of his analysis is given to commentary on the mechanical advantages and defects of the truck carriage, aimed to address criticisms raised by 19th century writers regarding its supposed design stagnation. As a general guideline to carriage design in the 18th and 19th centuries, the book is a valuable source.

Another useful work is a *Mariner's Mirror* article written by J.D. Moody in 1952, entitled "Old Naval Gun Carriages." It represents one of only scholarly work solely devoted to gun carriages. His work focuses on the stages of growth in the "common ship carriage," between the 16th and 19th centuries (Moody 1952:301). He devotes more time to the history of the truck carriage than its inherent mechanical prowess, and he also provides a useful discussion on the other carriage types that existed in the truck mounting's early days. Much of Moody's observations on design changes and development come from his in-person evaluation of gun carriages in various museums and repositories around Great Britain. His observations provide a useful launchpad for further research, though they remain general.

Spencer Tucker's 1989 *Arming the Fleet* provides an excellent discussion on gun carriage construction, with greater focus on proportionality and the smaller details of design change. He relates the truck carriage to the land-based garrison carriage and undertakes a comparison of British and American carriages. He pulls much of his information from John Muller's *Treatise of Artillery* from 1757 but distills it in an understandable manner. The accompanying data on American cannon make Tucker's book a useful reference in examining the relationship between carriages and their cannon.

Perhaps the most comprehensive examination of gun carriage design over time is the two volume *History of English Sea Ordnance*, written by Adrian B. Caruana in 1994 and 1997. He generated several illustrations outlining his hypothesis of truck carriage development and contextualizes new carriage patterns with gun design. His schematics of these carriage patterns set the stage for more detailed chronological comparative analysis and highlight useful primary sources within repositories like the British Library or National Archives.

The exact development of the truck carriage is unknown. Caruana (1994) provides some illustrations detailing the development of the truck carriage from older stock mountings, but these are mostly conjecture. The earliest archaeological evidence currently available dates to the mid-16th century, from the English warship *Mary Rose*. Design elements from some of the *Mary*

Rose carriages match descriptions found in Italian treatises (Hildred 2011:40). At least one Venetian ship, *La Lavia*, carried a truck carriage during the Spanish Armada's ill-fated invasion of England in 1588 (Birch and McElvogue 1999:273). It is quite possible that any one of the seafaring European navies developed the truck carriage, but further, multinational research is needed to explore its early development.

Ship and garrison inventories shed light on the integration and adoption of the truck carriage, occurring at different rates across Europe, but seemingly complete by the 17th century. Researchers rarely discuss the carriages of the 17th century, though some, like Lavery (1984) publish partial ship inventory lists from the time. From these, it can be noted that carriage wheels no longer are included, and further standardization in inventory design have occurred. More information on 17th century carriages is needed. *Vasa* and *La Belle* both contain archaeological examples of 17th century gun carriages, as does *HMS London.*

By the 18th century, the truck carriage found heavy use aboard western warships and were a subject of interest by numerous artillery treatise writers including, John Muller (1757) and John Robertson (1776). Caruana (1997) traces several design changes in truck carriages throughout this century. Truck carriages continued to see use in the American Navy to at least the 1870s, for smooth-bored shot-firing cannons (Brandt 1870).

This thesis embraced an interdisciplinary approach in its examination of carriages, pulling from history, archaeology, and statistics. The results of these endeavors are presented in three chapters. Chapter 2 covers the first phase of research, focused on tracing the historical development of the truck carriage. It discusses the origins of general gun carriages, the shift from sledge to truck design, the integration of carriages in warships and garrisons, and the institutions and people responsible for supply and development. It also serves to consolidate prior research.

Though its primary purpose lay in combat, the truck carriage also provides a context through which to examine the logistical challenges of supplying armaments to warships and fortifications. They provide insight into the everyday person employed by naval administrations to meet these challenges.

Information for Chapter 2 came from both primary and secondary sources. Primary evidence included artillery and sailing treatises, ship inventories, receipts, bills, warrants, and schematics. These primary sources came from a variety of locations, including: secondary sources, the National Archives in Washington D.C., the archives at the Castillo de San Marcos, Historic Ships in Baltimore, and the library at Fort Ticonderoga. Many of the secondary resources and treatises resided in East Carolina University’s Joyner Library at the time of this project. The secondary sources represent primarily naval and military history, along with some invention and patent histories.

Next, Chapter 3 highlights the notable archaeological studies upon sites containing well preserved gun carriages. This represented the second stage of research and is meant to demonstrate the enormous data potential of ethically excavated and documented gun carriages. The four case studies are *Mary Rose*, *Vasa*, *La Belle*, and *Betsy*. The English *Mary Rose* (1545) and Swedish *Vasa* (1628) were purpose-built warships. *La Belle* (1686) served as a French civilian exploration ship, while *Betsy* (1781) began life as a merchant vessel. Each project took a different approach in studying their carriages, highlighting the multiple roles they played aboard ships. These case studies also highlight the changes to archaeology and conservation practices in the decades spanning the projects.

The chapter provides the excavation, conservation, and curation histories for each case study, along with a discussion and analysis of their findings. Site maps, photographs, and technical drawing supplement these discussions. The major carriage findings of these sites related to construction, modification and reuse patterns, and role in deck organization and partition of space. In addition to the case studies, the chapter examines *Stirling Castle, Hamilton,* and *Scourge* as promising avenues of further research. Information found in this chapter came from major publications, archaeological reports, and museum and organization websites. The Virginia Department of Historic Resources (VDHR), The Hamilton and Scourge National Historic Site, and the Texas Historical Commission (THC) provided additional resources.

Gun carriages from each of these sites furnished data for the database described in Chapter 4. The author visited several institutions along the East Coast of the United States in May of 2018, recording historic carriages and historically accurate replicas. These included the Castillo de San Marcos, Fort Ticonderoga, the Mariner's Museum, the Lake Champlain Maritime Museum (LCMM), Historic Ships in Baltimore, and the History Museum of Mobile. Additionally, the author visited the National Archives in Washington D.C. and the archives of the Castillo de San Marcos in Jacksonville, Florida to gather additional documentary data.

Measurements included the dimensions (length, width, height/depth) of major carriage parts (the trucks, side pieces or cheeks, the transom, the carriage bed, and axletrees) and cannon parts (bore diameter, length, second reinforce diameter, trunnion dimensions, base ring diameter, and cascabel). Scaled photographs supplemented this information. The author utilized additional data from measurements and scaled photographs for sites that proved impossible to visit in person. For future research, the measurements derived from scaled photographs would be well served to be replaced with direct measurements.

In total, 27 carriages produced enough data for inclusion in the database, created using IBM's SPSS statistical software. It is available free to East Carolina University students. Data fell into either nominal or interval/ratio categories. Nominal information included country of origin, year in which the associated ship sank, and housing institution. Interval/ratio data included the major measurements. The database served three purposes: to generate a functioning list of proportions, to examine the relationships between the major components of the carriage and evaluate change over time. Additionally, the database allowed for observed proportions to be compared with those suggested by Muller (1757). Using proportions rather than raw measurements allowed for the comparison of different sized carriages together.

The author first ran correlations on the database between the major elements of the truck carriage: the cheek, forward and rear trucks, forward and rear axletrees, and the transom. These elements appeared in most iterations of the truck carriage and thus serve as the best markers for design stability or change over time. Correlations of sufficient strength and significance provided the basis for the subsequent proportion list. Several of the proportions listed by Muller failed to meet the strength and significance requirements of the study. This section highlighted some of the difficulty in relying solely on artillery treatises for carriage reconstruction.

The proportions resulting from the correlations then underwent regression analysis, to determine the degree and nature of their relationships. Since regressions reflect cause and effect, they allowed for the creation of equations, from which the dimensions of one carriage part could be used to estimate the dimensions of another. Though small in scale for this study, an expanded list of equations could provide archaeologists with a toolset to use for the reconstruction of partial carriages.

The third and final analysis aimed to examine change in carriage design over time, using Analysis of Variance (ANOVAs). The resulting graphs show the change in each proportional relationship based on century. These revealed a complex process of non-linear development, undermining 19th century arguments of carriages being unchanging and technologically backwards. Notably, trends persisting through the 16th to 18th centuries sometimes dramatically reversed in the 19th century, suggesting some level of increased experimentation.

The fifth and final chapter summarizes the major findings of the thesis and consolidates all the possible avenues of additional study. It aims to highlight the wide array of useful data the truck carriage can supply to researchers, despite the stigma it received in the 19th century. The truck carriage is of great historic and archaeological value and its continued study promises to be fruitful. Additional historical studies could focus on the early manufacturing process, the people responsible for them, and the logistics surrounding their supply. A multi-national cooperative study would yield interesting comparative data and reveal important information about the practices in other navies. It is quite possible the ultimate origins of the truck carriage lie with them. A multi-national archaeological study would also be useful in examining construction, design, and role of the gun carriage in shipboard organization. Experimental archaeology could also shed light on the performance of each design iteration, allowing for a better understanding of cannon and carriage design change. Further statistical studies could build upon the proportional lists discussed here, provide a more nuanced understanding of design change over time, and a deeper look at the relationship between carriage parts.

Several appendices supplement this thesis. Appendix A is the permission form to use images belonging to the Virginia Department of Historic Resources. Appendix B shows the basic parts of a typical truck carriage. Appendix C is a partial list of sites at which gun carriages have been discovered. Appendix D is the form used to collect gun carriage data. Appendix E is a selection of the photographs taken of gun carriages recorded by the author. Finally, Appendix F is the code book used to construct the database

The primary goal of the thesis is to demonstrate that the truck carriage played a complex, multi-faceted role in the history of shipboard armament. Its construction has the potential to shed light into the practices of carpenters and blacksmiths and the conditions impacting their work. It underwent non-linear design changes over the course of its history, often tied to cannon development, rather than remaining monolithic and stagnant. There existed complex relationships between the various components, which cannot be fully understood through an examination of artillery treatises alone. Aboard the ship, the truck carriage served to not only allow gunners to control their pieces, but also may have impacted the partition of their living and working space. Gun carriages appear with surprising frequency on archaeology sites and represent a relatively untapped resource. Future archaeological and statistical analysis of gun carriages of all types would prove fruitful.

CHAPTER 2
HISTORY OF THE TRUCK GUN CARRIAGE

Introduction

Historians writing of the naval renaissance of Europe agree that the introduction of the gun to the warship forever altered the character of naval conflict. While the gun itself receives well deserved scholarly attention, the gun carriage supporting it sometimes overlooked, despite being a vital support technology. During the Age of Sail, the truck carriage represented the predominant naval mounting, so named for the four wheels upon which it rested (Robertson 1921:140). Other names for it include the “common gun carriage,” “the common ship carriage,” or simply the “sea carriage” (Muller 1757; Simmons 1812; and Moody 1952:301). Through the examination of artillery treatises, ship and garrison inventories, and secondary historical studies, this chapter explores the introduction and use of English, American, Spanish, and French carriages.

Any study related to gun carriages must contend with assumptions developed during the later 19th century, which sometimes permeate later historical writings. Chief of these is the belief that the truck carriage design never altered. An anonymous 1862 writer argues that the truck carriage spent three hundred years without any material alteration (cited by Tucker 1984:89). H. Garbett, in 1897, calls wooden truck carriages, “crude relics of the Middle Ages, which prevailed up to even a few years ago” (Garbett 1897:135). Frederick Robertson, in his history of naval arms, believes this hostile attitude stems from the view that the truck carriage embodied technological backwardness (Robertson 1921:140). Some modern writers also embrace the view that truck carriages underwent an extended period of design stability. Margarete Rule, writing on the *Mary Rose*, states that its carriages, “vary only in detail from the carriages used on Nelson’s flagship, *HMS Victory*,” but she later admits that differences emerge under close observation

(Rule 1982:160). Spencer Tucker, in his *Arming the Fleet,* agrees with the sentiment that carriage design underwent little significant change (Tucker 1984:89). Conversely, Adrian Caruana, in his examination of English sea ordnance, takes note of several design changes and further suggests that the design elements which remained the same likely did so for good reasons (Caruana 1997:358). Moody also argues that carriage experienced some change over the course of its history (Moody 1952:310).

Types of Carriage

John Muller, author of a 1757 English artillery treatise, notes three types of gun mountings: garrison carriages, naval carriages, and field carriages (Muller 1757:94). The field carriage supported lighter ordnance meant for use against armies in the field. Garrison and naval carriages of Muller's time only differed in the presence of iron rings and material used in their wheels (Muller 1757:94). Garrison carriages mounted heavy ordnance for use in defense against besiegers or sea-based threats.

By 1545, ships carried a mix of land-inspired designs and the early ancestors of the truck carriage (McElvogue 2015:33). Within a century, a variant of the well-established truck carriage emerged. Some carriages for lighter guns, such as those found aboard the Cromwellian pinnace *Swan,* wrecked in 1641, sported chocks in place of their rear trucks, to reduce recoil (Martin 2004:87).

Historiography

Primary and secondary resources contribute to this examination of the truck carriage. Primary sources include artillery treatises and ships' inventories, along with their associated imagery, and occasional warrants and receipts. Artillery treatises exist for both land and sea service, primarily serving civilian markets (Caruana 1994:227). They provide useful schematics for the comparative analysis of design throughout the period of interest. Ship inventories documented the naval goods and materials available to individual vessels and served to aid naval bureaucracies in running and organizing fleets. They grant insight into the adoption and integration of gun carriages aboard vessels, and the transition from sledge/field designs to a purely seagoing carriage. The inventories from garrisons such as the Castillo de San Marcos or Fort Ticonderoga are also useful in this regard.

Secondary sources also play a notable role in this study. They draw from a wide variety of research in other fields and grant limited access to otherwise unreachable primary sources. They would also be valuable in a comparative study of European naval mountings, as they could access primary documents in a wide range of languages.

Archaeological publications embody great potential in the study of gun carriages. Carriage remains appear with increasing frequency in wrecks; subsequent publications contain useful information, such as measurements and construction details. Gun carriages began their development prior to the advent of treatise writing, making archaeological examples quite useful in examining early design. Chapter 3 will delve further into the archaeology of truck carriages.

Developing and Integrating the Truck Carriage

The exact origins of naval gun carriages remain only vaguely understood. The earliest unchallenged report of guns used for ship defense dates to 1356, aboard a French fleet (cited by Tucker 1984:2). In his 1849 artillery treatise, C.P. Kingsbury argues for the introduction of four-wheeled land-based carriages around 1400, a mere eighteen years prior to the development of bronze guns (Kingsbury 1849:27). Moody argues that truck mountings came into use at the same time as cast bronze muzzle loaders (Moody 1952:302).

By 1487, land ordnance came in two distinct types: heavier guns for use against fortifications and field pieces to combat troops (Kingsbury 1849:29). A basic field carriage consisted of a longitudinal piece of wood (the stock), which rested on an axletree capped on either end by spoked wheels; the trunnions of the piece fit in the sides of the carriage, called cheeks or side pieces (Kingsbury 1849:88). It is unknown when exactly these field carriages first made their way to ships, though archaeological evidence from vessels such as the Cattewater wreck (c.1500), Studland Bay wreck (c.1500), and *Lomellima* (1516) suggest within the first quarter of the 16th century. Field pieces also found use in garrisons. In 1579 at the Castillo de San Marcos, for instance, likely field carriages are described in a report detailing the visit of an important Spanish administrator (Junco 1579). The Castillo historians believe that, by 1740 (the timeframe the modern National Monument interprets the fort), the Spanish utilized garrison versions of the truck carriage.

There are two competing origin stories for the sea gun carriage. Tucker argues that, at first, a gun would be allowed to recoil along the deck; as the forces produced by guns increased, they were placed in grooves in the deck, before finally being laid on a grooved log, to which wheels and trucks were eventually added (Tucker 1984:4). Caruana describes the transformation from grooved log to truck carriage in greater detail. While most of his work heavily relies on theory and conjecture, Caruana is one of the few authors to trace the physical development of the truck carriage. He states that a stock mounted gun could easily be placed on a trestle table equipped with axles and trucks, creating a crude truck carriage, as seen in Figure 2.1 (Caruana 1994:172).

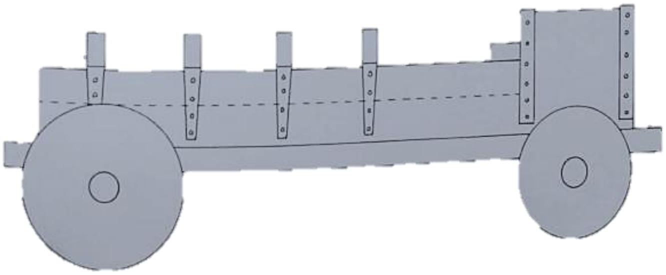


Figure 2.1: Early stock mounted trestle table carriage (Caruana 1994:172).

The carriage in Figure 2.1 theoretically saw use up to the invention of trunnions between 1460 and 1470, at which point square side panels with trunnion notches appeared (Caruana 1994:172). Caruana believes that the increasing weight of the gun and the new ability to change elevation sparked the need for fulcrums of various heights to be added to the carriage soon after (Caruana 1994:173). Figure 2.2 shows these proto-steps and the trunnion panels, along with a basic breech-supporting block.

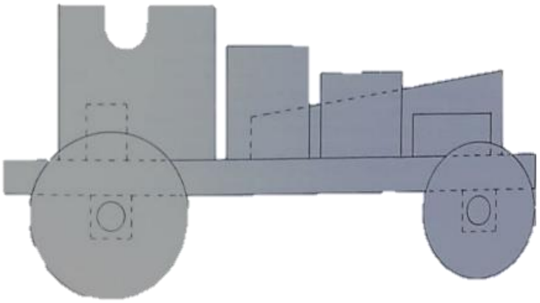


Figure 2.2: Theoretical truck carriage with elevation blocks, post-1460, drawn by Adrian Caruana (Caruana 1994:173).

Robertson, conversely, argues that the truck carriage itself developed from the garrison carriage, stationed in fortresses, and transferred to ships initially without any modification (Robertson 1921:142). They utilize the same proportion system and are visually very similar (Manucy 2003:49). Determining the degree these progression lines overlapped will require additional study.

The two scenarios outlined above hint at a gradual developmental process for the truck carriage, rather than a sudden event. Social historians observe similar trends in their studies of inventions and invention history. Most inventions are products of an incremental process and the work of a large number of people; they emerge as products of ideal conditions (Lemley 2012:711-712 citing Robert Merton 1961:470). In the case of the truck carriage, it is possible that several nations found themselves with an ongoing need to control increasingly powerful weapons, or as Caruana describes, the need to elevate and aim weapons of ever-increasing sophistication (Caruana 1994). Many probably saw the potential of the application of artillery aboard ships and worked to make that vision a reality. Therefore, the truck carriage likely represented a step in a process that extends into the 19th century and beyond, developed by a great many people. Additional research is needed to determine the people responsible for the incremental development, but some speculation is possible. It seems likely that the gunners working directly with the pieces, in conjunction with their officers and carriage constructors, used their experience to develop design improvements.

The nation or nations responsible for the invention of the truck carriage is currently unknown. *Mary Rose* researchers found an Italian artillery treatise written by Biringuccio dating to 1540. He describes the use of two-plank carriage beds, examples of which can be found aboard the *Mary Rose* (Hildred 2011:40 citing Biringuccio 1540:314). The presence of the Biringuccio treatise suggests that the Italians may have utilized truck carriages aboard their vessels before 1540. Conversely, Yorktown Victory Center researcher Nicholas Hole, formerly of the Royal Armories at Fort Nelson, suggests that the truck carriage may have been a Portuguese innovation (Nicholas Hole 2017, pers. comm). The earliest definitive archaeological evidence for truck carriages comes from *Mary Rose.* Based on the theories of inventions described above, it could be that multiple nations developed the truck carriage simultaneously, independent of each other.

English Carriages

Based on the accounts and inventories of England's King Henry VII, compiled by the Royal Records Society, carriages (wheeled or otherwise) did not appear aboard English ships before 1497 (Oppenheim 1896:xxxiv). It is possible that ships carried some form of gun carriage at this time, which were simply not noted in any inventories. The compilation's editor, Oppenheim, suggests that until early in the reign of Henry VIII, guns laid on lightly built "gun rests," or were mounted on scaffolds (Oppenheim 1896:xxxiv). Then, he argues, field carriages would have first been employed aboard ships (Oppenheim 1896:xxxiv). Gun carriage parts show up roughly eighteen years later in a 1514 inventory of the English navy, primarily represented by wheels, trucks, and linchpins. Table 2.1 below summarizes this information.

TABLE 2.1: Gun Carriage Parts in the English 1514 Naval Inventory (Knighton and Loades 2000).

Ship	Guns on "Trotill Wheles"	Guns on Iron-shod wheels	Guns on Unshod wheels	Linch pins
Henry Grace a Dieu	31	15	1	4
Trinity Sovereign	4	8	0	0
The Gabriel Royal	0	12	1	0
The Great Barbara	5	3	0	0
Great Nicholas	8	0	0	0
John Baptist	0	1	0	0
The Peter Pom Granett	0	2	0	0
The Katherine Galley	0	1	0	0
Storehouse at Erith	0	7	7	0

The table does not include every vessel in the 1514 inventory, only those which specified either the types of gun mounting they used or mentioned spare parts. "Trotill" wheels are simply another term for trucks (Knighton and Loades 2000:180). Only some ships in the inventory reported the type of carriage their guns rested upon and generally did not list the mountings for every gun. Spare stores are only occasionally mentioned. Much like the armament themselves, the carriages do not exhibit standardization. The character of the data presented in Table 2.1 may stem from carriages being irregularly supplied to ships, and therefore not universally reported. Another possibility could be that some ship suppliers did not view carriage pieces as important materials to document. A third possibility is that carriages were considered an extension of the gun, thus not reported separately. This seems to be the case with another English naval inventory, the Anthony Roll. It contains no mention of gun mountings directly, only spare axletrees, wheels, “truckelles” or trucks, wood for quoins and forelocks, and breeching rope. Spare wooden components, such as cheeks or beds, are not specified. Another marked difference between the 1514 inventory and the 1545 Anthony Roll is the level of standardization present in the latter’s format. All vessels include the same information, such as the accounting of spare parts. Table 2.2 summarizes gun carriage supplies in the Anthony Roll (the 20-ton row barges are excluded).

TABLE 2.2: Gun Carriage Supplies in the Anthony Roll (Knighton and Loades 2000).

Ship Name	Tonnage	Breeching	Spare wheels	Spare trucks	Spare axletrees
Henry Grace a Dieu	1000	10	4	4	12
Mary Rose	700	10	4	4	6
Peter	600	8	4	4	6
Matthew	600	8	2	3	6
The Great Bark	500	6	2	3	8
The Jesus of Lubecke	700	8	2	4	4
The Pawncy	450	6	3	4	6
The Murrian	500	6	1	2	4
The Struse	450	4	1	2	4
The Mary Hambrough	400	4	1	2	Unknown
The Christoffer of Breanne	unknown	4	1	2	4
The Tynite Harry	250	6	1	2	4
The Small Bark	400	6	2	3	6
The Sweepstake	300	6	2	3	6
The Minion	300	6	2	3	6
The Lartygue	100	6	0	2	3
The Mary Thomas	90	6	0	2	4
The Hoye Barcke	unknown	3	0	1	2
The George	60-100	4	0	2	3
The Mary James	60	3	0	2	2
The Grand Masterys	420-450	6	2	2	4
The Anne Gallante	450	6	2	2	4
The Harte	300	6	2	2	4
The Antelope	300	8	2	2	4
The Tiger	200	6	1	2	4
The Bull	200	6	1	2	4
The Salamander	300	6	2	2	4
The Unicorn	240	6	1	2	4
The Swallow	300	6	1	4*	4
The Galley Subtle	200	1	0	2*	2
The New Bark	200	6	1	4*	4
The Gray Hound	200	4	2	2	4
The Jennet	180	3	1	2	2
The Lyon	140	4	0	4*	4
The Dragon	140	4	0	4*	3
The Falcon	80	3	0	2*	2
The Saker	80	1	0	2*	2
The Hind	80	3	0	2*	2
The Roo	80	2	0	3*	3
The Phoenix	70	2	0	2*	2
The Marlin	40	2	0	2*	2
The Less Pinnace	40	2	0	2*	2
The Bryggendyn	40	2	0	2*	2

*=not a pair

The three largest vessels in the fleet carried four pairs of spare wheels and four pairs of spare trucks. The smaller vessels often carried more spare trucks than they did wheels. It is possible to see the nascent beginnings of supplies allotted according to ship size, perhaps as a prelude to distinct vessel classes. Trucks in the inventory were generally called "truckelles." In some instances, they are listed as pairs and likely refer to the trucks themselves; in other cases, the pair is not specified (Knighton and Loades 2000:180). The compilers of this version of the Anthony Roll suggest that this refers to the whole carriage itself (Knighton and Loades 2000:180). This would represent the first instance of the carriage being mentioned as a unit, independent of the gun. Truckelle pairs only occur in the inventories of vessels three hundred tons or less and, with one or two exceptions, are present in all vessels below 80 tons.

Because of these three inventories, a tentative timeline for carriage presence on English ships can be suggested. Prior to 1497, ships carried no separate mounting unit for their guns. Between 1497 and 1514, ships began carrying wheeled field carriages, and between 1514 and 1545 a purely naval gun carriage developed. By 1545, there were several different varieties of gun carriage for both land and sea.

The use of land gun mountings likely persisted for some time after the introduction of the four-wheeled truck carriage, perhaps as far as the early 17th century. John Smith, in his *Sea-Man's Grammar,* states that a gun carriage ought to be one-and-a-half times the length of the gun cylinder, the ratio used for field carriages (Smith 1653:133). Smith additionally lists the main difference between land and sea-service carriages as being their wheels: land carriages used spoked wheels while sea carriages used trucks (Smith 1653:86). He makes no mention of physical structure. One type of sledge carriage from *Mary Rose* rested upon solid wooden wheels closely resembling trucks, and it is possible an offspring of this type survived into Smith's time.

The conversion from field/sledge carriages to truck carriages did not occur at a universal rate across all of Europe's seafaring nations. Archaeological evidence from vessels like the carvel-built ship at Franska Sternarna (first half of the 16th century) and *Mars* (1564) indicate that the Swedish utilized sledge carriages with truck like wheels after the introduction of the truck carriage aboard the *Mary Rose* (Eriksson and Rönnby 2017:103 and Adams and Rönnby 2013:113). By 1628, the Swedish warship *Vasa* carried sophisticated truck carriages (which will be further discussed in Chapter 3). The Spanish seemingly adopt the truck carriage at a later date as well. Various 1588 Armada wrecks, such as *La Trinidad de Valencera* (Martin 1988) possess field, siege, or sledge carriages. However, as mentioned earlier, one vessel, *La Lavia* carried a truck carriage (Birch and McElvogue 1999:273). The specifics of this carriage are unknown, and there are no additional publications regarding the site. Another ship, carrying Venetian ordnance and carriages found off the Carmel Coast, Israel, dates to the late 16th or early 17th century (Ridella et al 2016:185). Conversely, A Dutch wreck lost in the 1590s, named by researchers Scheurrak SO 1, carried several three-truck carriages (Puype 2000). This site demonstrates the existence of truck carriage variants and would be worth examining in a broader study.

By 1626, the truck carriage became the preferred gun mounting for English ships. In their dictionary of ship and navigation terms, Sir Henry Manwayring and the Marquis Arthur W.P.W.B.T.S. Hill, use a truck carriage as their example of a typical seaborne gun carriage (Manwayring and Hill 1626:41). They go further to state that this carriage is superior to land-based models (Manwayring and Hill 1626:41 and Robertson 1921:143). Robertson argues that from Queen Elizabeth's time to Queen Victoria's, the gun carriage underwent no further major changes in design (Robertson 1921:143).

Later in the 17th century, gun carriages gain greater prominence in ship inventories. In an inventory of five Royal Navy ships dating from 1661-1662, both gun carriages and spare parts are listed (cited by Lavery 1984:178). Table 2.3 below displays the inventory contents.

TABLE 2.3: 1661-1662 Royal Navy Inventory, PRO WO 55/1650 (cited by Lavery 1984:178)

Carriages For:	*Royal James*	*Swiftsure*	*Fairfax*	*May*	*Montague*
Demi-cannon	23	20	20	20	20
culverin	25	28	4	4	4
Demi-culverin	22	14	22	0	26
saker	0	0	6	0	0
falcon	0	0	0	0	2
Spare parts					
sledges	3	2	1	1	1
beds	82	84	60	66	78
quoins	146	140	120	126	154
Truck pairs	8	8	6	6	8
axletrees	10	10	12	8	8

In the 1661 inventory, carriages are fully integrated components of ships stores. They are reported individually and organized by the type of ordnance they support. All five ships came equipped with most carriage types and spare materials (except for falcons and sakers). The ships carried more spare supplies than did their 1545 counterparts, though since tonnage does not appear in this inventory, no statement can be made about the relation between amount of supplies and ship size. Spare shod and unshod wheels no longer appear. This implies that the English navy no longer employed land carriages in its ship armament. The wreck of *HMS London* (1665) further suggests the predominance of truck carriage by this time (discussed by Evans 2017). By 1677, the Board of Ordnance established set guidelines for gun carriage supply for each rating of naval vessel, summarized in Table 2.4.

TABLE 2.4: Gun Carriage Supplies by Ship Rating, 1677 (cited by Caruana 1997)

Item	1st Rate	2nd Rate	3rd Rate	4th Rate	5th Rate	6th Rate
Carriages	100	90	70	54	30	20
Spare beds	12	10	8	6	4	2
Spare trucks	12	10	8	6	4	2
Spare axletrees	12	10	8	6	4	2
Breechings	100	90	54-70	54	32	20
Linch pins	400	360	280	216	128	72

Compared to the Anthony Roll, these guidelines exhibit rigid standardization, and suggest a shift in the Royal Navy's perception of carriages. The guidelines list them independent of their guns, treating them as discrete objects, no longer a mere extension of the gun.

Spanish Carriages

The earliest records for the Castillo de San Marcos (the Castillo) date to the late 16th century. A document from 1579 details some of the findings of an inspection of the Castillo by a Spanish administrator, written by Captain Juan de Junco (Junco 1579). The administrator toured the bastions and inspected the state of the artillery and other armaments. Each item is discussed in a brief narrative, outlining its location, status, and any recent modification (Junco 1579). Carriages are only mentioned in conjunction with the artillery they supported and do not have separate entries. For instance, the inventory describes one reinforced cannon as being well mounted on a new gun carriage with wheels (Junco 1579). The two other weapons with any discussion on the state of their carriages are a falcon with a worn carriage and a demi-saker on a carriage with no wheels (Junco 1579). The manner in which this document addresses carriages suggests that the Spanish also viewed them as extensions of the gun. Separate mention of them during inspection reports was unnecessary, except in conjunction with new installations or the need to replace old material. An additional Spanish document written by Luis Collado in the same century provides some additional information on carriage use in fortifications. He states that carriages can be modified for either fortress use or field use, based on the type of wheels they employ (Collado 16th century). This suggests that during the 16th century, the Spanish used the same type of carriage for field and garrison service, modifying the wheels to suit either duty. At this time, the Spanish did not seem to utilize garrison versions of the truck carriage.

By the mid-18th century, the Spanish embraced truck garrison carriages in earnest. Carriages are mentioned more frequently in inventories, such as that written in 1764 detailing the delivery of artillery supplies from St. Augustine to Havana ("Bill of Lading" 1764). The Spanish organized material by the ship from which it came. Table 2.5 summarizes the ship, artillery, and carriage components delivered.

TABLE 2.5: Carriage Supplies Delivered to Havana ("Bill of Lading" 1764)

Ship	Cannon	Carriage parts
Nuestra de la Soledad	NA	28 sides of mahogany for 4 and 6 caliber carriages with transoms and axles.
Nuestra Senora de Regla	4, 4-caliber cannons	4 wheels
Admiral Saunders	NA	10, 24-caliber carriage brackets
La Samtisima Trinidad	33, 18-caliber cannons; 1, 16-caliber	10 dismounted gun carriages (6, 24 caliber; 3, 18 caliber;1, 16 caliber)
San Antonio	2, 18-caliber cannon; 2,16-caliber cannon	8 dismounted carriages; their bolts, wheels, and axles; thirteen transoms for other gun carriages.

Like the English, the Spanish underwent some additional standardization to their inventories, organizing their information by ship and avoiding long descriptive narratives. It seems that all components to make a carriage were not necessarily delivered together. In some instances, all the needed parts (bolts, axletrees, and cheeks/brackets) are delivered together, such as aboard the *San Antonio* ("Bill of Lading" 1764). In others, components were on separate ships, such as the thirteen extra transoms, again on the *San Antonio*, or the four wheels delivered on *Nuestra Senora de Regla* ("Bill of Lading" 1764). Often, the guns and carriages were carried on separate vessels. This perhaps demonstrates that the Spanish viewed carriages as separate objects from the cannons they support. It could also simply be tied to the logistics of using small ships like schooners and brigantines to move multiple heavy objects. In 1764, light four- and six-pounder field carriages still found use in the Castillo, despite the increased use of truck carriages (Manucy 1939a).

In 1812, another inventory of the Castillo's armament took under the direction of the Spanish, during the Second Spanish Period of the fort's history. In several cases, this document only refers to carriages if the inventory compiler mentioned whether a given tube was mounted (Manucy 1939b:2). In others, a carriage was mentioned in conjunction with the tube it supported, as is the case with one of the 18-pounder iron cannons (Manucy 1939b:2). The reason for the differing ways of alluding to carriages is unknown. National Park Service (NPS) historians working with the inventory in 1939 did not have much time to examine the document and were only able to translate brief summaries (Manucy 1939b:2). It is possible the original document contains further information on carriage supplies.

The inventories discussed here suggest that the Spanish took a slightly different view of carriages than the English. Even in the latest inventory of 1812, carriages rarely get their own entry; instead, they are only mentioned in conjunction with specific cannon. Carriages are discussed in the 1764 inventory, but mostly as disassembled pieces or without cannon. It is possible the way they were shipped indicated a change in attitude towards carriages, but the separation could also be due to small ships' inability to carry a full load of cannons and the carriage parts needed for them. This suggests that the Spanish viewed the carriage as an extension of the gun, which did not need its own inventory entry.

French Carriages

The exact date the French began to use the truck carriage is unknown, though archaeological evidence from *La Belle* supports its use by the mid-17th century. It is likely that it was used even earlier. By the mid-18th century, truck carriages were the preferred mounting and reported independent of their guns in inventories, as seen in a 1757 example from Fort Carillon. The carriages in the inventory are designated as either field or naval and distinguished by the caliber of gun they could hold (C11A F102 211-213v). At this time, 28 naval carriages were stored at Carillon, 18 of which were meant to support 12-pounder iron guns, of which there were 16 (C11A F102 211-213v).

Rather than having numerous spare axletrees and trucks like the English, the French furnished Fort Carillon with whole spare carriages. One cause for this difference could be that the English inventories discussed in the previous sections all relate to shipboard practice, rather than that for fortresses. However, an examination of the ordnance inventories for the Tower of London reveal that the English generally relied on spare parts more than whole spare carriages (Blackmore 1976:222 and 278). This suggests some continuity in practice for the storage and supply of carriages on land and sea. Thus, it seems that the French and English differ in their approach to providing enough surplus to replace damaged or faulty carriages.

Supply of Truck Carriages in the Royal Navy

While the study of naval administrations, particularly that of the British, is extensive, little of the discussion centers on the construction, supply, and development of gun carriages. However, some general information is known. In 1509, responsibility for the navy lay in the hands of the monarch's personal government; in less than forty years, several additional offices developed, along with a specific office of the Naval Treasurer (Smith 1974:48). This development occurred in the context of a wider development of government administrative bodies, called the "Tudor Revolution" by historians (Smith 1974:48).

These trends eventually resulted in the Office of Naval Ordnance, which held primary responsibility for the manufacture and supply of ordnance and related material, including gun carriages (Smith 1974:54). It purchased raw materials from a wide array of sources, along with needed wheels, axletrees, and iron fittings for the carriages (Smith 1974:55). The cost of elm and ash, the primary materials for carriage manufacture, typically ran 10d a load or 10s per ton (Smith 1974:56). Wrought iron cost significantly more at ₤1 3s 4d per ton; Spanish iron used to bind carriages was roughly 12s a hundredweight (Smith 1974:56).

Suppliers shipped these materials to storehouses at major dockyards, at which point carpenters, sawyers, and other workmen repaired or built ordnance equipment (Smith 1974:55). Teams of craftsmen, recruited and supervised by a master carpenter, built and repaired carriages in addition to maintaining wharves, storehouses, and yards (Smith 1974:55). The master carpenter earned 14d a day for his work, whilst those he recruited typically earned 8d (Smith 1974:55). To mount, fit, and test ordnance, the Office of Naval Ordnance hired gunners directly, paying the master gunner 12d a day and his subordinates 8d; they held primary responsibility for placing guns onto the new carriages (Smith 1974:55). This lends credence to the possibility of naval gunners playing a role in the subsequent development of the truck carriage and primarily pushing its improvements forward. Both gunners and carpenters would have come into frequent contact with gun carriages aboard ships as well. Perhaps those with previous sea experience with the carriage eventually worked for shore facilities and influenced design development.

The supply of carriages was not always smooth or efficient. H.C. Tomlinson, in his study of the Ordnance Office, discusses the issue in detail. Several historians argue that the Ordnance Office of the 17th and early 18th centuries experienced issues with everything from corruption to sloth (Tomlinson 1975:19). Many of the reported problems occurred in the supply of gun carriages, sometimes delaying ship departures for days or weeks (Tomlinson 1975:19). For example, in 1688, efforts to get a fleet outfitted to repel William's invasion met delays because of widespread issues supplying guns and carriages (Tomlinson 1975:20). In another incident, a captain beat a storekeeper over the head with a cane because the storekeeper refused to supply gun carriages until ordnance incorrectly delivered to the captain's ship were returned (Tomlinson 1975:24). Most of these delays (or violent encounters) seemed to stem from the muddied communication lines between the Navy and Ordnance offices, and the difficulties associated with establishing a clear line of command or jurisdiction (Tomlinson 1975:20).

The storage of ordnance materials at the dockyards provided additional trouble. In the late 17th century for instance, Portsmouth lacked the necessary room to store gun carriages ashore, so ordnance officers requested instead that they be placed aboard ships in ordinary (Tomlinson 1975:33). Eventually, additional wharves and docks were built to increase the storage space, but problems persisted, as evidenced by an officer's complaint of inconveniently placed storehouses relative to the docks, contributing to a further delay in moving ordnance materials to their ships (Tomlinson 1975:33).

Despite these troubles, the Ordnance Office enjoyed immense growth throughout the centuries. Additionally, the supply and manufacture of gun carriages grew more centralized. At some point in the 17th century, primary carriage manufacture seemed to be focused in Deptford, before transferring to Woolwich in 1668 (Vincent 1885:113). Woolwich remained the primary focal point of land and sea carriage construction for the next two centuries. By 1812, gun carriage manufacture fell under its own inspectorate (under the auspices of the Carriage Department), which, along with the inspectorates for artillery and gunpowder, employed 3500 people (Morriss 2011:193). The centralization of carriage construction likely allowed for tighter control to be exerted on design, testing, and manufacture, helping in the push towards greater standardization. As such, deeper study of carriage development may someday lead to a better understanding of the development of conditions which allowed for eventual broadscale industrialization.

Supply of Carriages in the American Navy

The initial Continental Navy lacked the sophisticated naval administrations seen in other European powers and was instead run by a network of committees and boards (Dull 2012:31). Therefore, the supply of ordnance and ordnance materials was likely a decentralized affair. This changed with the creation of the War Department in 1789, which brought more direct control of the supply and manufacture of ordnance and ordnance materials to the government (Records of the Bureau of Ordnance 2016). A formal Department of the Navy came into existence in 1798 and took over the control of naval ordnance and supplies, including carriages (Records of the Bureau of Ordnance 2016 and Dull 2012:43). During this time, primary responsibility for the furnishing of ordnance fell under the direct control of the Secretary of the Navy, assisted by a three-man Board of Naval Commissioners starting in 1815 (Records of the Bureau of Ordnance 2016).

From a sizeable report to Congress issued by Thomas Jefferson in 1803, some information about the costs and supply of carriages to the early American navy can be discussed. The report covers all naval expenditures from 1797 to 1803. Naval carriages were contracted out to individual craftsmen (tracked with expense vouchers), with carriage components supplied independently. For instance, between 1 April and 30 June 1797, carriage blocks were supplied by a Mr. John Weaver at the cost of $3,724.33, while all iron components were supplied by Mr. John Dorsey for $2208.01 (Jefferson 1803:15). At this early stage, before the creation of the Department of the Navy, carriages were not furnished fully by a single craftsman. However, once the department was created, whole carriages seem to be supplied to the navy as seen in a 31 December 1798 entry detailing the $210.00 paid to Mr. William Rotchford for 14 gun carriages (Jefferson 1803:30). There are still occasional instances in which parts of gun carriages, such as bolting beds and trucks, were furnished on an independent basis. In many cases, however, entire carriages can be attributed to individual craftsmen.

One possible explanation for the shift from individual part supply to whole carriage construction could relate to the adaptation of naval suppliers to meet demand. To assemble an entire carriage, a craftsman must be skilled in both carpentry and blacksmithing. It could be that more of the suppliers began practicing both crafts in order to furnish carriages. An advantage to the shift would be that responsibility for assembling various components shifted from the navy itself to the craftsman supplying it. It suggests the development of a cadre of specialists to meet the carriage supply needs of the navy. Such specialization can be seen in the French navy of the mid-18th century. From 1750 to 1754, the French arsenal at Rochefort employed one master gun carriage and patternmaker, one second master, one foreman, and 22 day workers (Pritchard 1987:114). It is possible the American navy encouraged the development of specialized carriage makers as it matured, following in the example set by the French. More study is needed on the development of specialized craftsmen for naval purposes across both American and European navies.

Although the supply arrangement described above proved more efficient than that originally in use during the American Revolution, it did not allow for the American navy to exhibit strict standardization or control protocols on the manufacture process. Nor did it allow for centralized testing and development of new designs. The creation of the Bureau of Ordnance and Hydrology in 1842 allowed for a greater degree of control and standardization (Records of the Bureau of Ordnance 2016). It regularly published instructions for all ordnance related activities and materials. According to these publications, all carriages and related materials were built to the specifications of the Bureau of Ordnance and Hydrology (Bureau of Ordnance 1860). These specifications likely came in the form of detailed plans and schematics housed with the bureau, though the distribution of these plans is unknown, as are the people responsible for determining the specifications. These plans play a role in modern carriage recreation, such as that undertaken by Historic Ships in Baltimore for the *Constellation* (Paul Cora 2018, pers. comm).

Records of the Bureau of Ordnance housed in the American National Archives indicate that the new administrative body better met the supply needs of the navy, partly reflected in the increased sophistication of records. By 1844, the gun carriages supplied to each ship were broken down by weight, type, and cost. For instance, the Bureau supplied the sloop *Saratoga* with carriages for Paschan guns, 32-pounders, and 12-pound carronades (*Journal of Supplies* 1844). These records demonstrate an increasing diversification of both shipboard ordnance and the carriages to supply them, indicating that use of the truck carriage was likely declining by this point. The *Saratoga* was also supplied with a single spare 32-pounder carriage and spare trucks (*Journal of Supplies* 1844), seeming to mix the practices of the British and French services. A dedicated study of the *Journals of Supplies* housed in the National Archives would be beneficial and likely trace the integration of other carriage types aboard naval vessels. Such a study could also track the costs of supplying each type of carriage.

Truck Carriage Design

Documentary and archaeological evidence provide plenty of material to trace the evolution of truck carriage design. The following sections discuss the evolution of design as seen through primary sources. The *Mary Rose* is an exception, as the primary drawings of the carriages are based off archaeological evidence, rather than a treatise. Chapter 3 provides a more in-depth discussion on the construction features of carriages pulled from several archaeology sites.

Mary Rose Design

One of the best vessels for examining varieties of early gun carriages is the *Mary Rose*, which met its end on 19 July 1545, taking its crew with it to the bottom (Rule 1982:37). Douglas McElvogue, during his examination of Tudor warship anatomy, notes at least six distinct types of gun carriage aboard the *Mary Rose*, four utilizing four wheels and two which are essentially sledges with wheels (McElvogue 2015:33). Both his and Margaret Rule's books on the *Mary Rose* provide useful archaeological drawings that show basic construction details.

The four wheeled carriage types have cheeks constructed in two distinct sections, with the steps separate from the square containing the trunnion notches, as seen in the remains of the carriage for the Owen gun, in Figure 2.3 (Rule 1982:158).

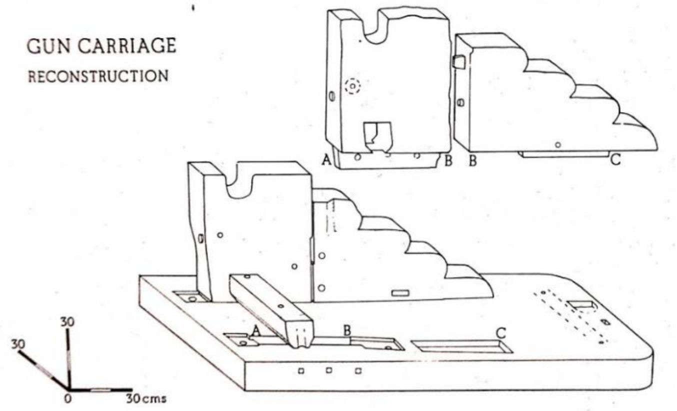


FIGURE 2.3: Owen Gun Carriage Bed (Rule 1982:165)

The Owen gun dates to 1537 and is close to twice the length of its carriage, while its wheels were close to a half meter in diameter (Rule 1982:165). Rule believes this wheel size did not reflect normal carriage practice and additionally notes that it is unknown if the carriage was original to the gun or a later development (Rule 1982:165). The cheek pieces connect to the carriage bed via mortise and tenon joints. The cheeks further support each other through the connection provided by two transverse iron bolts, visible in Figures 2.4, 2.5, and 2.6. The bed consists of one or two planks, the front edges left square and the back edges often rounded off (Rule 1982:158). There are three possible variations in the trunnion notch pieces (low, medium, and tall), which do not seem to correspond to the size of the gun, as seen in Figures 2.4, 2.5, and 2.6.

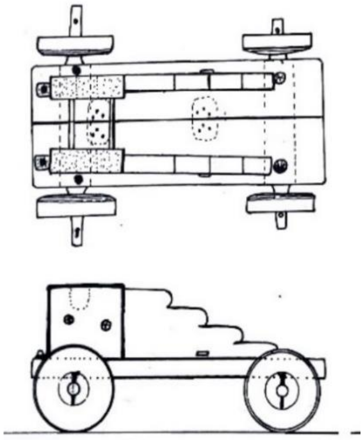


FIGURE 2.4: Reconstruction of “low” truck carriage from the *Mary Rose* (McElvogue 2015:122).

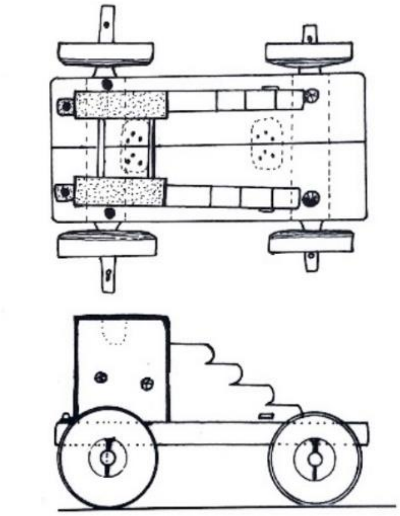


FIGURE 2.5: Reconstruction of a "medium" truck carriage from *Mary Rose* (McElvogue 2015:122).

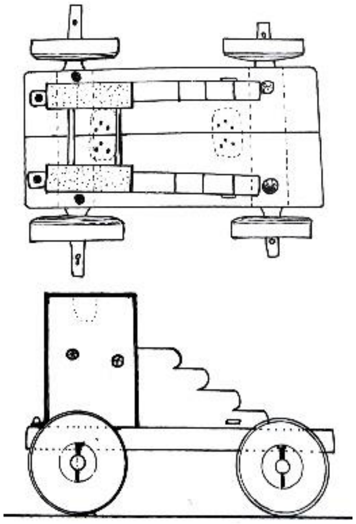


FIGURE 2.6: Reconstruction of a "tall" truck carriage from *Mary Rose* (McElvogue 2015:122).

The trunnions rest in u-shaped notches lined by iron cap squares, travelling around the square part of the cheek (Rule 1982:160). There are generally four steps of the same height, with their edges rounded off.

. Additionally, there are two ways to mount the axletrees. One method, as seen in Figures 2.4, 2.5, and 2.6, places the bed of the carriage directly atop the axletrees, which Rule suggests raises the height of the carriage, indicating its use lower in the ship (Rule 1982:160). In the other, as seen in Figure 2.3, the axletrees are placed on top of the carriage bed, with the cheeks notched to accommodate them; this gives the carriage a low-slung look and allows it to be used higher in the ship (Rule 1982:160). The trucks tend to be varied sizes, and different thicknesses, such as seen in the partial gun carriage found in the upper castle deck of the *Mary Rose* (McElvogue 2015:160).

Early 18th Century Design

Caruana provides an excellent discussion on 18th century gun carriages, pulling information from otherwise inaccessible primary sources. By the beginning of the 18th century, a single truck carriage design pushed forward from the Tudor era, called the “bracket and bed” carriage, containing two light transoms and a carriage bed running the entire length of the cheeks, as seen in Figure 2.7 (Caruana 1997:363).

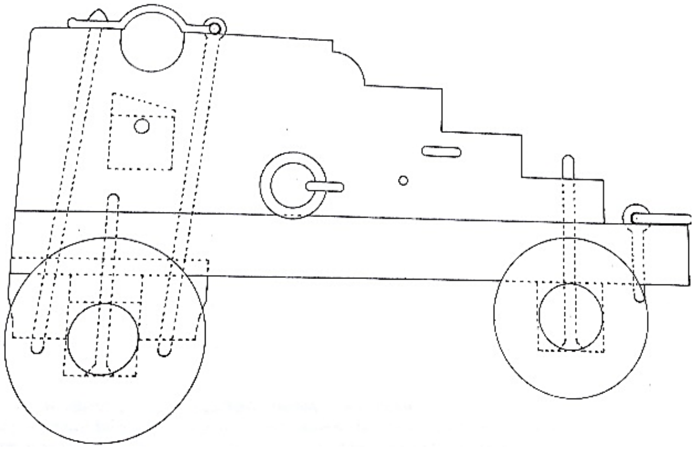


FIGURE 2.7: Bracket and Bed Carriage (Caruana 1997:363).

During the century, the British developed several new types of guns, prompting the creation of new patterns of carriage, occurring in 1725, 1727, and 1732 (Caruana 1997:364). John Muller wrote a 1757 treatise describing the 1732 carriage pattern in detail, which was followed by two more redesigns in 1791 and 1795 (Caruana 1997).

The first new pattern of carriage developed in response to Albert Borgard's new cylindrical horizontal-axis trunnion design in 1716 and 1719 (Caruana 1997:354). The change meant the brackets only contended with vertical stresses, allowing for the carriage bed and two-transom system to be gradually replaced with a single, heavier transom below the trunnions, resulting in the "bracket and transom" carriage (Caruana 1997:354). Figure 2.8 shows this design. Caruana argues that experimental use of the new design likely started in late 1724 or early 1725; based on a warrant for elm ship carriages of the "new pattern," for the warship *London,* and a bill for painting carriages "without bottoms" (PRO WO 51-116, cited by Caruana 1997:366).

However, he believes widespread use did not occur until the Armstrong class gun developed in 1727 (Caruana 1997:367). The use of beds in carriages could have extended further, to at least 1795, based on a storage and equipment list written in that year. It includes provisions for spare axletrees, trucks, and beds and quoins (Morriss 2011:199, citing TNA, ADM 160/150). An additional benefit of this document is that it definitively states that whole spare carriages were not supplied to English warships. Once designers fully eliminated the carriage bed, they carved arcs into the lower faces of the cheeks, between the trucks, though their purpose is unknown (Caruana 1997:368).

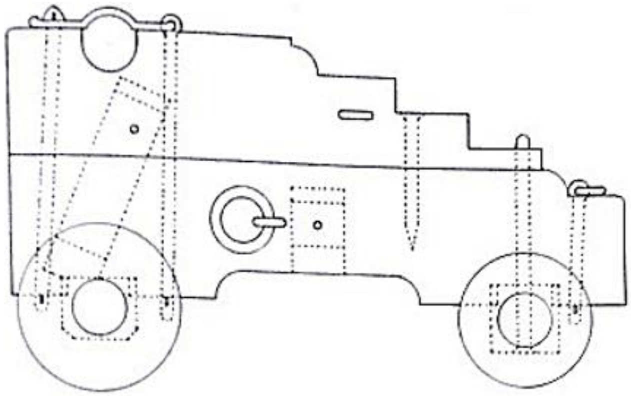


FIGURE 2.8: Bracket and transom carriage (Caruana 1997:354)

Muller's Treatise

John Muller wrote an artillery treatise in 1757, based on the 1732 carriage design. Unlike later authors and historians, Muller calls this design a ship carriage, rather than truck carriage. Muller calls a different design a truck carriage, containing two parallel cheeks or side pieces without steps, and the trucks with distinct treads. Muller states the dimensions of the carriage in terms of cannon features or shot size and provides a plan and profile view of a general ship carriage. Figure 2.9 is the plan view, which also contains annotations on the important dimensions.

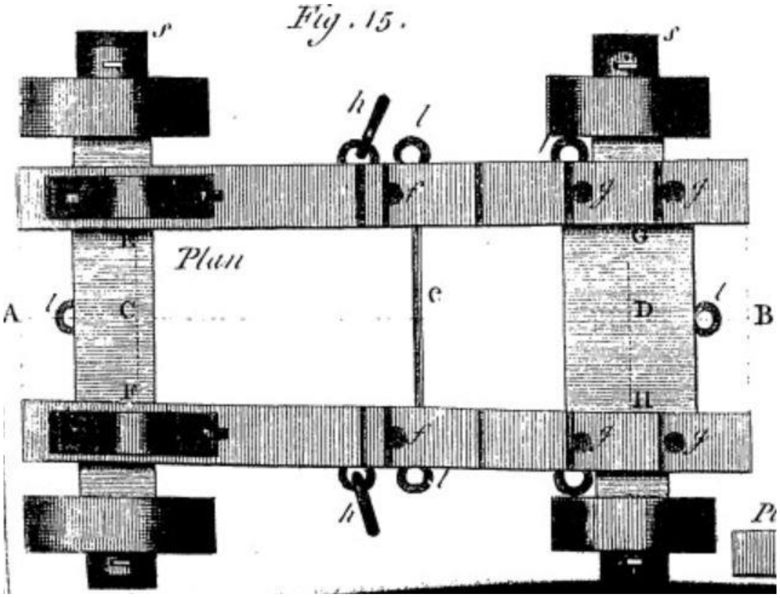


FIGURE 2.9: Plan view of Muller's ship carriage c.1757 (Muller 1757:95)

The distance between the carriage cheeks (or side pieces) narrows as the gun tapers from breech to bore (Muller 1757). The cheeks are connected through a single transverse bolt, below the first step. The carriage sports no carriage bed. The breech end of the cheeks (represented by line GH in Figure 2.9) are spaced a distance equal to half the diameter of the base ring, while the front end spacing (line EF, Figure 2.9) is equal to half the diameter of the second reinforcement ring (Muller 1757:95). Line CD in Figure 5 should equal three-sevenths the gun cylinder's length, while the thickness of the cheeks themselves equals the gun's caliber or bore diameter (Muller 1757:95). The overall length of the whole carriage (line AB) is determined by adding line CD with lines AC and DB; AC equals half the diameter of a truck with half the diameter of a trunnion, while line DB equals the length of the cascabel (Muller 1757:95). The trunnion holes are a caliber in diameter, and the centers should be located a quarter inch below the upper surface of the cheek and are aligned with the centerline of the fore axletree (Muller 1757:95). The hole is semi-circular, with a hinged cap square finishing the circle, and running a short distance on the top of the cheek, as seen in Figure 2.10.

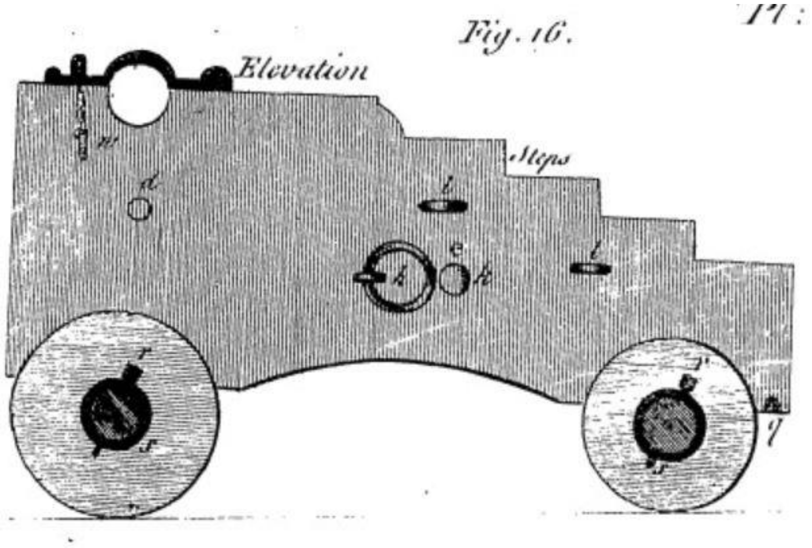


FIGURE 2.10: Profile view of Muller's ship carriage c.1747 (Muller 1757:95).

Figure 2.10 shows a profile drawing of the same gun carriage. The maximum height of the cheeks is equal to four and three-quarters the diameter of the shot, while the minimum height is half the maximum height (Muller 1757:95). The cheeks are in a single continuous section (made of two slabs of timber), smoothly connecting the forward part of the carriage with the steps. Their bottom surfaces are slightly arched between the trucks. There are four steps and one quarter round of equal height that aid in changing elevation (Muller 1757:95). The fore axletree supports a transom one shot diameter wide and two shot diameters high, placed in the middle of the height of the cheeks (Muller 1757:96). Generally, the fore trucks should be four shot diameters in diameter, while the hind trucks should be three and a half, however, this will change dependent on the height of the ship's portholes (Muller 1757:97). Their breadth should equal that of the cheeks (Muller 1757:97).

The trucks directly connect gun carriage design with ship design. If the gun port heights were standardized across all vessels, then gun carriages would be easily transferable with all fixtures. However, if a gun port height depended on its location or the size of the ship, it would indicate that the trucks themselves were built with a specific service location in mind (Muller 1757). As will be discussed in Chapter 3, in the early years of truck carriage use, trucks seemed to be tailored to operate at specific locations of the ship.

Most researchers examining British or American gun carriages utilize Muller as a baseline. However, another treatise writer, John Robertson, disputes some of Muller's work. Robertson states that, "the British establishment differs considerably from that proposed by this gentleman [Muller]" (Robertson 1775:206). Robertson, the headmaster of the Royal Academy at Portsmouth, obtained permission from shipyard authorities to measure several guns and gun carriages stored at the Gun Wharf (Robertson 1775). It is possible that the proportions he discusses more closely match reality. However, this thesis focuses primarily on comparing Muller's work with physical examples of the truck carriage rather than with Robertson.

1791 and 1795 Design

After 1732, two additional carriage patterns emerged. One, occurring in 1791, sported a forty-five-degree bevel around the outer edges of the cheeks, but otherwise remained the same as the 1732 design (Caruana 1997:379). The last design change of the 18th century occurred in 1795, following the introduction of the Bloomfield gun (Caruana 1997:379). These carriages featured breast protrusions, likely meant to help control the gun's distance from the side of the ship, and "preventer cleats" which kept the breeching and tackle ropes from entangling (Moody 1952:306 and Caruana 1997:379).

The Sea-Gunner’s Vade-mecum

The next treatise to discuss proportions in gun carriages was written in 1812 by Robert Simmons. He also used his work to advocate for an alternative carriage, which evidently reduced the manpower needed to fire a full broadside by two-thirds (Simmons 1812:128). Figure 2.11 below illustrates his version of the truck carriage.

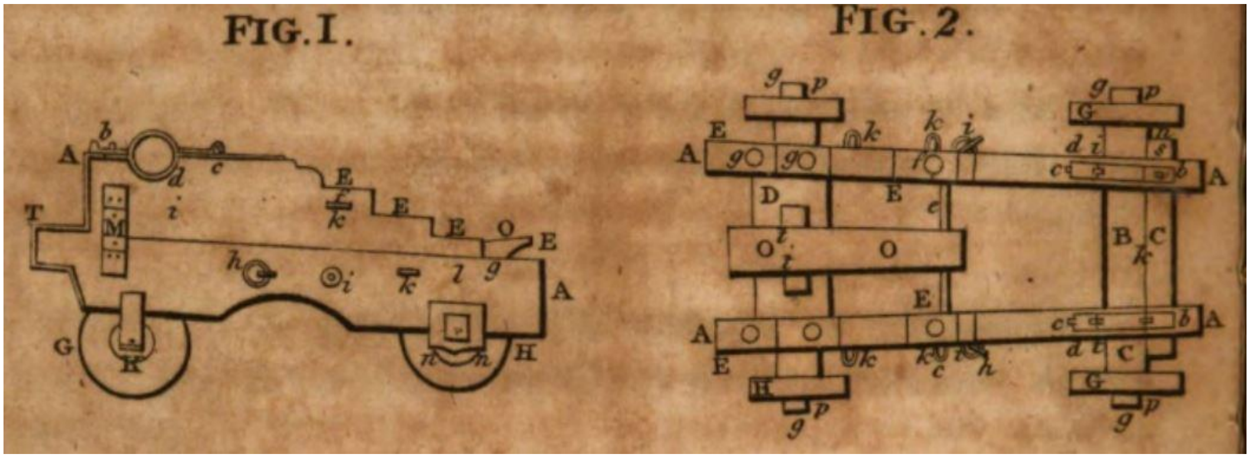


FIGURE 2.11: Simmons' truck carriage design c. 1812 (Simmons 1812)

He does not describe ideal proportions or specific relationships between the gun and carriage to the same degree as Muller or Robertson (1775). From Figure 2.11, several general design features are visible. The side pieces or cheeks decrease in elevation via four steps and a quarter round. The cheeks are continuous from the forward part to the steps; the forward part contains a square protrusion, a feature also noted by Moody (Moody 1952:306). The trunnion notch is semi-circular and covered with a hinged cap square. The fore and hind trucks seem to have slightly different diameters and are narrower than the breadth of the cheeks. The hind end of the carriage contains a stool bed, upon which the breech can rest (Simmons 1812).

Gunnery Catechism, 1870

Four wheeled truck carriages neared the end of their use by the mid-19th century. By 1851, shipboard ordnance came in two varieties: shot firing smooth bores and shell firing guns

(Bureau of Ordnance and Hydrology 1851). Gunners designated the former by the size of the shot they fired and the latter by the diameter of the bore (Brandt 1870). By 1870, all shell firing guns and larger 64-pound shot firing guns rested in pivot carriages; the rest of the shot firing guns continued to use the truck or Marsilly carriages (Brandt 1870:106). The design seen in the 1870 treatise bears a close resemblance to plans published in the early 1850s by the Bureau of Ordnance and Hydrology, as seen in Figures 2.12 and 2.13. These plans relate to carriages for VIII-inch shell firing guns (1851) and 32 pounders (1854), suggesting that, for at least a couple years, the truck carriage saw some use for newer, shell firing ordnance. The VIII-inch carriage did not possess a bracket bolt and seems to be slightly more robust than its 32-pounder counterpart, otherwise they bear a strong resemblance to each other.

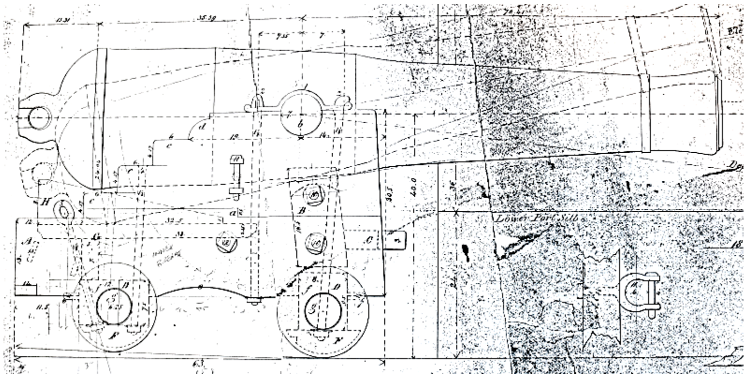


FIGURE 2.12: Carriage for VIII-inch shell firing gun (Bureau of Ordnance and Hydrology 1851).

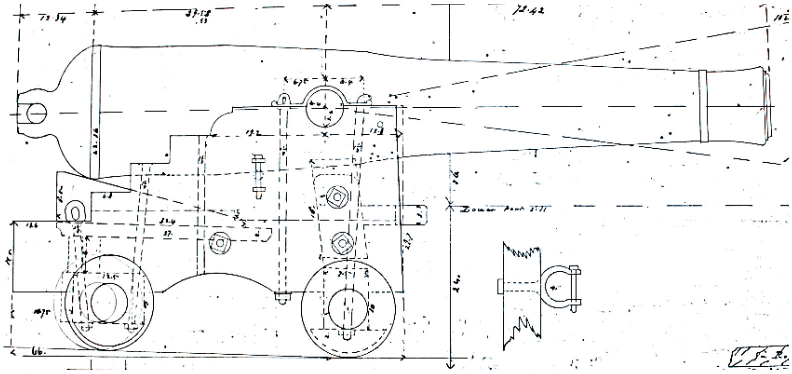


FIGURE: 2.13: Carriage for 32-pounder smooth bore (Bureau of Ordnance and Hydrology 1854).

There are several notable differences between the carriage design seen from 1850 to 1870, and that from 1812. The trucks are the same width as the cheeks, and the cheeks are a single continuous surface, without the protrusion carved into their front faces. Instead, a breast protrusion installed in front of the transom provides a buffer between the rest of the carriage and the side of the ship (Moody 1952:306 and Caruana 1997:379). The trucks are fairly close in diameter and, according to Historic Ships in Baltimore, were constructed of three disks of wood, with the seams offset to provide additional strength (Paul Cora 2018, pers. comm). The trunnion notch is semi-circular and covered with a capsquare. In the horizontal plane, the steps curve inward, as seen in Figure 2.14. Additionally, the 1850-1870 designs were relatively taller than their 1812 counterpart, allowing for a greater degree of elevation control.

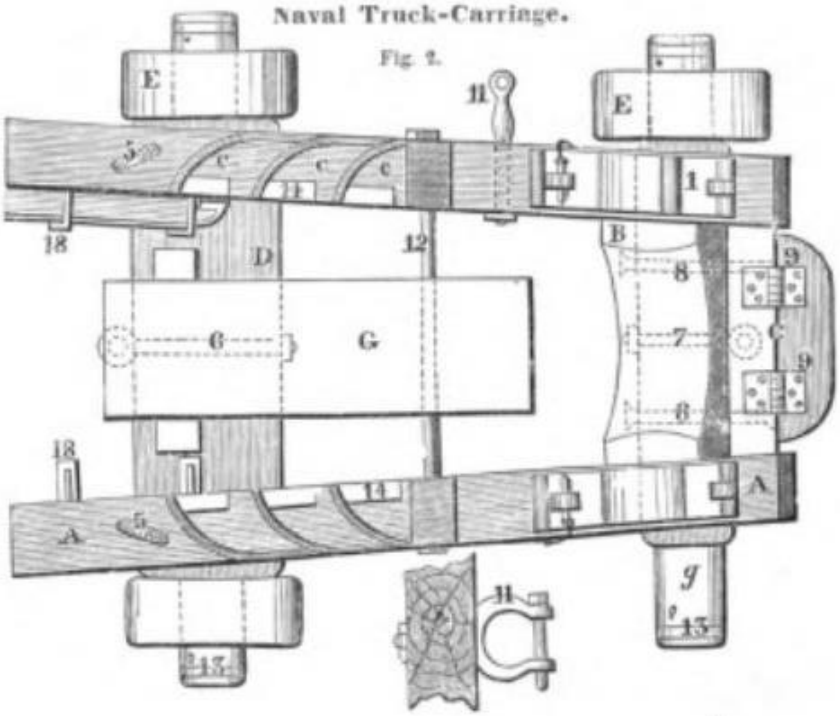


FIGURE: 2.14: Plan view of carriage in 1870 treatise (Brandt 1870).

Design Changes Over Time

Despite the allegations of disgruntled 19th century writers, the truck carriage of 1545 looks quite different from its counterparts in the 19th century. In basic features: four trucks, four steps, and made of wood, no fundamental change occurs. However, the manner of construction and several design elements receive modification over the centuries, something Moody also observed in his own research (Moody 1952:303). The most dramatic changes relate to the support system for the breech of the gun and the construction of the cheeks or brackets. In the 1545 carriages, the cheeks rested in a carriage bed, with the axletrees either above or below it, as discussed by McElvogue (2015) and Rule (1982). By 1732, a single, more substantial transom replaced the old two transom-and-bed system, as seen in Muller's treatise and observed by Caruana (Caruana 1997:359). Muller's drawing shown in Figure 2.9 does not feature a stool or stool bed, though Caruana asserts both would have been present in the 1732 pattern carriage. The stool bed, though not physically fixed to the gun carriage, likely existed in tandem with the carriage bed for a time (Puype 2000:111). It is possible that Muller did not include it in his drawings because it could be easily removed. Later diagrams include this feature. By 1812, the ship carriage featured a stool bed resting atop the hind axletree without any carriage bed, visible in Figure 2.11. Stool beds continue in use through the rest of the truck carriage's life.

The design of the cheeks underwent notable change as well. In 1545, they were constructed in two sections: a squared section containing the trunnion notch and cap square, and a second section housing the steps and is further discussed by Hildred (2011:39). The cap square iron covered all three exposed sides of the squared section. The steps were rounded off in the vertical plane and of equal size. There was no quarter round. The squared section could be three different sizes. Figures 2.4, 2.5, and 2.6 highlight these features clearly. Two transverse bolts connected the cheeks together and provided support.

In 1725, the quarter round became a standard feature of British guns (Caruana 1997:366). In 1727, designers carved arcs into the bottom surfaces of the cheeks, between the trucks (Caruana 1997:368). By 1732, the cheeks are a single continuous section, and the width difference in the forward and aft ends of cheeks is more pronounced. A single bolt connected the cheeks, along with the previously mentioned heavy transom and transom bolt. The capsquare iron was greatly reduced, covering only a small part of the upper surface of the cheek. In 1795, carriages began sporting protrusions at their fronts and cleats on their sides (Caruana 1997:379). This carriage type is featured in Simmons' 1812 manual. The maximum height of the carriage also seems slightly reduced; but because neither Muller or Simmons include scales with their carriage illustrations, it is impossible to be certain. The steps in the 1870 American gun carriage were curved in the horizontal plane, as seen in Figure 2.14. Additionally, the cheeks of these later carriages seem relatively taller than their ancestors.

The trucks also underwent some transformation as well. The 1545 trucks contained beveled edges and mounted to long skinny axletree arms which projected a fair distance (Hildred 2011:40). Their breadth seemed close to that of the cheeks. By 1748, the trucks no longer contained bevels, and the axletree arms were thicker, with less projection. The trucks, like the cheeks, were a caliber wide (Muller 1757:97). This persisted through 1812 and into 1870. As seen in Figure 2.13, the front and rear truck diameters seem very similar.

Proportional Changes

Muller and Simmons include detailed dimensions for the carriages of the most common guns of their times. Table 2.6 compares their designs for a 32-pounder gun.

TABLE 2.6: Dimensions for a 32-pounder Carriage (Muller 1757 and Simmons 1812)

Carriage Part	1757 Dimensions (Inches)	1812 Dimensions (inches)
Width enclosed before trunnions	18	18
Width enclosed after trunnions	23.5	26
Fore axletree length	57	57
Fore axletree body length	36.6	36
Fore axletree body height	10.8	10.75
Fore axletree body breadth	6.8	6.75
Axletree arm length	10.2	10.125
Axletree arm diameter	6.2	6.125
Hind axletree length	57	57
Hind axletree body length	36.6	36
Hind axletree body height	6.8	6.37
Hind axletree body breadth	12	12
Fore truck diameter	19	19
fore truck breadth	6	6
Hind truck diameter	16	16
Hind truck breadth	6	6
Side piece height before trunnions	26.2	26
Side piece length	78	76
Side piece breadth	6	6
Trunnion distance from front of side piece	8	8

Proportion-wise, the two carriages were extremely similar. The greatest change in any dimension was two-and-a-half inches. The 1812 carriage had a wider space for the breech, and the side pieces were shorter. These two treatises suggest that there existed some level of design stability for at least 64 years. However, as will be discussed in Chapter 4, examination of physical gun carriages reveals several deviations from the proportions and measurements listed in artillery treatises. Statistical testing further shows that, broadly speaking, the truck carriage underwent design and proportional changes over the course of its history.

Conclusion

Though often maligned in the 19th century, the naval truck carriage represents an integral component of shipboard cannon technology and is therefore of great historical and archaeological significance. The truck carriage underwent some notable changes from the 16th century English navy to the American navy of 1870. They transformed from irregularly mentioned obscure naval stores in the 16th century to integral, standardized gunnery material by the late 17th century.

Naval ordnance administrations held primary responsibility for the supply and construction of naval gun carriages. Carpenters and gunners employed by these organizations likely played a key role in their creation and subsequent development. It is possible that the need to supply truck carriages eventually led to specialized craftsmen with training in both carpentry and blacksmithing to meet naval demand.

Evolved from stock mountings on either land or sea, the truck carriage quickly overtook other gun mountings for sea service. From 1545 to 1748, the construction of the cheeks, placement of axletrees, the shape of the trucks, and the support system for the breech and body of the gun all underwent notable alterations. By 1748, basic proportional rules dictated carriage design, which treatises suggest remained relatively unchanged through 1812. Between 1812 and 1870, the diameter of the trucks changed yet again, as did the shape of the steps, and the height of the cheeks. Statistical testing described in Chapter 4 contradict some of these findings and will be described further.

Great potential exists in further archival and archaeological research into gun carriages, and they are an important technology to study. There exists little comparative analysis of truck carriages between various nations, nor are carriage manufacturing processes well understood.

More can be learned of the supply, maintenance, and general design of carriages through records existing in places like the National Archives and Greenwich National Maritime Museums. The physical examination of gun carriages, pulled from museums and archaeological sites, would further refine design and construction changes and allow for the proportion system expressed by Muller to be evaluated. Preliminary efforts in this direction are discussed in Chapter 4. Additional research could tie together gun design changes with that of the carriage, expanding on Caruana's work, providing a clearer picture of cannon technology than currently in existence.

Finally, the truck carriage can shed some light on the practices of naval gunners and the craftsmen involved in carriage construction and testing. These people are likely behind the various developments described in this chapter, giving them a lead role in pushing forward artillery development. Through studying their work and lives, the conditions (social, intellectual, and technological) that allowed for advancing standardization in artillery and other naval technologies can be better understood.

CHAPTER 3
GUN CARRIAGE ARCHAEOLOGY

Introduction

Archaeology accounts for a great deal of knowledge related to the truck mounting. Intact carriages can shed light into construction and manufacturing practices, along with patterns of modification and reuse. In instances they are at their stations, such as with *Vasa* or *Mary Rose,* they provide a glimpse of the organization of gun decks and the partition of space. The focus and attention given to gun carriages vary from project to project. Several, such as those associated with the *Mary Rose*, *Vasa*, *La Belle*, and *Betsy* serve as excellent case studies, highlighting the usefulness of gun carriages to archaeologists. There are also many other sites upon which archaeologists found gun carriages, awaiting further attention by researchers. The purpose of this chapter is to present four case studies highlighting the contributions gun carriages make to archaeology projects and to suggest future avenues for research.

Sources

Several types of sources furnished data for this chapter. The *Mary Rose* and *La Belle* both produced sizeable publications containing construction narratives, scaled photographs and drawings, and measurements. The *Vasa* Museum (Vasa Museet) in Stockholm, Sweden maintains an online version of their collections for the public, allowing direct examination of the carriages in their inventory. Researchers are also in the process of publishing a monograph series. Because most of the carriages in the collections database are shown disarticulated, features normally not readily visible are clearly discernable. This highlights the usefulness of partially intact carriage components as well as fully assembled examples. Appendix C contains a table summarizing some of the archaeological work conducted on sites with gun carriages or carriage parts. It was compiled using research from the Joyner Library at East Carolina University and the *Encyclopedia of Underwater and Maritime Archaeology* by James Delgado.

Archaeology of Gun Carriages

The following four sections will detail the archaeological methods, conservation, curation, and major findings related to gun carriages pulled from the *Mary Rose, Vasa, La Belle,* and *Betsy*. Each of these projects produced extensive publications and their carriages are part of exhibits. They contribute greatly to general knowledge of gun carriage construction and organization, adding unique insight into the wrecks upon which they were found.

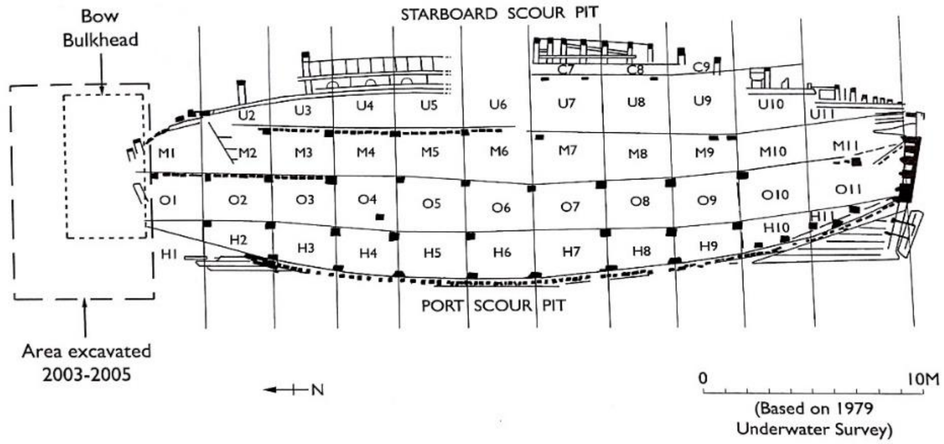
Mary Rose

Discovery and Excavation

Mary Rose served as one of the most advanced ships in Henry VIII's navy, preserving an evidence of a massive naval modernization effort (Hildred 2011:xxx and 1). Commissioned in 1512, *Mary Rose* enjoyed a long career and experienced a major refit in 1531 that modernized it (Hildred 2011:9). On 19 July 1545, *Mary Rose,* took most of its crew to the bottom during an engagement with French forces, becoming half embedded in sediment on its right side, at a 60-degree angle (Hildred 2011:xxx and Rule 1982:59). Initially, Henry VIII wanted the vessel salvaged, but efforts to do so bore no fruit and eventually *Mary Rose's* location was forgotten (Rule 1982:42). The exposed portions of the ship spent the next several centuries eroding away (Hildred 2011:xxx). Overtop the Tudor layer of silts, a layer of hard clay developed, further protecting the wreck (Rule 1982:42).

It remained lost until the 1840s, after John and Charles Deane found some exposed timbers that regularly snagged fishing nets (Rule 1982:45). They recovered several guns and turned them over to the Board of Ordnance, which immediately formed a committee to manage the objects (Rule 1982:45). The Deane brothers spent the next four years recovering an assortment of objects, including skulls, additional guns (some associated with elm beds), pottery, and yew bows (Rule 1982:46).

After the Deane’s interest, the site was again left alone and remained undisturbed until the 20th century. During the latter half of the 1960s, journalist Alexander McKee started “Project Solent Ships”, with the help of the British Sub-Aqua Club, to search for *Mary Rose* and other historic vessels in the Solent (Mary Rose Trust 2018a and Rule 1982:47). In 1967, McKee convinced EG&G International to run one of their sonars over a location marked on a map the Deane brothers produced in the 1840s (Rule 1982:50 and 52). They undertook general exploration of the area but did not find ship remains until 1971 (Rule 1982:56). From 1972 to 1976, archaeologists cut exploratory trenches into the seabed outside the wreck; one such trench cut across the bow of the ship confirmed that it was mostly articulated (Hildred 2011:xxxi). Figure 3.1 shows the location of this trench. They spent the next few years mapping the exposed timbers and uncovering additional artifacts (Rule 1982:58).



FFIGURE 3.1: Trench system for the Mary Rose Excavations (Hildred 2011:xxxv).

The team reorganized into the Mary Rose Trust in 1979, supported by a full-time staff, 5000 volunteer divers, and numerous shore-based volunteers (Mary Rose Trust 2018a). In 1980, archaeologists opened 12 three-meter-wide parallel trenches that crossed the ship east to west (Hildred 2011:xxxi). The sides of these trenches coincided with the exposed ends of major deck beams, with the ship's decks delineating different sections (Hildred 2011:xxxi). Figure 3.1 shows the resultant grid system.

As seen in Figure 3.1, each "unit" in the grid system was identified by the deck (Hold, Orlop, Main, or Upper) and trench (1 through 12) in which it resided (Hildred 2011:xxxi). Archaeologists excavated the hull deposits stratigraphically, assigning context numbers to each layer, and utilizing the direct survey method to record several of the objects they uncovered (Hildred 2011:xxxi). After establishing a system of datums and linking them to the UK National Grid system, they measured key objects and features to four datums (Rule 1982:96 and Hildred 2011:xxxi). Subsequent artifacts were then mapped in relation to these items using triangulation, trilateration, or direct tape measurement (Hildred 2011:xxxi). Every artifact received an alphanumeric ID noting the year it was uncovered, its object type, and a four-digit sequential number (Hildred 2011:xxxii). All the gun carriages from *Mary Rose* carry the "A" or "artifact" designation. All finds, including the carriages, were listed in a sequential finds journal containing its unique identification number, association, context, and positional details (Rule 1982:89). The team duplicated this information onto find cards, which accompanied the objects onshore and were updated to include material, object type, and measurements (Rule 1982:89). Finally, shore personnel drew and photographed the artifacts before sending them to conservation (Rule 1982:89).

All the *Mary Rose* gun carriages utilized in this thesis were excavated between 1979 and 1981 and were primarily focused on the main and upper decks, in the waist or stern. One carriage was located in the bow. Table 3.1 summarizes the carriages utilized in the database, the type of guns they carried, the year of the guns' castings, and basic provenience information.

TABLE 3.1: Carriages of the *Mary Rose* (Derived from Hildred 2011)

Carriage ID	Gun ID	Type	Year	Location aboard ship
26	79A1276	Cannon royal	1535	Port, main deck, amidships
27	81A3003	Cannon	Unknown	Starboard, main deck, amidships
28	81A3000	Demi cannon	1542	Starboard, main deck, stern
29	79A1277	Demi cannon	1542	Port, main deck, stern
30	81A3002	Demi cannon	1535	Port side, upper deck
31	81A1423	Culverin	1543	Starboard, main deck, bow
34	80A0976	Culverin	1535	Starboard, upper deck, stern

Though the date that the truck carriage first came aboard the *Mary Rose* is unknown, archaeologists found eight out of *Mary Rose's* ten bronze guns associated with early truck carriages, demonstrating a clear link between gun type and mounting (Hildred 2011:37). Four of the gun and carriage pairs were discovered run out through lidded gun ports, still at their action stations (Rule 1982:120). Divers raised three of the gun and carriage pairings (81A1423, 81A3000, and 81A3003) together as single units; two other guns (79A1232 and 80A0976) had to be removed from their mountings underwater and the components raised individually (Hildred 2011:37). The final gun (81A3002) was found upside down beneath the upper deck in the stern, suffering from damage associated with salvage (Hildred 2011:37).

By 1982, the Mary Rose Trust team completely cleared the hull of artifacts and set about recording the hull in detail, in part to allow for the construction of a purpose-built support cradle (Rule 1982:103). After deciding to raise the vessel, the Trust constructed a stilt frame and cradle to lift it from the seabed via crane (Mary Rose Trust 2018a). The wreck broke the surface for the first time since 1545 on 11 October 1982 (Rule 1982:214).

Conservation

After mapping and recovery, artifacts were often cleaned and measured; most wooden objects were then sent to a warehouse leased by the Trust for conservation (Rule 1982:91). Most spent some time in passive storage while awaiting attention by conservators; small objects sat in bags of polyethylene glycol (PEG) and larger timbers resided in unsealed water tanks (The Mary Rose Trust 2018b).

Generally, the team aimed to conserve objects of similar materials and size together (Rule 9182:94). Typical practice for wooden artifacts started first with the removal of soluble and insoluble marine and iron salts (Rule 1982:92). Researchers used a cascade washer to remove the soluble marine salts, followed by a 24-hour soak in a five percent disodium salt of ethylene diamine tetracetic acid bath to remove insoluble iron salts (Rule 1982:92).

Objects spent the next six weeks soaking in solutions of PEG 3400, increasing in concentration from five percent to 25 percent in two-week increments (Rule 1982:93). Next, they sat in PEG heated to 35-40 degrees Celsius in varying concentrations, starting at a concentration of 25 percent and increasing to 50 percent in week long intervals (Rule 1982:94). Finally, conservators freeze-dried the artifacts at -20 degrees Celsius, sublimating them in a vacuum chamber (Rule 1982:94).

Conservators devoted sizeable effort to coming up with improved conservation methods for wooden and composite objects recovered from the wreck (Rule 1982:92). Over the course of this process, they eventually developed a slightly different technique for composite wooden and iron objects, such as gun carriages. Researchers found that acid formed in composite wood-iron artifacts upon exposure to oxygen, due to the presence of iron and Sulphur (The Mary Rose Trust 2018b). The *Mary Rose* Trust treated composite artifacts with strontium carbonate to neutralize the acid. It is likely that the gun carriages underwent this treatment, as well as the general protocol for wooden artifact conservation following their recovery.

Curation

The ship and its artifacts currently reside in the Mary Rose Museum, part of the Portsmouth Historic Dockyard. Most of the gun carriages and their guns have finished their stabilization programs and are now integrated parts of museum displays (Alastair Miles 2017, elec. comm).

Major Findings

The *Mary Rose* possessed the earliest known shipboard truck carriages. The Trust discusses these early constructions in *Weapons of Warre: The Armament of the Mary Rose*, the third in the *Archaeology of the Mary Rose* series. All of them follow the same basic construction patterns and share the same inventory of parts: a rectangular carriage bed, two-piece cheeks, two axletrees, and four trucks (Hildred 2011:39). Mortise and tenon joints, wrought iron bolts and wedges, and oak pegs secure the carriage components together (Hildred 2011:39). They also share the same capsquare mechanism. Figure 3.2 shows a typical *Mary Rose* truck carriage and demonstrates the manner in which its parts fit together. Several important details regarding the placement and organization of the gun carriages were revealed through the analysis of construction and will be discussed throughout the next few paragraphs. There exists some variation off this basic design, including differing heights for the front and rear portions of the cheek, the construction of the carriage bed, and the placement of the axletrees. Additionally, there are several instances in which modification and reuse patterns are clearly visible.

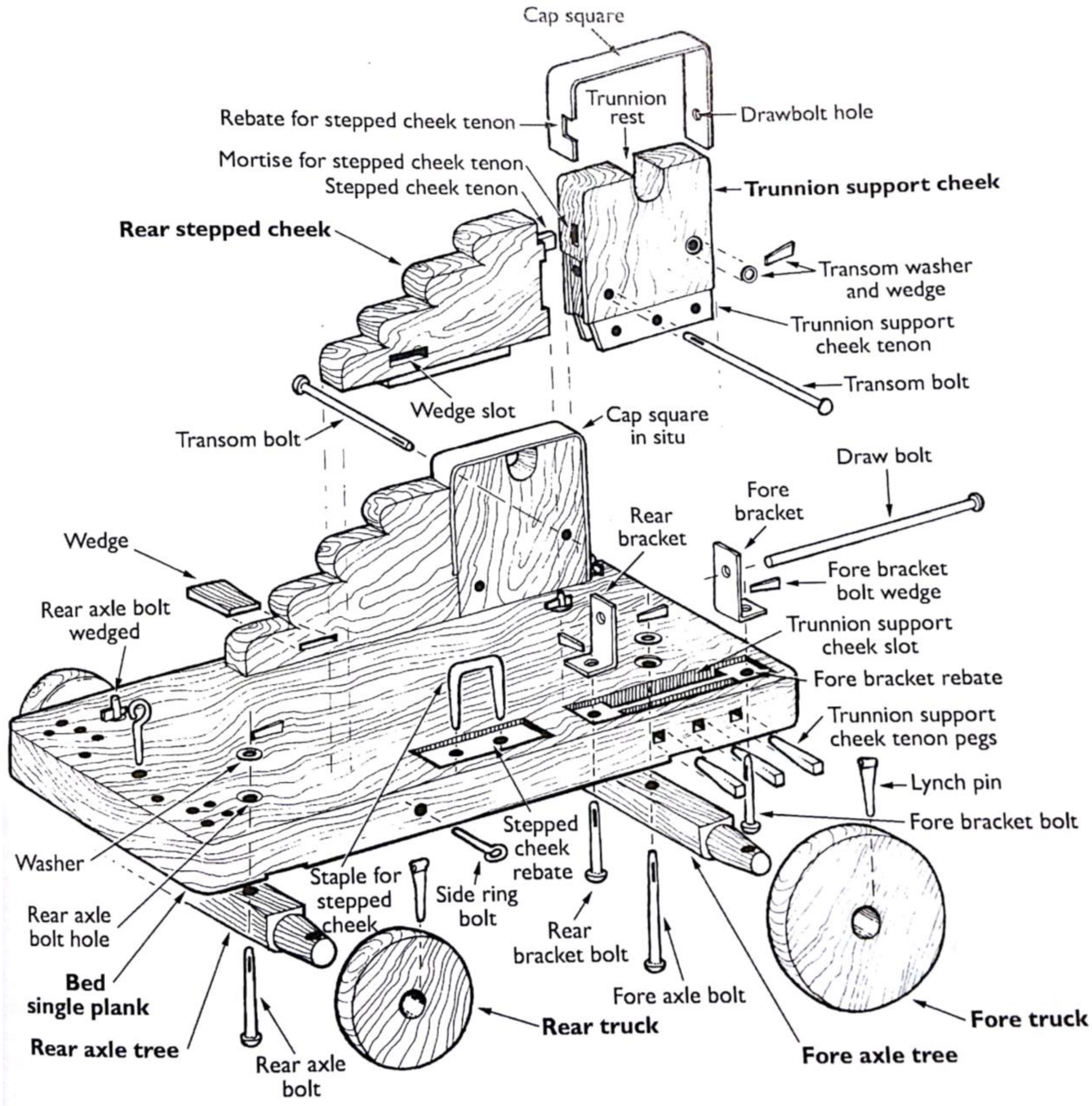


FIGURE 3.2: Parts of the early truck carriage (Hildred 2011:41).

The carriage beds aboard the *Mary Rose* are built either of a single large plank or two smaller planks (often made of elm) held together with tongued joints secured with wooden pegs; the two-plank design matches Italian artillerist Biringuccio’s description of ship carriage mounting from 1540 (Hildred 2011:40). The two-plank design also allowed the builder to utilize smaller, younger trees rather than harder-to-find older trees, which may serve useful purposes in other areas of ship construction (Hildred 2011:40). The two guns attributed to Italian gun founder Arcana (79A1277 and 81A3002) rested on two-plank carriage beds, matching Biringuccio's design (Hildred 2011:40). Figures 3.3 and 3.4 showcase the differing bed designs. The carriage bed in Figure 3.4also displays evidence of modification to hold the demi cannon with which it was found (Hildred 2011:61). The remains of two axlebolt holes are visible on the rear edge of the carriage, with a partial recess corresponding to it on the bed's bottom face. Eight inches further forward are a newer set of bolt holes with no corresponding rebate (Hildred 2011:61). The carriage bed has also been shortened.

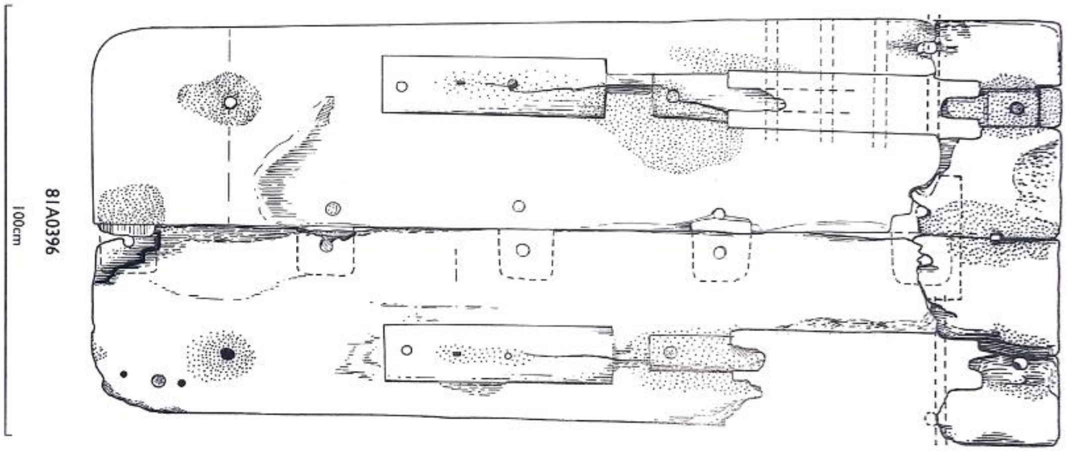


FIGURE 3.3: Double planked carriage bed (Hildred 2011:67).

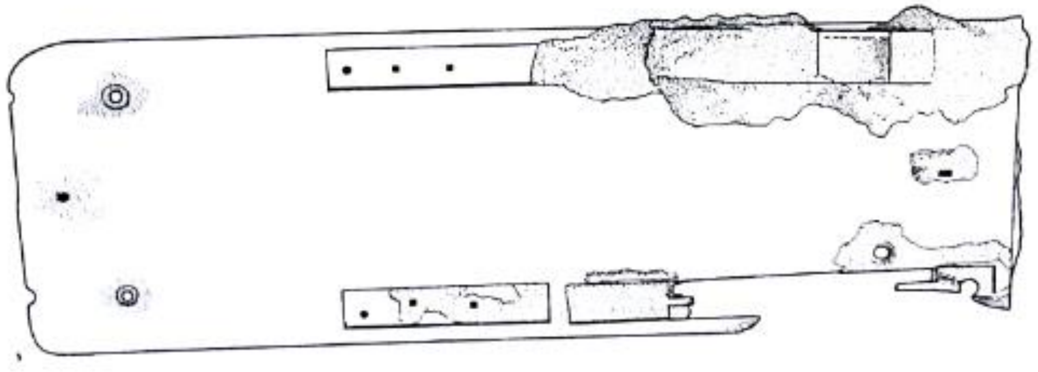


FIGURE 3.4: Single plank carriage bed for gun 81A3000 (Hildred 2011:62). Not to scale

The cheeks rest atop the carriage bed, as seen in Figure 3.5. Those for *Mary Rose's* gun carriages consist of two parts, one containing the trunnion rest and the other the steps. Researchers believe this division prevented splitting, which would likely occur upon firing of the guns and that later improvements in recoil dampening allowed for the transition to single piece cheeks (Hildred 2011:40).

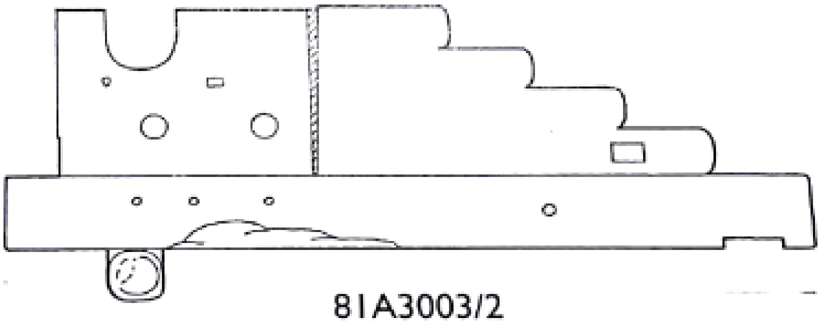


FIGURE 3.5: Profile view of Carriage 81A3003 (Hildred 2011:53).

The foremost part of the cheek (trunnion support cheek or TSC), contains the trunnion rest or trunnion notch. The TSCs connect to the carriage beds through single or dual parallel tenons, which fit into corresponding mortises in the carriage bed, visible in Figure 3.2 (Hildred 2011:40). They are secured through three oak pegs driven through the sides, seen in Figure 3.5. Internal iron brackets surrounding the TSC and two wrought iron transom bolts provide additional supports to the forward part of the carriage (Hildred 2011:40).

Researchers believe the height of the TSC dictated the location at which the carriage operated within the ship. The five carriages with the same maximum heights for both parts of the cheek were found on the main gun deck, where extreme elevation requirements were unnecessary, as the lower sills on the gun ports were only between 16.2 inches and 25 inches tall (Hildred 2011:43). They are also all culverins, demi cannon, or cannon. The bronze guns placed on the upper deck, however, required higher elevations due to the increased height of the gun port, the lower sills being roughly 40 inches in height, necessitating taller TSCs (Hildred 2011:44). Two of the carriages aboard the *Mary Rose* are of the “tall” variety and are additionally supported with two ancillary wooden transoms (Hildred 2011:45). The gun’s function likely dictated elevation needs as well, making researchers believe that a combination of firing location and gun function determined the height of the trunnion support cheek (Hildred 2011:44). Figures 2.4 through 2.6 in Chapter 2 show the varying heights of the TSC. Figure 3.6 is a reconstruction of the gun organization aboard *Mary Rose.*

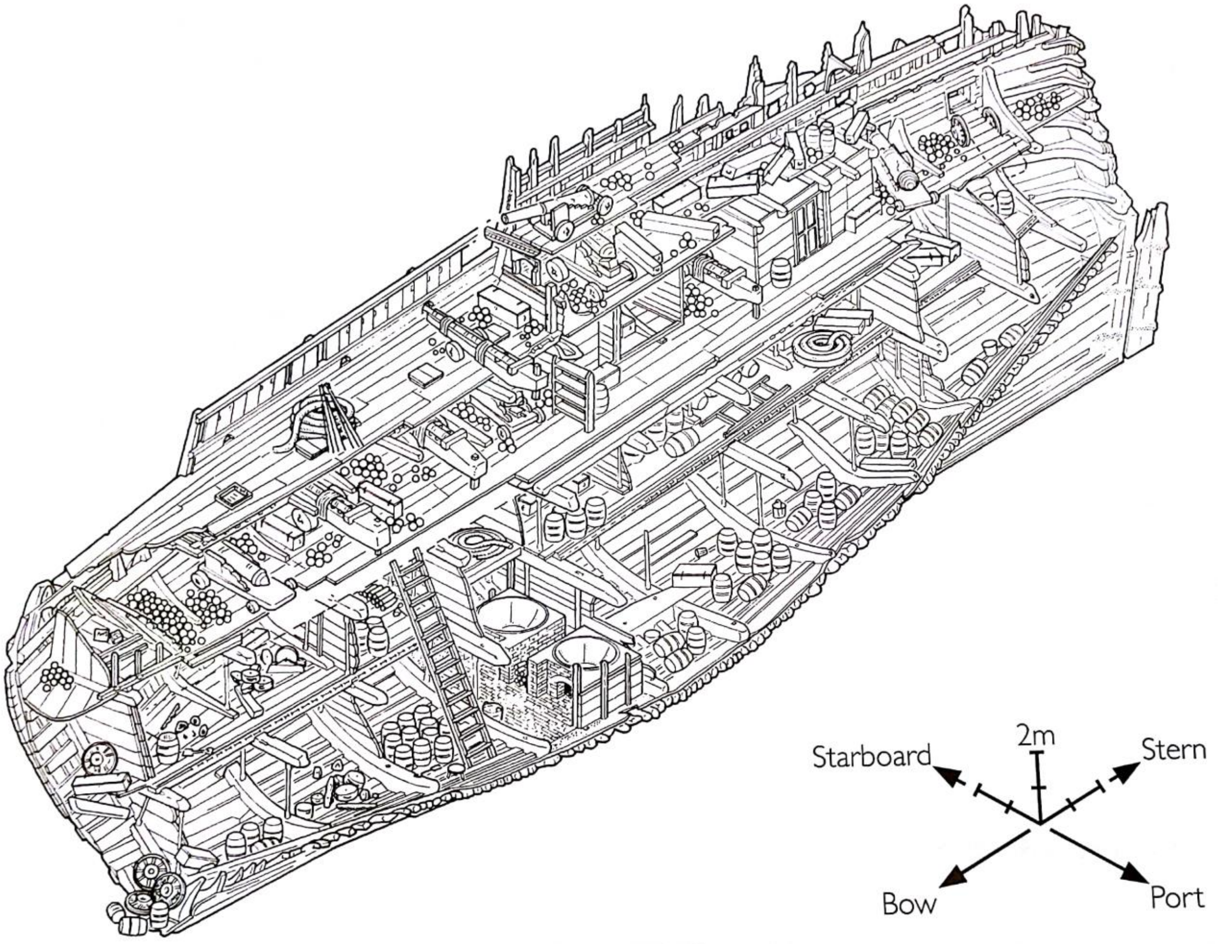


FIGURE 3.6: Reconstruction of gun locations and equipment organization *(*Hildred 2011:xxxiii*).*

Figure 3.6 clearly shows the two “taller” carriages placed on higher decks within the stern castle, while the “shorter” carriages are visible along the main gundeck as described by Hildred (2011). The rear stepped cheeks (RSCs) make up the second component of the cheek system and contain four heavily curved steps, which aid in the elevation of the gun (Hildred 2011:40). They are typically constructed of elm. The back face of the TSC contains a rebate, into which a tenon carved into the front face of the RSC fits (Hildred 2011:40). This tenon tends to be placed closer to the outside face of the RSC, giving it a definitive left and right side (Hildred 2011:40). A shallow tenon running the full length of the bottom face of the RSC slots into a corresponding mortise in the carriage bed, anchoring the two together (Hildred 2011:40). Additionally, the RSCs are often hollowed out to accommodate a large staple or pronged plank. The grain in the RSCs runs perpendicular to that of the TSCs, to aid in directing the force of the gun discharge down the length of the carriage bed (Hildred 2011:40).

There is some evidence that the rear stepped cheeks could be modified to accept larger guns than for which they were originally built (Hildred 2011:69). The inner faces of Carriage 79A1277’s RSCs are relieved slightly to allow for the gun to barely fit. Additionally, the cascabel aligns with the very end of the carriage bed and the gun barely tops the higher placed transom bolt (Hildred 2011:69).

The capsquare secures the guns to the cheeks. The capsquare, visible in Figure 3.2, consists of a three-sided wrought iron strap, with sections cut out to fit around tenons and bolts (Hildred 2011:40). It overlaps the front and rear faces of the TSC and is held in place with a draw bolt piercing through the front face of the TSC (Hildred 2011:40). This bolt passes into the rear stepped cheek and is held in place with wedges. Both the RSC and the draw bolt must be removed before the capsquare can be removed (Hildred 2011:41).

The axletrees, constructed from ash and visible in Figure 3.7, are either mounted to the bottom face of the carriage bed or placed on top of it, giving the carriage little clearance above deck level (Hildred 2011:40). The rear axletree rests in a shallow groove running the width of the carriage bed (Hildred 2011:41). The axletrees' grains run perpendicular to that of the carriage bed itself, directing the force of weapon detonation down to the trucks; their ends are chamfered to accept the trucks, which also have holes drilled into them to accept linchpins to secure the trucks (Hildred 2011:41). The front axletree aligns directly below the trunnion rest, whilst the rear axletree is mounted behind the rear stepped bolt (Hildred 2011:40-41). They are each secured with a pair of wrought iron axlebolts driven from the bottom faces into the carriage bed (Hildred 2011:41).

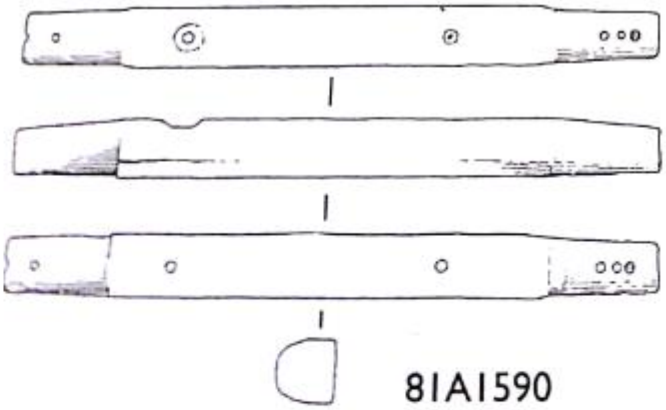


FIGURE 3.7: Front axletree for Carriage 81A3000 (Hildred 2011:53).

The trucks are convex on their inner faces to reduce rubbing and sticking and attach to the axletree arms; those at the front of the carriage are larger than their rear counterparts (Hildred 2011:40). The diameter and thickness of the trucks vary depending on the position of the ship and the weight of the gun. Carriages found in the upper and castle decks have trucks with larger diameters and thinner widths than those on main deck carriages, which have smaller trucks (Hildred 2011:44). Trucks are also sometimes modified to work in specific areas of the vessel. For instance, in Carriage 81A3000, the right fore truck is 3.5 inches smaller than the one on the left; at the station it was found, a knee had a groove cut into it to accept an object of this size (Hildred 2011:64). This indicates that both the ship and the carriage were adapted for specific guns to function at specific locations; the gun itself was cast in 1542, so these modifications are amongst the newer ones aboard the *Mary Rose* (Hildred 2011:64). Researchers also hypothesize that Carriage 79A1277 possessed similarly modified trucks to allow smooth operation near a knee or chocked up in some manner to increase its sternward angle (Hildred 2011:69). Figure 3.8 shows the rear trucks for 81A3003 and Figure 3.9 shows the modified trucks for Carriage 79A1277.

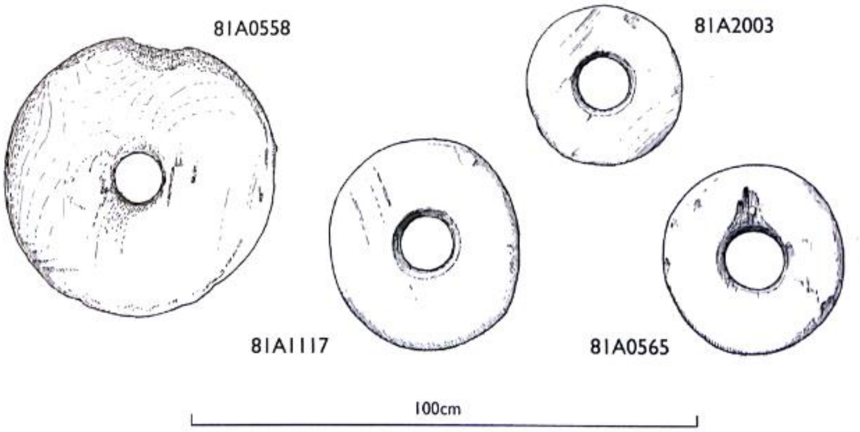


FIGURE 3.8: Trucks for Carriage 79A1277 (Hildred 2011:68).

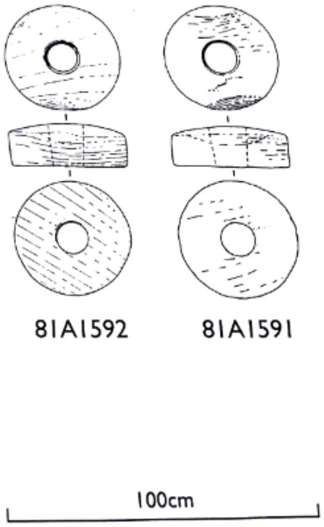


FIGURE 3.9: Rear trucks for Carriage 81A3003 (Hildred 2011:53).

The archaeological evidence shows that these early carriages were heavily constructed, able to support some of the earliest bronze artillery afloat. While many of the carriages seem to have been built specifically for their guns (Rule 1982:162), there also exists evidence of modification and reuse (Hildred 2011). This suggests that the effort and craftsmanship required to build the carriages prompted dockyard officials to look for any way to repurpose older carriages. It could also reflect a critical need for new mountings. Another possibility is that it was more cost and time effective to modify a carriage to operate at a certain location or with a certain type of gun than to build a new carriage from scratch. In any case, the carriages seem to represent a sizeable investment of materials, labor, and cost.

Vasa

Discovery and Excavation

Gustav II Adolf ordered the construction of the *Vasa* as part of a large shipbuilding program based out of the yard at Skeppsgården in Stockholm, which began in 1618 (Vasa Museet 2016). It was part of a broader military modernization and expansion initiative aimed to make Sweden a major Baltic power. Part of that modernization included the standardization of land and sea weapons and the ancillary support technologies (Vasa Museet 2016). The 24-pounder cannon aboard the *Vasa* represent a new design which found concurrent use as land based mobile siege weapons. They were half the weight of the traditional naval 24 pounder and exhibited a greater degree of standardization (Vasa Museet 2016).

Like the guns, the gun carriages were more heavily standardized than previously seen in the Baltic (Vasa Museet 2018a). Prior to 1622, their manufacture occurred in a specialized workshop at Lådmakargården at Norrmalmstorg before migrating to the navy yard in Skeppsholmen (Vasa Museet 2018a). Although the ship sailed with eight of its guns missing, the carriages for them had already been delivered, suggesting that carriage manufacture occurred independent of the tubes (Vasa Museet 2018a).

Vasa sank on 10 August 1628 within minutes of setting sail, in front of a large crowd of onlookers (Vasa Museet 2016). During the 1680s, salvagers recovered most of *Vasa's* guns from the wreck (Cederlund 2006:142). Interest in the vessel persisted over the next several centuries, as evidenced by numerous records of soundings, possible diving operations by the 1840s, and artifact recovery (Cederlund 2006:42). *Vasa* researchers believe it possible that the Swedish navy conducted training dives on *Vasa* during the 1930s. However, it was not until the work of Anders Franzén that interest in the wreck expanded beyond simple searching, soundings, or irregular salvage (Cederlund 2006:139).

Franzén conducted extensive archival research on numerous historic Swedish warships and made a hobby of trying to find them; he started searching for *Vasa* in 1954 (Cederlund 2006:176). To search for *Vasa*, he and Per Edvin Fälting, a civilian diver employed by the Swedish Naval Dockyard, dragged a grapnel across a target area, looking for objects extending up through the seabed (Cederlund 2006:143 and 176). After a "hit," they dropped a homemade gravity powered corer into the water and checked the resulting plug for historic woods (Cederlund 2006:176). On 25 August 1956, they found a target near the Gustav V dock that was at least 20 meters long and made of wood (Cederlund 2006:177).

To determine the nature of the discovery, Franzén requested that Commodore Gustav Lindgren, the Inspector of the Submarine Service, use the site for the navy's annual heavy diver exam (Cederlund 2006:178). That September, Fälting was designated dive leader for the exercise. He scaled up *Vasa's* side and found a closed gun port and carvings. The dive determined that *Vasa* rested upright and partially embedded in the sea floor, with part of a mast still in place (Cederlund 2006:178). Franzén, the National Maritime Museum, which supported his archival research, and the Royal Swedish Navy all emerged as primary stakeholders in the subsequent work on *Vasa* (Cederlund 2006:179-180). From October to December, the navy authorized diving on the site, conducted by Fälting and three coastal artillery divers. They cleared the deck of silt and mud, recorded basic dimensions, and noted the bottom conditions, information vital to any attempts to raise the ship (Cederlund 2006:181).

These dives determined that the *Vasa* held extensive archaeological significance, prompting the creation of a special committee to hold responsibility for the ship (Cederlund 2006:196). The Vasa Committee formed in December 1956 to determine salvage feasibility and plan early archaeological work (Cederlund 2006:206). In 1959, the Vasa Committee reorganized in to the Wasa Board to prepare for salvage and eventually plan excavations (Cederlund 2006:190). The Neptune Salvage Company agreed to lend equipment and expertise to the project for free, so long as the Board agreed to use conventional salvage methods (Cederlund 2006:207). They decided to attach the ship to lifting pontoons via slings and tow it to shallower water. Over the course of several days, they would pump water out of the lifting pontoons and move the ship to increasingly shallow water until it surfaced (Cederlund 2006:207).

Divers in heavy dress conducted most of the preparatory work, using suction and water jetting to create tunnels under the hull through which to run the slings (Cederlund 2006:207). During these activities, they uncovered some 3000 artifacts from the gundeck and surrounding seabed (Cederlund 2006:292). These included some larger carriage elements, such as beds and cheeks (Cederlund 2006:324). On 24 April 1961, *Vasa* broke the surface, floating freely on its own keel by 5 May (Cederlund 2006:306).

Concurrently with salvage operations, the Wasa Board laid the groundwork for excavation, hiring eleven archaeologists, a professional photographer, and six laborers (Cederlund 2006:295-296). Per Lunsdtröm served as the senior archaeologist and designed the excavation program, which began 25 April 1961 (Cederlund 2006:309). He decided to excavate each deck as discrete units, using deck beams to break space down into individual excavation units (Cederlund 2006:300). Each deck received a two-letter code for identification purposes (Cederlund 2006:300):

- ÖD= *Övre Däck*, upper or main deck
- ÖB= *Övre Batteridäck,* upper gundeck
- UB= *Undre Batteridäck,* lower gundeck
- HS=*Hålskeppet,* hold
- BD= *Barlastdäck*, ballast deck

At first, archaeologists identified the deck beams by their distances in centimeters from the inner face of the stem (Cederlund 2006:304). Because of some inconsistency in recording, the deck beams eventually received numerical identifications (Cederlund 2006:304). Figure 3.10 shows the deck beam numbering system.

Objects typically were not measured or mapped in the same manner done today, but instead were associated with deck beam intervals and specific ship structures (Cederlund 2006:304). The decks themselves provided the primary vertical controls, though occasionally an excavator noted the height of an artifact or feature above deck level (Cederlund 2006:304). Other times, the distance of an object from the centerline of the ship towards port or starboard was noted (Cederlund 2006:304). The *Vasa* project took place before stratigraphic unit excavation was practiced in Europe (Cederlund 2006:400). As a result, the entire ship served as a single chronological context, with compartments acting as general units or individual contexts (Cederlund 2006:400).

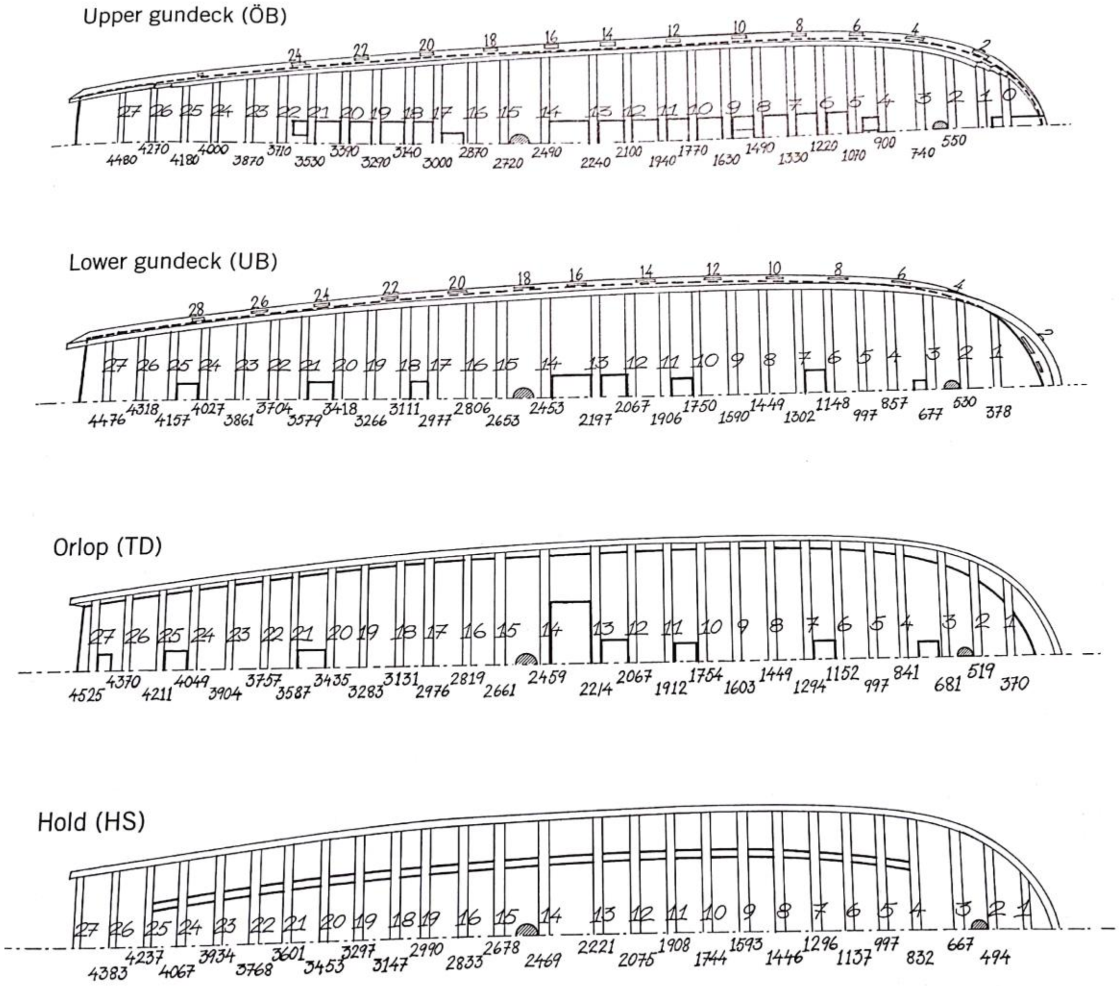


FIGURE 3.10: Deck beam numbering system for *Vasa* (Cederlund 2006:301).

The archaeologists operated in three teams, working in different portions of the ship. They excavated the gun decks from one end towards the other and the storage decks from the middle outwards (Cederlund 2006:300). They first removed copious amounts of sterile sludge, using conventional excavation tools and water sprays (Cederlund 2006:300). Because of the nature of excavating in a cramped vessel, Lunsdtröm decided that an open area excavation by layers was generally impossible. Instead the units were treated more like trenches and excavated horizontally, after establishing an open face (Cederlund 2006:301).

Lunsdtröm opted for a continuous numbering system to track artifacts, which were recorded in finds logs made of water-resistant paper and PVC coated fabric covers (Cederlund 2006:298). Each log contained 50 numbered entries and a carbon copy, which accompanied the artifact back to the conservation department. The entries recorded the object type, dimensions, find location, and included a sketch (Cederlund 2006:298). Finally, the information would be recorded onto A5 catalogue sheets in triplicate, creating three loose leaf catalogues, one arranged topographically, another numerically, and a third by item (Cederlund 2006:299).

Archaeologists cleared the main deck first, recovering 15 artifacts including a small carriage truck, before proceeding to the upper gundeck (Cederlund 2006:310). It consists of an open area from the bow to deck beam 22, with bulkheads forming additional compartments (Cederlund 2006:310). Figure 3.11 shows the distribution of space on the gundeck.

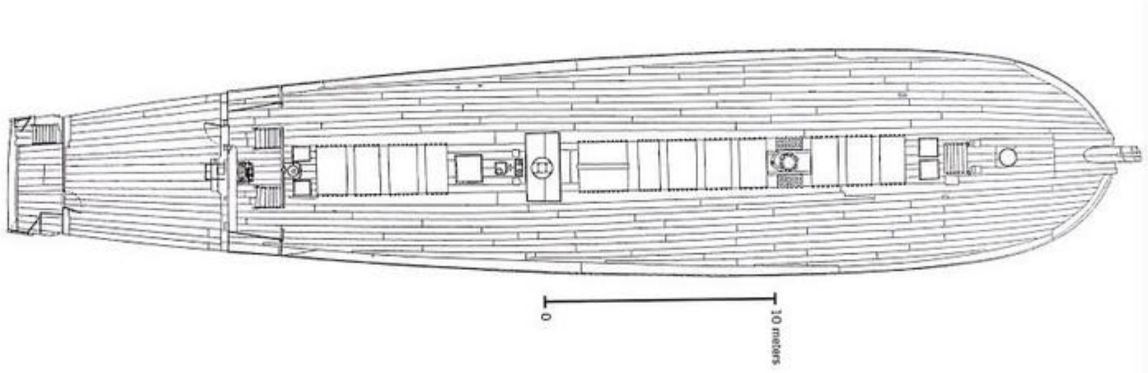


FIGURE 3.11: Upper gundeck of *Vasa* (Cederlund 2006:311).

To preserve the stability of the ship, engineers had to cut holes through the deck down to the orlop to drain heavy mud and water, which disturbed some of the finds (Cederlund 2006:311). They found several carriage parts associated with quoins, toggles, blocks, and breeching (Cederlund 2006:324). Additionally, archaeologists found the remains of Individual A in the bow at Beam 5 (Cederlund 2006:331). Three of the gun carriages used in the database (see

Chapter 4) came from this deck and are listed in the table below, along with their general provenience information, which was pulled from the digital collections catalogue of the Vasa Museet.

TABLE 3.2: Provenience of Upper Gundeck Carriages aboard *Vasa* (Vasa Museet)

Vasa ID	Project ID	Provenience
03234	19	Port, upper gun deck, between beams 7 and 8.
03839	23	Port, upper gun deck, between beams 14 and 16
03637	24	Starboard, upper gun deck, between beam 14 and 15

Researchers found VASA 03234 in the front fourth of the ship, whilst VASA 03839 and 03637 were found roughly amidships. Twenty-four other intact carriages resided on this deck (Vasa Museet 2018).

Work transferred to the lower gundeck around 1 June 1961, after the completion of the upper gundeck (Cederlund 2006:334). Prior to excavation, the project photographer recorded the entirety of the deck (Cederlund 2006:341). Most of the deck, extending from the bow to Deck Beam 23, consists of a large open area, with masts, pumps, and ladders running down the centerline (Cederlund 2006:334). A sizeable compartment occupies the aft portion of the ship, called the “artillery store” by archaeologists (Cederlund 2006:334). Figure 3.12 shows the layout of the lower gundeck.

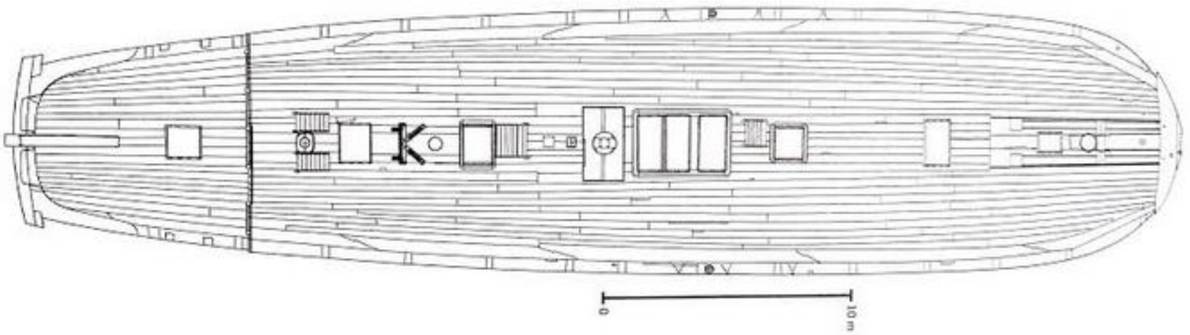


FIGURE 3.12: *Vasa's* lower gundeck (Cederlund 2006:335).

The lower gundeck suffered less disturbance than the upper decks, with many larger objects at or near their original stations. Of particular interest, most of the gun carriages remained run-out at their ports (Cederlund 2006:338). Because of the preserved state of the carriage locations, archaeologists decided to leave all the carriages in place until the other objects could be removed and the deck washed down (Cederlund 2006:339). Three carriages utilized in the database described in Chapter 4 came from the lower gundeck, all from the starboard side of the ship. Table 3.3 summarizes the provenience information, which was pulled from the digital collections catalogue of the Vasa Museum.

TABLE 3.3: Provenience of Lower Gundeck Carriages Aboard *Vasa* (Vasa Museet)

Vasa ID	Project ID	Provenience
16033	20	Starboard, lower gun deck, between beams 13 and 14
15986	21	Starboard, lower gun deck, between beams 5 and 6
15951	25	Starboard, lower gun deck, between beam 0 and 1

Carriages 15986 and 15951 were located in the forward section of the ship and Carriage 16033 just forward of the mast. Archaeologists found 30 other carriages and associated equipment (Cederlund 2006:250). Other finds included barrels of crew possessions and the remains of a crewman pinned under one of the carriages at gun port 16 (Cederlund 2006:339 and 346). In total, the archaeology team cleared off between 250 and 300 cubic meters of silt from the lower gundeck (Cederlund 2006:343). After the removal of other artifacts and cleaning, archaeologists dismantled and removed the carriages (Cederlund 2006:335).

Because of further stabilization concerns, archaeologists had to remove the ballast and clear the hold before work could proceed on the orlop deck (Cederlund 2006:359). They drilled a hole through the bottom of the hull to drain the hold and ballast of accumulated sludge, silt, and water, with the help of bilge pumps (Cederlund 2006:360). The ballast clearing lasted through 1

September 1961, while the hold excavations began in mid-June, overlapping with work on the lower gundeck (Cederlund 2006:361).

The orlop deck excavations began on 22 August 1961 and contained two large gun carriages retaining their iron fittings (Cederlund 2006:398). The orlop deck is divided into several compartments, as shown in Figure 3.13. Archaeologists decided to render a full map of the orlop deck as well, thus the distribution of finds is also shown in Figure 3.13.

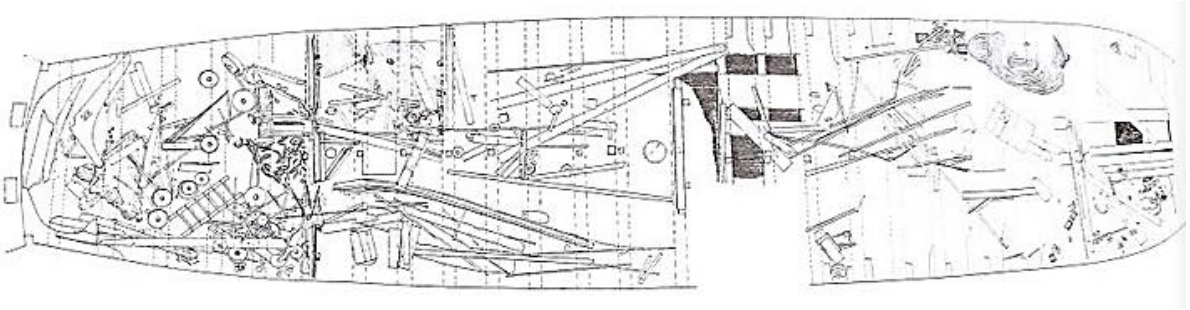


FIGURE 3.13: Orlop Deck of Vasa (Cederlund 2006:382).

One of these carriages, VASA 19696, was utilized in the database. It was found on the port side of the ship between Beams 22 and 23, in compartment T5 (Cederlund 2006:398). As seen in Figure 13, researchers also found a large quantity of gunnery equipment and spare trucks in the compartment (Cederlund 2006:398). After the completion of the orlop deck, concluding the excavation portion of the project, archaeologists transferred their finds to the Conservation Department of the National Maritime Museum (Cederlund 2006:400 and 430). The find catalogues listed over 14,034 entries, representing roughly 28,000 individual objects (Cederlund 2006:400).

Conservation

The bulk of conservation occurred at specially built facilities on the island of Beckholmen, with 2000 artifacts stored in water tanks aboard a nearby iron barge, *Menja* (Cederlund 2006:432). Conservators organized material into six find categories: sculptures, structural elements, gun carriage parts, rigging parts, ship's equipment and personal belongings (Cederlund 2006:453). A large portion of the 23,000 recovered wooden artifacts spent time in passive conservation in 14 open-air water vats outside the conservation facilities, with another 5300 objects in vats located in a storage cavern (Cederlund 2006:453). Five of the vats contained mainly gun carriage parts (Cederlund 2006:453).

Once removed from general storage, wooden objects of like size and type spent time in stainless steel tanks containing PEG 4000 solution, with a two percent solution of boric acid and borax to hamper the growth of microorganisms (Vasa Museet 2018b). Over time, conservators heated the solution to 60 degrees Celsius and gradually increased the concentration of PEG in daily increments, ending in a concentration of 40 to 45 percent (Vasa Museet 2018b). The impregnation process took between 18 and 24 months to complete. Objects then transferred to *Menja's* hold to air dry, with the humidity gradually reduced from 90% to 60% and another protective layer of PEG 4000 applied (Vasa Museet 2018b).

Curation

Up through 1990, *Vasa* and its artifacts rested in the care of the National Maritime Museum in Sweden, prior to the creation of a *Vasa* Museum (Cederlund 2006:421). The *Vasa* Museum is part of a larger consortium of other maritime museums, including the National Maritime Museum, called *Statens Maritimer Museer*. The *Vasa* Unit of this organization holds primary responsibility for the *Vasa's* hull and its associated artifacts (Cederlund 2006:421).

Located in the royal parkland, Djurgården, in Stockholm, the Vasa Museum caters to 1.5 million visitors annually and reports with the other maritime museums to the Swedish Ministry of Culture (*Vasa* Museet 2018c).

Major Findings

Researchers primarily focused on the importance of the *Vasa* carriages' distribution on the gundeck and their association with other artifacts. After *Vasa's* loss, the king ordered a trial to determine the cause, during which it was claimed that *Vasa's* guns were not lashed in place (Cederlund 2006:341). However, on the lower gundeck, archaeologists found 28 carriages still at their ports, with their front trucks resting against the hull of the ship (Cederlund 2006:350). Figure 3.14 shows the lower gundeck with the carriages in place prior to excavation and Figure 3.15 shows the deck cleaned up prior to the removal of the carriages.

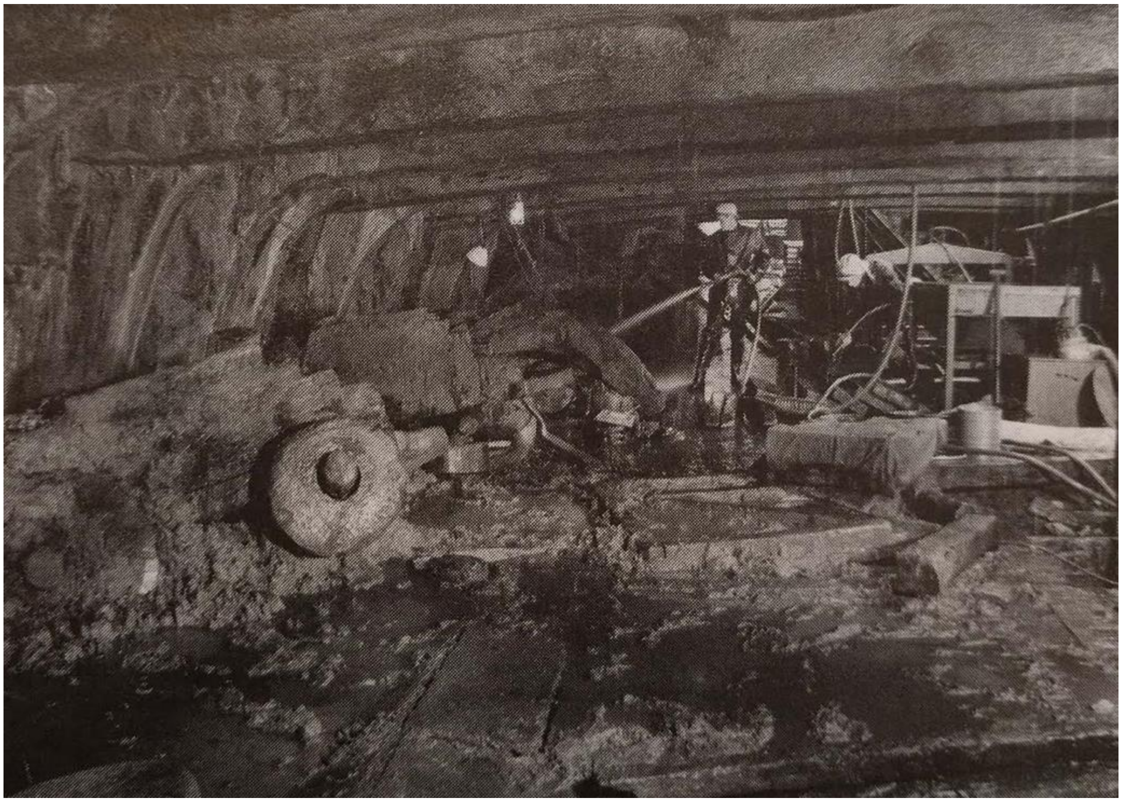


FIGURE 3.14: Vasa's lower gundeck before excavation (Cederlund 2006:343).

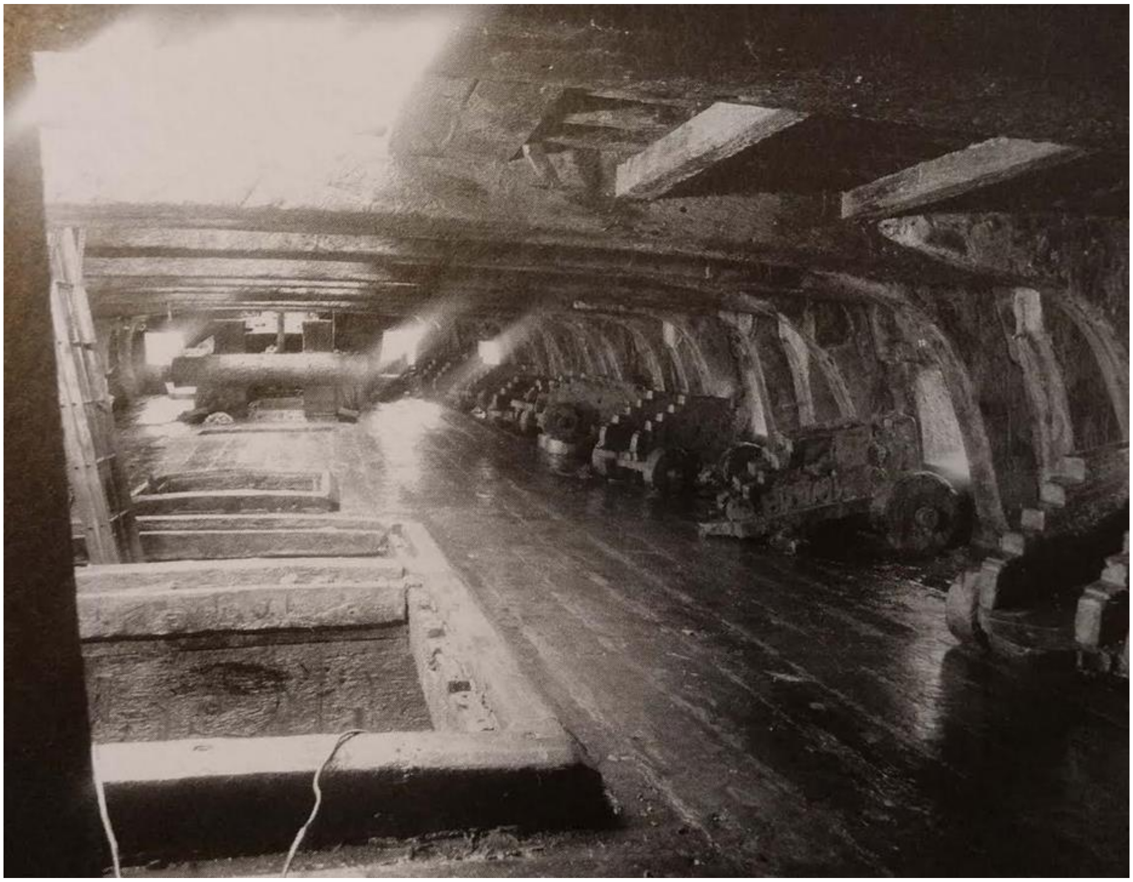


FIGURE 3.15: Starboard side gun carriages looking forward after excavation (Cederlund 2006:343).

Researchers interpret the location of the gun carriages as definitive proof that the guns were lashed down and run out at the time of sinking, proving that claims to the contrary during the trial were false (Cederlund 2006:339).

The excavation revealed other important information about the layout of the gundecks. The carriages acted as miniature bulkheads, dividing the space into discrete units, providing easy excavation blocks to researchers (Cederlund 2006:346). They further argue that the carriages formed miniature rooms along the sides of the ship (Cederlund 2006:348). Barrels of personal possessions were found stowed between the carriages still on station (Cederlund 2006:339). This suggests that carriages played a role in partitioning and determining the living space of the crew. In conjunction with gun port location, knowing carriage dimensions would provide insight into the organization of "living" space. The study of such organization aboard other vessels would likely be a fruitful endeavor.

Though not the primary focus of current publications, some information on the construction of *Vasa* carriages can be gleaned from an examination of their remains. The carriage beds consist of single planks, which match the taper between the second reinforce and base ring of the gun. They are squared at the front and decoratively rounded at the rear, which extends out past the cheeks a short distance (Vasa Museet 2018a). Figure 3.16 shows a plan view of the bottom of the bed for VASA 15986.

FIGURE 3.16: Bottom face of VASA 15986 bed (Vasa Museet).

The axletrees rest in shallow grooves carved into the bottom faces of the carriage beds. The *Mary Rose* beds only have grooves for the rear axletree, whilst the *Vasa* beds provide recesses for both. Additionally, three bolt holes for the securing of the cheeks to the bed are clearly visible, along with those for nails. There are no mortise and tenons joining the cheeks to the carriage bed. *Vasa carriages* instead rely more heavily on iron hardware to secure components together. The reason for this could be an improvement in iron working, which may have facilitated the increased use of bolts. It could also be a time saving measure.

At some point between the *Mary Rose* and *Vasa*, carriage builders transitioned to a continuous cheek construction, as seen in Figure 3.17. The new single plank is of uniform thickness and cut square with a rounded upper corner; the rear half descends to bed level through a series of squared steps, the last of which has decorative molding (Vasa Museet 2018a). The trunnion rest (also called trunnion notch by *Vasa* researchers) consists of a semicircular cut in the top face of the cheek with a rectangular rebate directly behind it, which houses a small metal wedge to help secure the trunnion (Vasa Museet 2018a). The outside face of the cheek contains two additional rebates: one for the single transom bolt securing the front of the two cheeks together, and another towards the back for the iron hook for the breech and train tackles, visible in Figure 3.17 (Vasa Museet 2018a). The center of the cheek contains a large hole to accommodate breeching, a feature Moody observed in the carriage of the 17th century frigate *Enigheden* (Moody 1952:304). Nail holes for the iron straps securing the axletrees are also visible on the outer face of the cheek (Vasa Museet 2018a).

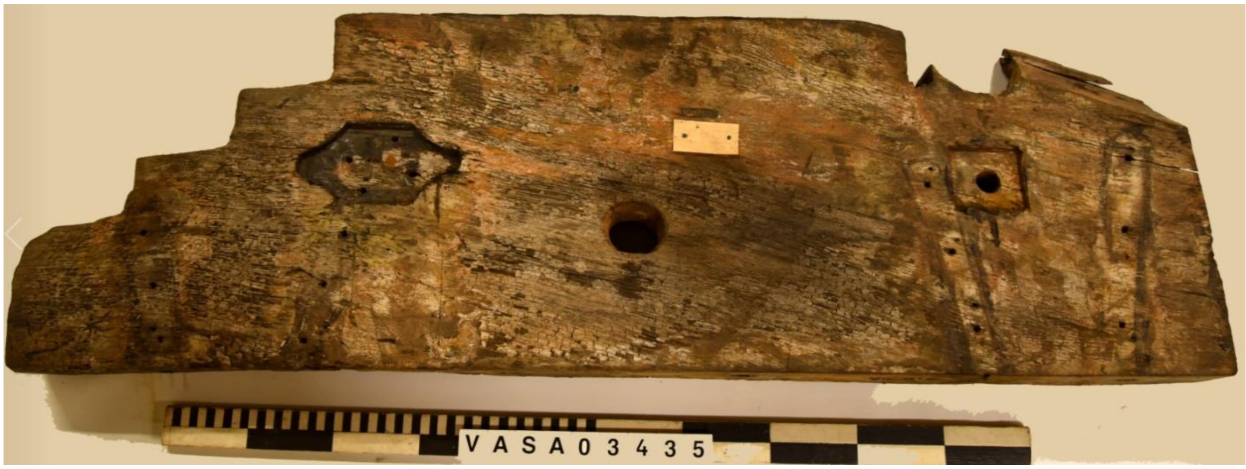


FIGURE 3.17: Profile view of right cheek for VASA 03234 (Vasa Museet).

Three bolts secure the capsquare, cheeks, and carriage bed together, which *Vasa* researchers call forelock bolts. Two are placed on either side of the trunnion notch, while a third is farther back securing the capsquare plate (Vasa Museet 2018a). The forward two bolts are in the same location as later carriages' joint bolts and eye bolts, while the third could potentially be the ancestor of the bracket bolt. A fourth bolt that does not go all the way to the carriage bed provides additional security to the capsquare plate (Vasa Museet 2018a). Additional reinforcement comes from a thin iron plate extending from the capsquare down the front face of each cheek and under the front of the carriage, secured with nails (Vasa Museet 2018a). The rear parts of the cheek attach to the carriage bed via nails driven up through the carriage bed.

The *Vasa* carriages all have transoms, blocks of wood nestled between the cheeks in the front of the carriage; they feature a uniform thickness, angled ends, and chamfered upper edges (Vasa Museet 2018a). Figures 3.18 and 3.19 present two views of a transom. While *Mary Rose* contains isolated cases of light transoms in its carriages, typically in those with both jointed beds and trunnion support cheeks taller than rear stepped cheeks (Hildred 2011:86), it is a uniform feature aboard the *Vasa*. Its presence indicates that at least for Swedish carriages, there was a brief overlap between carriage beds and thicker transoms, before the carriage bed was replaced with the stool bed and the bottom faces of the cheeks were arced. The exact progression of these events is not well studied and likely occurred at different rates (and in different orders) across Europe. A carriage recovered from *Stirling Castle* some eighty years later, for instance, possesses a carriage bed but has no preserved evidence of a transom. Some later carriages have the top of the transom carved to follow the curve of the cannon. Some will also be placed at an angle or have protrusions in front of them, extending past the front faces of the cheeks.

FIGURE 3.18: overhead view of transom for VASA 16033 (Vasa Museet).

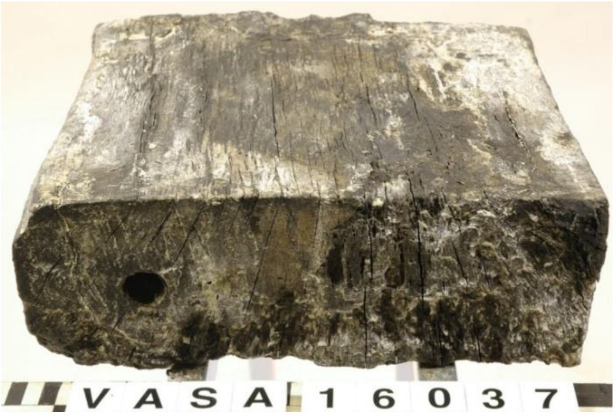


FIGURE 3.19: side view of transom for VASA 16033 (Vasa Museet).

Like many of the *Mary Rose* carriages, those from *Vasa* rest atop two axletrees. The axletrees possess two distinct parts, as seen in Figure 3.20. The middle two thirds of the structure are square in cross section, while the remaining third is divided into two chamfered arms, onto which the trucks are secured (Vasa Museet 2018a). Each arm possesses a hole through which the linchpin passes, to keep the trucks in place. Two iron spikes driven through the top of the bed secure the axletrees in place (Vasa Museet 2018a). Additionally, iron straps pass around the axletrees and travel up the outer faces of the cheeks; the iron staining and nails from these features are still visible on many cheeks, such as that displayed in Figure 3.17 (Vasa Museet 2018a).

FIGURE 3.20: Axletree for VASA 16033 (Vasa Museet)

Researchers discovered evidence of adaptable trucks in the *Vasa* carriages. Many are thick wooden disks with their centers hollowed out to accept axletree arms, reinforced with an iron ring, and slightly chamfered edges (Vasa Museet 2018a). Others consist of two disks: one larger than the other, held together with nails. Researchers believe these could indicate cases in which the truck for a lighter carriage was adapted for use on a heavy carriage (Vasa Museet 2018a). The trucks do not come in the same variety of sizes as those aboard the *Mary Rose.* Figure 3.21 is an example of a truck from Carriage 03234.

FIGURE 3.21: Truck for VASA 03234 (Vasa Museet 2018a).

Perhaps the largest fundamental design change between *Mary Rose* and *Vasa* occurred in the capsquare. Unlike the complex system utilized in the *Mary Rose*, the *Vasa* capsquares do not require partial disassembly of the carriage to operate as described by Hildred (2011). As seen in the reassembled carriage from the *Vasa* Museum in Figure 3.22, the capsquare is closer to a hinge operation than the *Mary Rose* carriages. Rather than extending past multiple faces of the cheeks, the capsquare is a relatively short, slightly curved piece of iron covering the trunnion notch. The forwardmost forelock bolt is shaped similarly to later joint bolts, whilst the middle forelock bolt is located in the same place as the eye bolt.

FIGURE 3.22: VASA 04394 reassembled (Vasa Museet).

The final *Vasa* publications on the armament of the vessel (complete with full measurements, photographs, drawings, and analysis from researchers who spent decades with the material) will shed additional light on the design of the carriages. Like those of the *Mary Rose*, the *Vasa* carriages have consistent parts from carriage to carriage, only with less sign of modification and reuse and less variation. The *Mary Rose* carriages saw existing carriages adapted to work at highly specialized portions of the ship (described by Hildred 2011), whilst *Vasa's* carriages seem to vary based on the type of gun they held (Vasa Museet 2018a). Trucks at the same end of the carriages were not hugely mismatched and the interior faces of the cheeks were not further carved out to hold ill-sized guns. This suggests that while not delivered necessarily at the same time, *Vasa* carriages were not recycled. The main concession to adaptation can be seen in the modification of some trucks from lighter guns to those for heavier (Vasa Museet 2018a).

It should be noted that some of the variation seen between the *Vasa* and *Mary Rose* carriages could be pegged to national origin rather than a pure product of the passage of time (or vice versa). To better get at the type and degree of variation, a joint study involving representatives from seafaring nations with a history of truck carriage use is needed.

La Belle

Discovery and Excavation

French explorer Robert Cavelier, Sieur de La Salle, undertook an expedition with *La Belle* and two other ships to find the Mississippi River in the fall of 1685, as part of his mission to establish a French colony in the region (Bruseth et al 2017:20). He sailed *La Belle* into Matagorda Bay, Texas and anchored it whilst he and some men went to search for the river on foot; he ordered the ship to moor until his return (Bruseth et al 2017:20). Over the course of several days, supplies and water ran low on *La Belle* and the crew resolved to sail for safety. The ship faced strong north winds and veered off course, eventually running aground on the southern shore of Matagorda Bay in 1686 (Bruseth et al 2017:20). Interest in the wreck renewed during the 1970s, culminating in the 1996 discovery of a bronze cannon in the bay by Texas Historical Commission (THC) archaeologists. (Bruseth et al 2017:3).

Upon further investigation, the THC found that a third of *La Belle* survived the intervening centuries and could be recovered (Bruseth et al 2017:45). They decided to excavate the site using a drained steel cofferdam, allowing for the use of both land and sea-based archaeological methods (Bruseth et al 2017:45). The *La Belle* project represented the first use of a pumped-out cofferdam in North America (Bruseth et al 2017:45). The two-walled cofferdam had a length of 150 feet and width of 120 feet, enclosing an 82 by 53-foot workspace (Bruseth et al 2017:46). The two walls were 33 feet apart and held in place with pilings driven through the bay's floor (Bruseth 2017:46). Sump pumps worked around the clock to address seepage and leaks. To prevent drying out, archaeologists regularly sprayed the exposed remains with water and kept them under plastic tarps while not examining them (Bruseth et al 2017:46). They utilized four forms: unit summaries, unit drawings, feature record sheets, and timber recording forms (Bruseth et al 2017:51).

Archaeologists divided the site into a grid of square meter units. Each unit was further divided into quadrants and excavated stratigraphically in ten-centimeter increments (Bruseth et al 2017:51). At each increment, units were illustrated with the help of a PVC grid system and extensively photographed, to produce a photomosaic (Bruseth et al 2017:52). They maintained vertical control by establishing an arbitrary zero line from which to measure. The first few centimeters of sediments were sterile or contained intrusive objects and cleared with shovels or large trowels (Bruseth et al 2017:51). Upon reaching the silty lower sediments, archaeologists switched to rubber spatulas, wooden skewers, curved pottery ribs, and a water spray and vacuum to excavate delicate hull remains and artifacts; concretions, conversely, had to be removed using pneumatic hammers and chisels (Bruseth et al 2017:51). They mapped the site using a total station and recorded information digitally using an SDR 33 Electronic Field Notebook (Bruseth et al 2017:52).

The team mapped artifacts and features *in situ* and gave each artifact a unique identifier (Bruseth et al 2017:53). All artifacts received a plastic tag recording their ID. Two-person teams mapped the location of the artifacts using total stations, using up to 100 individual points to map larger artifacts (Bruseth et al 2017:53). After drawing, mapping, and photography, archaeologists removed the artifacts.

Five weeks into the excavation, in October 1996, archaeologists located a gun carriage outside the hull on the port quarter (Bruseth et al 2017:373). It rested between frames 9 and 10 and, though mostly intact, was fragile and missing its left rear truck (Bruseth et at 2017:373). It was found in Unit N 2011 E 2008 at layer LVA-80 cm, as shown in Figure 23 (Bruseth 2017:373).

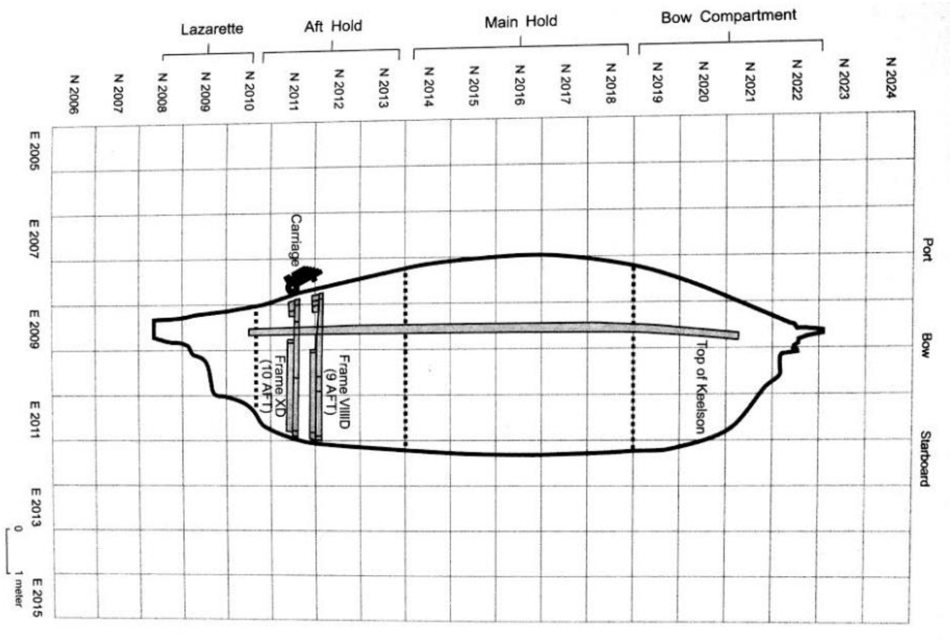


FIGURE 3.23: Location of gun carriage (ID 2049) (Bruseth et al 2017:383).

Due to its fragility, the carriage could not be removed as a single unit. Archaeologists raised the cheeks and transom, the trucks, and bed and axletrees as discrete parts (Bruseth 2017:374).

Conservation

The Nautical Archaeology Program's Conservation Research Lab (CRL) at Texas A&M University handled the conservation of the carriage. Lab researchers organized the carriage components into sublots, numbered one through five, and seven (Amy Borgens 2018, elec. comm.). The wooden components underwent tap and deionized water rinses before undergoing controlled dehydration. The CRL treated them with a standard polymer passivation process using Silicone oil (Amy Borgens 2018, elec. comm.). Epoxy molds were made of iron components from the shapes preserved within the concretions.

Curation

The 1.6 million *La Belle* artifacts belong to France, under the jurisdiction of the Musée National de la Marine (Bullock Museum 2018a). The hull and 30 of the artifacts currently reside at the Bullock Texas State History Museum in Austin, Texas (Bullock Museum 2018b). The Corpus Christi Museum of Science and History, located at the Sports, Entertainment, and Arts District of Corpus Christi, Texas houses the gun carriage (Amy Borgens 2017, elec. comm.).

Major Findings

According to two French carriage proportion tables, different parts of the carriage are ideal for different types of guns (Bruseth et al 2017:381). The trunnion notch would fit a three-pounder iron gun of the time; while the rear axletree matches the dimensions of an iron four-pounder (Bruseth et al 2017:382). The cheek thickness, on the other hand, matches that of an eight-pounder; ultimately researchers decided that it probably held a for a four-pounder bronze gun (Bruseth et al

2017:382). The difficulties archaeologists faced with matching the carriage to a single type of gun based on treatises suggest two possibilities. First, that gun carriage manufacture did not follow treatise parameters exactly. Second, that the carriage itself is a fluke that mixes up dimensions for different carriages due to haste or inexperience. Further research is needed to state which is the case, but preliminary statistical analysis discussed in Chapter 4 suggest that there may be some variation between treatise parameters and typical practice.

Like some of the *Mary Rose* carriages, *La Belle's* gun carriage is based around a carriage bed built out of two planks (edge joined with blind trunnels and two butt joins) following the taper of the gun (Bruseth et al 2017:375). The left plank is slightly larger than the right, and the seam travels at a slight diagonal down the length of the bed, perhaps as a method to combat longitudinal sheer (Bruseth et al 2017:375). The front of the bed is squared off, while the rear exhibits a gradual curve (Bruseth et al 2017:375). There is none of the decorative molding or carving as seen in the *Vasa* carriages. Recesses carved into the bottom of the carriage bed (called axletree dados by researchers) hold the axletrees, though are not parallel to one another; the axletrees are closer together on the right side than left (Bruseth et al 2017:376).

Bolts, iron spikes, and nails are all used to secure the axletree to the carriage bed (Bruseth et al 2017:377). Each end of the axletrees has a bolt passing through the body of the axletree and bed, terminating prior to entering the cheek. Iron fasteners spaced along the body of the axletree, three for the front and four for the rear, provide additional security (Bruseth et al 2017:377). Two iron spikes in the rear and one in the front were also driven into the carriage bed and partly through the axletrees (Bruseth 2017:367). Figure 3.24 shows the underside of the bed, featuring the axletree recesses and the seam between the two-part construction,

FIGURE 3.24: Carriage Bed for Artifact 2049 from *La Belle* (Bruseth et al 2017:375).

The cheeks recovered from *La Belle* share several similarities with the *Vasa* carriages. Like *Vasa*, each cheek on the *La Belle* carriage was constructed of a single piece of timber and mounted flush with the front of the carriage bed (Bruseth et al 2017:376). Additionally, breeching rope passes through central holes in the cheeks on the *La Belle* carriage; on the left side, this hole was cut at a knot in the wood (Bruseth et al 2017:377). While the *Vasa* transoms rested directly against the inner faces of the cheeks, *La Belle's* carriage cheeks feature grooves carved in the inside front face of both cheeks for the transom, in line with the trunnion notches (Bruseth et al 2017:377). The cheeks also sport quarter rounds, transitioning from the unstepped forward part of the cheek to the elevating steps. This is one of the earliest archaeological examples of the quarter round. Figure 3.25 shows the better-preserved right cheek

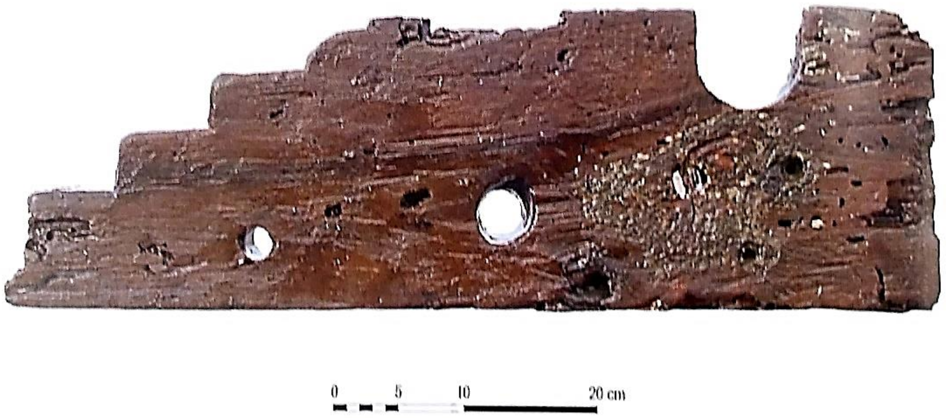


FIGURE 3.25: Right cheek for Artifact 2049 from *La Belle* (Bruseth et al 2017:374).

As discussed above, the transom for the *La Belle* carriage rests in slots carved on the inner face of the cheeks directly below the trunnion notch. The upper edge of the transom however, is chamfered and recessed to accommodate the underside of the gun barrel (Bruseth et al 2017:377). Two small spikes or square nails driven through the outside of the cheek into either side of the transom secure it in place (Bruseth et al 2017:377). The transom itself is slightly lopsided, with the right side taller than the left by six millimeters (Bruseth et al 2017:380).

As typically seen in truck carriages, the rear axletree of *La Belle* is longer than the front axletree, though is trapezoidal rather than square in cross section (Bruseth et al 2017:377). Researchers found that though the rear axletree is longer, the front axletree is heavier built (Bruseth et al. 2017:378). Both sets of axletree arms are canted slightly up and to the rear, making the trucks slightly angled towards each other in the back; this provides an additional brake to the recoil (Bruseth et al 2017:378). The linchpins are set into the ends of the axletree arms at 45-degree angles (Bruseth et al 2017:278). In both the *Mary Rose* and *Vasa*, the axletree bodies and arms are fully aligned, with the linchpins passing straight through the axletree arms.

Both of *La Belle's* front trucks were preserved, though only one remained attached to its axletree; they were each carved from single pieces of timber (Bruseth et al 2017:379). Because of the differing diameters of the axletree arms, researchers believe that the front trucks were wider than their rear counter parts (Bruseth et al 2017:278).

Researchers discovered and recovered the *La Belle* carriage with its capsquares still attached, held in place with staples behind the trunnion notches (Bruseth et al 2017:379). Rather than being arched to accommodate the trunnion, the capsquare is flattened, similar to the manner seen in the *Mary Rose,* though the left and right capsquares are not entirely symmetrical (Bruseth et al 2017:380). Furthermore, there is no preserved evidence of a forelock bolt or joint bolt.

The *La Belle* researchers believe that the carriage found aboard the ship was a poorly constructed example of the truck type, either made in haste or by an inexperienced carpenter (Bruseth et al 2017:380). The timber chosen for the carriage is filled with knots, of poor quality, and lacks basic symmetry, with one cheek higher than the other and of differing thicknesses (Bruseth et al 2017:380). The carriage bed does not exhibit bilateral symmetry and there is a pronounced lack of through bolts holding the various carriage components together (Bruseth et al 2017:380).

Despite its lopsidedness, the *La Belle* carriage is a useful entry in the history of carriage construction. Like several of the *Mary Rose* carriages, the *La Belle* carriage had a bed constructed from two planks, rather than a single plank. The *Mary Rose* researchers discussed several possibilities as to the reason for this, including preference for younger, new growth trees (Hildred 2011:40). Such trees may have been more abundant or easier to acquire, which fits into the scenario outlined by the THC that the carriage was built in haste (Bruseth et al 2017: 380). The other gun carriages from *La Belle* were not recovered, so it is unknown if the poor construction is consistent through the entire gun battery or if this was simply a hurriedly slapped together, last minute replacement (Bruseth et al 2017).

HMS Betsy

Discovery and Excavation

Betsy began its career as a collier brig, built in 1772 in Whitehaven, England (Broadwater 1996:xv and 141). After being leased out to the Royal Navy, it and numerous other vessels served the Southern British Army, under command of Major General Charles, Earl of Cornwallis (Broadwater 1996:6). He moved his forces, including his fleet of warships and transports, into Yorktown on 1 August 1781 with the intent to set up winter quarters (Broadwater 1996:7).

The French and American forces, seeing an opportunity to capture the British, sent a French fleet out of the West Indies under the command of the Comte de Grasse (Broadwater 1996:8-9). Though a British fleet under the command of Thomas Graves fought an inconclusive engagement with de Grasse, it ultimately withdrew, leaving Cornwallis without mobility (Broadwater 1996:9-11). With the noose tightening, Cornwallis safeguarded himself from a French amphibious assault by scuttling numerous transport vessels near the banks of the York River (Broadwater 1996:11-12). One of these transports, *Betsy*, went down in twenty feet of water, coming to rest flat on its keel in deep sediments and was completely buried within a couple of years (Broadwater 1996:21 and 161). Over the next month, Cornwallis lost or scuttled even more of his fleet and became trapped in an American siege, prompting his surrender on 19 October 1781 (Broadwater 1996:12-15).

Ownership of the British surviving fleet and scuttled vessels fell to the French, and they spent the rest of 1781 and 1782 attempting to salvage the ships (Broadwater 1996:22). They assigned Captain La Villebrune of the *Romulus* and four ships to accomplish the salvage, but his efforts proved difficult without salvage equipment (Broadwater 1996:22). For the next century and a half, various individuals visited the site or attempted recovery, including a joint NPS, Mariner’s Museum, and Newport News Shipbuilding and Dry Dock effort in the 1930s (Broadwater 1996:24). Concentrated scientific interest in Yorktown built in the early 1970s, eventually culminating in the Virginia Historic Landmarks Commission nominating the site to the National Register of Historic Places (Broadwater 1996:26).

This breakthrough sparked graduate research by John O. Sands and later a joint archaeological survey of the site by Sands, John D. Broadwater, and Gordon P. Watts, Jr. (Broadwater 1996:26-27). Their efforts, supported by the Virginia Historic Landmarks Commission and the Mariner’s Museum, helped to pass a landmark piece of underwater cultural heritage legislation, the Underwater Historic Properties Act (Broadwater 1996:27). More remote sensing surveys and a small archaeological project headed by George F. Bass followed the passing of the act; this work highlighted the immense potential of the wreck and paved the way for a full time Yorktown Shipwreck Project (Broadwater 1996:27-28). Through a survey heavily employing remote sensing, nine ships were discovered and the most well preserved of them, designated 44Y08, identified for full excavation in 1979 (Broadwater 1996:28-29). Site maps of 44Y088 and the other vessels were produced using trilateration from a set baseline and a beam compass (Broadwater 1996:37).

Because of unfavorable site conditions, the team built a cofferdam to act as a “stiller” around the wreck, 45 feet long and enclosing half a million gallons of water (Broadwater 1996:48). Construction of this tool ended in October of 1982 and excavations commenced, supported by volunteers and a regular East Carolina University field school (Broadwater 1996:50).

To map and excavate the site, the team established a five-foot by five-foot grid system based on the cofferdam, along with a reference vertical datum (Broadwater 1996:51). To facilitate the use of the direct survey method, researchers attached multiple tape measures to carefully mapped points on the cofferdam walls (Broadwater 1996:53). Excavation occurred in four-inch increments, with strata and sediment data taken along the way (Broadwater 1996:51). Archaeologists removed the first of the loose silt layers using hand fanning and the more compressed sediments with trowels, all of which passed through airlifts (Broadwater 1996:53). All removed material filtered through a quarter-inch mesh attached to the airlift outflow, to catch smaller artifacts, which were carefully catalogued for each four-inch layer (Broadwater 1996:53). Archaeologists mapped each layer of the units onto mylar using a one-inch to one-foot scale (Broadwater 1996:54). In some instances, groups of units were mapped together on a single large mylar and slate. Excavation of the wreck concluded in October of 1988 (Broadwater 1996:58).

Conservation

After mapping, archaeologists brought artifacts to the surface, gave them catalog numbers recording provenience information, and temporarily stored them in containers filled with river water (Broadwater 1996:55). They drew and measured all artifacts before placing them into different categories (Broadwater 1996:33). Conservators kept objects suitable for display or with high diagnostic value for permanent curation, conducted extensive documentation on diagnostic objects with little display value, and reburied items of little diagnostic value or with poor preservation (Broadwater 1996:128).

Archaeologists constructed a conservation lab to specifically handle *Betsy* material, which processed 60% of retained artifacts before closing in 1990 (Broadwater 1996:32 and 34). Wooden artifacts, such as the gun carriage, underwent PEG 540 Blend or PEG 3350 impregnation based on extent of deterioration and type, before slowly airdrying (Broadwater 1996:33).

Curation

After conservation, objects either went to the curatorial facilities belonging to the VDHR in Richmond, or to the Yorktown Victory Center for display (Broadwater 1996:34). The gun carriage found aboard *Betsy* is currently on display at the new American Revolution Museum in Yorktown, with the VDHR retaining ownership (Katherine Ridgeway, 2018 elec. comm.).

Major Findings

Archaeologists found the gun carriage in *Betsy's* hold, along with an assortment of seemingly incomplete objects (Broadwater 1996: P-1). The carriage lacked any sign of wear and was missing two bolts and a truck, suggesting to researchers that it was being constructed aboard the ship at the time of its scuttling (Broadwater 1996:P-1 and P-2). In conjunction with the other partially assembled artifacts and raw materials, the *Betsy* team hypothesized that the ship served as a floating factory to help free up space at Yorktown's docks (Broadwater 1996:144-145). Figure 3.26 shows the right side of the carriage.

FIGURE 3.26: Betsy carriage (2303) from right side. Courtesy of the Virginia Department of Historic Resources.

The *Betsy* carriage represents one of the few carriages preserved during its assembly process, making it an invaluable addition to carriage study. Partially assembled carriages can reveal deeper insight into the construction process itself. Based on the amount that survived, this carriage seems to have been in the end stages of construction. Both eye bolts and the capsquares are missing, along with a truck, as noted by researchers (Broadwater 1996: P-2). It suggests that the capsquare was one of the last components of the carriage to be attached. The top face of each cheek has two holes near the location the eye bolt would go, which are not complete, as seen in Figure 3.27. The presence of two holes is interesting. It suggests that the builders decided to change the location of the eye bolt and started drilling a new site for it at the time Cornwallis ordered the vessel sunk. One reason for the change could be the placement of the side ring bolt, through which breeching would run. The rearmost hole aligns with this feature and the two would have intersected each other. The builders seemingly opted to move the eye bolt to compensate.

FIGURE 3.27: Top view of Carriage 2303 from Betsy. Courtesy of the Virginia Department of Historic Resources.

Other small components are missing from this carriage as well. As seen in Figures 3.26 and 3.27, the axletree arms looked to have been carved to accept an iron band, and the linchpins used to secure the trucks are missing. The area surrounding them does not seem as heavily stained as the timber near intact iron hardware, so it is possible these features had yet to be added at the time of the scuttling.

The carriage has several unique features, many atypical of other Revolutionary War carriages, such as those pulled from Lake Champlain off *Royal Savage* and *Philadelphia*. Some brief comparison is useful, as both sets of carriages were built outside typical Royal Navy control (Broadwater 1996:P2). As noted by researchers, Carriage 2303's cheeks are built of single planks, the front portion containing the trunnion notch and the rear portion the steps (Broadwater 1996:P-2). This feature is visible in both Figure 3.26 and 3.27. They possess long shallow arcs carved into their undersides, along with extremely shallow rebates for the axletrees. The design does not include a quarter round transitioning from the forward part of the cheeks to the steps. Two transom bolts and a bed bolt span the cheeks. The transom bolts rest close together just forward of the trunnion notch. The eye bolt, joint bolt, and rear axletree bolts represent the only vertically aligned iron hardware within the carriage.

In contrast, the replica *Philadelphia* carriages, modeled directly off the originals housed in the National Museum of American History, use a two-part cheek construction, a shorter arc between the trucks, and feature a quarter round. All four carriages recovered from Lake Champlain utilize two rear axletree bolts, or an axletree bolt and vertically aligned ringbolt, while *Betsy* only has one rear axletree bolt. Like the *Betsy* carriage, the bed bolt in the *Philadelphia II* carriage is placed fairly low on the cheek, aligning with the first step. Figure 3.28 shows these features. The *Philadelphia* carriages also showcase bracket bolts, though those from *Royal Savage* do not. In *Royal Savage's* case, the bolts may not have been preserved, but no evidence of them exist in the surviving portions of the cheeks. Figure 3.28 shows one of *Philadelphia II's* carriage. The recesses for the axletrees are additionally deeper than those from *Betsy*.

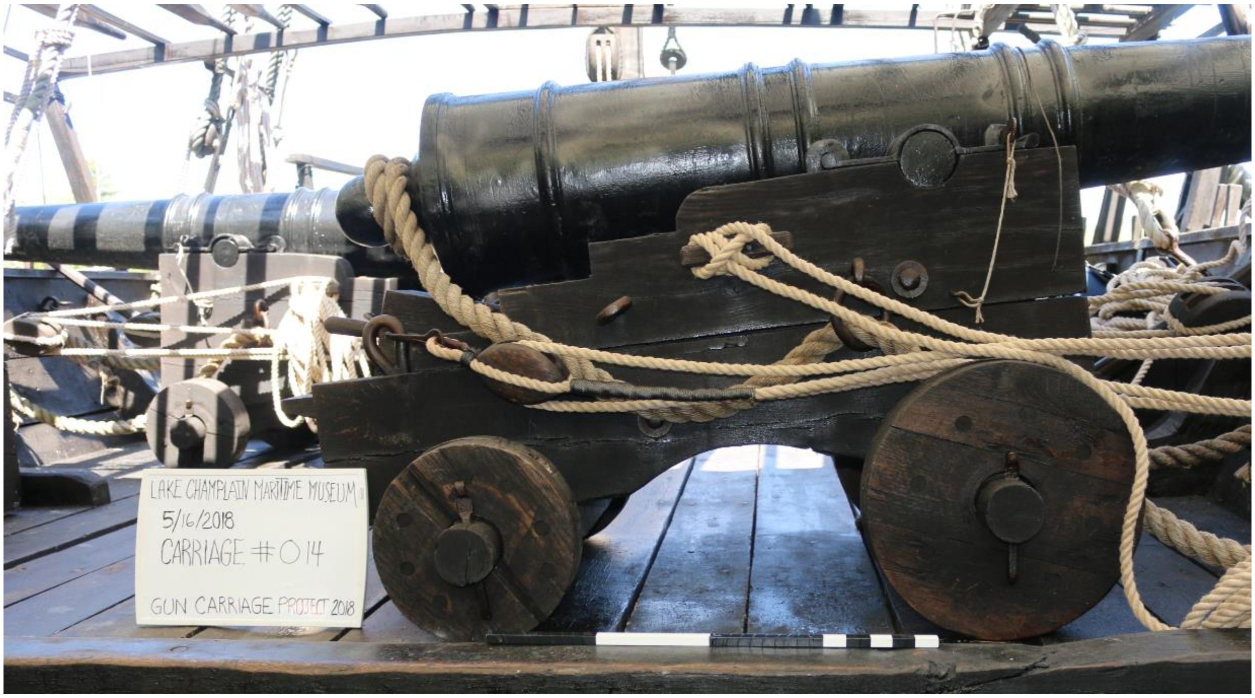


FIGURE 3.28: Waist carriage for *Philadelphia II*, at the LCMM. Photograph taken by author in May 2018.

The axletrees from *Betsy* are similar to those from *Royal Savage* and *Philadelphia.* The bodies are rectangular in cross section, with ends carved into distinct arms to mount the trucks. The main difference is the protective iron bands that would have been placed on Carriage 2303's axletree arms. This feature can also be found in Spanish garrison carriages at the Castillo de San Marcos, based on designs from the 1740s (Chapter 4 describes the origin of these carriages in further detail). Images of these carriages can be found in Appendix E. The *Philadelphia II carriages* lack this feature, as do the preserved remnants of the *Royal Savage* carriages. Both the *Betsy* and *Royal Savage* carriages have a ringbolt centrally anchored in the rear axletree. That for *Royal Savage* is pictured in Figure 3.29.

FIGURE 3.29: Rear ring bolt for *Royal Savage* carriage, at Fort Ticonderoga. Photograph taken by author in May 2018.

One of the biggest differences between the Great Lakes carriages and that from *Betsy* lie in the trucks. *Betsy's* trucks, visible in Figures 3.26 and 3.27, are built from single pieces of timber, with two grooves carved on the edges of the tread. Based on a technical drawing by John Broadwater, the front truck for *Betsy* is of a greater diameter than those in the rear, causing the carriage to rest at an angle. Conversely, the carriages pulled from the Great Lakes exhibit trucks constructed from multiple disks, secured with a series of pins. There exists some slight variation between the Great Lakes carriages as well. The trucks pulled from *Royal Savage* consist of two, two-part disks held together with four pins. One gap was carved between two of the disk parts, which can also be seen in the rear truck for Carriage 14 (Figure 3.28), off the *Philadelphia II.* Figures 3.30 and 3.31 show a truck from *Royal Savage.* The trucks from *Philadelphia* use eight wooden pins to secure the disks together and have a greater variation in size.

FIGURE 3.30: Truck from *Royal Savage*, at Fort Ticonderoga. Photograph taken by author May 2018.

FIGURE 3.31: Side view of *Royal Savage* truck, at Fort Ticonderoga. Photograph taken by author *May 2018.*

The final major component of the *Betsy* carriage is its transom. The transom is generally rectangular, with the top face carved to fit the bottom of a gun tube. It rests directly atop of the front axletree, aligned with its leading edge. The *Philadelphia II* carriages have their transoms resting on an angle on top of the front axletrees and without the carving to accommodate the gun tube.

Evidence from the *Betsy* suggest a carriage approaching completion, sporting some unique design features but of generally good quality. The use of single timbers in the truck and cheek construction shows some evidence of the type of timber available to the British at Yorktown, despite the siege. They had access to material large enough to make large individual components out of single pieces. The Americans at Lake Champlain, conversely, built many of their larger carriage components out of multiple timbers. General supply problems and ordnance shortages greatly impacted the construction of the gondola fleet at Lake Champlain (Bratten 1997:28 and 32). It is possible larger timbers had greater need in vessel construction, thus the people responsible for the carriages relied on smaller, younger trees to build them, like *Mary Rose* researchers suggest (Hildred 2011:40). The *Betsy* carriage showcases some of the carriage construction process, highlights a unique function of the vessel, and hints at timber access and resource allocation for the British during the Yorktown siege.

Further Research

These four sites are among several at which intact gun carriages have been discovered. There are numerous projects that can provide additional information into gun carriages. Appendix C is a list of wrecks that contain gun carriages or fragments, including early sledge types, truck type, and several of the truck carriage's replacements. This list includes: the primary or one of the primary organizations responsible for onsite activity, the number of carriages discovered, the state of the carriages, if the provenience is known, curation location, and a reference source. Some standout examples from this list related to truck carriages include *Stirling Castle* and the *Hamilton* and *Scourge.*

Stirling Castle

Stirling Castle was one of 20 third-rate warships constructed during Samuel Pepys' 1677 shipbuilding program, which totaled thirty new vessels (Maritime Archaeological Trust [2017] and Pascoe and Peacock 2015:133). It was launched in 1679 and enjoyed a twenty-year career before being rebuilt and refitted between 1699 and 1701, prior to its second commission (Maritime Archaeological Trust [2017]). The vessel met its end during a 1703 squall, which caused it and *Northumberland* to run afoul of each other, sending both to the bottom with all hands, along with the *Restoration* (Pascoe and Peacock 2015:133). Archaeological work occurred onsite between 1996 and 1998 by the Isle of Thanet Archaeological Society and the Ramsgate Maritime Museum (Maritime Archaeological Trust [2017]). They found the carriage, shown in Figure 3.32, in 2000 and raised it from the seabed using personal funds (Peacock 2000:5). Funding was acquired for conservation by 2006 and the team sent the carriage to French conservation company ARC Nucléart for stabilization in 2007 (ARC-Nucléart 2010). Treatment lasted until 2011, at which point it was released to the *Mary Rose* Archaeological Trust (ARC-Nucléart 2010).

The carriage itself is one of only a handful of well-preserved examples of its type from the late 17th century to early 18th century (Peacock 2000:5). Figure 3.32 shows the carriage after preservation. Great potential exists in the further study of this carriage and those from other vessels from the same wrecking event, such as the *Northumberland.* Depending on the degree to which the ships are intact, the analysis of carriage location may provide additional insight into the role of carriages in the partition of crew living and work space. Even if the ships are not preserved to such a level, important construction and design details could be gleaned from these carriages.

FIGURE 3.32: Stirling Castle Carriage after preservation (ARC-Nucléart 2010).

Hamilton and *Scourge*

Hamilton and *Scourge* began their careers as the merchant schooners *Diana* and *Lord Nelson* respectively, operating on Lake Ontario (Crisman et al 2014:123-128). *Diana* was the older of the two vessels, built in Oswego, New York in 1809, while *Lord Nelson* was constructed in Upper Canada in 1811 (Crisman et al 2014:123). With the breakout of hostilities between the United States and Britain, the former eventually obtained and refit the two vessels in 1812, along with several other merchant schooners (Crisman et al 2014:123). From historical documents, it is known that the gun carriages for *Scourge* were built independent from the guns, which experienced delays in reaching the outfitting crews (Crisman et al 2014:125).

Hamilton's refits finished first and it joined Commodore Isaac Chauncey's squadron ahead of *Scourge* (Crisman et al 2014:125). By 22 July 1813, both ships were well integrated into the squadron, which set sail to meet British forces (Crisman et al 2014:129). In the early morning hours of 8 August 1813, a squall overtook the squadron as it attempted to regroup after missing the British forces; the storm sent both *Hamilton* and *Scourge* to the bottom, leaving only 16 survivors between them (Crisman et al 2014:129 and 130).

Efforts to locate and study the vessels began in 1971, headed by the Royal Ontario Museum and Dr. Daniel A. Nelson. Remote sensing studies began in 1972 and identified a likely site using side scan sonar in 1973, which was visited in 1975 (Crisman et al 2014:131). Researchers found the two ships resting upright on the seabed, each with two masts, bowsprits, and guns still in place (Crisman et al 2014:131). The site received a National Historic Site of Canada designation in 1976, sparking an environmental study and acoustic survey, which were complete by 1978. Throughout the next two and a half decades, researchers conducted remote sensing and photographic studies of the wrecks (Crisman et al 2014:131-136). Technical divers visited the site in the 2000-2001 dive season (Crisman et al 2014:136). They discovered an infestation of quagga mussels, prompting researchers to make plans for condition assessments (Crisman et al 2014:136).

The site is a model for the value of remote sensing techniques and use of submersibles for archaeological studies. The two ships also showcase the beginnings of efforts to phase out truck carriages, a process that continued through the Civil War and concluded by the 1870s. Three types of gun carriage: truck, pivot, and carronade are showcased aboard the two ships, which could be used for comparative studies (Michael McAllister 2019, elec. comm). Depending on the degree to which the mussels cover the gun carriages, it may be possible to someday take scaled photographs or brief measurements to aid in a study of their design. Additionally, their action positions are well preserved, along with some of the equipment at the gun ports, paving the way for a study of the organization of open-air gun decks. Should more intact ships with guns at their stations be found, it may be possible to gain a better understanding of the changes gundeck organization underwent over time. Figure 3.33 shows one of the starboard carriages still at its gun port aboard *Scourge*.

FIGURE 3.33: Starboard gun aboard the Scourge. Photograph by Emory Kristof (City of Hamilton).

Unfortunately, the presence of the mussel colonies may hinder future studies as, according to Michael McAllister of the *Hamilton* and *Scourge* National Historic Site, the mussels greatly reduce archaeological visibility (Michael McAllister 2017, elec. comm.). They are currently monitoring the situation and watching for the development of a non-destructive mussel removing methodology (Michael McAllister 2019, elec. comm.).

These two sites and the others shown in Appendix C, especially those sites mapped or excavated archaeologically, represent the best avenue through which to pursue further research.

Such possible directions future research could take include: material culture studies, exploration into woodworking and metallurgy, further examination of carriage design and relation to a wider array of treatises, shipboard organization, dendrochronological studies, experimental archaeology, and further studies into the relation of cannon and carriage design.

Conclusion

Gun carriages have been found at landmark sites, which shaped subsequent archaeological and conservation practices. Archaeological methods changed a great deal over the decades spanning the four wrecks, from the general contextual information present in *Vasa* (Cederlund 2006:409) to the tight unit excavation of *La Belle* (Bruseth et al. 2017) and *Betsy* (Broadwater 1996). Conservation grew from the use of PEG alone to eventual freeze drying and Silicone treatments. The approach to gun carriages varied greatly as well. The *Mary Rose* and *La Belle* researchers focused on the design of the carriages and the details of their construction. *Vasa* scientists focused on the importance of the carriage locations aboard the ship and in relation to other artifacts. It is possible more details of their construction will emerge from subsequent publications. *Betsy's* researchers related evidence seen in the carriage to the ship's broader activities.

A large number of archaeology sites have preserved carriage and carriage parts, which bear further examination. These could reveal additional insight into the construction of different carriage types, the transition from sledge to truck carriages, the transition from the truck carriage to other mountings, and provide material to compare with artillery treatises. They and pre-existing archaeological examples could also produce useful data through material culture studies and a host of other research projects. Their role in shaping deck space and their possible relation to ship design also bear additional examination. In short, there exists a wealth of archaeological material upon which to continue the study of gun carriages. As evidenced by the four case studies, gun carriages can furnish a great deal of insight into a wide variety of subjects, from carriage construction to gundeck organization. Thus, they are worth researchers’ continued attention.

CHAPTER 4
STATISTICAL ANALYSIS

Introduction

The statistical examination of truck carriages affords researchers with several opportunities. First, it can potentially provide insight into broad design changes and trends over time, allowing for a close study of proportional relationships discussed in artillery treatises. Second, statistical analysis allows for the in-depth study of the relationship between major carriage components and those components with the cannon. Third, these relationships can be translated into useful tools and models that archaeologists can use in instances they find a cannon without a carriage or vice versa. Fourth, because of the hinted at relationship between carriage design and ship design, with enough study, the gun carriage could bridge the gap between the two. Eventually, this would allow for archaeologists to make some basic determinations about gun port height or other ship features, which generally do not survive in the archaeological record. Overall, statistical studies of gun carriages will provide deeper insight into trends and characteristics observed in the historic and archaeological records. To accomplish these goals, a database was created in IBM's SPSS statistical software and subjected to correlation, regression, and ANOVA analyses. The following questions were explored:

- What are the major relationships between cheeks, trucks, transoms, and axletrees (the four components consistently present throughout the truck carriage's history)? The relationship between these parts and the cannon?
- How do these proportional relationships compare to Muller's treatise? Can Muller's proportions be applied outside the 18th century? Does it reflect the primary design?
- What are the trends at work in truck carriage design? Does design remain stable? Does it fluctuate?
- Can the dimensions of one carriage part be used to predict the dimensions of a different carriage part?

Data collection to populate the database occurred in two parts. First, the author visited eight institutions to measure gun carriages directly and gather additional archival resources.

Travel occurred between 6 May and 20 May 2018. The institutions visited include: The History Museum of Mobile in Mobile, Alabama; the Castillo de San Marcos Archives in Jacksonville, Florida; the Castillo de San Marcos National Monument in St. Augustine, Florida; the Mariner's Museum in Newport News, Virginia; Fort Ticonderoga near Ticonderoga, New York; the Lake Champlain Maritime Museum in Vergennes, Vermont; the *U.S.S. Constellation* at the Historic Ships in Baltimore, Maryland; and the National Archives in Washington D.C. This stage of research produced information for eighteen carriages. The second part of data collection involved gathering measurements from archaeological publications, museum websites, and other researchers.

Of the eighteen carriages recorded during the first stage of data collection, fifteen were truck carriages. Three of these experienced heavy deterioration and thus were incomplete, while a fourth carriage had too many construction inaccuracies, leaving eleven complete carriages for the database. Additionally, three non-truck carriages were briefly examined for comparative purposes but are not included in the database. Fifteen additional carriages were obtained during the second part of data collection; sites represented include the *Mary Rose, Vasa, La Belle,* and *Betsy*.

The Carriages

The carriages in this project represent British, French, American, Swedish, and Spanish style naval and coastal defense tools, including both historical examples and historically accurate replicas. Table 4.1 below summarizes the housing institution, type, and nature of the carriages.

TABLE 4.1: The Truck Carriages Represented in the Database

Carriage Number	Institution Identification	Housing Institution	Carriage Type	Historic or Replica?
1	Not given	History Museum of Mobile	Ship/truck	Replica
2	Not given	History Museum of Mobile	Garrison/truck	Historic
3	CASA 1593	Castillo de San Marcos	Garrison/truck	Replica
4	For gun *La Sibila*	Castillo de San Marcos	Garrison/truck	Replica
5	for gun *El Camilo*	Castillo de San Marcos	Garrison/truck	Replica
6	Middle demo gun	Castillo de San Marcos	Garrison/truck	Replica
7	For gun *El Jazmin*	Castillo de San Marcos	Garrison/truck	Replica
8	1935.0131.000001	The Mariner's Museum	Garrison/metal	Historic
9	from *Royal Savage*	Fort Ticonderoga	Ship/truck	historic
10	From *Royal Savage*	Fort Ticonderoga	Ship/truck	Historic
11	From Royal Armouries	Fort Ticonderoga	Ship/truck	unknown
12	N/A	Lake Champlain Maritime Museum (LCMM)	Ship/truck	Historic
13	N/A	LCMM	Ship/truck	Replica
14	N/A	LCMM	Ship/truck	Replica
15	N/A	LCMM	Ship/sliding	Replica
16	N/A	Historic Ships in Baltimore	Ship/truck	Replica
17	N/A	Historic Ships in Baltimore	Ship/truck	Replica
18	N/A	Historic Ships in Baltimore	Ship/truck	Replica
19	VASA 03432	Vasa Museum (website)	Ship/truck	Historic
20	VASA 16033	Vasa Museum (website)	Ship/truck	Historic
21	VASA 15993	Vasa Museum (website)	Ship/truck	Historic
22	VASA 19696	Vasa Museum (website)	Ship/truck	Historic
23	VASA 03839	Vasa Museum (website)	Ship/truck	Historic
24	VASA 03637	Vasa Museum (website)	Ship/truck	Historic
25	VASA 15951	Vasa Museum (website)	Ship/truck	Historic
26	For gun 79A1276	Mary Rose Foundation (pub)	Ship/truck	Historic
27	For gun 81A3003	Mary Rose Foundation (pub)	Ship/truck	Historic
28	For gun 81A3000	Mary Rose Foundation (pub)	Ship/truck	Historic
29	For gun 79A1277	Mary Rose Foundation (pub)	Ship/truck	Historic
30	For gun 81A3002	Mary Rose Foundation (pub)	Ship/truck	Historic
31	For gun 81A1423	Mary Rose Foundation (pub)	Ship/truck	historic
32	Carriage for *La Belle* Artifact # 2049	Texas Historical Commission/ Corpus Christi Museum	Ship/truck	historic
33	Carriage 2303 from site 4400088	Department of Historic Resources Virginia and Yorktown Victory Center	Ship/truck	historic
34	For gun 80A0976	Mary Rose Trust	Ship/truck	historic

Because replicas were utilized, it is necessary to discuss the history behind their construction, the sources used in their creation, and address possible limitations in their use. The History Museum of Mobile, the Castillo de San Marcos, Fort Ticonderoga, the LCMM, and Historic Ships in Baltimore all contributed replicas to the database.

Replicas

Carriage 1

Carriage One supports a 32-pound smoothbore gun found with the wreck of the Confederate privateer *C.S.S. Alabama,* originally placed on the starboard side. The British built the ship in secret at the John Laird Shipyard at Birkenhead, England before sailing it to the island of Terceira in the Azores (History Museum of Mobile 2018). Roughly a week later, the guns for the vessel arrived aboard an English tender, including the 32-pounder currently in the museum (History Museum of Mobile 2018). The *Alabama* enjoyed more success, and caused more damage, than any other Confederate commerce raider (History Museum of Mobile 2018). The steamer sunk in battle against the *U.S.S. Kearsarge* near Cherbourg, France on 11 June 1864 (History Museum of Mobile 2018). A French naval minesweeper, *La Circe,* discovered the wreck in 1984 in 190 feet of water (History Museum of Mobile 2018). A mutual agreement between the French Ministry of Culture and the U.S. Naval Historical Center saw to the joint excavation, recovery, and management of the vessel (History Museum of Mobile 2018). In total, the team recovered 19 artifacts, including several pieces of carriage hardware.

The History Museum of Mobile currently houses the gun, on loan from the American Navy (History Museum of Mobile 2018), mounted on a replica carriage constructed by the *C.S.S. Alabama* Association. Researchers with the association consulted two resources while designing the carriage: *C.S.S. Alabama: Anatomy of a Confederate Raider* by Andrew Bowcock (Bowcock

2002), and *C.S.S. Alabama: Builder, Captain, and Plans* by Charles Grayson Summersell (Philip Nassar 2018, pers. comm). Mr. Bowcock based his work upon a series of plans and blueprints related to the *Alabama* from the John Laird Shipyard, which he saved from being discarded after the shipyard closed. Among the *Alabama* documents were plans for naval carriages dated to 1862 (Philip Nassar 2018, elec. comm). The work by Mr. Summersell also contains line drawings and blueprints. These plans were followed exactly in the design of Carriage One (Philip Nassar 2018, elec. comm). City carpenters in Mobile undertook actual construction of the carriage, with the assistance of an engineer (Philip Nassar 2018, elec. comm). Because it was created directly from original Royal Navy blueprints found in the Laird Shipyard, amongst papers related to the *Alabama,* it is likely Carriage One closely mirrors the gun's original mounting. Figure 4.1 shows the carriage.

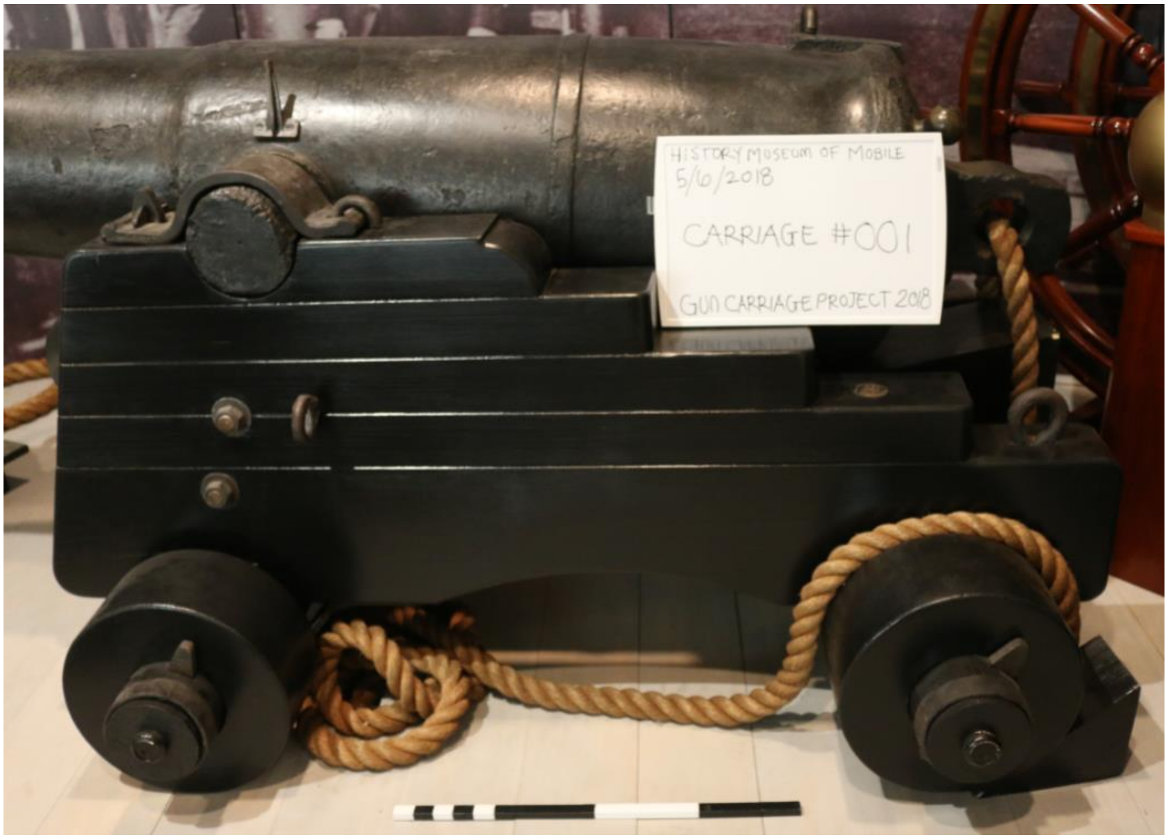


FIGURE 4.1: Carriage 1, housed in the History Museum of Mobile. Photograph taken by author in May 2018.

Carriages 3 through 7

The Castillo de San Marcos National Monument ("the Castillo") housed Carriages Three through Seven. These have since been replaced due to age. The carriages, along with several others of the same dimensions, supported historic guns, several of which are original to the fort. These guns represent several different phases of the fort's life and are all mounted on replica Spanish garrison carriages in a design dating to roughly 1740 (Castillo de San Marcos National Monument [2010]). Although not found aboard ships, there exists no fundamental difference between carriages used in fortifications and those used aboard ships at this time, except the material used to construct the trucks (Manucy 1944:37). Garrison carriages, therefore, can be used to approximate naval carriages of this time period. The full background of these replicas, from their initial conception to final installation is available in the Castillo's archives, housed in Jacksonville, Florida.

The park's interest in gun carriage design dates to 1936, at which time park historian Thor Borreson wrote a memo outlining the dimensions of the cheeks, front and rear axletrees, and three transoms of Spanish 24-pounder marine and garrison carriages (Borreson 1936). The use of three transoms for garrison carriages is unique to the Spanish, as most other nations include the use of a single transom in front and a stool bed supported by a rectangular bolster. By 1939, Borreson, along with fellow historian Albert Manucy, firmly established the need for authentic garrison gun carriages to better interpret their collection of ordnance, most of which rested on concrete mounts (Borreson 1936 and Manucy 1939a). To kick off the project, Manucy conducted research on the type and quantity of armament available to the Castillo (then called Fort Marion) throughout the fort's life, with special focus on the mid-18th century through an examination of several of the fort's Spanish and English inventories and other documents spanning from 1579 to 1814 (Manucy 1939a). These contained information on construction materials used for the gun carriages, the type of guns and mountings in play at the fort, as well as the quantity and storage of spare parts. Meanwhile, Borreson conducted an evaluation of current ordnance held by the park, to determine the types of carriages they would need (Manucy 1939a).

They ultimately sought to interpret the fort as it was during the Second Spanish Period, around 1740 (Manucy undated). Manucy examined Spanish and English artillery treatises to determine the measurements needed for the Castillo guns. The general standard for English carriages comes from the 1757 treatise written by John Muller and another by John Robertson from 1775, while details of Spanish carriages are outlined in Tomas de Morla's treatise (Manucy 1944:37). They utilized the second edition of the de Morla treatise, published in 1816. From these treatises, Manucy noted three different proportions governing carriage design: the distance from trunnion to base ring; the diameter of the base ring; and diameter of second reinforce ring (Manucy 1944:33). He also found that Spanish carriages tend to be more complex, with highly decorative elements and carefully mortised components (Manucy 1944:38).

It is unknown if Manucy drew primarily from Spanish or English design in this description of carriage proportionality, but it is suspected that the majority likely came from the treatise by de Morla. Manucy likely found that certain guidelines, such as that governing carriage width, were shared across national boundaries. The carriage physically needs to accommodate the second reinforce and the base ring in order for the carriage to fit. In other areas, such as the size of axletrees, height of the cheeks, and the formulation and number of steps, the list provided by Manucy differs from that outlined by Muller in 1757. It is likely that in some basic overall proportions, related to the width of the carriage in the front and rear, carriage builders of all nations followed similar guidelines by the mid-18th century. Because they were constructed based on treatises, the Castillo carriages will not be primarily relied on for the portions of this analysis related to the comparison of physical carriages to artillery treatises.

The historians completed the majority of research for the project in 1944 (National Park Service 1968), at which point attention turned to finding funding and a company for construction. The Castillo initially reached out to Lorton Industries, in Lorton, Virginia for aid in constructing the carriages. Communication with Lorton began as early as 1955, and they agreed to aid in the project so long as the materials were wood or iron (Peterson 1955). The historians at the Castillo advocated for pressure treated wood with wrought iron hardware (Peterson 1955). Lorton took the contract and built the carriages, completing and delivering them by April 1967 (National Park Service 1968). Figure 4.2 shows Carriage 5, while Appendix E contains photographs of the rest of the Spanish carriage recorded at the Castillo.

FIGURE 4.2: Carriage 5, housed at the Castillo de San Marcos. Photograph taken by author in May 2018.

Carriages 13 through 15

The Lake Champlain Maritime Museum is home to a full-sized replica of the American gunboat *Philadelphia,* which served in Benedict Arnold’s hastily built fleet during the American Revolution. The Continental Congress in 1776 ordered the construction of *Philadelphia* and eight other gunboats, armed with two waist guns and a bow mounted sliding gun (National Museum of American History [2014] and Bratten 1997:1). It was built at an American shipyard in Skenesborough (now Whitehall) New York, launched 30 July 1776 (Bratten 1997:1). The gunboats joined a small flotilla, consisting of 17 ships, which delayed the British attempts to cut off New England from the rest of the colonies (National Museum of American History [2014] and Bratten 1997:1). It had a very short career, sinking in combat on 11 October along with twelve other vessels; only four ships out of the seventeen-unit fleet escaped (Bratten 1997:2-3). In 1935, civil engineer Lorenzo F. Hagglund discovered and recovered the *Philadelphia* and its equipment, and it remained on display at the lake until 1964, at which point it passed to the Smithsonian’s National Museum of American History (National Museum of American History [2014]). It occupies a sizeable display in the museum today. *Philadelphia* is the oldest intact warship on display in North America (Bratten 1997:1).

The Lake Champlain Maritime Museum began construction on a full size, authentic replica in May 1989, using a mix of authentic hand tools and modern power equipment (Lake Champlain Maritime Museum 2017). Replica gun carriages were also constructed at this time. Gun Carriages 13 through 15 are direct copies of the carriages recovered with the gunboat, matching all proportions and construction detail. The former two are truck design, while Carriage 15 slides on wooden runners. It provides an example of truck carriage elements finding use in other carriage types but will not be the primary subject of analysis. The original carriages closely match ordinary British design of the time; John Raymound Bratten, during the course of his dissertation research on the *Philadelphia*, states that the only differences between the gondola's carriages and that described by Muller are the size of the trucks and spacing of iron components (Bratten 1997:183). This will be examined further. Figure 3.28 in Chapter 3 shows one of the *Philadelphia II* truck carriages.

Carriages 16 through 18

Carriages 16 through 18 are aboard the *U.S.S. Constellation,* moored at the Historic Ships in Baltimore along with several other historic vessels. It is the second vessel to hold the name, the first being a 38-gun frigate launched in 1797 and served with distinction during the War of 1812 (Historic Ships in Baltimore 2012). The original was broken up in the Norfolk shipyard in 1853, with the new *Constellation,* a sloop-of-war, built the following year at the Gosport Navy Yard (Historic Ships in Baltimore 2012 and Paine 1997:120). Its original armament included 16 VIII-inch shell guns, 4 32-pounder smoothbores, and a couple types of parrot gun (Paine 1997:120). The sloop enjoyed a colorful career, serving at both the Mediterranean and African stations, seeing extensive action against rogue slavers during the Civil War, spending 75 years as a training vessel, and serving as a relief flagship for two admirals during World War II (Historic Ships in Baltimore 2012 and Paine 1997:120).

The American Navy permanently decommissioned *Constellation* in 1953 and a private non-profit moved it to Baltimore, MD for restoration and preservation; however, funds were scant, and the process took a decade (Historic Ships in Baltimore 2012). This first restoration modeled the ship after the first *Constellation.* Since no funds existed for maintenance, the ship experienced significant dry rot, and was closed to the public in 1994, at which point a new *Constellation* Foundation launched a larger restoration and maintenance program (Historic Ships in Baltimore). The project ran from 1996 to 1999 and restored the ship to its original configuration as a sloop-of-war from 1854, opening to the public in July of 1999 (Historic Ships in Baltimore 2012).

During this most recent restoration, museum staff pulled gun carriage plans for VIII-inch shell guns and parrot guns from the National Archives, to reference for the recreation of accurate armament mounts (Paul Cora 2018, pers. comm). These date to 1851, only a few years prior to the construction of the second *Constellation*, and likely the types of carriages with which the ship would have been equipped. From these plans, they built carriages for 16 VIII-inch shell guns and a single 20-pound parrot gun. They did not make any 32 pounder carriages but retained copies of the plans housed in the National Archives (Paul Cora 2018, pers. comm). The 32-pounder armament is represented by a donated 32 pounder gun and carriage replica which served as a movie prop, gifted to the museum (Paul Cora 2018, pers. comm).

Carriage 16 is the donated 32-pounder and for the purposes of general display, it is well suited. It contains the correct general shape of a typical mid-19 century gun carriage. Due to some inaccuracies in small details, it could not be included in the database. Carriage 17 belongs to one of the replica VIII inch shell guns, and is accurate in proportionality and construction details, having been based directly off original naval plans. Carriage 18 supports a small parrot gun, housed on the upper deck of the sloop. Figures 4.3 and 4.4 show Carriages 17 and 18 respectively.

FIGURE 4.3: Carriage 17, *U.S.S. Constellation*, Historic Ships in Baltimore. Photograph taken by author in May 2018.

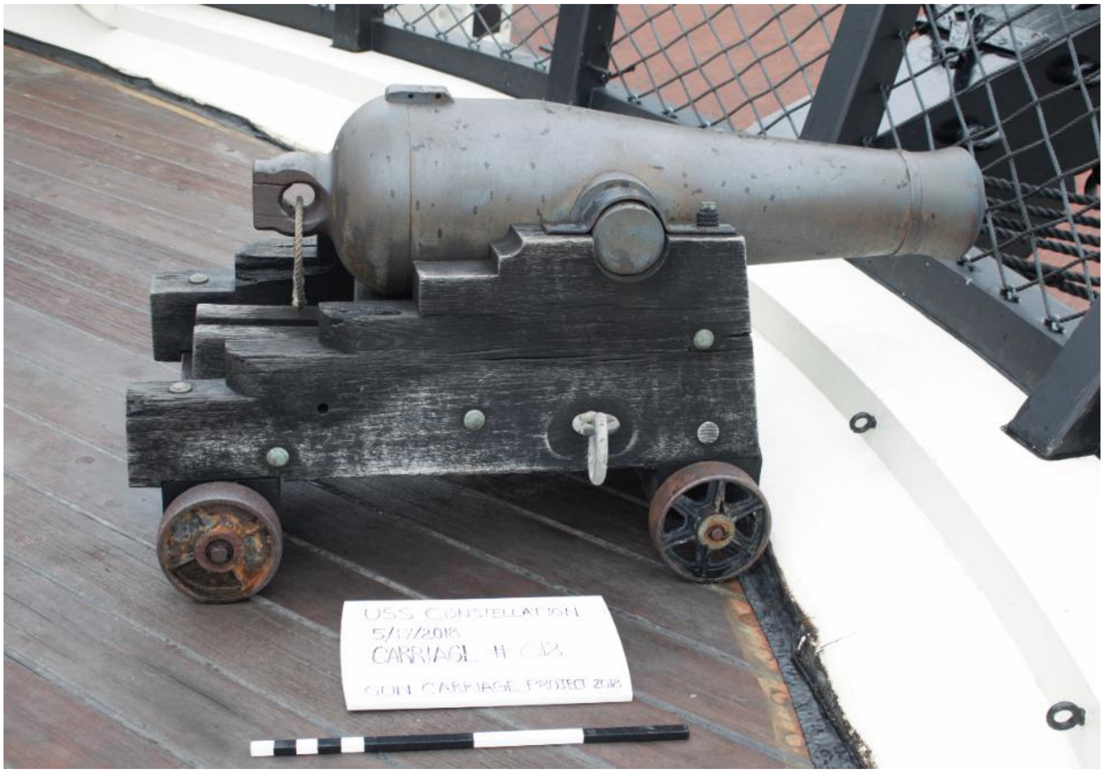


FIGURE 4.4: Carriage 18, *U.S.S. Constellation*, Historic Ships in Baltimore. Photograph taken by author in May 2018.

Methods

This section discusses the recording and photography methodologies utilized during data gathering. The process began with the creation of a single-page recording sheet, highlighting various measurements of the carriage and any associated cannon. Next, in-person recording took place during the middle two weeks of May 2018. Throughout the rest of May and June, archaeological publications were examined for additional carriage measurements. Database creation began in late June and lasted through early August. Data analysis began in earnest in September and lasted through November. Each of these steps will be discussed in this section.

Developing the Recording Sheet

To organize carriage measurements, the author developed a recording sheet, shown in Appendix D. It includes a section for identification purposes, listing the housing institution, project-specific carriage identification number, the identification used within the housing institution, and the date of the recording. Hand written information includes provenience, country of origin, and a general date of construction or use. The recording form contains eleven sections for all major carriage components and their features: the cheeks, axletrees, transom, stool beds, carriage beds, capsquares, trucks, and associated cannon. It should be noted that no single carriage contains all elements, due to variation in features over time.

Section one of the recording sheet contains the overall dimensions of the carriage, including length, the width at both extremities, and height at both extremities with and without the trucks. Generally, these correspond with the dimensions of the cheeks themselves, though there are exceptions. In the cases of the *Vasa* and *Mary Rose,* the carriage bed extends past the cheeks, changing the overall dimensions. Some later carriages, such as the *Alabama*, have protrusions in front of the transom that also change the overall length of the carriage. The overall height and cheek height differ in carriages with carriage beds.

Section two houses the dimensions of the cheeks, including the length, width, and height at both ends. It also contains the dimensions of the steps (length and height), quarter round (radius), trunnion notch (distance from the front, length of the unstepped section, depth of the center, and trunnion notch shape). Finally, the distance from the front of the arc carved into the cheek’s bottom face was recorded, along with its depth and length.

Section three contains details on the transom, including its maximum height, length (measured between the inner faces of the cheeks), and width. While the recording sheet has width and length designated for top and bottom, the distinction proved unnecessary, as no transom measured had any taper. Several were scalloped to better fit the tube of the gun resting upon them; while recorded in the margins, the scallop is not an official variable.

Sections four and five relate to the front and rear axletrees respectively. The axletrees are divided into the body section, fitting into the underside of the carriage, and the arms, upon which trucks are fitted. The measurements related to the body are length, width, and height, while those for the arms are length, width and height (changed to diameter in the field), shape (which proved unnecessary), and the distance of the linchpin from the end of the arm.

The front and rear trucks are dealt with in sections six and seven and include diameter of the hole through which the axletree arm passes, the overall diameter of the truck, and its width. Construction features, such as the presence of multiple disks, pins, or iron cladding are noted in the margins or on the back of the sheet.

Section eight houses the measurements for the carriage bed, including length, width, and height (thickness). In some cases, the carriage bed followed the taper of the cheeks, and the minimum and maximum widths were recorded. Later carriages did not possess this feature.

Section nine concerns the stool bed, one of the features which replaced the carriage bed later in the truck carriage's history. Measurements include the distance of the stool bed from the rear of the carriage, its length, width and height. In some cases, it stuck out past the rear end of the cheeks.

Measurements for the capsquare in section ten include the length, width and height of the arch. Its distance from the front was additionally recorded in the margins.

Finally, the measurements for the associated cannon make up section eleven. These include overall length, the inner width of the bore, features of the trunnion (length, taper, and length between trunnions), the diameters of the base ring and second reinforce, and the length of the cascabel. In artillery treatises, all these items share direct proportions with the carriage. It should also be noted that the overall length of the cannon includes the cascabel.

While recording Carriage One at the History Museum of Mobile, it became apparent that additional data could be pulled from each carriage and that some areas of the recording sheet could use alteration. For instance, while the recording sheet calls for the lengths (circumference) of the base ring and second reinforce, the diameter was recorded instead. The diameter plays a more direct role in determining the width of the carriage at any given point than does the circumference. Additional sections (such as the inclusion of both the diameter of the breech of the cannon and the base ring) proved redundant.

Though not present in the database, the location and dimensions of iron bolts were taken, beginning with the carriages at Fort Ticonderoga.

A complete list of measurements can be found in Appendix F, which contains the codebook listing all variables in the database. These roughly correspond with terminology on the recording sheet, though there were a few variables which needed to be renamed for clarification purposes. Several variables, related to proportions, were added after the examination of correlations.

Tools and Materials

The basic recording tools included a tape measure marked in feet and tenths, a one-foot-long rectangular photo scale, a two-foot-long rectangular photo scale, a high definition digital camera, and a pencil and clipboard for note taking. Feet and tenths were used throughout. The photo scales served the additional purpose of creating extensions from feature locations not accessible by the tape measure alone. They were created using white rectangular wooden rods of appropriate length from the hardware store, wrapped in black electrical tape in tenth-of-an inch increments, alternating the white of the rod with the black of the tape. A whiteboard allowed for the easy organization and tracking of Carriage IDs and photographs. For each carriage, the Carriage ID, housing institution, date, and project name "Gun Carriage Project 2018" was written on the whiteboard in black dry erase marker.

In-Person Recording

Recording officially began 6 May 2018 at the History Museum of Mobile, with Carriage One. Initially, the order on the recording sheet was followed for obtaining measurements. However, working from one end of the carriage to the other improved efficiency. Carriage One took over and hour to record, while Carriage 17 (recorded 17 May) took roughly 30 minutes.

Though the approach to measuring each carriage varied based on its storage, accessibility, and size, several general guidelines were followed to aid consistent data gathering.

Measurements were obtained from the same side of the carriage, unless a specific feature was too heavily deteriorated to record. In such cases, the other side was utilized instead. This is possible because carriages are generally mirrored longitudinally, with only minor variation. Overall length included any features, transom protrusions, or decorative molding found in the stool or carriage beds. Overall carriage height was taken in two parts: with and without the trucks. The height of the cheek without the truck is the height of the cheek plus the height of the axletree outside the axletree recess. Overall width was measured in both the front and rear of the carriage. In all cases except the *Mary Rose*, this distance was simply measured between the outside faces of the cheek. *Mary Rose's* carriage beds do not follow the cannon taper, making the front and rear widths the same. In some rare cases, like Carriage 18, there was a taper from bottom to top as well.

Axletree distances were taken from either the front of the carriage to the front edge of the front axletree, or from the rearmost point of the carriage to the rear-facing edge of the hind axletree. For noting the locations of features on the top face of the cheeks, such as capsquares and trunnion rests, measurements were taken from the front of the cheek to the leading edge of the feature.

For objects visible from the sides of the carriage, such as transom bolts and side ring bolts, two measurements were obtained. The first noted the distance of the object from the front or back of the cheek, while the second related to the distance from the top or bottom of the cheek. Measurements were taken to the nearest edges of the bolts, followed by the dimension of the bolts themselves (generally diameter and protrusion from the side of the carriage). Vertically aligned bolts also had their heads recorded. For the bracket bolt and rear axletree bolt, the distance from the end of the step tread they rest in was utilized to note their locations.

Additionally, all carriages underwent photographic recording. These included several general photographs, as well as those unique to each carriage. All carriages were photographed from both sides, the front, and back as possible. Specific detail shots included a top view down of the front and rear trucks, the capsquare assembly, location of bolts, visible construction or deterioration features, stool bed, and transoms. Variation in individual carriage dictated if any additional photographs needed to be taken. Because of their size and weight, *in situ* recording proved the only method to obtain data. As a result, the photographs do not have sterile backgrounds or lighting. All overall shots included the presence of a whiteboard containing identifying information for the carriage, to aid in later analysis and organization.

Recording from Website, Publication, or Drawing

Archaeological publications, museum websites, and state agencies provided additional gun carriage information. The *Mary Rose* and *La Belle* wrecks produced detailed publications containing the measurements for the gun carriages associated with them. Information for the *Vasa* came from the *Vasa* Museum's extensive online collection database. Virginia's Department of Historical Resources, owner of the *Betsy* (currently loaned to the Yorktown Victory Center) kindly provided a condition report and several scaled photographs from which additional measurements could be pulled. While several measurements were provided directly from these sources, it was necessary to utilize a ruler and scale factor to obtain additional data from scaled drawings and photographs. The use of scale factors and photographs is not ideal, but necessary for this thesis, due to accessibility of certain collections, particularly that of the *Vasa.* Any further carriage studies would benefit from relying more heavily on in-person recording.

Database

The purpose of the database is to closely examine variations and trends across carriages through the centuries, study the relationships between various carriage components, and develop reconstruction tools for archaeologists. Through exploring these topics, it is hoped that researchers will gain deeper insight into trends and features visible from the historic and archaeological record. To accomplish these goals, correlations, regressions, and ANOVAs were undertaken.

Database Creation

Database creation began with the generation of a list of basic variables, derived from the recording sheet, called a codebook, shown in Appendix F. A codebook allows for the easy organization of variable information, and interpretation of the database by other users. This list contains the full variable name, the shortened label used in the database, and the variable type (either nominal or interval/ratio).

After the variables were added to the database, data entry began. The variables were displayed as columns, much like a normal data table such as those seen in Microsoft Excel. Because the order on the recording sheet was followed, the data entry process was rapid.

Correlations

The first step of analysis was the identification and development of proportional relationships. Strong, consistent relationships allow for the meaningful examination of change over time and eliminate the differences in relative carriage size, allowing both small and large examples to be examined together. Correlations are well suited to this task. To develop these proportional lists, carriage dimensions related to the cheek, transom, axletrees, and trucks were run in a single correlation, along with the parts of the cannon.

The resultant table was quite sizeable, but only a certain number of the correlations were strong and statistically significant. “Strong” for the purposes of this project refers to those correlation coefficients of +/- 0.70 or greater. Statistically significant refers to the p-value, which determines the likelihood of the results in the correlation occurring due to random chance. Variable pairs selected for the proportional examination were required to have p-values of 0.05 or below. The lower the p-value, the greater the statistical significance of the correlation. There were 23 carriage variables selected for the correlation analysis. In the resulting output, 29 correlation pairs met the dual requirements of strong correlation coefficient and p value of 0.05 or below. Seventeen additional correlations between the listed cannon and carriage variables also met the requirements.

Some carriage variables had strong significant correlations with multiple other variables. For instance, the front axletree body length correlated with five other carriage variables. Transom length, similarly, had five strong significant correlations with several cannon variables. Instances such as these were set aside for multiple regression analysis and were not explored as proportions. A total of six variable pairs (with minimal repeats) proved both strong and statistically significant and were added to the database for proportional examination.

The other goal of this examination was to explore relationships mentioned in artillery treatises. Though some of these dimensions do not meet the specified requirements for inclusion as proportions, they are still examined because of their reference in artillery treatises. Many times, these relate to overall dimensions of the carriage, like the widths in the front or rear of the carriage and carriage length. Muller lists thirteen individual proportions, mainly between cannon and carriage parts. There are of course, several other carriage variables which did not make it into the analysis; later examination of gun carriages can make use of the database to conduct additional statistical studies beyond the limited scope of this project. Table 4.2 shows which variables were paired together to create the proportions, the Pearson coefficient, and significant p-values that resulted from the correlation. The correlation pairs derived from Muller's treatise are separated from the rest.

TABLE 4.2: Proportional Pairs and Correlation Results

Variable 1	Variable 2	Pearson Coefficient	Significance
Front Cheek H	Rear axletree body H	0.789	0.000
Front axletree arm L	Rear axletree arm L	0.852	0.00
Rear axletree body H	Rear axletree arm D	0.780	0.002
Front Truck D	Rear Truck D	0.762	0.00
Transom H	Base ring D	0.754	0.00
Front axletree body L	Cannon L	0.799	0.00
Trunnion Notch Depth	Bore W	0.823	0.001
Proportions from Artillery Treatise			
Cheek W	Bore W	0.772	0.003
Trunnion Notch L	Bore W	0.581	0.009
Front Truck D	Bore W	0.507	0.111
Rear Truck D	Bore W	0.093	0.774
Front Cheek H	Bore W	-0.258	0.418
Rear Cheek H	Front Cheek H	0.561	0.004
Transom W	Bore W	0.703	0.119
Transom H	Bore W	0.717	0.109
Front Truck W	Cheek W	0.479	0.024
Rear Truck W	Cheek W	0.614	0.002
Front W	2nd Reinforce D	0.885	0.000
Rear W	Base ring D	0.889	0.000
Cannon L	Carriage L	0.877	0.000

The correlation pairs in the first half of the table all possess Pearson coefficients between 0.754 and 0.852, along with high levels of significance. The proportions derived from Muller vary greatly, with Pearson coefficients between -0.258 and 0.889 and significance between 0.000 and 0.774. Only four of Muller's proportions meet the criteria for correlation strength or significance. The presence of large Pearson values suggest that the variables involved in the correlation have some regularity in their interactions, though only regressions can account for the influence of one variable on the other. For the purposes of this project, a strong correlation hints at key interactions between variables that are worth further exploration.

After relevant pairs were identified, their proportions (derived from Variable 1 divided by Variable 2) were added to the database as new variables. These new variables underwent regression and ANOVA analyses, the results of which are discussed below. As seen above, several of the proportions put forward by Muller fail to meet the strength and significance requirements. This suggests that the Muller's proportions cannot be universally be applied to carriages.

Regressions

Regression analysis allows for the examination of how variables relate and interact with each other. Unlike correlations, regressions suggest influence and causal relationships. Broadly speaking, regressions allow for the creation of models that use carriage or cannon components to predict the values of other components. Such a tool would be useful to archaeologists attempting to recreate full carriage dimensions from fragments found on archaeological sites.

Regression R-values run between zero and one; the closer to one the R-value is, the stronger the relationship. They come in two varieties: simple and multiple. Simple regressions examine the direct relationship between one independent (x) variable and one dependent variable (y). Multiple regression examines the impact of multiple independent (x) variables on a single dependent (y) variable. As with correlations, R values greater than 0.7 and p-values less than 0.05 were used as guidelines for determining strength and significnace.

Simple Regressions

Simple regressions were conducted on all variable pairs which met the strength and significance requirements in the correlation section. Multiple regressions were conducted on those variables which correlated with several others. Table 4.3 below summarizes the results of the simple regressions, based on the variable pairs found to correlate significantly.

TABLE 4.3: Simple Regressions

ID	Independent (x)	Dependent (y)	R-Value	Constant	B coefficient	Error	Sig.
1	Rear Axletree Body height	Front Cheek H	0.789	0.264	3.325	0.365	0.000
2	Rear axletree arm Length	Front axletree arm L	0.852	0.052	0.973	0.152	0.000
3	Rear Axletree Arm Diameter	Rear Axletree Body\ H	0.780	0.130	0.889	0.0881	0.000
4	Rear Truck Dia.	Front Truck Dia.	0.762	0.269	0.982	0.22341	0.000
5	Base Ring Dia.	Transom H.	0.754	-0.090	0.740	0.18896	0.000
6	Cannon L.	Front Axletree Body L.	0.799	-0.141	0.290	0.41939	0.000
7	Bore Width	Cheek W.	0.675	0.124	0.589	0.06684	0.001
8	Bore W.	Trunnion Rest Depth	0.800	-0.113	0.944	0.07557	0.000
9	Bore W.	Front Truck Dia.	0.281	1.064	1.021	0.33442	0.274
10	Bore W.	Rear Truck Dia.	0.029	1.234	0.075	0.27678	0.907
11	Bore W.	Front Cheek H.	0.233	2.381	-1.270	0.55096	0.323
12	Front Cheek H.	Rear Cheek H.	0.499	0.198	0.201	0.20540	0.010
13	Bore W.	Transom W.	0.437	-0.320	1.820	0.31131	0.118
14	Bore W.	Transom H.	0.456	0.239	1.479	0.24021	0.102
15	Cheek W.	Front Truck W.	0.479	0.238	0.563	0.10606	0.021
16	Cheek W.	Rear Truck W.	0.526	0.201	0.672	0.11093	0.010
17	Second Reinforce Dia.	Front W.	0.807	-0.459	2.158	0.36606	0.000
18	Base Diameter	Rear Width	0.845	-0.185	1.728	0.32019	0.000
19	Cannon Length	Cheek Length	0.430	2.595	0.239	1.00537	0.041
20	Cannon Length	Carriage Length	0.829	1.289	0.492	0.64936	0.00
21	Trunnion Rest Length	Bore Width	0.581	0.202	0.571	0.08547	0.009

The above table summarizes the R-value, B-coefficients, standard estimate of the error, and significance for all the simple one-to-one regressions based on the proportions discussed in the ANOVA section. The regressions are given a numerical ID to help track them. The R-values vary greatly in Table 4.3, falling between 0.029 and 0.852. Eleven variables failed to meet the strength or significance requirements. The remaining ten were developed into full equations. The simple regression linear models are based on the standard linear equation format $y=mx+b$. The B-coefficients in Table 4.3 correspond to m, whilst the constant corresponds to b. The Model A equations are in this standard format. The Model B equations are the same, only with the x variable isolated, rather than the y. Each of the regressions that met the strength and significance requirements (identified by the Regression ID in the leftmost column of Table 4.3) has a Model A and Model B equation. Table 4.4 displays these equations.

TABLE 4.4: Significant Regression Models

Regression ID	Model A	Model B
1	y= 0.264+3.325x	x=(y-0.264)/3.325
2	y=0.052+0.973x	x=(y-0.052)/0.973
3	y=0.130+0.889x	x=(y-0.130)/0.889
4	y=0.269+0.982x	x=(y-0.269)/0.982
5	y=-0.090+0.740x	x=(y+0.090)/0.740
6	y=-0.141+0.290x	x=(y+0.141)/0.290
8	y=-0.113+0.944x	x=(y+0.113)/0.944
17	y=-0.459+2.158x	x=(y+0.459)/2.158
18	y=-0.185+1.728x	x=(y+0.185)/1.728
20	y=1.289+0.492x	x=(y-1.289)/0.492

The Model A equations are meant to be used in instances where the independent (x) value is known and dependent (y) is unknown. The Model B equations are meant to assist researchers in instances they know the dependent (y) variable but not the independent (x) variable. Both sets of variables can be found in Table 4.3. Table 4.3 and Table 4.4 are meant to be used in conjunction with each other.

The following scenario outlines the use of Table 4.3 and Table 4.4. For instance, a rear axletree is pulled from an archaeology site, relatively intact. Based on Regression 1 from Table

4.3, it is possible to estimate the front height of the cheek from the height of the rear axletree. Archaeologists measure the height of the axletree as 0.5 feet. They could input this value into the Model A equation for Regression 1, found in Table 4.4. The calculation is as follows.

Calculation 1

$$y=0.264+3.325x$$
$$y=0.264+3.325(0.5)$$
$$y=0.264+1.6625$$
$$y=1.9265 \text{ ft}$$

The rear axletree body height for this example was taken from Carriage 7. The front height of the cheek was measured to be 1.9 feet, closely matching the prediction made by the model.

Archaeologists in the above scenario would now know the maximum height of the cheek, gaining insight into the elevation capabilities of the gun mounted on the carriage and one of the major dimensions of the missing carriage. With further research and testing, it may be possible to generate a more complete set of regressions to model the relationships between more carriage dimensions. Furthermore, additional regressions could be conducted between additional cannon and carriage parts. If a cannon were discovered without a carriage, it would be possible to estimate the parameters of the carriage or vice versa. Additionally, the link between ship design and gun carriage design could be further explored. This would allow for the carriage to serve as a proxy between cannon design and ship design, thus helping in ship reconstruction efforts as well.

The ten models discussed here were graphed onto the scatterplots of their variables, to provide some insight into their fit. Several, such as that for Regression 1, fit the data extremely well, whilst others follow the general trend but do not fit the data as closely. The four with the best fit are displayed below.

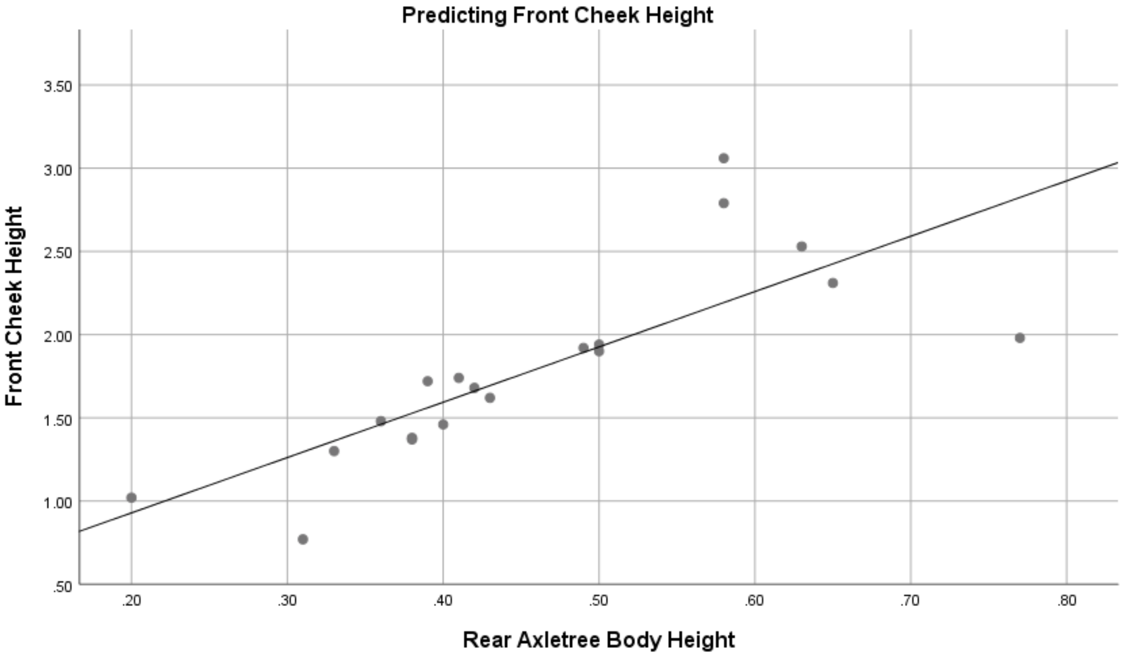


FIGURE 4.5: Predicting Front Cheek Height; y= 0.264+3.325x. Figure by author 2018.

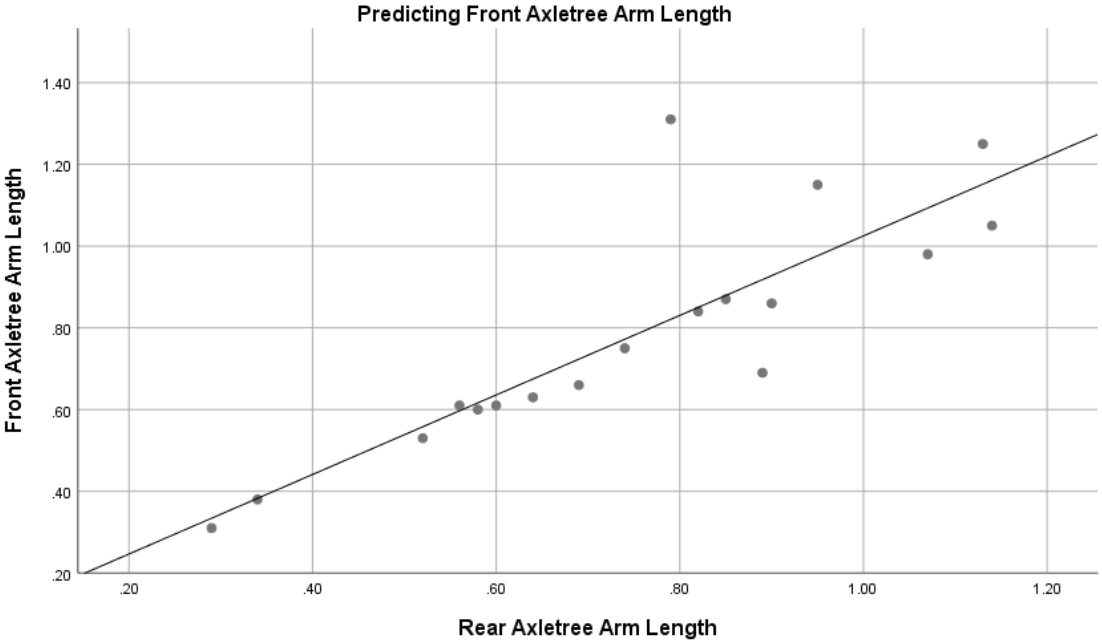


FIGURE 4.6: Predicting Front Axletree Arm Length; y=0.052+0.973x. Figure by author 2018.

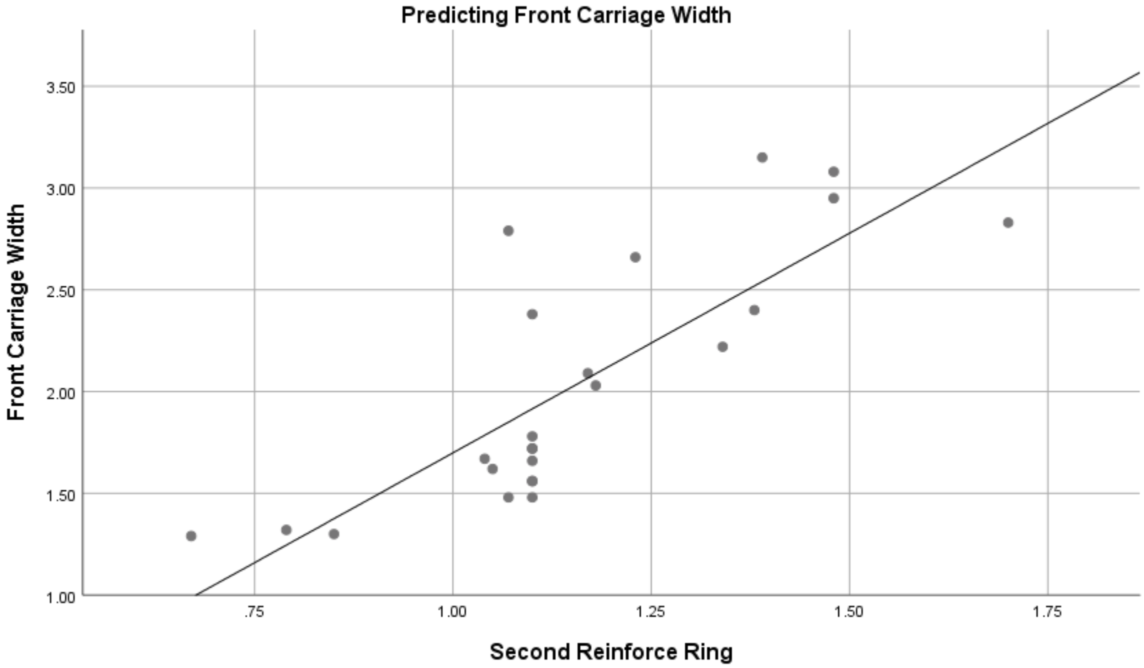


FIGURE 4.7: Predicting Front Carriage Width; y=-0.459+2.158x. Figure by author 2018.

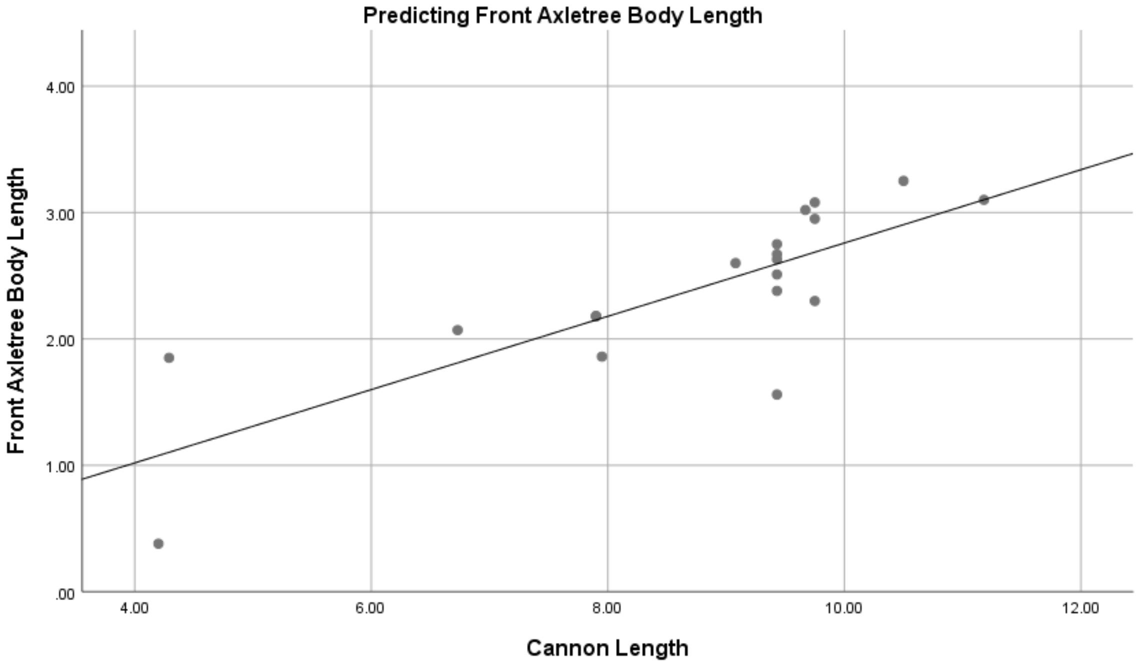


FIGURE 4.8: Predicting Front Axletree Body Length; y=-0.14+0.290x. Figure by author 2018

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Multiple Regressions

Within the correlations of the four principle carriage components, six variables were found to correlate strongly and significantly with multiple other variables. These included: Cheek width, transom length, front axletree body length, front axletree body width, front axletree arm diameter, rear axletree arm diameter, and rear axletree body length. Multiple regressions imply that multiple independent variables have an impact on the dependent variable. In other words, its characteristics cannot be explained or predicted by one variable alone. Multiple regressions are useful in determining more complex relationships amongst carriage parts. The results discussed here hint at further possibilities and are not all-inclusive or totally comprehensive. Table 4.5 summarizes the results of the multiple regressions. There are multiple independent (x) variables, the single dependent variable, the R-value of their overall regression, and overall significance. They are also assigned a Regression ID, continuing from the simple regressions in Table 4.5.

TABLE 4.5: Multiple Regressions

Regression ID	Independents (x)	Dependent (y)	R-Value	Error	Sig.
22	x_1=Trunnion end diameter x_2=Second reinforce x_3= Rear axletree body length x_4=Transom length x_5=Step height	Cheek width	0.978	0.02447	0.000
23	x_1=Transom height x_2=Rear axletree body length x_3=Cheek width x_4=Bore width x_5=Trunnion length x_6=Trunnion end diameter x_7=Base ring diameter x_8= second reinforce	Transom L	0.982	0.06678	0.012
24	x_1=Front axletree arm diameter x_2=Rear axletree body length x_3=Rear axletree arm diameter x_4=Front truck width x_5=Rear truck width	Front axletree body length	0.864	0.46363	0.015
25	x_1=Rear axletree body height x_2=Rear axletree arm diameter x_3=Front truck width x_4=Rear truck width	Front axletree arm diameter	0.958	0.04153	0.000
26	x_1=Front truck width x_2=Rear truck width	Rear axletree arm diameter	0.867	0.06074	0.000
27	x_1=Cannon length x_2=Bore width x_3=Trunnion length x_4=Trunnion end diameter x_5=Base ring diameter	rear axletree body length	0.845	0.39755	0.067

As with the simple regression, each of the regressions produced a constant *b,* and B-coefficients, which corresponds to a coefficient *m* in the multiple regression equation: $y=b+m_1 x_1 +m_2x_2+m_3x_3+\ldots m_nx_n$.. Each of the *m* values correspond to an independent (x) variable, shown in the table above. By inputting the B-coefficients and constants from the SPSS output, multiple regression models were created. Only Regression 27 failed the significance criterion and was not transformed into a model. Table 4.6 reports these models.

TABLE 4.6: Multiple Regression Models

Regression ID	Model
22	$y=-0.005+1.046x_1+0.120x_2+0.022x_3-0.237x_4+0.170x_5$
23	$y=0.091-0.268x_1+0.058x_2-2.482x_3+0.628x_4+0.659x_5+2.590x_6+0.309x_7+0.611x_8$
24	$y=-0.502+2.470x_1+0.491x_2+2.011x_3+1.267x_4-1.714x_5$
25	$y=0.016-0.087x_1+1.002x_2+0.105x_3-0.010x_4$
26	$y=0.003-0.078x_1+0.905x_2$

The calculations for multiple regressions are similar to those for simple regressions, only with more variables. The regression values for these equations are generally stronger than those associated with the simple regressions. Half of them have R-values above 0.9 and lower estimated errors, which suggests that these models would be useful tools in examining the more complex relationships existing between carriage parts. The main limitation for their application to reconstruction of carriage components is that more information is needed for predictions than in simple regressions. Thus, they would work for better preserved carriages, rather than fragments.

The models created from the simple and multiple regressions suggest that truck carriages consist of a series of complex relationships, both between carriage parts and between carriage parts and the gun. This study only scratches the surface in regard to these relationships, highlighting a select few which suggested themselves based on the limited correlations conducted on the database. It has been demonstrated that many of the resulting models closely predict the value of one carriage part based on the values of other cannon or carriage components. Thus, a comprehensive series of regression models would prove quite useful for approximating the dimensions of carriage components, matching carriages to guns, or reconstructing missing carriages. Treatises still have uses in carriage reconstruction, but they should not be the only tool.

ANOVAs

ANOVAs, or Analysis of Variance, allows for change to be examined between groups. By grouping carriages together by the century they were built, broad change over time can be explored. To do this, the "year" variable was recoded to "century" in SPSS. An entry of "1" represents all carriages constructed in the 16th century, while "4" represents all carriages from the 19th century.

Of the 19 proportions developed from the correlation section, 11 showed significant variance over time. Table 4.7 summarizes the F-values and significance for each of the ANOVAs.

TABLE 4.7: ANOVA Results

Proportion	F-Value	Sig.
Front Width to Second Reinforce	5.919	0.005
Trunnion Notch Depth to Bore Width	11.429	0.000
Front Truck Diameter to Bore Diameter	4.038	0.031
Rear truck diameter to Bore Diameter	5.032	0.013
Front Cheek Height to Bore Diameter	9.657	0.001
Rear Cheek Height to Front Cheek Height	4.074	0.019
Transom Width to Bore Diameter	11.394	0.001
Front Truck Width to Cheek Width	10.357	0.000
Front axletree arm diameter to rear axletree arm diameter	13.695	0.000
Rear axletree body height to rear axletree arm diameter	4.351	0.031
Transom Height to Base Ring Diameter	3.890	0.033
Trunnion Rest Length to Bore Diameter	1.752	0.199

The following sections will discuss the significant results displayed in the table, including discussion on the degree to which these trends mirror patterns hinted at in treatises (with specific focus on Muller), the implications for design and performance, and wider trends in armament construction.

It should be noted that these ANOVAs assume that the carriages from various nations are generally similar to each other at any given point in time. They do not consider national variation. The only nationalities which appeared in multiple centuries are Britain and the United States. Spain, Sweden, and France only appear in single centuries, thus much of the change observed in them could be temporally related instead. As a result, national variation cannot be isolated from change across time, and thus will not be examined in this dataset.

Front Carriage Width and Second Reinforce

The first of the proportions is between the front width of the carriage and the second reinforcement ring on the cannon. It varied significantly. Figure 4.9 below is the means graph, displaying changes in the variable.

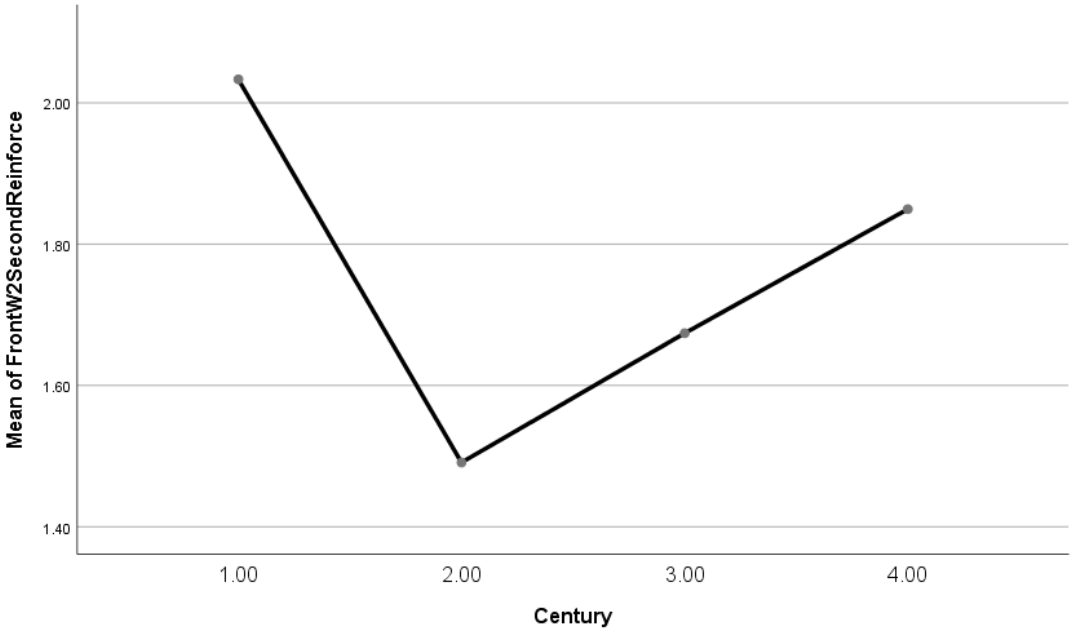

FIGURE 4.9: Changes in between the front with and second reinforce ring. The “1” stands for the 1500s and “4” for 1800s. Figure by author 2018.

Figure 4.9 indicates that during the 16th century, the overall width of the carriage, from the outside faces of the cheeks, was a little more than twice that of the second reinforce. By the 19th century, this dropped to over 1.83 times the diameter of the second reinforce. There exists a major drop from the 16th to 17th centuries. One cause for this could be that the *Vasa* guns have not all been discovered. The measurements placed in the database are based on the one or two currently housed in the *Vasa* Museum, but do not relate to any single carriage in the database. While the *Vasa* cannon are more standardized than other artillery of the time, there still may be enough variation that the carriages were meant for specific cannon and were not readily interchangeable. Researchers have undertaken a project to identify and track *Vasa's* guns, so perhaps in a couple of years efforts can be made to try to match carriage and cannon characteristics more closely.

The proportion increases steadily from the 17th century to the 19th century, but it never again reaches the levels seen in the *Mary Rose* carriages. Since the overall front width includes the thickness of both cheeks, it is possible that some variation in cheek width could be at the root of this trend. To check, the cheek width was subtracted from overall width and ran as a new variable in the database, called FrtInnerW. The proportion between the new variable and the second reinforcement ring resulted in an ANOVA significant to 0.024 and follows the same trend as seen in Figure 4.9. This suggests that the trend seen in Figure 4.9 was not due to changes in cheek thickness.

The variation in the proportion could be due to changing standards in the clearance given between the cheek and sides of the gun tube. The minimum front carriage width is directly tied to the diameter of the second reinforcement ring, as Muller suggests, but some additional room is still needed to keep the tube from chafing against the carriage during elevation. The additional clearance would also allow ropes to be passed through during the mounting and unmounting process. Different sized guns may require different clearances between them and the cheeks. Several guns in the database are heavy 24 or 32 pounders, but others are of smaller calibers, such as four pounders and nine pounders. It appears that the larger guns required additional room for the ropes used to move them on and off their carriages.

Trunnion Notch Depth and Bore Diameter

The second proportion to exhibit significant change over time is that between the depth of the trunnion notch and the bore diameter. Figure 4.10 displays its trends.

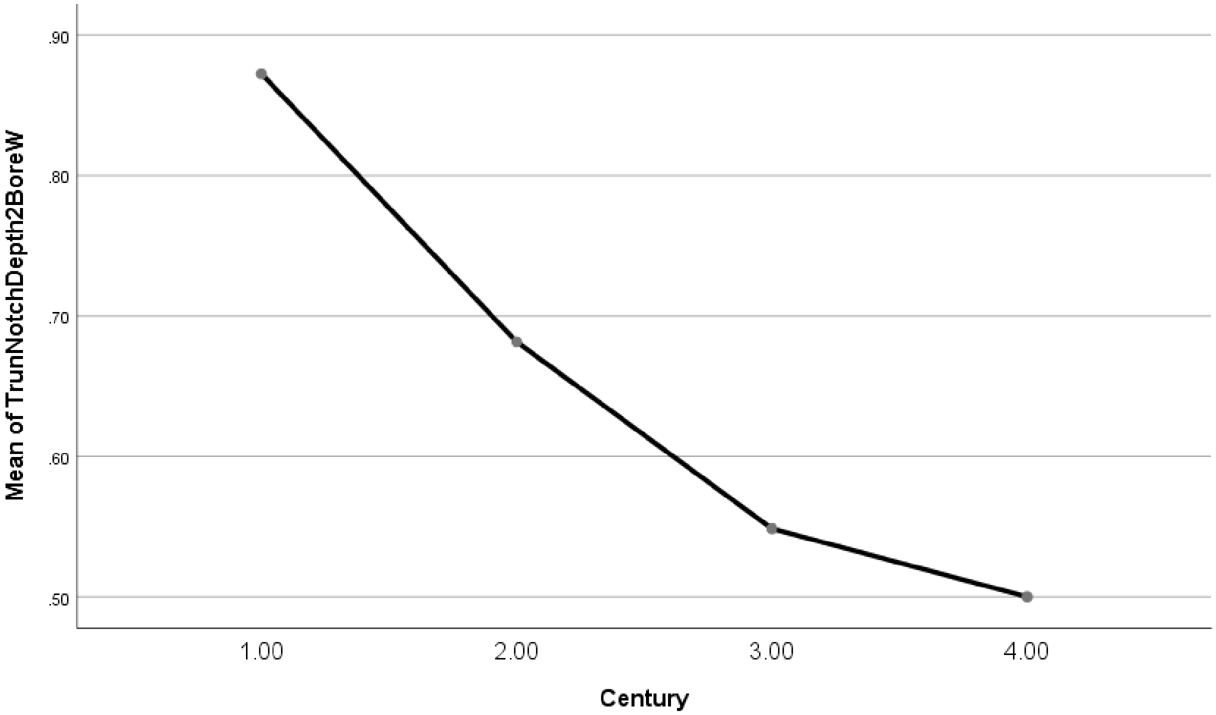

FIGURE 4.10: Trunnion notch depth to bore width (diameter) over time. Figure by author 2018.

Unlike the proportion between the front width of the carriage and second reinforce on the cannon, the proportion between trunnion notch depth and bore width (diameter) possesses a notable downward trend. In the 16th century, the average trunnion notch is a little under 0.8

times the bore diameter, and downtrends notably from there. The rate of this decrease slows down between the 18th and 19th centuries, culminating in a trunnion notch depth half the diameter of the bore.

The decreasing depth in the trunnion notch may be due to the change in the way the trunnion rests in the notch. In the *Mary Rose* carriages, the entire trunnion fits in the notch, with the capsquare closing flat over it. In the 19th century carriages, the top of the trunnion extends beyond the top face of the cheek, and a semi-circular capsquare secures it. One reason for this could be that having the entire trunnion rest in the cheek caused significant wear and tear on the cheek, eventually widening the bottom of the notch in the face of repeated firings. After enough time, the trunnion could get lodged into one side of the trunnion notch, becoming difficult to remove. This could potentially cause problems in elevating the gun as well. A shallower trunnion notch with a curved capsquare may have addressed these problems. The iron capsquare was likely strong enough to take repeated firings without deformation, lasted longer, and was easier to replace than an entire cheek. In the *Mary Rose,* the capsquare's only purpose would have been to close over the top of the cheek, whilst the cheek took the brunt of firing recoil. In later years, the capsquare played a more direct role in recoil absorption, rather than simply ensuring the cannon did not accidently relocate. This scenario fits in with the broader trend towards increased reliance on iron hardware. That in turn can likely be tied in with the refinement of ironworking techniques and increased production capability.

Front Truck Diameter and Bore Diameter

The third significant proportional change over time occurred between the front truck diameter and the bore diameter. According to Muller, the front truck diameter should be roughly four times that of the bore (Muller 1757:97). Figure 4.11 displays the means graph resulting from the ANOVA.

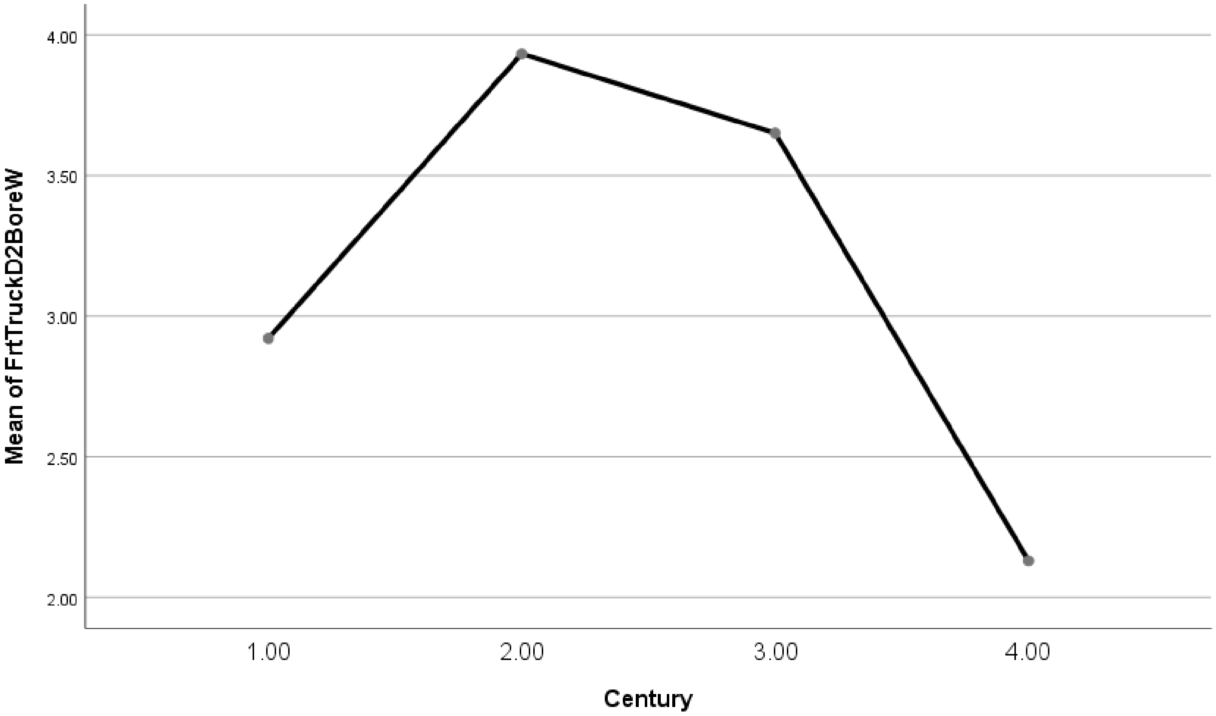

FIGURE 4.11: Front truck diameter to bore diameter over time. Graph by author 2018.

Based on Figure 4.11, the earliest truck carriages in the database possessed front trucks averaging under three times the diameter of the bore. By the 17th century, front truck size peaked at under four times the diameter of the bore, before dropping again. In the 19th century, the front trucks were notably smaller than their 16th century counterparts, at just over 2 bore diameters. These mean values do not match Muller’s specifications for front truck size. There are five instances in the database where the proportion surpasses Muller’s 4 diameter mark, but none of the carriages actually match it. In the 18th century at the time of Muller’s writings, average front truck size is just over 3.5 times greater than the bore diameter, closer to the 3.245 bore diameters that John Robertson discussed in 1775 (Robertson 1775: 219). The carriages from the 18th century come from the Castillo, *Philadelphia*, and Fort Ticonderoga. Bratten notes that the truck dimensions did not match that of Muller, and he goes onto argue that the *Philadelphia* carriages matched the rest of the Muller proportions (Bratten 1997:64). Another important significance in this graph is that it demonstrates that the same proportions did not exist for the trucks throughout the carriage's history. Muller's proportions cannot be universally applied throughout multiple centuries.

Rear Truck Diameter and Bore Diameter

The proportion between the rear truck diameter and the bore diameter also underwent significant change over time, as seen in Figure 4.12.

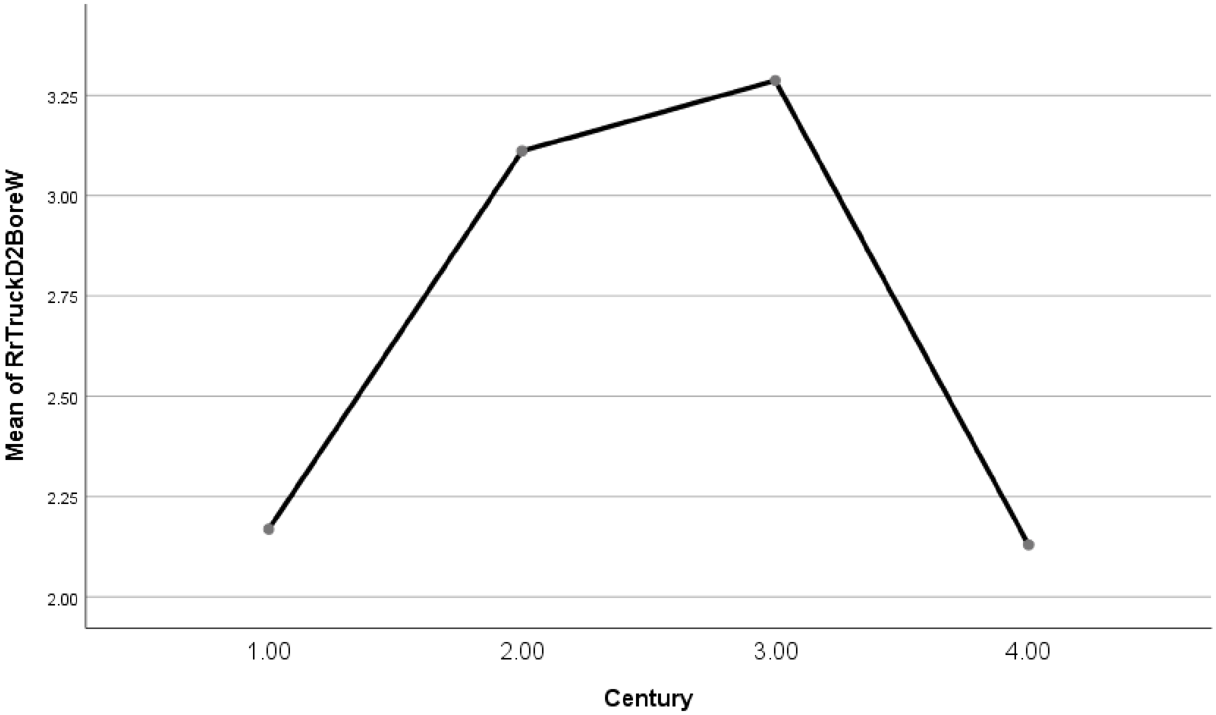

FIGURE 4.12: Rear truck diameter to bore diameter over time. Figure by author 2018.

The general trends seen in the relationship between front truck and bore diameter are also present in that between the rear trucks and bore diameter. Average rear truck size peaked to over 3.25 bore diameters in the 18th century, before dropping dramatically down to 2.125 bore diameters. Muller calls for the rear trucks to be 3.5 times greater in diameter than the bore (Muller 1757:97).

Patterns seen in the relationship between truck diameter and bore diameter could be caused by the location of the carriages aboard the ship. This is certainly visible in *Mary Rose's* case, where trucks were purposely sized to operate at very specific locations, as described by the *Mary Rose* Trust researchers (Hildred 2011). The carriages for *Mary Rose* and *Vasa* come from several locations throughout the ship, scattered across several decks. Those for *Philadelphia come* from a single deck. The Castillo guns all operated off of gun platforms placed on open aired bastions. The original operating location for *La Belle's* carriage is unknown and the *Betsy* carriage was discovered in the hold.

Larger studies may be able to control the location from which a carriage operated to determine if location aboard ship impacted truck size. By the 19th century at least, there seemed to be no difference in truck dimensions based on locations. Surviving carriage plans do not describe multiple, interchangeable trucks dependent on ship location. Additionally, none of the treatises describe using different sized trucks for different ship locations. If location is not a factor, then it is possible the trends in truck design reflect something occurring in ships or fortresses, such as gun port height or height of wall or bulwark in relation to the gun tube. Muller hinted at the possibility of a direct relationship between truck height and gun port height (Muller 1757:97). A closer study of ship design, with attention given to gun port shape and height would be useful in exploring this possibility.

Front Cheek Height and Bore Diameter

Muller also discussed the front height of the cheek in terms of bore diameter. Figure 4.13 highlights its trends.

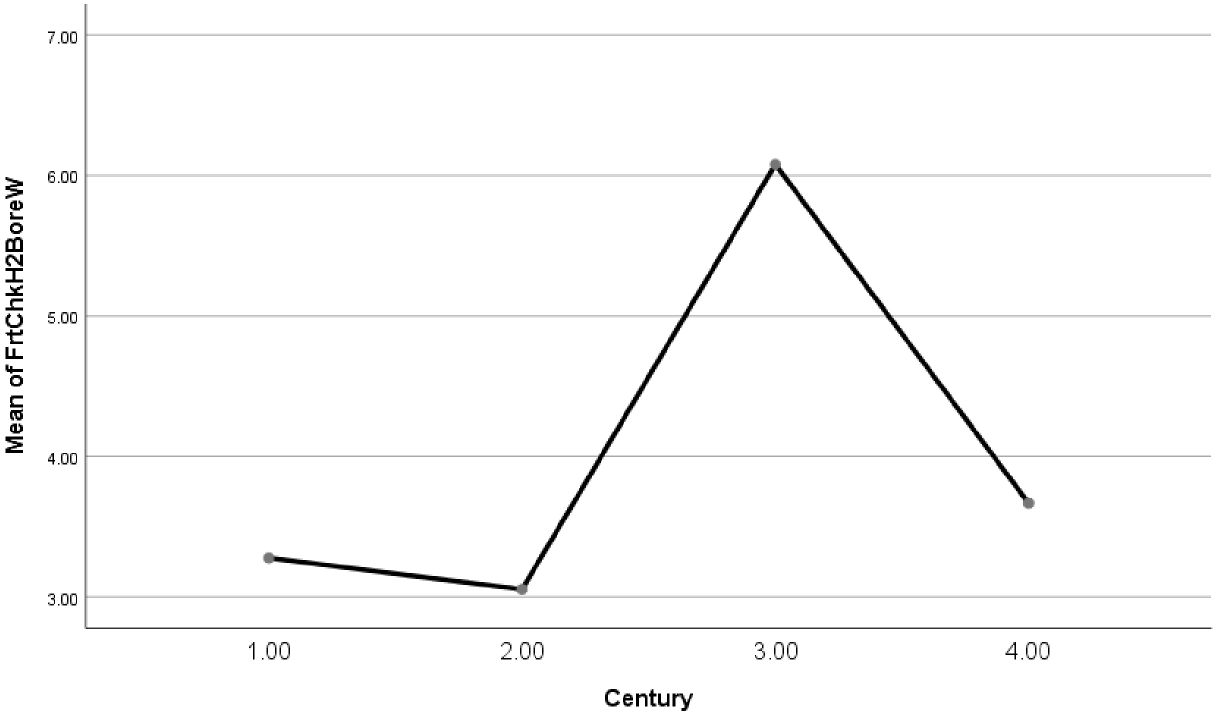

FIGURE 4.13: Front cheek height to bore diameter over time. Figure by author 2018.

As with the trucks, Muller discussed the height of the front of the cheek in terms of bore diameter. He argued that the front cheek height should be 4.75 calibers or shot diameters (Muller 1757:95). The difference between bore diameter and shot diameter was probably not that drastic, but future studies could examine it further. In the 16th and 17th centuries, the front height of the cheek was small, at just over three times the diameter of the shot. Height increased dramatically in the 18th century, up past six bore diameters, before dropping again below four diameters in the 19th century. The front height of the cheek directly impacted a cannon’s ability to elevate above and below the level line. Taller cheeks granted additional degrees of elevation.

Most of the carriages in the 18th century are from the Castillo de San Marcos. They were not hampered by the confines of a gun port and required a higher degree of elevation to hit far off targets. Two other 18th century guns, from the *Philadelphia,* operated from an open deck. From the 16th to 19th centuries, however, there was a general increase in cheek height. Over time, both cannon size and ship size increase, which likely afford the need and ability to make gun ports larger. The gun ports themselves may also be higher off the deck than in previous centuries. An examination of changes in general gun port dimensions may be useful but is beyond the scope of this project.

Rear Cheek Height and Front Cheek Height

According to Muller, the rear of the cheek should be half the height of the front (Muller 1757:95). Figure 4.14 illustrates the change from century to century below.

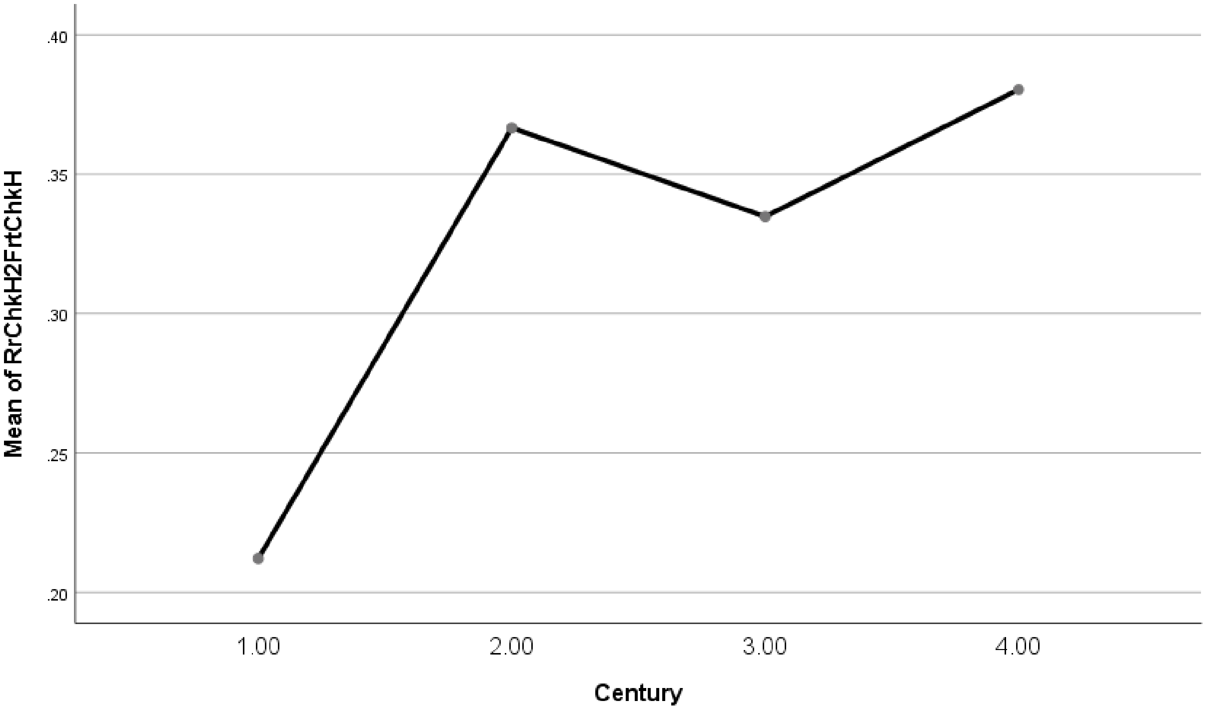

FIGURE 4.14: Rear cheek height to front cheek height over time. Figure by author 2018.

There is a clear upward trend in average rear cheek height throughout the centuries. In the 16th century, the rear of the cheek was a bit over 0.2 times the height of the front cheek. From the 16th to 17th centuries, the rear cheek height increased to over 0.35 times that of the front cheek. In the following century, it dropped below 0.35 times the height of the front cheek before increasing again to around 0.38 times the height. While the average values for each century do not meet Muller's specifications, the two *Philadelphia* carriages come close at 0.51 and 0.52 times the height of the front of the cheek.

The general increase could be due to the needs associated with securing the rear axletree and to offset the loss of the carriage bed. In the 16th and 17th centuries, the axletree rested in shallow recesses carved into the bottom of the carriage bed. By the 18th and 19th centuries, deeper recesses carved directly into the bottom of the cheek replace these. A taller rear section of the cheek would accommodate this. Additionally, rear axletree bolts and rear ring bolts come into more frequent use in later centuries, and it could be that a taller rear cheek was needed to support these bolts. However, these explanations do not account for the spike seen in the 17th century, likely caused by the *Vasa* carriages, which did not use rear hardware or have recesses carved into the underside of the cheek. One possibility is that the cheeks are taller to accommodate the decorative molding at their rear ends, to accompany that seen in the carriage bed. It could also perhaps be due to data error.

Transom Width and Bore Diameter

Another of the relationships touched upon in treatises is that between the width of the transom and diameter of the bore. Muller states that the transom width should equal the bore diameter (Muller 1757:96). Figure 4.15 summarizes the trends in this relationship.

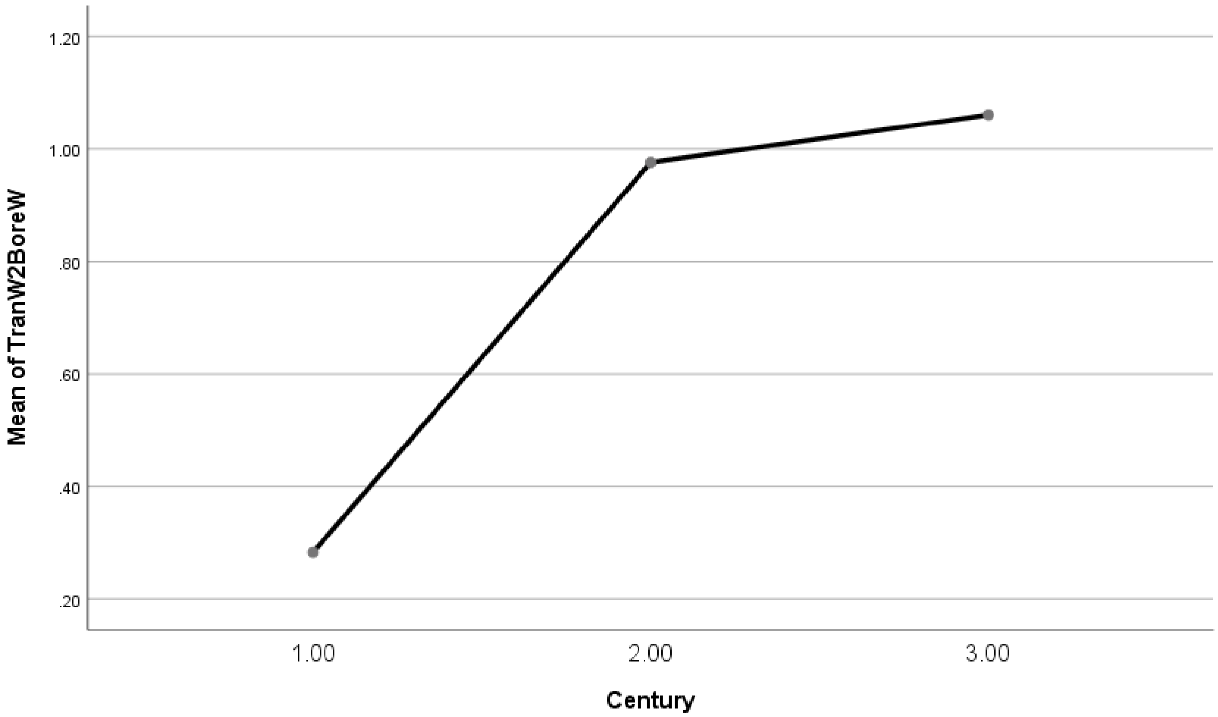

FIGURE 4.15: Transom width to bore diameter over time. Figure by author 2018.

The transoms in the 16th century are little more than thin planks of wood, likely with little supportive value; by the 17th century they are more substantial and are quite close to the size Muller describes (Muller 1757:96). They remain close to this size into the 18th century. Data was not available for the 19th century, so it is not included in the graph. Transoms provide support below the trunnions and give lateral support to the front of the carriage. It is the first feature discussed thus far that matches Muller's descriptions and remains fairly stable across two centuries. This suggests that there is some level of design stability in some parts of the truck carriage, along with some instances of broad design change.

Front Truck Width and Cheek Width

The next proportion with significant change over time was that between the cheek width and front truck width, shown in Figure 4.16.

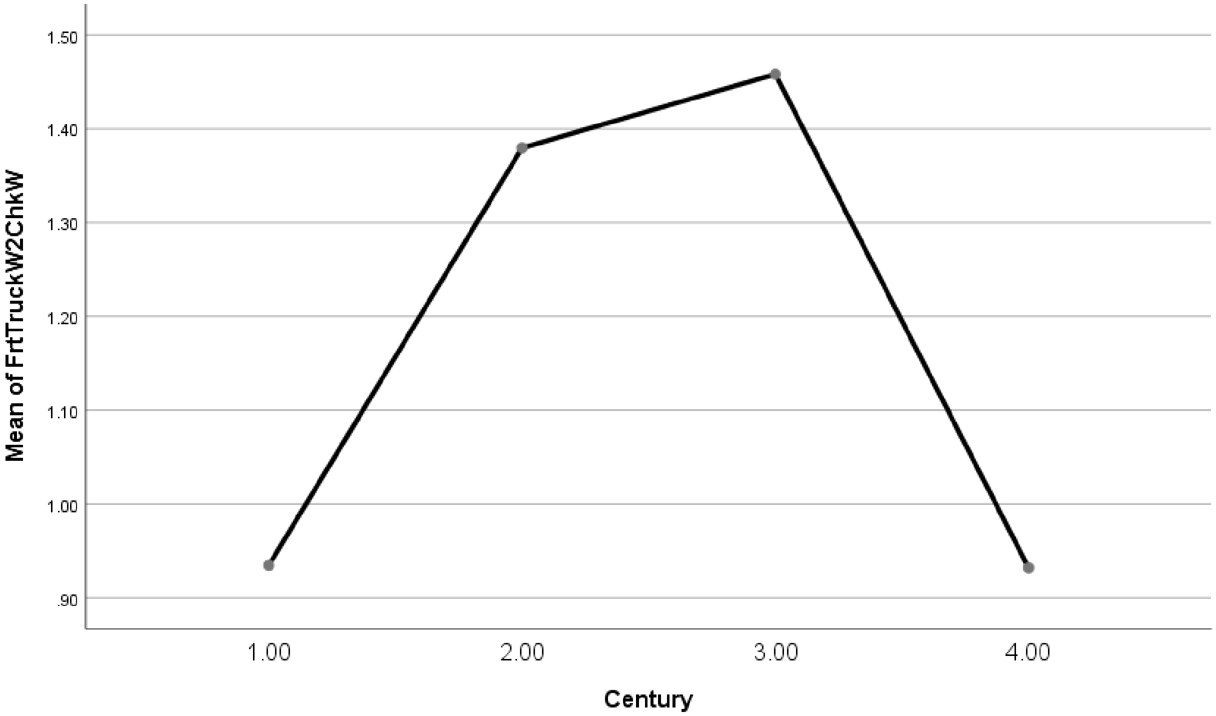

FIGURE 4.16: Front truck width to cheek width over time. Figure by author 2018.

The trend present in Figure 4.16 shares several similarities with those seen between the diameters of the front and rear trucks and that of the bore. The minimum values occurred in the 16th and 19th centuries and the peaks occurred in the 17th and 18th centuries. At these minimum values, the trucks were thinner than the cheeks, roughly 0.95 times the thickness of the cheeks, while the trucks in the 18th century are roughly 1.45 times thicker than the cheeks. One of the 19th century carriages possessed extremely small trucks; eliminating it changes the trend slightly, as seen below in Figure 4.17.

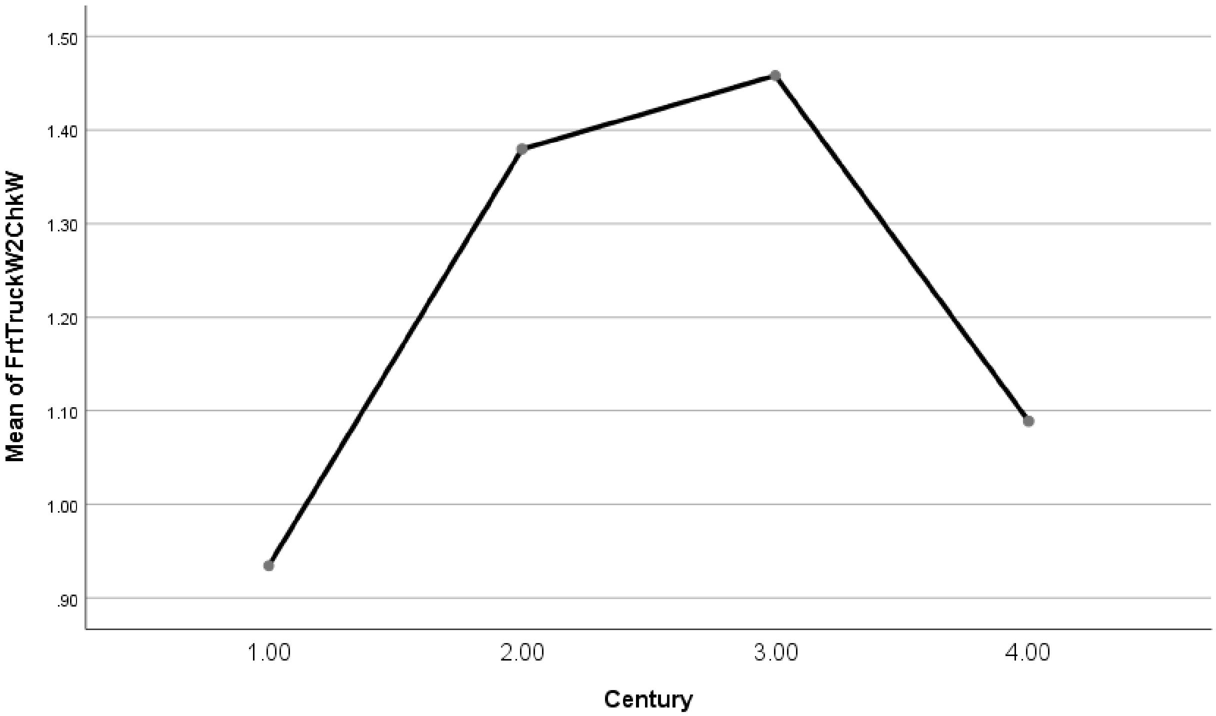

FIGURE 4.17: Front truck width to cheek width, without outlier. Figure by author 2018.

While there is still a sizeable drop from the 18th to 19th centuries, the truck widths are now closer to 1.10 times that of the cheek in the 19th century. The average front truck to cheek widths do not equal the direct one to one relationship described by Muller (Muller 1757:97). There are three cases in the database where that relationship is reached. These include the *La Belle* carriage, one of the *Mary Rose* carriages, and the VIII-inch shell gun from *Constellation.* They are widely separated by time and scattered between three different nations. Two additional carriages from the *Mary Rose* come close, with truck diameters 0.95 and 0.98 times that of the cheek. Some additional light on this trend may be shed with expansion of this dataset.

The trends seen in Figures 4.12, 4.13, and 4.17 might result from issues in the database related to its relatively small size and broad focus, or due to national rather than temporal variation. However, it is also possible that the graphs reflect something drastic occurring in the 18th century to cause the drop in three different proportions.

The 19th century witnessed dramatic industrialization with a great deal of scientific experimentation. There existed active, ongoing efforts to refine or replace the truck carriage in this timeframe, and it is possible the sudden drop we see reflects the results of those efforts to "perfect" the carriage. Through scientific testing, they appear to have determined that the extremely thick trucks did not necessarily assist the carriage in its role. The Carriage Department at the Royal Arsenal in Woolwich conducted rigorous scientific testing on various types of timber (Barlow Jr. 1832), which supports the possibility of additional scientific testing.

Alternatively, the diameter of the axletree arm could have increased relative to the overall diameter of the truck, which may have provided more recoil control than having a wider surface area for friction. As a result, they could have shrunk the truck size and width, and increased the axletree arm diameter instead. While a cursory visual examination of the carriages in the database hints at this, there exists no strong, significant correlation between these variables. The database is fairly small, and only 17 out of the 27 entries in the database possess data to run the correlation and regression analysis. Additionally, experimental archaeology could shed some light on the matter. However, with this dataset, the trend does not exist.

Front Axletree Arm Length and Rear Axletree Arm Length

The relationship between the front and rear axletree arm lengths underwent significant temporal change as seen in Figure 4.18. The majority of these developments occurred between the 16th to 17th centuries. In the 16th century, the front axletree arm averages over 1.6 times that of the rear. By the 17th century, they exhibit an almost one to one ratio. From the 17th to 18th centuries, this value rose slightly above the one to one ratio, but not by much. Between the 18th and 19th centuries, the front axletree arm became slightly longer than the rear again, at roughly

1.05 times the length. This increase across three centuries is relatively steady, though do not reach the sizes seen in the 16th century.

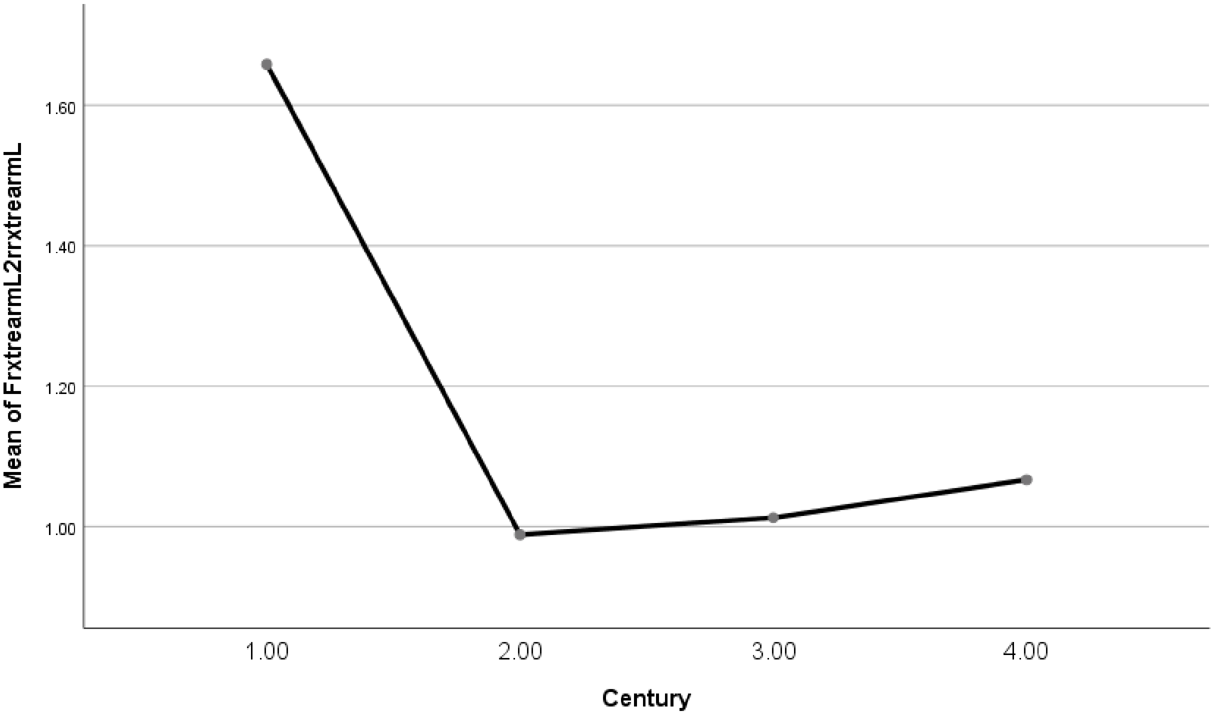

FIGURE 4.18: Front axletree arm length to rear axletree arm length over time. Figure by author 2018.

The overlong front axletree arms from the 16th century carriages result in overall front axletree lengths sometimes being somewhat greater than the rear axletree length. In looking at the *Mary Rose* carriages from above, the front axletree arms project much further from the sides of the carriage than the rear axletree arms. This would make the carriage more susceptible to catching on something. Perhaps this initially was the goal. The overlong front axletree arms could arrest motion if they came up against a block. Alternatively, the extra length allowed them to rest up against blocks or bulwarks meant to keep the carriage from chafing against the ship. However, the relative narrowness of the diameter would potentially cause the arms to break, so neither of these would serve as practical solutions in the long term. This could be one possible reason for the decrease in arm length. By the 18th century, the axletree arms began having iron reinforcement bands placed on their ends to better protect them, as seen at the Castillo (Carriages 3-7) and the donated 1790s truck carriage at Fort Ticonderoga (Carriage 11). The *Betsy* carriage (Carriage 33) possesses these bands. The feature continued into the 19th century, as seen in the *Alabama* (Carriage 1) and *Constellation* (Carriage 17) truck mountings. As the feature became more common, it could have caused a slight increase in arm length to accommodate the bands and still allow enough room for the linchpins used in truck security.

Rear Axletree Body Height and Rear Axletree Arm Diameter

The *Mary Rose* possessed few fully intact rear axletrees, so the carriages from it are excluded from the following analysis. There is an overall positive trend between the proportion between the rear axletree body height and rear axletree arm diameter, as seen in Figure 4.19.

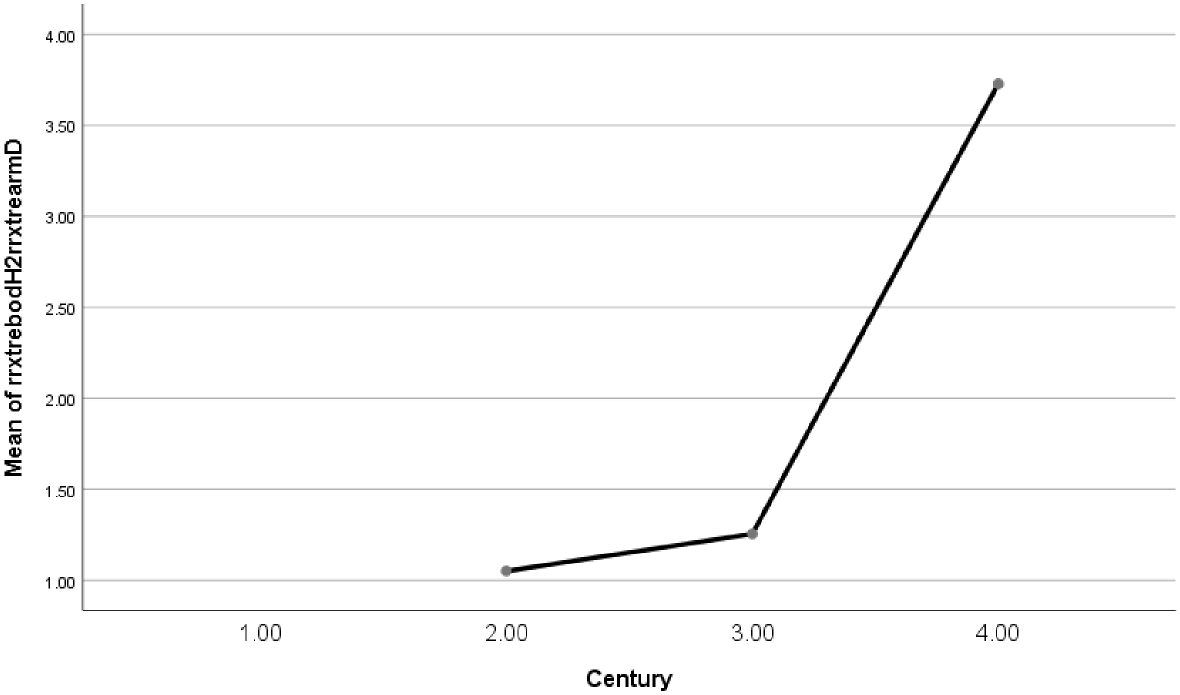

FIGURE 4.19: Rear axletree body height to rear axletree arm diameter over time. Figure by author 2018.

Beginning in the 17th century, the height of the axletree body and the diameter of the arm possessed an almost one to one relationship. During this time, as seen by the *Vasa*, the axletree arm was essentially the same size as the body, only slightly tapered and curved to accommodate the truck. The increase in height suggests that the axletree body underwent some changes, moving towards a more rectangular shape. The rear axletree body grew more distinct from the rear axletree arm. Figures 4.20 and 4.21 highlight this growing distinction. Figure 4.20 is the rear axletree for Carriage 19 off the *Vasa* and Figure 4.21 is part of the rear axletree body, arm, and truck from Carriage 17, from *Constellation.*

FIGURE 4.20: Rear axletree body for Carriage 19 from *Vasa* (Vasa Museet)

FIGURE 4.21: Rear Axletree arm and truck for Carriage 17, *U.S.S. Constellation.* Photograph taken by author in 2018.

In Figure 4.20, there is not much distinction between the body of the axletree and the arm; they possess virtually the same dimensions, with the body being square and the arm being circular. By the mid-19th century, the axletree arm diameter is smaller than the height or width of the body, as seen in Figure 4.21. Increased axletree size could relate to the removal of carriage beds from general design. The beds helped evenly distribute the weight of the gun across the entire axletree. Without it, the weight of the gun goes directly down the cheeks into the outer ends of the axletree body, rather than being evenly distributed. In other carriages with carriage beds, the rear axletree body and arm retain relatively the same dimensions. However, in all the carriages without beds, the rear axletree is larger than the axletree arm, no matter the nationality. This suggests that after the carriage bed was removed, the axletrees were reinforced to support the weight of the gun.

Transom Height and Base Diameter

The transom provided additional support to the front portion of the carriage, almost directly below the pivot point of the gun. The base ring refers to the widest portion of the gun tube, located at the breech end. Based on Figure 4.22 below, the transom was roughly 0.7 times the base ring diameter in height and remains consistent from the 17th century onwards. Essentially, this ties the transom to another dimension of the cannon, one typically not discussed in artillery treatises. Should a cannon be heavily concreted and the bore diameter unobtainable, the base diameter could be utilized as a substitute for the transom height. With the exception of *Mary Rose*, the relationship between transom height and the base ring remains fairly consistent, with only a slight dip in the 18th century.

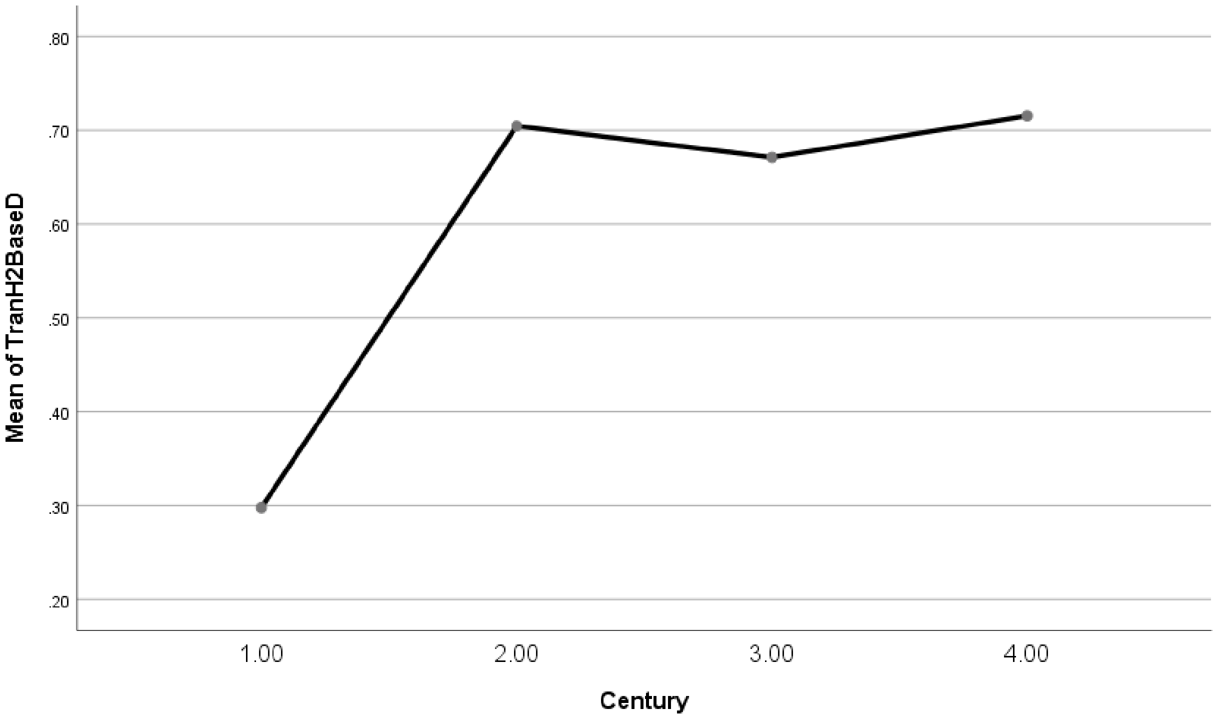

FIGURE 4.22: transom height to base ring diameter over time. Figure by author 2018.

This figure supports the notion that some carriage proportions remain relatively stable throughout time, even as others undergo a great deal of change. The truck carriage is not monolithic; rather it plays host to several complex patterns and processes, reflective of changing naval artillery technology and advances in woodworking and metallurgy. As some elements are refined and altered based on changing operating parameters, others stabilize and remain relatively unchanged from century to century, similar to the transom height relative to base ring diameter.

While the relationship (discussed by Muller) between transom height to bore diameter does not undergo statistically significant change, there is some change, as seen in the Figure 4.23.

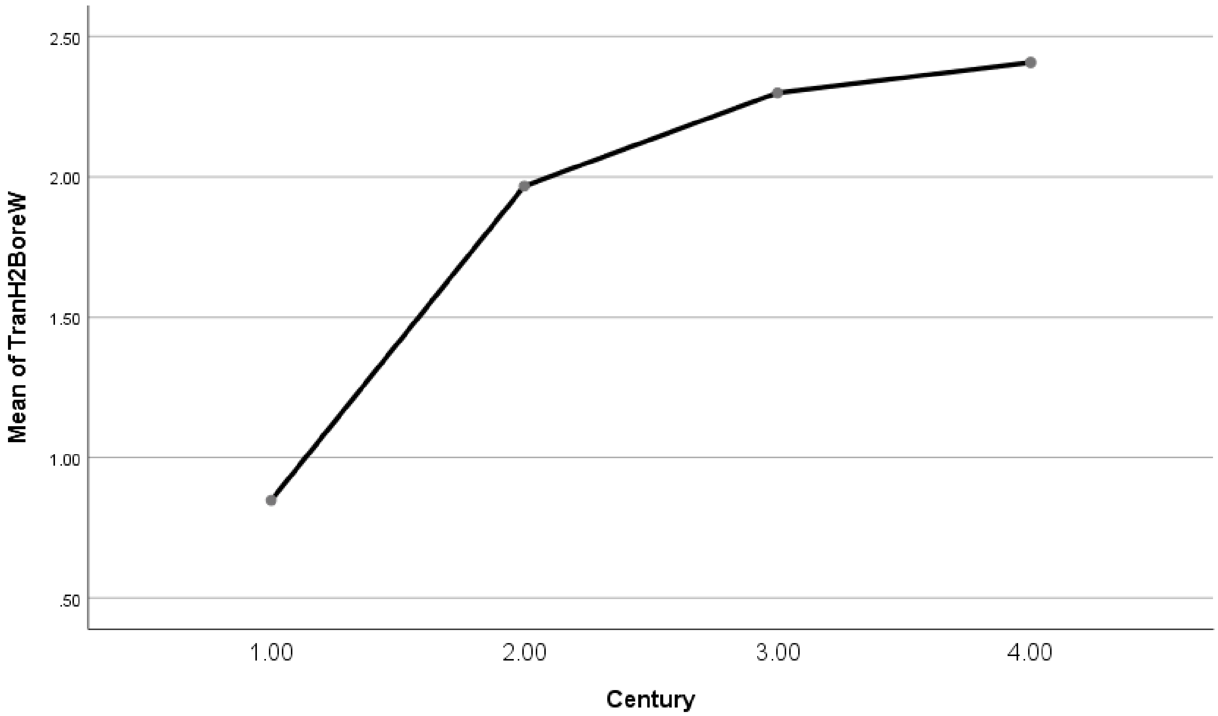

FIGURE 4.23: transom height to bore diameter over time. Figure by author 2018.

The height of the transom nearly doubled relative to shot diameter. In Muller’s treatise, transoms are supposed to be twice the diameter of shot in height (Muller 1757:96). The 17th century was close to this specification, but by the 18th and 19th centuries, transoms approached 2.5 bore diameters in height. However, the relationship between the base ring and the transom remains unchanged. This suggests that there were some changes in the design of the breech end of the gun. The increased power of naval artillery likely required heavier reinforcement of the breech of the gun, to deal with increased shock of firing. Changes in carriages, therefore, are related to changes in gun design as well. The relationship between gun change and carriage change is only hinted at in this study, highlighting the need for additional research.

There are three major takeaways from the ANOVAs displayed here. First, carriage design development and refinement are multi-faceted, non-static processes. Change in carriage design across time was not always linear and is often characterized by rapid development and irregular periods of stabilization. However, if stabilization occurred in one area of carriage design, change almost always occurred in a different area. Broadly, this means that carriages constantly undergo refinement, development, and alteration throughout their history, rather than remaining static and constant. This contradicts claims by 19th century detractors (Garbett 1897:135) and modern scholars (Tucker 1984:89; Rule 1982:160; and Moody 1952:301) that carriages remained stagnant and unchanging since their creation. A carriage from 1545 would not be able to successfully control a 19th century cannon, so some level of change had to occur in order for the carriage to continue to meet the demands of firing heavy ordnance.

Second, change was not always linear. In some variables, no discernable positive or negative change was visible, rather, it occurred in dips and spikes. In several cases, trends lasting through the 16th to 18th centuries suddenly reversed in the 19th century. The change in these cases appear to be the result of increased experimentation and testing in carriage design. Even as they maligned the truck carriage, 19th century artisans, designers, scientists, and naval personnel continued to experiment with the design.

Third, the data suggests that sole reliance on artillery treatises in carriage examination would be a mistake. The ANOVAs examined thirteen proportional relationships listed by the most commonly cited treatise writer, John Muller (Muller 1757). It was chosen in an effort to determine if its proportions appeared in earlier or later centuries. Not only do many of them change dramatically across time, others do not seem to exhibit a relationship at all. Several of Muller’s proportions did not meet the parameters for the study of strong, significant correlations or regressions. In a few cases, some carriages meet one or two of Muller's proportions, however, this is not systematic or widespread phenomenon. Further study is needed, with a larger dataset and more treatises, to explore the differences between actual carriage design and treatise design. This study suggests that, for the most part, Muller's proportions cannot be applied to carriages to other centuries.

Conclusion

Through the creation and examination of a large database, the nature of truck carriage development and the relationships between its various components were explored. Four carriage parts: the cheeks, axletrees, trucks, and transoms served as the focus of correlation, regression, and ANOVA studies. The correlation and regression analyses suggest that several relationships recorded by Muller do not occur in most physical carriages. The ANOVAs hint at a complex, irregular pattern of change in development throughout the history of the truck carriage, interspersed with design stability. Some of the trends could possibly reflect improvements in metallurgy or increased scientific experimentation. In a larger dataset, the ANOVAs could be run on a decade to decade level, revealing a more nuanced understanding of carriage development.

Rather than being an unchanging medieval relic, this dataset suggests that the truck carriage underwent almost constant development and adjustment, and that the relationship between its parts and the cannon are extremely complex. It also demonstrates that models developed from simple and multiple regressions can be used to predict some dimensions more accurately than treatises, and that there exist other relationships beyond the few mentioned in treatises. Truck carriages should not be left as footnotes in archaeological projects or recreated solely from the study of treatises. Overall, the results of this analysis directly contradict findings of 19th century inventors, some modern scholars, and some treatise writers.

CHAPTER 5
CONCLUSIONS

The truck gun carriage represented the cutting edge in naval mountings at the time of its introduction to the European warship. A product of an era of rapid technological development, the truck carriage became a common sight aboard warships and fortifications by the 17th century and saw use through the late 19th century. During the 19th century, concerted efforts to replace the truck carriage sparked the belief that it embodied technological backwardness and stagnation. This narrative permeates later research, leading to a general consensus that the truck carriage underwent little change from its initial conception. This thesis sought to examine this claim, as well as contextualize the truck carriage's place in the historical and archaeological records. It posed five central questions related to: the origins of the truck carriage, the organizations involved in its manufacture and distribution, design and construction, the character of archaeological investigations, and future research potential.

Though the exact origins of the truck carriage remain unknown, it likely emerged out of a pressing need to develop a sea going artillery mount that could control the increased strength of bronze-firing guns. Documentary evidence suggests that the truck carriage developed gradually, thanks to the efforts of multiple groups of people, working throughout Europe. English, Venetian, and Dutch vessels house the earliest examples of truck carriages or close truck carriage offshoots, some of which showcase Italian design elements. Some researchers indicate that Portugal may have utilized the new design as well. Regardless of its origins, the truck carriage evolved with the cannon over the subsequent centuries, allowing for a weapons system of increasing sophistication and power.

The design and construction of the truck carriage fell under the auspices of naval administrations. These administrations came into being around the same time as the truck carriage. The need to build and supply the truck carriage presented great challenges to these budding organizations. Over time, they developed sophisticated internal bureaus to meet these challenges. Gunners, carpenters, and blacksmiths hired or contracted by naval administrations built and tested carriages. These people were likely responsible for pushing forward design developments. In some places, such as France and possibly the United States, the need to supply the truck carriage possibly led to the rise of specialized craftsmen trained in both carpentry and blacksmithing.

The early truck carriages aboard the *Mary Rose* exhibit an intricate construction, using numerous mortise and tenon joints and wooden pegs. The major components included distinct two-part cheeks, a carriage bed, two axletrees, four trucks, a capsquare mechanism, proto-transoms, transom bolts, and small axletree bolts. They likely required a high degree of skill to assemble or disassemble, representing sizeable investments of resources and time. By the 17th century, the capsquare mechanism simplified greatly, and at least the French incorporated quarter rounds in their design. By the 18th century, at least with England, the truck carriage underwent a series of several changes. The stool bed and bolster replaced the carriage bed, whilst the bottom faces of the cheeks were carved into arc (Moody 1952:306). The transom became larger, more large bolts came into use (bed bolt, multiple transom bolts, bracket bolts, axletree bolts, eye bolts and joint bolts), and the capsquare simplified. Caruana (1997) discusses the progression of these developments in English carriages. In the 19th century, carriages exhibited heavy standardization, with design extensively regulated by entities such as the United States' Bureau of Ordnance and Hydrology.

This study relied on a database of truck carriage measurements to examine the proportional relationship between its major parts. Out of 34 carriages examined, 27 met the parameters for inclusion in the database. They underwent correlation, regression, and ANOVA analyses. The correlations tested Muller's proportional relationships and generated several others. Out of the 13 Muller proportions examined, nine failed to meet the strength (correlation coefficient of +/- 0.7) or significance ($p<.05$) parameters used in this study. Seven additional proportions meeting both strength and significance parameters emerged from the correlation analysis.

The proportions then underwent regression analysis, to explore the relationships between the carriage elements they represented. Two equations resulted from each of the strong and significant regressions. These equations allow for one measurement to be estimated from a second measurement, which would prove useful in efforts to reconstruct partial carriages, determine the dimensions of a cannon from the carriage, or vice versa. Both simple and multiple regressions produced equations.

Finally, the proportional pairs underwent ANOVAs, to determine if they underwent any change over time. Of the 12 significant proportions found during the correlation analysis, 11 exhibited significant change over time. Many of the changes proved to be non-linear. In several cases, trends established in previous centuries suddenly reversed in the 19th century, suggesting some sort of major alteration, the probable result of scientific testing. The ANOVAs suggest that there existed some change in the proportional relationships used in the carriages, even if the two variables involved in the relationship remained the same.

The material with which to conduct additional statistical testing will likely come from archaeology sites. Archaeologists uncovered gun carriages (from early sledge to later slide and pivot mounts) from over 35 archaeology sites. As evidenced by the research conducted at the *Mary Rose, Vasa, La Belle,* and *Betsy* sites, gun carriages have a great deal to contribute. These four sites represent pivotal or key projects related to maritime archaeology, pushing forward archaeological and conservation practices. The gun carriages from all four can be found in exhibits across the globe.

The *Mary Rose* and *La Belle* projects revealed important details about the construction of carriages and the ways that construction can be influenced by material availability, the skills of the builder, and time constraints. *Mary Rose,* along with *Vasa,* produced evidence of modification and reuse, which allowed for carriages to be adapted to specific locations or specific guns. The *Vasa* carriages additionally highlighted the importance of the location of carriages aboard the ship. They demonstrate that carriages played a role in the partition of living and working space aboard warships, directly impacting the lives of the crews. Finally, *Betsy's* carriage aided in revealing important information about the ship's function, and about the order in which carriage assembly at Yorktown occurred as discussed by Broadwater (1996).

There exist numerous research opportunities in relation to the gun carriage. More information is needed about the origin, integration, design, construction, and supply of carriages in other navies. A multi-national research project involving historians and archaeologists from nations with a history of gun carriage use would allow for the broad examination of documentary and archaeological evidence. It would provide a better understanding of the national variation (if any) in carriage design and development. Additional research could focus on the different roles gun carriages played aboard the ship, from their roles as gun platforms to their impact on crews' living and working conditions. A closer examination into the changes in carriage design, as they relate to gun design, along the lines presented by Caruana (1997), would also prove fruitful. From Muller's (1757) treatise, there may also be a relationship between ship design and carriage design that could be further explored. Finally, an examination into the people responsible for constructing and testing carriages would yield important results, as preliminary evidence suggest they played a key role in pushing carriage development forward.

To conclude, the truck carriage saw centuries' worth of use and development aboard Western ships and garrisons. They were complex, dynamic parts of early artillery systems that played important roles in the lives of the crews that served them. They can reveal insights into the logistical challenges facing naval administrations and serve as a record for development in gunnery, carpentry, and blacksmithing. They may also help trace ship and gun design, providing a link between the two that may someday help with ship reconstruction from carriage or cannon components. The truck carriage's development allowed for the modernization of western navies. From this perspective, rather than being a relic of technological backwardness, the development of the truck carriage actually helped secure the foundation for modern navies.

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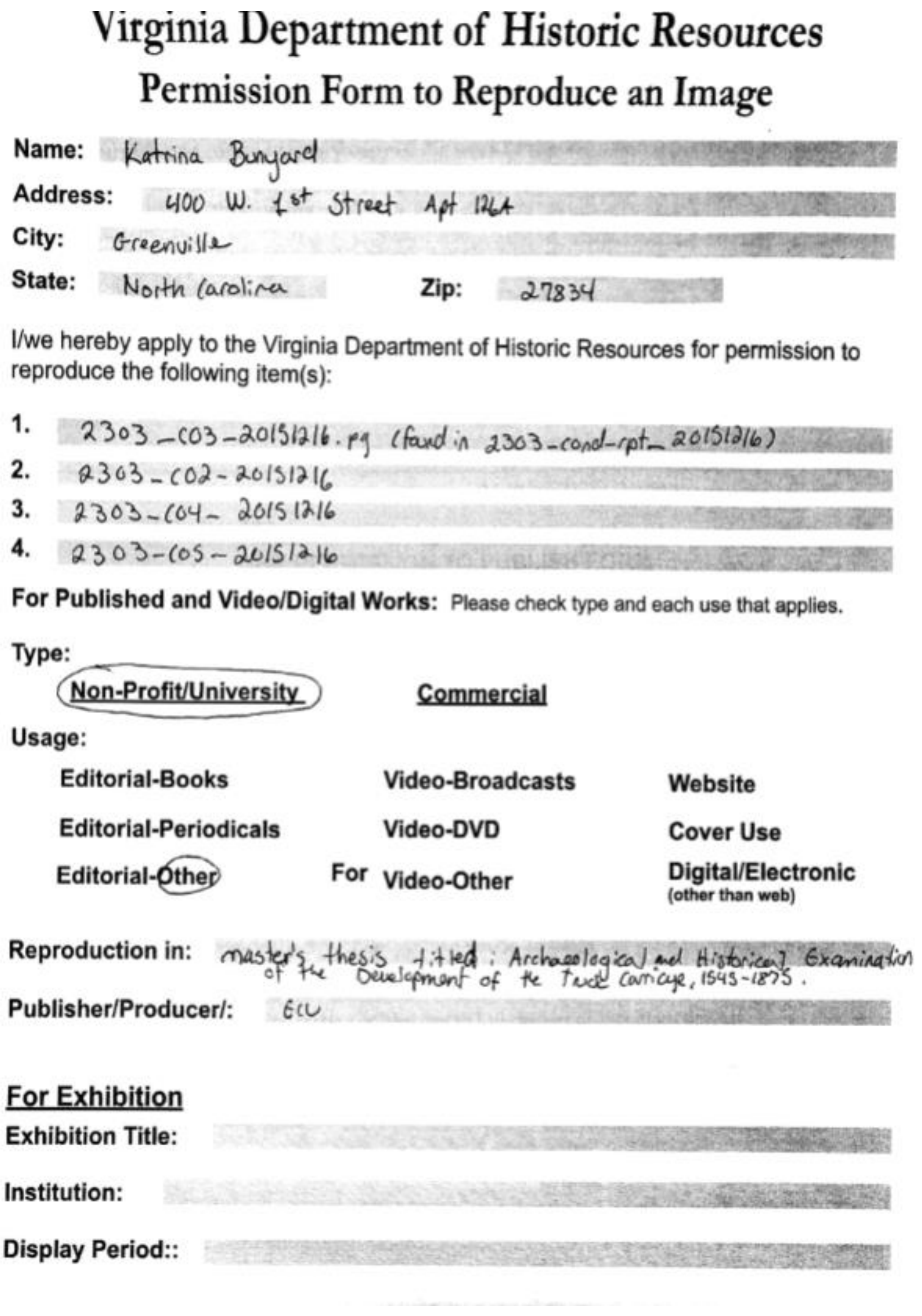
APPENDIX A
VIRGINIA DEPARTMENT OF HISTORIC RESOURCES PERMISSION FORM



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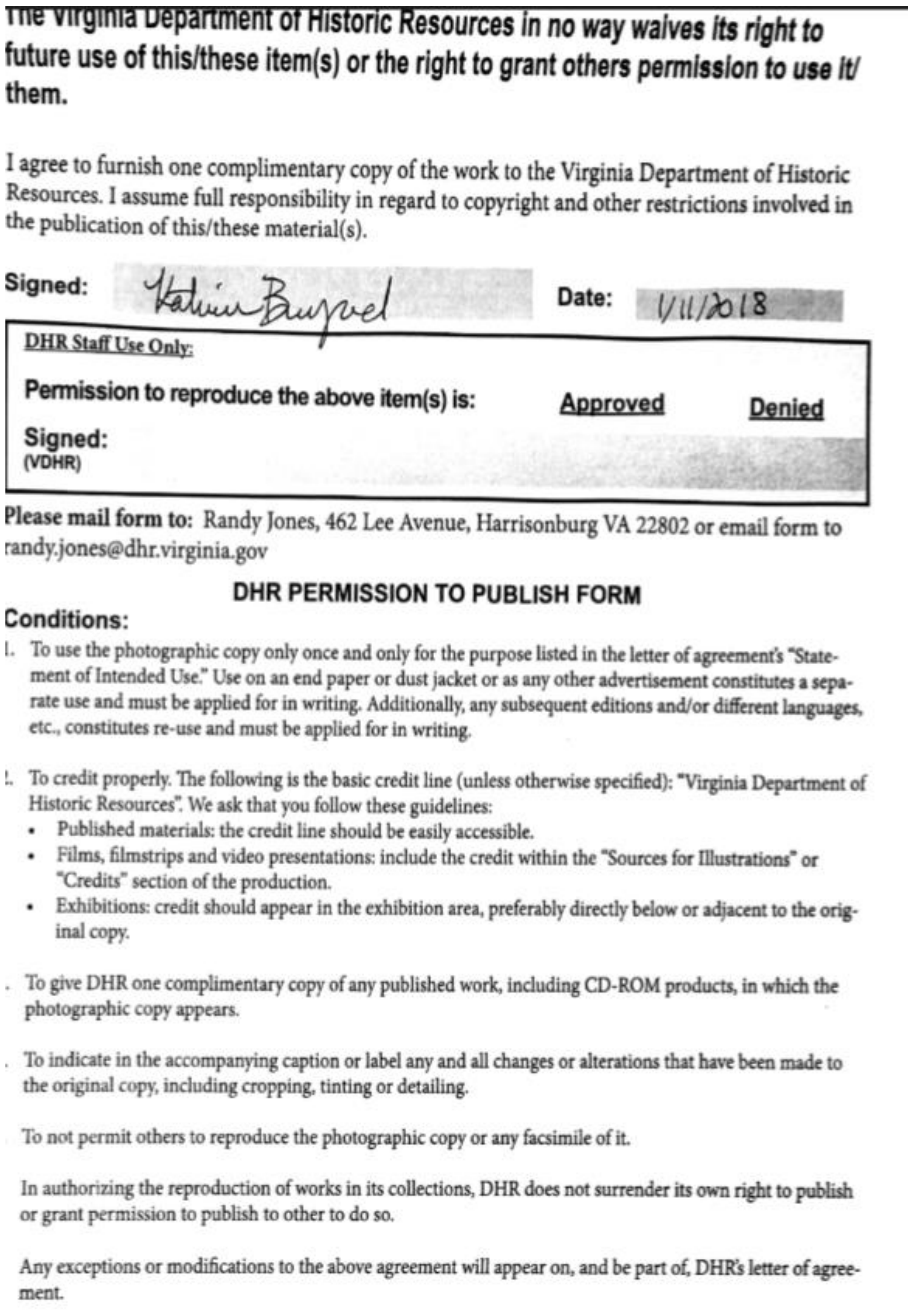

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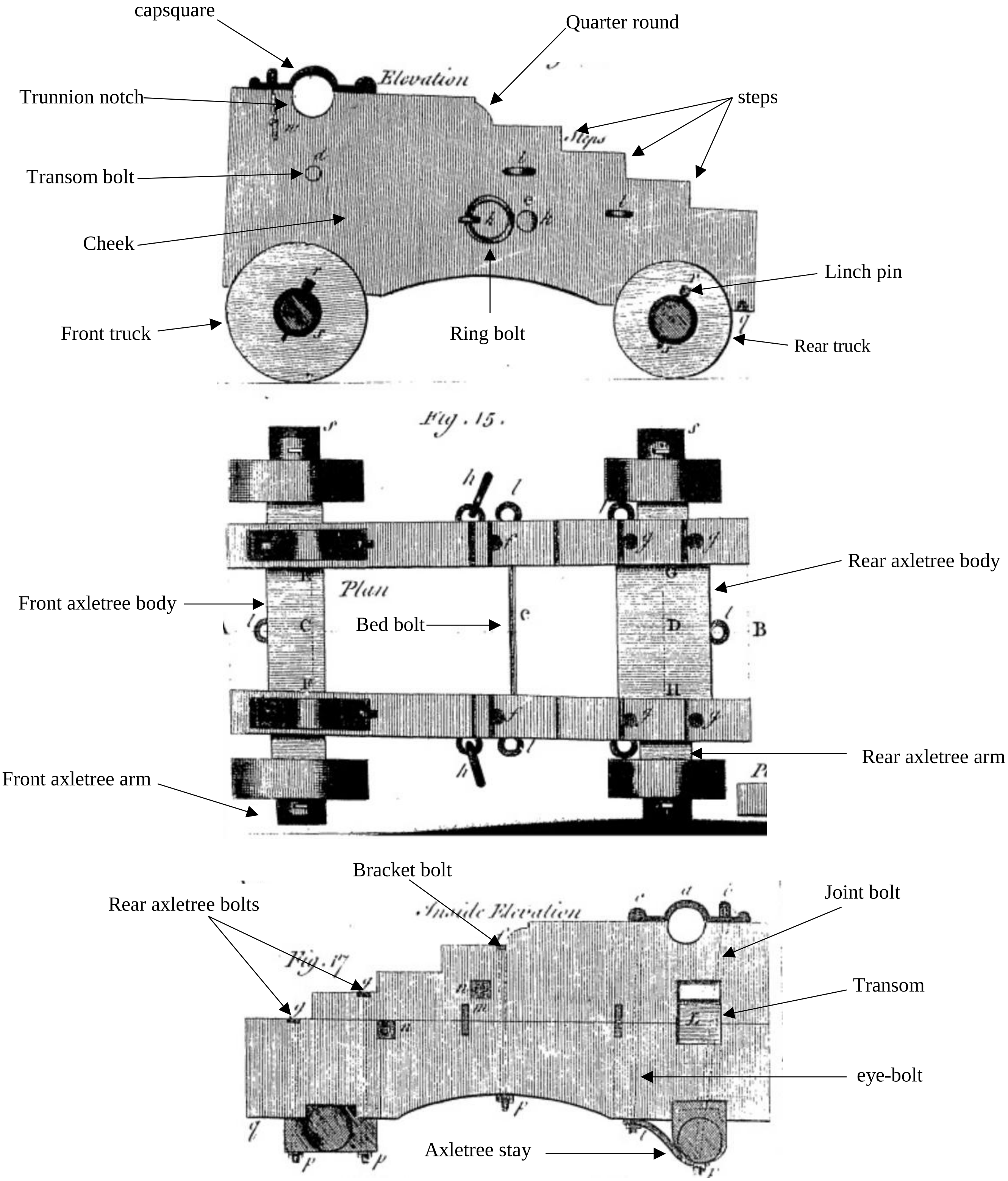
APPENDIX B
BASIC PARTS OF A TRUCK CARRIAGE



(Adapted from Muller 1757)

APPENDIX C

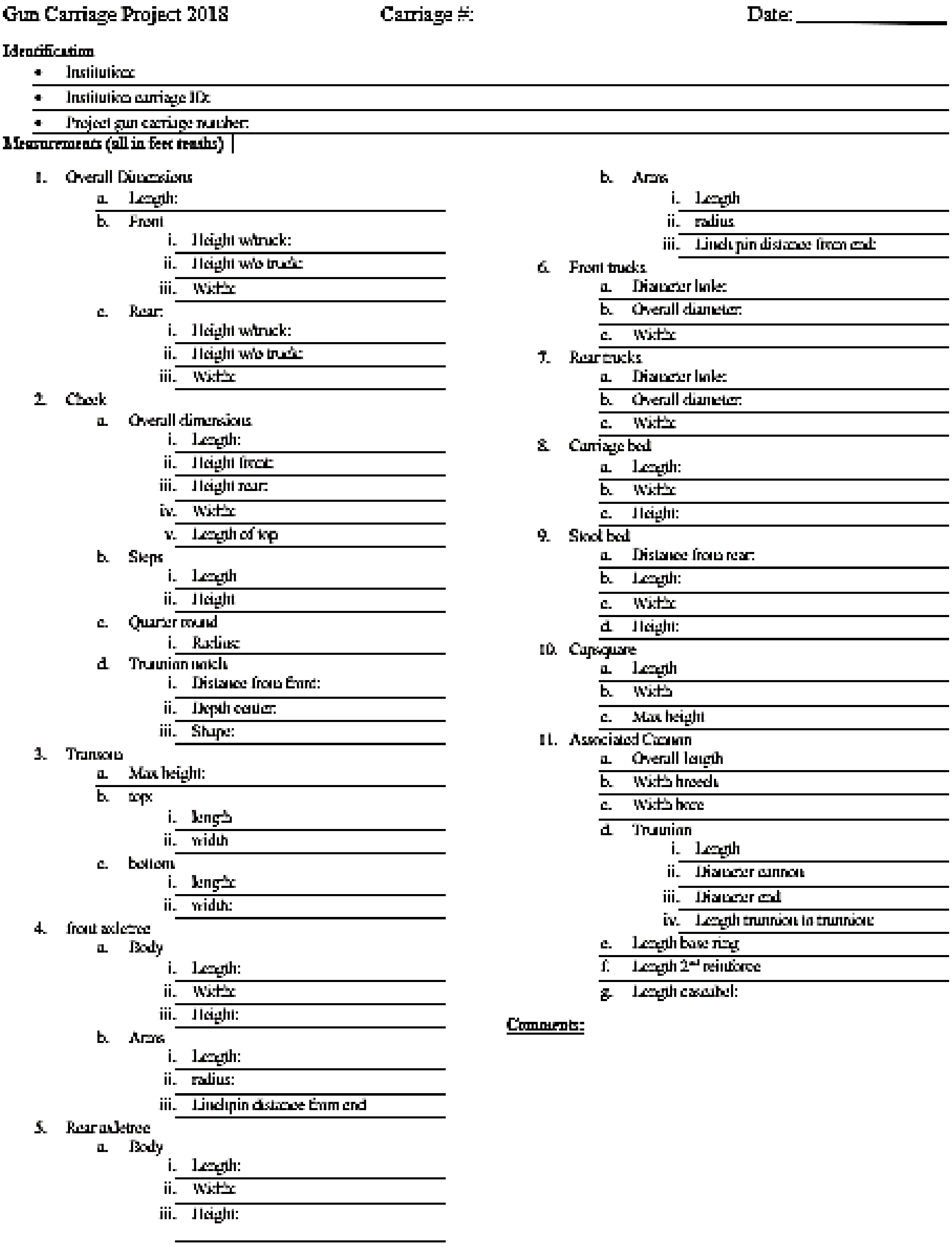
PARTIAL LIST OF GUN CARRIAGE SITES

Site	Wreck Year	Origin	Type	Number	Primary Investigative Agency	Provenience	State	Curation	Further Research
Lomellina	1516	Genoa	sledge	4+	Musée de la Marine	known	Intact	Preserved in situ	Guérot 2017
Studland Bay Wreck	Early 1500s	Span	sledge	1+	Studland Bay Wreck Project	known	unknown	Poole Museum	Poole Museum website
Cattewater Wreck	Early 1500s	Spain	sledge	1+	National Maritime Museum Greenwich	Known	fragmented	Protected in situ	Redknap 1984
Mary Rose	1545	England	Sledge truck	6+ 11+	Mary Rose Trust	known	Intact	Mary Rose Trust	Rule 1982 Hildred 2011 McElvogue 2015
Franska Sernarna Carvel vessel	1500-1550	Sweden	Sledge	14+	Swedish National Maritime Museum	known	Intact (without wheels)	Recorded in situ	Adams and Rönnby 2013
Mars	1564	Sweden	sledge	1+	Maritime Archaeological Research Institute at Södertörn University	known	intact	Ship Preserved in situ (carriage fate unknown)	Eriksson and Rönnby 2017
TK06-AD	1560-1590	England	Unknown	Unknown	RPM Nautical Foundation	known	fragments	surveyed	Royal and McManamon 2010
La Lavia	1588	Venice/ Spain	Truck sledge	1	Institute of Maritime Studies St. Andrews University	known	degraded	Preserved in situ	Birch and McElvogue 1999
La Juliana	1588	Spain	sledge	unknown	St. Andrews University	known	Fragment (only wheels)	Protected in situ	Brich and McElvogue 1999
La Trinidad de Valencera	1588	Venice/ Spain	field	unknown	National Monuments Service	known	Mix of intact and disassembled	Tower Museum, Derry	Martin 1988
Punta Restelos wreck	1596	Spain	Siege	1	Institute of Nautical Archaeology	Known	fragments	Museo do Mar de Galicia	Institute of Nautical Archaeology website
Yarmouth Alberghetti cannon site	1500-1600	Italy	field	1	Isle of Wight County	Known	fragments	unknown	Tomalin et al 1988

					Archaeology				
Carmel Coast Wreck	1500-1600	Venice	sledge	1	Underwater Excavation Society of Israel	known	Fragment/ degraded	Examined in situ	Ridella et al 2016
Scheurrak SO 1	1593	Netherlands	Truck variant	2	Netherlands Institute of Ship and Underwater Archaeology (NISA)	1 carriage known 1 carriage unknown (recovered by sport diver)	intact	NISA	Puype 2000
Vasa	1626	Sweden	truck	62	Wasa Board	known	Intact	Vasa Museet	Cederlund 2006 Vasa Museet
Fame	1631	Netherlands	Truck	2+	Bournemouth University	known	Intact	Poole Museum	Poole Museum
Swan	1653	England	Truck variant	1	Archaeological Diving Unit of St. Andrews University	known	intact	National Maritime Museum, Greenwich	Martin 2004
HMS London	1665	England	truck	2	Cotswold Archaeology	Known	intact	Southend Museums	Evans 2017
Kronan	1676	Sweden	Unknown	5	Kalmer County Museum	known	Intact		Einarsson 1990
La Belle	1686	France	truck	1	Texas Historical Commission	known	intact	Corpus Christi Museum of Science and Technology	Bruseth et al 2017
Northumberland	1703	England	truck	3	Thanet Island Archaeological Unit	known	fragments	Preserved in situ	Pascoe and Peacock 2015
Stirling Castle	1703	England	Truck	2	Thanet Island Archaeological Unit	known	Mostly intact	Mary Rose Trust	Peackcok 2000
Beaufort Inlet Shipwreck site 0003BUI	1718	France	Truck	unknown	North Carolina Department of Natural and Cultural Resources	Known	Fragments	Queen Anne’s Revenge Lab	Queen Anne’s Revenge Project website
Royal George	1756	England	truck	1	unknown	unknown	unknown	Royal Armouries (1952)	Moody 1952
Philadelphia	1776	United States (USA)	Truck slide	2 1	Lorenzo F. Hagglund	unknown	intact	National Museum of American History	Bratten 1997
Royal Savage	1776	USA	truck	2	Lorenzo F. Hagglund	unknown	degraded	Fort Ticonderoga	Fort Ticonderoga
New York Gun site	1777	USA	truck	1	Lake Champlain Maritime Museum	known	fragments	Lake Champlain Maritime Museum	Lake Champlain Maritime Museum

HMB Endeavor discarded gun remains	1778	England	truck	Unknown	Academy of Natural Sciences, Philadelphia	known	Fragments	Australian National Maritime Museum	Australian National Maritime Museum website
Defence	1779	USA	truck	Unknown	Main Maritime Academy; Massachusetts Institute of Technology	known	fragment	Maine State Museum	Switzer 1983
Betsy	1781	England	truck	1	Virginia Department of Historic Resources	known	intact	Virginia Department of Historic Resources; Yorktown Victory Center	Broadwater 1996
Hamilton	1813	USA	Pivot carronade	18	Royal Ontario Museum	Known, surveyed remotely	intact	Hamilton and Scourge National Historic Site	Crisman et al 2014
Scourge	1813	USA	truck	10	Royal Ontario Museum	Not excavated	intact	Hamilton and Scourge National Historic Site	Crisman et al 2014
U.S.S. Monitor	1862	USA	Custom for XI-inch Dahlgren guns	2	National Oceanic and Atmospheric Administration	known	intact	Mariner's Museum	Mariner's Museum
Black Warrior	1862	Confederate states (CSA)	Truck	1	North Carolina Department of Natural and Cultural Resources	Known	Intact/ burned	Museum of the Albermerle	Ruby 2001
C.S.S. Alabama	1864	CSA	truck	1	United States Navy; Musée de la Marine	known	fragments	History Museum of Mobile	Bowcock 2002

APPENDIX D
GUN CARRIAGE RECORDING SHEET



Gun Carriage Project 2018 **Carriage #:** **Date:** ______________

Identification

- Institution:
- Institution carriage ID:
- Project gun carriage number:

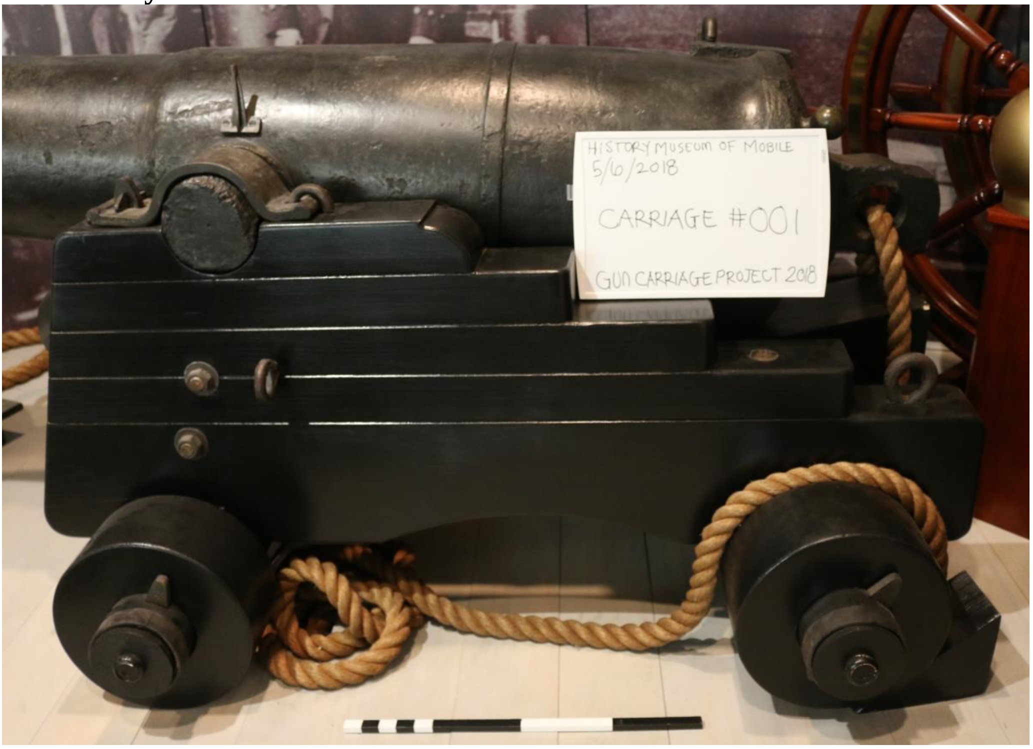
Measurements (all in feet tenths)

1. Overall Dimensions
    a. Length:
    b. Front
        i. Height w/truck:
        ii. Height w/o truck:
        iii. Width:
    c. Rear:
        i. Height w/truck:
        ii. Height w/o truck:
        iii. Width:
2. Cheek
    a. Overall dimensions
        i. Length:
        ii. Height front:
        iii. Height rear:
        iv. Width:
        v. Length of top
    b. Steps
        i. Length
        ii. Height
    c. Quarter round
        i. Radius:
    d. Trunnion notch
        i. Distance from front:
        ii. Depth center:
        iii. Shape:
3. Transom
    a. Max height:
    b. top:
        i. length
        ii. width
    c. bottom
        i. length:
        ii. width:
4. front axletree
    a. Body
        i. Length:
        ii. Width:
        iii. Height:
    b. Arms
        i. Length:
        ii. radius:
        iii. Linchpin distance from end
5. Rear axletree
    a. Body
        i. Length:
        ii. Width:
        iii. Height:
    b. Arms
        i. Length
        ii. radius
        iii. Linchpin distance from end:
6. Front trucks
    a. Diameter hole:
    b. Overall diameter:
    c. Width:
7. Rear trucks
    a. Diameter hole:
    b. Overall diameter:
    c. Width:
8. Carriage bed
    a. Length:
    b. Width:
    c. Height:
9. Stool bed
    a. Distance from rear:
    b. Length:
    c. Width:
    d. Height:
10. Capsquare
    a. Length
    b. Width
    c. Max height
11. Associated Cannon
    a. Overall length
    b. Width breech
    c. Width bore
    d. Trunnion
        i. Length
        ii. Diameter cannon
        iii. Diameter end
        iv. Length trunnion to trunnion
    e. Length base ring
    f. Length 2nd reinforce
    g. Length cascabel:

Comments:

APPENDIX E
CARRIAGES RECORDED MAY 2018

Carriage 1: History Museum of Mobile

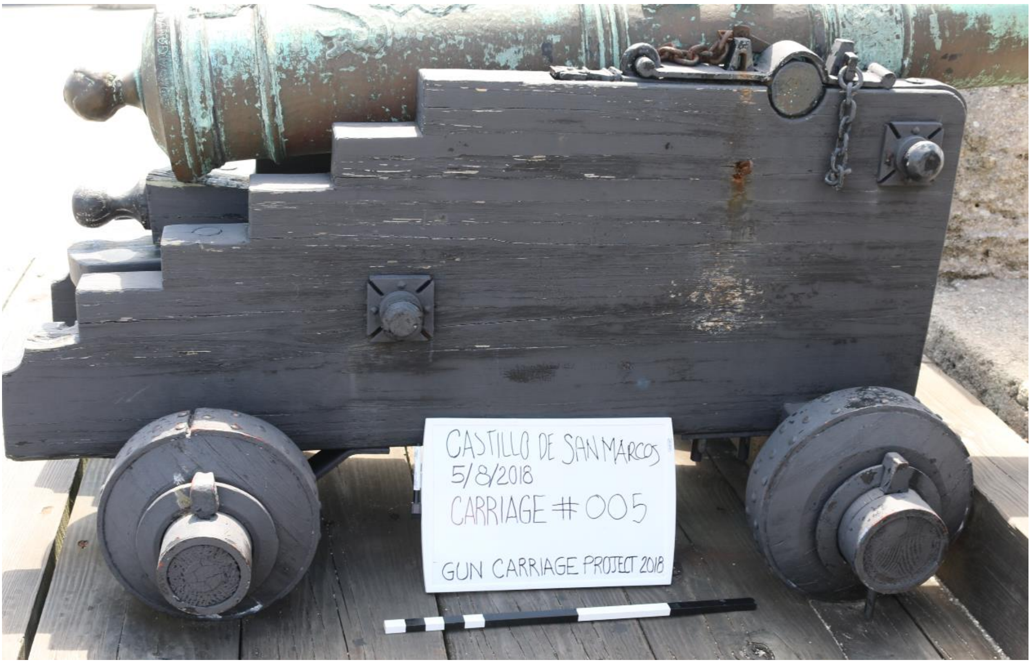


Carriage 2: History Museum of Mobile

Carriage 3: Castillo de San Marcos

Carriage 4: Castillo de San Marcos

Carriage 5: Castillo de San Marcos



Carriage 6: Castillo de San Marcos

Carriage 7: Castillo de San Marcos

Carriage 8: The Mariner's Museum

Carriage 9: Fort Ticonderoga

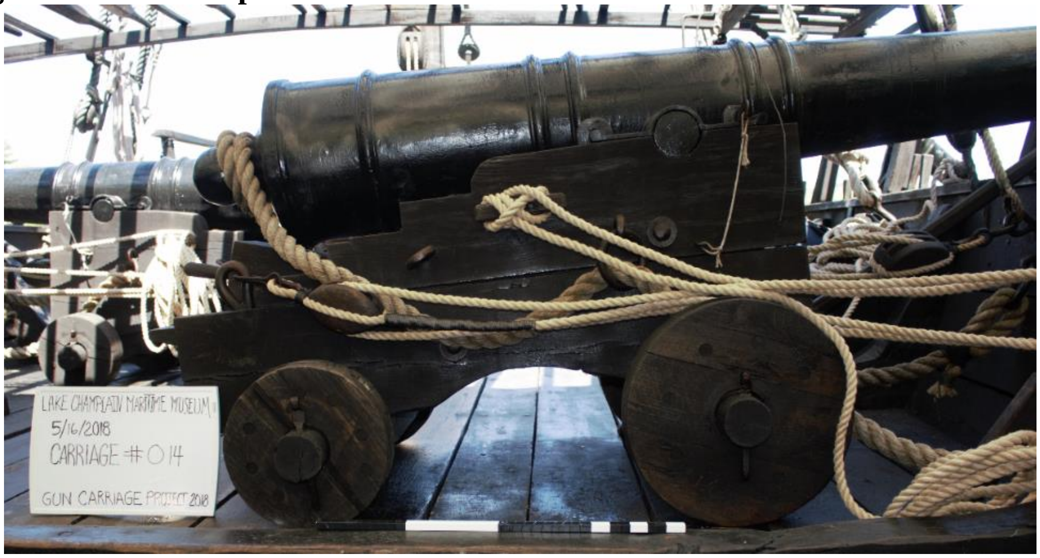
Carriage 10: Fort Ticonderoga

Carriage 11: Fort Ticonderoga

Carriage 12: Lake Champlain Maritime Museum

Carriage 13: Lake Champlain Maritime Museum

Carriage 14: Lake Champlain Maritime Museum



Carriage 15: Lake Champlain Maritime Museum

Carriage 16: Historic Ships in Baltimore, *U.S.S. Constellation*

Carriage 17: Historic Ships in Baltimore, *U.S.S. Constellation*

Carriage 18: Historic Ships in Baltimore, *U.S.S. Constellation*

APPENDIX F
SPSS CODE BOOK

Name	ID	Variable Type
Carriage ID	carriageID	Nominal
Curating institution	Institute	Nominal
Curate institution ID	curateID	Nominal
Country of origin	Country	nominal
Year	Year	interval
Overall length	length	Ratio
Overall front height with truck	frheightwT	ratio
Overall front height without truck	frheightT	ratio
Front width	frwidth	ratio
Rear height with truck	rrheightT	ratio
Rear height without truck	rrheight	ratio
Rear width	rrwidth	ratio
Cheek length	cheekL	Ratio
Cheek height front	cheekHfr	Ratio
Cheek height rear	cheekHrr	Ratio
Step length	stepL	Ratio
Step height	stepH	Ratio
Length of top	topL	ratio
Quarter round radius	QroundRAD	Ratio
Trunnion notch distance from front	TrunnotchF	Ratio
Trunnion notch depth at center	Trunndepth	Ratio
Trunnion notch shape	Trunnshape	nominal
Carriage Length	Carriage L	Ratio
Cheek Length to Height Ratio	ChkLtoHRatio	ratio
Top length to Cheek Length	ToL2CheekL	ratio
Trunnion Rest Length	TrunnionRL	ratio
Trunnion Shape	TrunShape	
Transom max height	tranH	Ratio
Transom top length	TrantopL	ratio
Transom top width	trantopW	Ratio
Transom bottom length	tranbotL	Ratio
Transom bottom width	tranbotW	ratio
Front axletree body length	frxtrebodL	Ratio
Front axletree body width	frxtrebodW	Ratio
Front axletree body height	frxtrebodH	Ratio
Front axletree arm length	frxtrearmL	Ratio
Front axletree arm radius	frxtrearmRAD	Ratio
Front axletree arm Linchpin distance from end	frxtrearmlpinDIST	Ratio
Rear axltree body length	rrxtrebodL	Ratio
Rear axletree body width	rrxtrebodW	Ratio
Rear axletree body height	rrxtrebodH	ratio

Rear axletree arm length	rrxtrearmL	Ratio
Rear axletree arm radius	rrxtrearmRAD	ratio
Rear axletree arm linchpin distance from end	rrxtrearmlpinDIST	Ratio
Front trucks hole diameter	frtckholeDIA	Ratio
Front truck overall diameter	frtrckoDIA	ratio
Front truck width	frtrckW	ratio
Rear truck diameter hole		ratio
Bottom Arc Distance from front	ArcDist	ratio
Bottom Arc Length	ArcL	ratio
Bottom Arc Depth	ArcDepth	ratio
Front axletree recess depth	FrxtreRecess	ratio
Rear axletree recess depth	RrxtreRecess	ratio
Carriage bed length	cbedL	ratio
Carriage bed width	cbedW	ratio
Carriage bed height (thickness)	cbedH	ratio
Stool bed length	stoolL	ratio
Stool bed width	stoolW	ratio
Stool bed height (thickness)	stoolH	ratio
Distance of capsquare from front	capDist	ratio
Capsquare length	capL	ratio
Capsquare width	capW	ratio
Capsquare height (curvature height)	capH	ratio
Capsquare thickness	capTh	ratio
Cannon length	cannonL	ratio
Bore width (diameter)	boreW	ratio
Trunnion length	trunnionL	ratio
Trunnion diameter at cannon	truncanD	ratio
Trunnion diameter at end	trnendD	ratio
Distance from trunnion end to trunnion end	Truntotrun	ratio
Base diameter	based	ratio
Cascabel length	cascaL	ratio
Second reinforce diameter	secondreinforce	ratio
Proportion between bore and cheek widths	borew2CheekW	ratio
Proportion between cannon and carriage length	CannonL2CarriageL	ratio
Proportion between front carriage width and second reinforce diameter	FrontW2SecondReinforce	ratio
Proportion between rear carriage width and base diameter	RearW2BaseD	ratio
Proportion between reunion notch depth and bore width	TrunNotchDepth2BoreW	ratio
Proportion between front truck diameter and bore width	FrtTruckD2BoreW	ratio
Proportion between rear truck dimeter and bore width	RrTruckD2BoreW	ratio

Proportion between front cheek height and bore width	FrtChkH2BoreW	ratio
Proportion between rear cheek height and front cheek height	RrChkH2FrtChkH	ratio
Proportion between transom and bore widths	TranW2BoreW	ratio
Proportion between transom height and bore width	TranH2BoreW	ratio
Proportion between front truck width and cheek width	FrtTruckW2ChkW	ratio
Proportion between rear truck width and cheek width	rrtruckW2chkW	ratio
Proportion between front cheek and rear axletree body height	FrChkH2rrxtrebodH	ratio
Proportion between front and rear axletree arm lengths	FrxtrearmL2rrxtrearmL	ratio
Proportion between rear axletree body height and rear axletree arm diameter	rrxtrebodH2rrxtrearmD	ratio
Proportion between front and rear truck diameters	frtruckD2rrtruckD	ratio
Proportion between transom height and base diameter	TranH2BaseD	ratio
Proportion between front axletree body and cannon lengths	frxtrebodL2cannonL	ratio
Proportion between front inner cheek width and second reinforce diameter	frtinnerW2secondreinfoce	ratio
Proportion between trunnion end diameter and bore width	trunendD2boreW	ratio
Proportion between front and rear truck diameters	FrtTruckD2RrTruckD	ratio
Propotion between front axletree body height and width	frxtrebodH2W	ratio
Proportion between trunnion rest length and bore width	trunRL2BoreW	ratio