AN ANALYSIS OF NAVIGATIONAL INSTRUMENTS IN THE AGE OF EXPLORATION: 15th CENTURY TO MID-17th CENTURY

A Thesis

by

LOIS ANN SWANICK

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF ARTS

December 2005

Major Subject: Anthropology

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Approved by:

Chair of Committee,	C. Wayne Smith
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ABSTRACT

An Analysis of Navigational Instruments in the

Age of Exploration: 15th Century to Mid-17th Century. (December 2005)

Lois Ann Swanick, B.A.; B.A., University of Alaska Anchorage

Chair of Advisory Committee: Dr. C. Wayne Smith

During the Age of Exploration, navigation evolved from a field filled with superstition into a modern science in Portugal, Spain, and England. The most common navigation instruments utilized and their subsequent innovations are discussed. The refinement of these instruments led to increased accuracy in cartography, safer shipping, and increased trade globally in the period.

In order to have the most comprehensive collection of navigation instruments, I investigated 165 shipwrecks dated between 1500 and 1700. Each of these vessels have been located, surveyed, and/or excavated in whole or in part. A comprehensive list of these vessels, compiled for the first time, has been included. This thesis analyzes navigation-related artifacts recovered from 27 of these shipwreck sites. These instruments provide the basis to develop a typology for archaeologists to more closely date these finds.

The navigation instruments recovered from the wreck of *LaBelle* (1686) are discussed in detail. These instruments and related historical documents kept by the navigator provide a more comprehensive picture of the instruments' accuracy and usefulness. This thesis particularly focuses on the nocturnal/

planisphere recovered from the site. This unique instrument is one of only four known to exist worldwide and remains accurate enough to be utilized today. Analysis by a modern astronomer has been included, as well as a partial translation of the common names for constellations inscribed on the instrument. These common names provide some important insights into the received knowledge of sailors and non-academic astronomy during this period.

It is hoped that this thesis will be of assistance to archaeologists working to identify, study, and appreciate navigational instruments recovered from shipwrecks. With increased documentation and closer dating, these instruments will become a more valuable portion of the archaeological record.

DEDICATION

To my beloved husband, Daren, and our son, Charlie.

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I would like to thank the Texas Historical Commission, particularly Jim Bruseth, Jeff Durst, and Steve Hoyt for their consistent support and permission to study and use photographs of the navigation artifacts recovered from *LaBelle*. Special thanks to Texas A&M University, specifically, the Department of Animal Science for use of their digital camera, Don Carona (Department of Physics) for generously sharing his time and knowledge, as well as Dr. C. Wayne Smith (Department of Anthropology) for the use of his equipment. I would also like to thank Helen Dewolf and Amy Borgens at the Conservation Research Laboratory

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While many authors provided valuable information, for his research into scientific instruments in this period, as well as his personal support for this research, I would like to thank Gerard L'E Turner. I owe a debt of gratitude to Lord High Admiral D. W. Waters and E. G. R. Taylor for their extensive writings on the history of navigation and mathematics in England. Without contest, their texts defined the science and history of navigation in this early period.

I wish to acknowledge the invaluable contributions of my committee, particularly Dr. C. Wayne Smith, who served as chair. Their contributions have greatly improved this thesis. Special thanks to the staff of the Evans Library Interlibrary Loan Office. Their unflagging efforts to obtain obscure documents and books, often in foreign languages, were extraordinary. I also wish to thank the Museum of the History of Science for permission to reproduce their photos of navigational instruments.

This thesis would not have been possible without the consistent support and encouragement of my parents, Ed Behrle and Gayle Behrle, who encouraged me every step of the way and believed in me. I would like to extend my eternal gratitude to Daren Swanick for his endless enthusiasm, support, and understanding. Specifically, thanks for his tireless efforts on the *LaBelle* planisphere. And last, but never least, thanks to my sweet Charlie for his support when the going got rough. You're the best!

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CHAPTER I

INTRODUCTION

This thesis will focus on the practice of navigation between 1550 and 1700 in Portugal, Spain, and England, in an effort to shed light on the many advances that made the Age of Exploration possible. Navigational instruments exist at a crossroads between available technology, scientific theory, and the long-term, daily practice of seamanship (Maddison 1969:4). Because of this pivotal position, these instruments provide valuable insights into the lives and thoughts of those who made and used the instruments. Each instrument was hand made by a craftsman or craftsmen. The instrument makers chose the raw materials and made the instrument to contain the most popular attributes. Some instruments were made for a particular buyer to his preferred specifications, such as the nocturnal planisphere discussed in detail in Chapter VI. The purchaser often further decorates and altered the instrument to their personal taste, often with the assistance of other craftsmen. Finally, the user would create a variety of wear marks on the instrument. Thus, each instrument tells a story of its history, repair, use, and ultimate discarding. By analyzing the physical clues left on the instrument, the archaeologist gains valuable insight into those who used them and the society that made them.

This thesis follows the style and format of *Historical Archaeology*.

In this period, the development of the science of navigation was the combined result of improvements to pre-existing instruments, as well as the development of new ones; an increase in mathematical and astronomical knowledge among navigators; as well as government support for additional training and longer, more complex voyages. The increased frequency of naval wars, as well as the development of the English Royal Navy, accelerated the integration of new instruments, techniques, and education within the navigational community. In 1550, England had little capital or expertise, and even less interest, in pursuing a global trade and/or colonization network; however, both Portugal and Spain had been active in these areas for over a century. By 1700, international control of the oceans had shifted significantly. The merchant and naval powers of both Spain and Portugal had declined in favor of the English. However, the rapid rise of the English merchant and naval powers was fueled by the hard-won expertise of the Portuguese and Spanish.

In 1570, Englishman Dr. John Dee stated “The art of navigation demonstrateth how by the shortest good way, by the aptest direction, and in the shortest time, a sufficient ship…be conducted” (Waters 1958:3). Navigation in this period was divided into two categories: coastal navigation (referred to as “pilotage”) and oceanic navigation. The practice of navigation in the period, whether coastal or oceanic, was considered an art, a task that required experience, as well as a science, a task that could be learned academically. Navigation also retained some of the superstition of earlier ages mixed with the scientific analysis prevalent in this period. The instruments used in pilotage versus oceanic navigation were different, so the level and type of training for each position also varied. Pilotage relied on keen observation of terrestrial objects, tide prediction, written sailing directions (called “rutters”), and cardes (a type of sketchy coastal map). Oceanic navigation focused on using a variety of instruments to observe astronomical bodies, taking measurements of the relationships between these bodies and the earth, then using mathematical computation and tables to translate these readings into a usable vessel location and course (Waters 1958:4-5). Both types of navigation utilized similar instruments and experience to estimate vessel speed and direction, water depth, timekeeping, and course notation.

While navigation successfully developed techniques for establishing latitude early in the period, the problem of determining longitude remained throughout (Maddison 1969:7). Due to the international nature of the crew of most vessels, it is difficult to credit either improvements or challenges in navigation to particular nations. For purposes of clarity in this study, the writings and instruments of navigators have been defined using national boundaries, but it should be noted that, in fact, these divisions remain arbitrary.

This thesis is divided into seven chapters. After introducing the main topics of the thesis in Chapter I, Chapter II provides a framework of the major events in Portuguese, Spanish, and English navigational history between 1400 and 1642. This history emphasizes those factors that inspired and/or hindered the development of navigational techniques and instruments in the period. The chapter includes two specialized sections focusing on the synergistic relationships that navigation formed with three other disciplines: mathematics, astronomy, and cartography/hydrography. Advances made in any of these three areas directly impacted the development of navigational science. Conversely, the needs of and improvements in navigational science led to enhancements in each of these three fields.

Chapter III surveys the pertinent anthropological and historical literature on navigation. Arranged chronologically, this literature review discusses the primary texts on navigational techniques, instrument design, and related fields published in Portugal, Spain, and England during this period. In modern times, all three countries have continued to analyze these primary texts and instrument collections from a purely historical perspective, which is evident in the analysis of available secondary texts. While navigational artifacts have been recovered from scores of archaeological sites, there has been no attempt by archaeologists to compare their material with available historical collections or develop literature to analyze the navigation tools recovered from sites. This thesis will begin the process of surveying the available data. In fact, few archaeologists have even included photos, drawings, measurements, or details of the recovered instruments in either their popular articles or their official site reports. Perhaps this oversight is due to the fact that the history of navigational artifacts in the period has been largely underappreciated by archaeology and, to the untrained eye, many of the instruments appear similar in design. It is hoped that analyses like this one will be of great assistance to the recovery, study, and appreciation of navigational instruments in developing a secondary archaeological literature.

Chapter IV highlights the evolution of instrumentation and navigation techniques between 1550 and 1700. The instruments have been divided, for ease in discussion, into four sections: 1) positional instruments, 2) direction, depth and speed instruments, 3) course and timekeeping instruments, and 4) drafting instruments. Each instrument type will be discussed in terms of its invention, use, and development during the period. Some of the instruments were developed before 1550, yet underwent significant improvement or were discarded in favor of newly developed instruments. Other instruments are purely the result of innovation within the period. In either case, the thesis will include an illustration of the instrument and, where possible, a depiction of it in use. After each instrument has been discussed, a final section will detail the portions of the instrument that can be expected to survive in the archaeological record. This will assist archaeologists in correctly identifying such objects in the future, as well as help identify navigational instruments that may languish in obscurity due to misidentification.

Chapter V analyzes the known navigational artifacts recovered from archaeological sites to date. The chapter will begin with a list of the ships and/or sites dated to between 1550 and 1700, based on historical and/or archaeological evidence. Next, the artifacts recovered will be discussed individually for each of the sites that yielded navigational instruments. Illustrations will not be included of the instruments under discussion in this chapter, due to lack of availability. A final section will analyze what these finds indicate about the development of a navigator's "tool kit" and how closely these finds mirror the instruments discussed and/or recommended by authors in the period. It should be noted that some sites were excavated by commercially-oriented businesses, commonly referred to as "treasure hunters." The artifacts from these sites have been included because they are vital to developing an accurate understanding of the instruments actually in use in the period under discussion. The inclusion of such sites should not in any way be considered a sanctioning of this type of activity. Clearly the long-term potential of the site to yield information has been compromised, even destroyed, by these ventures and the sale and/or distribution of these artifacts has detrimentally impacted the development of a comprehensive archaeological record of navigational technology.

Chapter VI will take a closer look at the navigational artifacts recovered from the French naval vessel, *LaBelle*, in regard to its navigational instruments. First, the site deposition and excavation will be discussed. The next two sections focus on the navigational artifacts recovered from *LaBelle*. Some of the navigational artifacts recovered were not recognized as such on site, but were identified during conservation. This may be due to the lack of secondary literature in archaeology regarding these artifacts or the fact that the artifacts were heavily encrusted, which made identification impossible until after conservation. A detailed analysis was completed on an instrument recovered from *LaBelle* and subsequently identified as a combination nocturnal/planisphere, revealing a wealth of data on the astronomy of the period outside academia, as well as the received knowledge of sailors. Rather than being an isolated phenomenon, I believe this research shows that further analysis of navigational instruments in this manner will reveal a wealth of information on the profession, technology, and evolution of navigation. A final section will compare the instruments recovered from *LaBelle* with the primary texts available, comparing the archaeological to the historical record. It is hoped that such comparisons will provide valuable insights into the reliability of the historical primary texts. In turn, perhaps these historical texts will assist future archaeologists in correctly identifying and valuing navigational artifacts as a resource.

While improvements in navigation between 1550 and 1700 resulted in more accurate coastal mapping, this thesis will not discuss cartographic materials, such as portolans, rhumb lines, or rutters (sailing directions), except where these advances directly impact the navigational instrument development. Also, this thesis is not intended to be an instructional manual for the utilization of drafting or navigational instruments of the period. However, the use of these instruments will be described to the extent necessary to understand their technology.

A variety of reference materials is included in the Appendix to assist the reader. Appendix A contains a complete alphabetical list of the vessels investigated in Chapter IV and Appendix B contains the same list arranged chronologically. Appendix C contains a list of the vessels removed from investigation due to their present status or lack of information. Appendix D contains the vessels known to have no recovered navigational instruments. Appendix E lists those vessels that contained navigational instruments known to have been recovered from archaeological contexts dating to between 1550 and 1700.

CHAPTER II

AN OVERVIEW OF NAVIGATIONAL HISTORY (1400-1642)

1400-1500

During the 15th century, the Portuguese moved the science of navigation forward by making significant voyages of discovery. Gaining valuable oral training from Genoese pilots, the Portuguese discovered the Azores in 1427. Their subsequent colonization of the Canary Islands (1402), the Madeira Islands (1418-1425), and the Azores (1432) became the basis for their subsequent push south to chart the coasts of Africa and record their navigational knowledge. In 1434, Gil Eanes became the first Portuguese explorer to successfully round the formidable Cape Bojador on the African coast. Cape Bojador had claimed the lives of many sailors in attempts to chart its treacherous coastline. In 1441, the first African slaves were taken and, from 1443 to 1446, occasional slave raids occurred. After this time, trading in both slaves and gold became annual events. By 1481, the Portuguese had crossed the equator and, seven years later, they rounded the Cape of Good Hope. Columbus, who learned navigation in Portugal, but sailed for Spain, discovered the New World in 1492. In 1500, Pedro Alvares Cabral became the first European to touch Brazil enroute to India. Magellan, a Portuguese also sailing in service to Spain, circumnavigated the globe in 1519 (Diffie and Winius 1977:xiii, 57, 61, 68, 77, 79; Waters 1958:39). These first exploratory voyages inspired academics to research navigational issues, improving instrumentation, and noting new cartographic data. The refinement of maps and instruments made repeat voyages possible. Rutters, or sailing directions, were developed from these new explorations and refined on each subsequent voyage, highlighting such information as supplies of water, food, and trade goods, friendly and unfriendly people groups, and navigational hazards. Rutters will be discussed later in this text with regard to Spain.

The science of navigation was taught in Portugal before 1500 (Leary 1926:6). However, the scope and importance of Prince Henry “the Navigator” and the center for scientific inquiry he founded at Sangres remains a contentious issue among historians, and as such, will not be discussed here. The first pilots used by Portugal were often recruited from native populations. Vasco da Gama hired an Arab pilot, Ahmed ibn Madgid, in Malinde to pilot his vessel across the Indian Ocean (Diffie and Winius 1977:180). Later, Portuguese explorer, Antonio de Abreu, was led from Malacca to Amboina by a Malaccan merchant ship and aided by Malay pilots (Diffie and Winius 1977:369). The use of native knowledge of local waterways became the basis for European navigational supremacy in international waters. The experiences and knowledge of local pilots was integrated directly into rutters for dissemination to future pilots and navigators.

Vasco de Gama showed how far navigation had progressed when he confirmed a new trade route to the Indian Ocean and the Indies in 1497 (Waters 1958:40). Sailed directly, the passage between Lisbon, Portugal and Calcutta or

Goa on the Indian subcontinent is about 10,000 statute miles; however, the actual voyage sailed by the Portuguese, due to variations in wind, current, and weather, covered about 23,000 statute miles and took nearly eighteen months. The hardships of the voyage gave meaning to the Portuguese proverb, "If you want to learn to pray, go to sea." Then, after arriving in India, Portugal strained its natural resources to fight those equally or better armed. Ultimately, given these factors, it was a fantastic feat for Portugal to establish its influence in India (Diffie and Winius 1977:195, 199, 201). The Portuguese had quickly gained detailed knowledge of vast areas of coastline and several oceans and seas, then used this navigational knowledge to build ships that better survived the rigors of the voyage, to train seamen to run these new vessels, and to enforce its will on empires and cultures half a world away.

Design of Portuguese ships evolved during their age of exploration. Until the end of the 15th century, explorers used caravels. While caravels were still sailing in the 16th century, a vessel was developed that was a combination of the caravel with the não, producing a ship that was heavier with more cargo space. The larger caravel used both lanteen sails, that were triangular, and square sails (*velas redondas*). This heavier, larger ship was closer to the caravel in sailing qualities, but more like the não in capacity. Trade took the Portuguese further abroad and these larger, heavier vessels could carry more cargo and better survive adverse conditions (Diffie and Winius 1977:119). Each of these vessels has particular sailing characteristics that require specialized navigation techniques. For example, a pilot, navigator, and/or captain would have to be intimately familiar with the draft of the vessel, its weight (with and without cargo), its handling in heavy seas or winds, etc. Thus, the navigation of these vessels required years of experience and education, in addition to verbal training by older, more knowledgeable men.

Of the European powers, Portugal was the first to conduct global explorations for several reasons. First, Portugal was located in southwestern Europe. Situated close to Africa, the Portuguese had fought in Morocco and were well aware of the riches to be made from trade and plunder in Africa. Also, Portugal had a seagoing merchant class and a shipping industry with the manpower to extend trade beyond Europe. Explorers were motivated to earn profits, have adventures, win honors and lands, or convert infidels. As a strong monarchy with a unified nation, Portugal was in a position to take advantage of the opportunities available (Diffie and Winius 1977:preface, xiii-xiv). The Portuguese were also able to synthesize and systematize the navigation techniques and tools developed by others into a national navigation knowledge base (Waters 1958:43). The wealth, adventure, and honors available served as heady motivation to continue to navigate and map far beyond the coasts of Portugal.

The Portuguese crown established the first centralized training and licensing facility for navigators in the 15th century. Specialists working in the *Casa de Guinea e India* (hereafter “Casa de Guinea”) drew charts and developed sailing directions for the trip to the Indies, as well as the New World. Interestingly, Portugal did not have a Pilot Major, a highly skilled, experienced navigator who oversaw navigator accreditation, as Spain later developed. During a voyage, the navigators were required to take extensive notes, modifying their charts if they were incorrect. Upon returning to Portugal, the navigator had to provide these corrections and notes to the Casa de Guinea, which later used them to correct the charts and amend the sailing directions (Diffie and Winius 1977:142; Waters 1958:62). These charts and sailing directions to the Indies or New World were considered state secrets. Pilots were closely monitored by spies on land and sea, forbidden from revealing their knowledge to any foreigner on pain of death. In general, the Portuguese released just enough information to other nations to correct world maps, but not sailing directions or charts for those areas considered of national importance (Waters 1958:81-82).

During the 15th century, the Portuguese advanced the science of navigation. A combination of dead reckoning and the instrumental observations of the height or altitude (*altura*) of the sun were used in the early part of the century to sail to Madeira or the Azores. Pilots used portulan charts, magnetic compasses, rhumb lines, and compass dividers to estimate the position of the ship. Arithmetic was performed on an abacus. The navigator would measure, using an astrolabe or cross staff, the angle the sun formed with the horizon at midday, called the “altitude of the sun,” then perform small mathematical calculations to determine the latitude of the vessel's location (Leary 1926:6). The instruments and techniques used to take these observations are described in detail in Chapter IV. Because of the wide-spread use of this technique, the literature and charts of the period describe each port as being located at a particular latitude (Diffie and Winius 1977:136-137). In 1456, Cadamosto mentions that his Portuguese pilots used the compass and sea chart, but not the astrolabe. The North Star and the Southern Cross were also used to determine direction (Diffie and Winius 1977:120). The use of these solar observations was pivotal to navigation because no accurate measurements were possible until these instruments were devised. Refinements of the solar altitude and star guidance systems form the basis for later navigational instrument innovation and increased accuracy.

Portugal's success in reaching India and the Far East threatened the trade monopoly of Venice, the most powerful maritime state in Europe at the time, as well as jeopardized the exclusive Muslim control of the lucrative eastern trade routes. The Venetians and Muslims could have worked together to defend their monopoly, but Venice was afraid to side with Muslims against Portugal, a Christian power. This infuriated the Muslims. The Muslims had several advantages. They were wealthier, more numerous, and traveled shorter distances than the Portuguese. However, their ability to defend their trade routes from Portuguese encroachment was limited for two reasons. First, they had no navy to keep the Portuguese out of their ports. Second, the Muslims lacked a tradition of government intervention in merchant affairs, so the government was less likely to feel a responsibility to build a defensive navy. This meant that the Muslims could not defeat the Portuguese at sea without the assistance of the Venetian navy. So, without serious contest from either the Venetians or the Muslims, the Portuguese, backed by Genovese and Florentine investment capital, began to make steady inroads into the eastern trade (Diffie and Winius 1977:196).

In Portugal, and later across Europe, the navigational instrument-making trade began in small, single-craftsman workshops. Regiomontanus established a workshop in Nuremberg in 1471. The workshops of Hans Dorn of Vienna (c. 1480), Pier Vincenzo Danti of Florence (c. 1490), and the Vulparia family of Florence all began in this period. Toward the end of the 15th century, the trade evolved into larger workshops filled with multi-skilled personnel. Workshops were established in the Netherlands as well, and these were influential to the later development of the instrument making trade in England (Maddison 1969:22). In addition to improving instrument designs and creating new instruments, these workshops published books and pamphlets on how to use the instruments (Maddison 1969:23). The instrument-making trade expanded as the need for instruments increased and as new designs were conceived and experimented with by Portugal and competitor nations. The vast wealth Portugal had gained from its new trade inspired envy in the other nations of Europe, who used Portuguese navigators to begin their own international trade programs.

Many of these navigators brought instruments purchased in their home countries to their new positions, thus disseminating the instruments for study and replication.

It should be noted that Spain was not active in exploration during the 15th century for several reasons. Spain suffered from extensive strife in the period, both internal regional conflicts between warring kingdoms and external conflicts with the Moors, North African Muslims who had occupied portions of the Iberian Peninsula since the 8^{th} century. The marriage of Ferdinand of Aragon to Isabella of Castile in 1469 assisted unification and the two kingdoms were formally joined five years later. The Moors were expelled in 1492, thus freeing the monarchs to support exploration (Carr 2000).

Despite England's location surrounded by the sea, the British Isles were not active in exploration in the 15th century for several reasons. From the eleventh to the 14th century, most monarchs had focused on building small vessels for local defense, usually paid for by their subjects. The caravel, which was originally developed in Spain and Portugal, was utilized in England as well. When the caravel was introduced in England, the size of the merchant vessel decreased significantly in favor of the new ship type. The caravel was a much smaller vessel, cheaper to build, as well as fast and maneuverable, however, totally unsuited to long-distance exploration. The caravel was commonly used for local trade, fishing, and defense. Thus, only coastal navigation was necessary during this period of English maritime history.

The reign of Henry V (1413-1422) saw the beginning of the Royal Navy. Henry V developed the first naval fleet, paid for by the crown. His fleet mainly consisted of a group of smaller vessels, including 15 balingers and barges. However, Henry V was most well known for his mammoth carracks, which are significantly larger and heavier, including the archaeologically excavated *Grace Dieu* (built between 1416 and 1418). Most of his naval vessels remained part-time, short-range, local defense forces consisting of small ships, often widely dispersed. The carracks of Henry V were so large that they were unmatched in size for 300 years. A substantial part of Henry V's famous 1416 invasion fleet was made up of Dutch and Flemish ships. The council ruling England in the name of Henry's infant son, Henry VI, sold all but four of the naval vessels after Henry V's death (Roger 1997:68, 72, 124, 143, 145).

Under Henry VI (1422-1461, 1470-1471), convoys of merchants began making regular trips to Iceland. In a political poem of the late 1430s, *Libel of English Policy*, an anonymous author refers to these convoys, stating that the vessels in the Iceland trade had only adopted the magnetic compass within the past 12 years, roughly sometime in the 1420s. While the English used the compass, even in the late 15th century, there is "no evidence" that any English seaman knew how to observe their latitude (Roger 1997:161-162). By 1456, England had lost all of her overseas possessions except Calais and parts of Ireland. King Henry VI became insane and the government was paralyzed (Roger 1997:153). The Wars of the Roses, a series of civil wars, were fought in

England between 1455 and 1487. The situation left England with little use for long distance trade or oceanic navigation, as national focus remained on the political situation at home and land battles abroad.

The governments of Edward IV (1461-1470, 1471-1483), Edward V (1483), Richard III (1483-1485), and Henry VII (1485-1509) did not have the money, the resolution, or the strategic sense to revive English sea power. England consistently suffered from piracy during these reigns due to its lack of naval power (Roger 1997:155). England's national focus remained on land until the reign of Henry VIII. However, the early emphasis on larger naval vessels continued. Only six ships, of all sorts, were known to have been built for the English crown between the accession of Henry VI (1422) and the death of Henry VII (1509)(Roger 1997:156). This meant that England in the 15th century was bedeviled by extensive piracy and was largely unable to be involved in exploration beyond its local waters.

1500-1550

The influence of Portugal on global exploration waned during this period for several reasons. A disastrous "crusade" against the Moors and a struggle for succession ultimately allowed Philip II of Spain, who had a claim to the Portuguese crown, to claim the throne of Portugal. Spain continued to rule Portugal until 1640 and Portuguese possessions and navigational knowledge passed to Spain. By the time Portugal regained its independence, it had lost most of its empire, including the valuable East Indies territories which had been occupied by the Dutch. Thus, the story of the 16th century belongs to the English and Spanish explorers.

The political and economic situation under Henry VIII (1509-1547) began to move England toward appreciating the need for trained navigators. Henry allied himself with Spain, fighting three wars against the French, from 1511 to 1514, 1522 to 1525, and 1540 to 1546 (Waters 1958:81). Charles V united the Netherlands with the Holy Roman Empire in 1519, which meant an enemy controlled land directly across the English Channel. For the first time, England realized that its security depended upon possessing a strong navy, not just a fleet to transport the army for land battles. Henry considered it a "grave concern" if the channel coast was not held by England or at least a strong power in alliance with England. This "grave concern" led to fundamental changes in the way England defended its maritime borders (Leary 1926:22).

Henry became focused on building a true Royal Navy. His interest in the navy led to improvements in ship design (Waters 1958:8). Henry VIII imported Italian master shipwrights specifically to improve his vessels' sailing capabilities. The shipwrights lengthened the vessel in proportion to the breadth, building the first naval vessels with flush decks, carvel sides, and no castles (Wilcox 1966:11). The ships were oiled from waterline to rail, and then painted above the rail. Flags, banners, and targets (wooden shields with coats of arms) were placed on the railings, masts, and other parts of the vessel for decoration

(Wilcox 1966:7-8). Henry also hired French pilots and German gun founders. For the first time, guns were mounted on board these new naval vessels (Waters 1958:82). The modifications developed a vessel with new loading, maneuvering, and sailing characteristics. To navigate them properly, navigators required additional education in mathematics. The received knowledge of older pilots was no longer sufficient and England began to develop education programs to train navigators in the new techniques and instruments needed to run these new vessels.

In their efforts to professionalize their work, navigators petitioned to be recognized as a guild. On March 19, 1513, Henry established a guild of pilots called the Corporation of Trinity House of Deptford Strand (Whitlock 1987:4). Trinity House, as it came to be known, became responsible for maintaining almshouses for aged and maimed sailors, conserving “the science or art of mariners,” and making laws among themselves for the increase of shipping. They were also responsible for training, licensing, and regulating English pilots (Waters 1958:9, 108). Additional guilds of mariners were established in Newcastle-upon-Tyne, Hull, and Dover (Waters 1958:109). Hull’s charter included a directive that the behavior of mariners would be reported after the voyage. A mid-17th century oath book from Hull shows that prospective pilots and masters were examined and incompetent candidates were failed. Successful masters or pilots were listed with the ports where they were authorized to sail (Waters 1958:112).

Changes in vessel design increased the demand for better educated, professional navigators, capable of both coastal and oceanic navigation. In this period, both merchant and naval vessels in England were built with large castles on the fore and aft parts of the ship. Sails and boats were handled at the waist of the vessel (Wilcox 1966:7-8). Merchant ships continued to be clinker built for some time, but gradually adopted carvel techniques. Vessels were single-masted, rigged with fore-and-aft sails, usually a jib and a spritsail. Larger merchant ships had square rigs, with three masts and a bowsprit. The fore and main masts had course and topsails, the mizzen mast had a lateen (triangular) sail, while the bow sprit had a sprit sail. The coarse clumsiness of this rigging system meant that merchant ships had to carry larger crews – an advantage when fighting pirates who attacked even in home waters, but often leading to increased health problems for the sailors. This sailing rig continued to be used on merchant vessels into the 18th century (Waters 1958:8, 82). The larger ships, crews, and cargoes led to an increase in the number of navigators carried on board. In an effort to improve accuracy, a naval vessel would often carry 3-6 navigators and/or pilots, often with their apprentices.

In 1546, Henry VIII reorganized the administration of the Royal Navy by developing the Navy Board to oversee England's first standing navy (Leary 1926:23). Before Henry, the Crown would commonly augment the fleet with armed merchant vessels, operating the ships with an impressed crew. The crew was disbanded after engagements and the ship either laid-up or rented out to merchants (Waters 1958:40-41; Wilcox 1966:7). According to Waters, by the time of Henry's death, his navy contained 28 ships of approximately 100 tons (1958:9). However, Wilcox states that the king's ships varied from 30 tons to 1,000 tons (Wilcox 1966:7-8). Great ships of the navy could only sail between April and October due to the vessel's inability to withstand the sea conditions of winter. Unlike naval vessels, merchant ships sailed year-round. Waters suggests that naval pilots learned their art in a mercantile school (Waters 1958:11), but does not provide any further details, so this is uncertain. Nonetheless, the development of the navy, as well as the longer sailing season and increasing size of England's naval vessels encouraged the later development of a systematic education system for navigators.

Under the early Tudors, merchants carried English wool, cloth, tin, and hides to trade for fish (Iceland), for fine cloth and Rhinish wine (Low Countries), for woad and French wines (Bordeaux and Biscay ports) and for fruit, wax, iron, and wine (Portugal and Spain). During his reign, Henry VIII established some new trade connections in the Baltic and Levant, using traditional English trade goods. However, English vessels rarely traveled to Italy or the Baltic (Waters 1958:7, 81). Further voyages to the Levant, Canaries, and Barbary Coast, as well as William Hawkins' voyage to Brazil, occurred rarely due to constant piracy by several nations (Leary 1926:23).

During incidents of piracy, navigators and their instruments became valuable booty. Historical documents document several instances of pirates targeting pilots, navigational equipment, rutters, and charts in the 16th century (Waters 1958:502-503). Nuño de Silva states that he was captured by Sir Francis Drake "because he knew I was a pilot acquainted with the Brazilian coast" (Waters 1958:535). Drake also took de Silva's astrolabe, navigation chart, and rutter, as well as the charts belonging to the master and boatswain, "dividing them among his officers" (Waters 1958:535). De Silva mentions that Drake habitually cross-examined pilots that were captured, later setting them free, but would regularly destroy navigational items to delay the vessel reaching land or cause its destruction. "The first thing he did when he had captured a vessel was to seize the charts, astrolabes, and mariner's compasses which he broke and cast into the sea," (Waters 1958:536). In 1558, Richard Hakluyt recorded an event of English piracy which provides insight into the minimal instruments required to manage a vessel. While taking two Danzig hulks as prizes, Captain William Towerson took all the navigational equipment from the vessels, then returned "a compasse, a running glass, [and] a lead and line" out of pity for the crew (Waters 1958:93).

Before 1547, few Englishmen were interested in transoceanic navigation or global exploration. Roger Barlow and Henry Latimer were exceptions. They learned navigation under Sebastian Cabot during a voyage in 1526 (Waters 1958:78). In 1547, no Englishmen could pilot to India, the Moluccas, Cathay, or the Pacific Ocean and few were interested in trying (Waters 1958:79). In 1458, Robert Sturmy of Bristol became the first Englishman to sail to the Levant in search of spices and wines. After this voyage, English merchants occasionally traded for wines from Chios and Greek currants, but the expansion of the Turkish Empire into the North African Barbary states limited the number of Mediterranean voyages (Waters 1958:88). William Hawkins of Plymouth and a few others had been to Brazil in the 1530s to get dye-wood, but it is likely they used foreign pilots and the French wars ended their expeditions. The only successful, royally funded explorations during Henry's reign were the voyages of John and Sebastian Cabot (Leary 1926:35), Italians who had learned navigation in Spain. Since their discoveries failed to yield a new way to the Orient, or even inhabited land for trade, England did not exploit or pursue their findings (Waters 1958:80).

The brief reign of Edward VI (1547-1553) saw a further decline in English trade. Portuguese and Spanish wealth, as well as pirate attacks, had been disrupting local English trade for sometime, endangering mariners and their livelihoods (Waters 1958:83). By 1549, the trade deficit was getting worse. The Spanish forbade the English to trade in Spanish or Portuguese colonies. English woolens were not appreciated as trade goods, except in Russia. The Mediterranean was closed due to the advance of the Turks along the Barbary Coast and the Guinea trade was unsuccessful (Waters 1958:100). A lucrative trade opportunity with the Kingdom of Morocco opened in 1551 and, the following year, Thomas Wyndham completed a successful voyage, carrying sugar, dates, almonds, and molasses to England (Waters 1958:89). However, the rise of the Moroccan corsairs quickly made this trip hazardous.

In contrast to England, Spain had become very interested in the development of a transoceanic empire in the 16th century. In 1508, Spain established its own national school of navigation, called the Casa de Contratación. Initially, navigators were trained by Portuguese mariners and then licensed after passing a thorough examination and being approved by the Pilot Major, the head of the Casa. In addition to accumulating hydrographic information, the Casa created an official map (*Padrón Real*), which was submitted to the Pilot Major for correction and re-publication (Leary 1926:6). Later, the Casa became active in compiling and publishing books on navigation (Waters 1958:62). Over time, the requirements to pass the pilot exam decreased. The decline in education and licensing requirements made Spain's vernacular textbooks on navigation unusable by its own pilots (Lamb 1995 [VI]:679), who often received better information from other navigators and captains. Some navigators even resorted to keeping secret, personal charts hidden from Casa inspectors, who would have confiscated and destroyed them in accordance with Spanish law.

The voyages of Columbus and others to the New World produced a need for the soldiers of the Reconquest (*Reconquista*) of Spain to become sailors and learn the rudiments of seamanship and navigation. Throughout the 16th century, Spain produced naval commanders with a thorough grasp of navigation and ship-handling. Spain continued to need commanders, sailors, navigators, and explorers for their rapidly expanding colonial possessions. In 1519, Hernan Cortes began the conquest of Mexico. Francisco Pizarro discovered the Inca Empire in 1524. Exploiting these conquests would fixate Spanish attention for nearly 200 years. For over a century, the Spanish convoys crossed the Atlantic unscathed by the naval forces of rivals until the capture of the Silver Fleet off Havana in 1628 by Piet Hein (Bertrand and Petrie 1952:406; Waters 1958:466).

1550-1600

The charter of the Merchants Adventurers by Queen Mary I (1553-1558) and her consort, Philip II of Spain (1556-1598), proved pivotal to the history of navigation in England. The Merchants Adventurers were the first attempt by the English to develop overseas trading routes and colonies. England had lost control of the port of Calais in 1558, further enflaming their trade deficit with local governments (Waters 1958:100) and convincing the monarchy to support global explorations. In 1553, the Merchants Adventurers set out to find a northwest passage to China (Leary 1926:39), an area long known to contain fabulous riches and their best hope for establishing lucrative colonies.

The Merchant Adventurers furnished navigational aids, including astrolabes and charts, to the pilots, as no navigational instruments were being produced in England at the time. The instruments may have been purchased in Flanders (Taylor 1954:20). Sebastian Cabot, in his *Ordinances* (1553), states

“Cardes, Astrolables, and other instruments were prepared for the voyage, at the charge of the companie,” so these instruments were not the possessions of the navigators, as they would be in later periods (Waters 1958:145, 509). Archaeologically, this is important to note because we might expect that the manufacture of multiple instruments by the same craftsmen could be represented by increased similarities between artifacts. We know that the Merchants Adventurers purchased a variety of instruments for Martin Frobisher’s expedition to find the Northwest Passage in 1576. On his first voyage in 1576, Frobisher had various brass globes and instruments, a little brass standing level, a cross staff (*balestotta*), a universal Mercator projection, six navigation charts, twenty compasses, eighteen hour glasses, and an astrolabe (Leary 1926:65-66).

In 1551, the first expedition of the Merchant Adventurers under Sir Hugh Willoughby failed after it was scattered by a storm. He had been attempting to find a sea route to China along the northern coast of Russia. Sir Willoughby and most of his men froze to death. However, his navigator, Richard Chancellor, survived and undertook another voyage towards Russia the following year, ultimately arriving in Moscow. He began negotiations and, in 1553, the Muscovy Company received a royal charter (Waters 1958:85-86). The Company provided valuable naval stores, such as pitch, hemp, and timber. The Hanseatic League had previously used their position in the Baltic to suppress shipping of these items to England in an effort to control the size of the English merchant and naval fleets. The Muscovy Company broke the embargo and, as a joint stock company, became the pattern for later financing of English trade ventures (Waters 1958:88).

In 1553, navigator Thomas Wyndham made history for England. Sailing with two Portuguese pilots, Anthony Pinteado and Francisco Rodrigues, Wyndham successfully traveled to Guinea for gold and to Benin for pepper. The navigator, Rodrigues, kept notes on the winds and currents of Guinea and gave them to Sebastian Cabot. This knowledge was later used to open the Africa trade (Waters 1958:90). The following year John Lok captained another voyage to Guinea and compiled his notes into an English sailing rutter (Waters 1958:92). England finally had the knowledge to sail along the coast of Africa and navigators who had successfully completed the voyage. While England was anxious to take part, Spain had taken over the Portuguese monopoly on the West African trade in the 1560s. John Hawkins, using a Spanish pilot, attempted to break the monopoly by bringing his first cargo of slaves to the West Indies in 1562. Two years later, he made a second trip. The Spanish Government was outraged and gave Elizabeth an ultimatum in October 1566. She forbade Hawkins from going to any of Philip's "prohibited ports," but Hawkins made secret voyages again in 1566 and 1568 (Waters 1958:117-119).

Under Elizabeth I (1558-1603), England made strides to maintain and increase the navy, improve navigation, and hire and train seamen, especially navigators. Under Sir William Cecil, later Lord Burghley, laws were passed to safeguard naval supplies, improve the number of seamen and masters available for shipping, maintain better seamarks, and make ports safer for landing cargo (Waters 1958:103). Waters believes the efforts to improve the professionalism of pilots and navigators were successful, stating, “In Elizabeth’s reign no royal ships were cast away or lost by stress of weather, faulty handling, or careless pilotage” (Waters 1958:107). Before this period, England had suffered substantial annual losses of vessels, cargo, sailors, and passengers to pilot/navigator errors.

In spite of the expansion of English interests, most trade still occurred locally until the 17th century. Merchants in ports on the eastern coast of England still predominantly traded with Muscovy, the North Sea, and the Baltic. The ports of Southampton, Plymouth, and Bristol continued to focus on local trade with Biscayan and Peninsula ports, as well as those in the Atlantic islands (Waters 1958:116). While England was slow to join the exploration and colonization of the globe, the pace increased in the 1560s. England became more aware of the potential benefits at the same time that conditions became favorable for trade and exploration (Waters 1958:115).

Navigation in England benefited from the immigration of instrument makers to begin an English instrument making trade. In the 1560s, religious refugees from Flanders brought the instrument making trade to London, crafting tools for navigators, surveyors, astronomers, and gun-layers. Until this time, England had lacked the mathematical training and a native brass industry necessary for making navigational instruments. Often subcontractors such as engravers and mathematical instrument makers later assisted in producing navigational instruments. Only a few instrument makers worked in the British Isles during the 16th century. The number grew more rapidly from the second half of the 17th century (Taylor 1957:xii-xiii; Waters 1958:97), due to increased demand by merchants, the navy, and professional navigators. By the end of the 16th century, England had acquired some knowledge of gunnery and mathematics, both vital to the expansion of trade connections and defense of shipping.

Sir Francis Drake's circumnavigation of the globe between 1577 and 1580 was a milestone in the history of English seafaring. For the first time an Englishman had completed a global voyage. However, Drake relied heavily on Spanish and Portuguese expertise, sailing with a Portuguese pilot, Nuña de Silva. He also had some charts and rutters of the Pacific seized from two Spanish pilots who refused to sail with him after he had taken their ship (Waters 1958:121). Drake plundered the Spanish possessions in the New World, returning to England with the richest cargo ever seen in an English port (Waters 1958:120). Another Englishman, Thomas Cavendish, repeated the feat between 1586 and 1588. Their notes, charts, and rutters became part of the training for transoceanic navigators, making it possible for England to expand its options for colonization and trade.

Between 1575 and 1588, England financed a variety of expeditions and colonies, including the Roanoke expeditions of half-brothers, Sir Humphrey

Gilbert and Sir Walter Raleigh, as well as Martin Frobisher's voyages to find the Northwest Passage, Arthur Pet and Charles Jackman's voyage to the Straits of Waigats, and John Davis' voyage to northeastern North America. John Davis also earned fame by almost sailing through the Straits of Magellan in South America, even though he was forced back through the Straits by bad weather. By this time, astrolabes, sectors, nocturnal, and other instruments were available in London, but costly due to the few instrument manufacturers in England at the time, as previously mentioned (Leary 1926:64; Taylor 1954:171-172; Waters 1958:122, 144). The war with Spain limited further exploration until the early 1600s.

In 1588, Spain attacked England with a fleet of ships that came to be known as the Great Armada. Wilcox estimated that Spain sent 130 large vessels and 30 smaller ships into battle (1966:12). England defended itself with only 34 vessels. Twenty-four of England's ships were over 100 tons, the largest being 1,000 tons (Waters 1958:9). The greater speed and maneuverability of the English vessels kept the Spanish men-at-arms from boarding and a variety of circumstances, including the weather, drove the rest of the Spanish fleet north (Wilcox 1966:12). The expertise of the English pilots helped to keep English naval losses to a minimum. King Henry VIII had officered his ships with nobility and many of these families developed a tradition of serving in the navy. The sons and grandsons of his officers, carrying the received knowledge of previous generations of sailors, developed the ships, naval ordinance, naval gunnery, and tactics that defeated the Armada (Waters 1958:463). Ultimately, most of the men and vessels of the Great Armada were lost on the dangerous coasts of Scotland and Ireland, largely due to their lack of expert pilots and relevant coastal knowledge. During the same year, Hawkins destroyed three vessels at San Juan de Ulloa, using only relatively long-range cannon-fire. These victories led to a new English warship design, among the first to be specifically built for the purpose of naval warfare (Waters 1958:120).

In 1591, James Lancaster reached the East Indies, but was wrecked on the return voyage to England. Queen Elizabeth granted a charter to the East India Company on December 31, 1599 and Lancaster, sailing for the company, successfully completed the first round-trip voyage to the Indies in 1600-1601 (Leary 1926:91; Waters 1958:122). By 1600, the sea power of Spain and Portugal was waning, leaving England "mistress of the seas." Within a mere fifty years, England had established overseas colonies and traded regularly on a global scale (Waters 1958:80). As Spain became more focused on its new colonial empire, they only needed navigators that could read and follow the charts that had been developed for colonial trade. After this time, the navigators of Spain and Portugal only had to follow well-developed routes and both countries began to actively recruit English navigators. After this time, England became the center of innovation, education, and expertise in navigation.

Several factors worked together to pressure England to create a professional cadre of pilots and navigators. Larger merchant vessels, the growth of the Royal Navy, the growing importance of London, and the increased use of the Thames all worked to bring regulation to the profession (Waters 1958:5-6). The combination of the apprentice system and the Trinity House guilds provided the Tudors with an adequate collection of skilled pilots and navigators (Waters 1958:112).

Education of more pilots and navigators, the codification of received knowledge, and the application of higher mathematics to navigational problems led to new discoveries and improvements in navigation and geography. These discoveries led to increased cartographic reliability. These new maps made it easier to find colonies and trading ports, leading to an increase in the successful number of voyages. The astronomical profits made on these early voyages encouraged an ever-increasing number people to invest in the joint stock companies trading overseas, such as the Muscovy Company (est. 1553) and the Levant Company (est. 1581). This widespread financial support made additional expansion in the 17th century possible.

1600-1642

In England, the Royal Navy and merchant sailors experienced far different fortunes during the reign of James I (1603-1625). The negotiation of a peace treaty with Spain nearly put the Royal Navy out of commission. Having inherited the finest fleet of man-of-wars afloat, James allowed it to rot away, spending more to upkeep a few ships than Elizabeth I did to fight the Armada

(Wilcox 1966:19). James stopped signing Letters of Marque, so naval careers were not as lucrative. Fewer men volunteered and the supply of future commanders dwindled. The Royal Navy had developed a program to train young men to read, write, calculate, and perform the tasks needed to gain expertise in navigation. The destruction of the Navy under James meant that these avenues for improvement were no longer available to the lower or middle class, who were the only classes interested in volunteering for sea duty. Nepotism, corruption, and graft had discouraged upper class gentlemen from going to sea. Young, inexperienced men from lower social classes were soon being promoted to captains. However, the new captains knew little about running a vessel and often left the running of the ship and the trimming of the sails to masters and mates who had better knowledge of seamanship (Waters 1958:464). As a result, the education of officers declined. Neglect and cruel treatment of sailors, in addition to lack of prompt payment of wages, decreased the number of men willing to volunteer to work in the navy. The only naval operation of note in the reign of James I was the expedition to destroy the pirates in Algiers (1620-1621), and that was a failure. As a result, the Navy was ineffectual in limiting the depredations of professional pirates and many merchant vessels stayed in port to avoid being captured (Wilcox 1966:34, 251).

Political and religious conflicts wracked Europe during this period (Waters 1958:251). Rivalry between France and England led to the seizure and retention of French prizes by English seamen. The two nations came into increasing conflict (Waters 1958:462, 474). The Dutch, who had continued to fight the Spanish and Portuguese for their overseas possessions, began to take control of local and global commerce. They controlled the lucrative coal trade to France, Holland, and Germany. By 1615, the Dutch also had the preponderant share of the Norwegian and Russian trades, monopolized the Baltic trade, and were strong competitors in the Biscayan and Peninsular salt pans, leaving little for English merchants (Waters 1958:251, 321). In February 1623, the rivalry between the Dutch and English over the spice trade turned deadly. A group of Dutch traders massacred English merchants trading in the East Indies at Amboyna. Negotiations after the massacre led to a geographical resolution: the Dutch controlled the East Indies trade while the English began trading in India (Waters 1958:252).

The political situation also limited opportunities for former naval sailors, including navigators, within the local English merchant fleets. English sailors left the merchant and naval fleets in large numbers to gain employment on foreign ships, where high demand existed for their expertise in navigation and gunnery (Waters 1958:255; Wilcox 1966:12). As a result, in 1605, 1606, and 1607, Scots and English navigators led Danish expeditions to Greenland to search for ancient Norse settlements. In 1612, John Adams arrived in Japan and taught the Japanese western shipbuilding techniques and navigation. After being forced into slavery, Thomas Ward, Sir Francis Verney, and Sir Henry Mainwaring taught the art of oceanic navigation to the Barbary pirates, thereby extending their reach, and depredations, into English and Irish territorial waters and port cities (Waters 1958:252-253).

English vessels were left open prey to pirates by the decommissioning of the Royal Navy, as well as James' refusal to issue any more Letters of Marque to merchants which stopped the custom of taking prizes. Eventually, England forbade small ships from trading at sea in an effort to keep them from being taken (Waters 1958:123). Professional pirates moved into English home waters, blackmailing merchants into paying illegal dues (Wilcox 1966:12-13). Professional pirates, generally called "Turks" if they were of North African origin and "Dunkirkers" if they were from the Channel or North Sea, constantly attacked shipping and trade, even raiding for slaves on the English coast. In 1625, the Mayor of Plymouth reported that the Turks had taken 27 ships and 200 men within 10 days. These same pirates landed at Baltimore on the Munster coast and carried off 237 men, women, and children into slavery (Wilcox 1966:33-34). Between 1609 and 1616, the Barbary pirates captured 466 English vessels, many of them in English waters (Waters 1958:252-253), almost ruining English trade, especially from southern ports.

The limitations on local trade and the need to band together against pirate attack led to the rise of the great chartered companies of the 17th century: the East India Company (est. 1600), Virginia Company (est. 1606), Newfoundland Company, the North-West Passage Company (est. 1612), the Hudson's Bay Company (est. 1670), the Royal African Company (est. 1672), and the New East

India Company, a rival of the earlier EIC but later absorbed by it (est. 1698, merged 1709). These companies became the training grounds of a new generation of English pilots and navigators (Waters 1958:256). For example, Henry Hudson learned his trade in the Muscovy Company (est. 1553), explored for England, and even worked for the Dutch East India Company. William Baffin also worked for the Muscovy Company (Waters 1958:252-253, 271, 277).

After 1607, English discoveries continued at a record pace, focusing on three areas: the northwest Atlantic, the American Atlantic seaboard and islands, and the Indian Ocean. Each of these areas provided economic inducements for trade and/or colonization by the English. England hoped that the northwest Atlantic would still yield a northwest passage to the Orient, giving England control of the “short cut”. Hudson (1610), Button (1611), Hall and Baffin (1612), Gibbons (1614), and Bylot (1615, 1616) all searched for the Northwest Passage in this period (Waters 1958:259). In 1614, John Smith surveyed and mapped the American Atlantic coast. Colonization and control of the established merchant traffic in the American Atlantic seaboard and islands, as well as the Indian Ocean, drove English exploration. Jamestown and Bermuda were established in 1609, followed by New Plymouth and Guiana in 1619 (Waters 1958:259-260). Samuel Purchas began collecting English discovery narratives for publication during this period as well (Waters 1958:260), indicating a growing popular demand for information on geography and cultural information in England. The increasing exploration led to increased demand for educated, professional navigators, which in turn, led to a variety of systematic programs to train navigators in the skills required for these voyages.

When James died in March 1625, Charles I, his second son, took the throne and reigned from 1625 to 1642. Charles renewed hostilities with Spain (Waters 1958:465). The Thirty Years War (1618-1648) raged on the continent. Exploration continued and England began to colonize the coasts and lesser islands of the Caribbean and South America. Barbados was established in 1624 and St. Kitts in 1625 (Waters 1958:446). Navigators developed extensive charts and rutters for areas of exploration and colonization, leading to greater accuracy in cartography and safer voyages.

Charles' first proclamation was "for the well manning and arming the ships of war belonging to this realm upon their setting for to sea," commanding that the crews of ships should be exercised regularly to learn the perfect use of their Arms (1625)(Waters 1958:471). Charles I levied a ship tax to build the fleet and succeeded in bringing some security from pirates to English waters, but there still was no navy of consequence. Much of the ship tax money was spent building and decorating a single, massive vessel, *Sovereign of the Seas* (Wilcox 1966:12-13, 33-34). The rest was spent improving dockyards and fixing naval vessels, which did little to address the heavy loss of expert manpower in the navy or merchant marine.

After 1642

By the 1640s, the maritime nations of Europe had attained a level of competency at sea and were capable of navigation on a global scale. The period wherein navigational instruments were developed gave way to a time when they were refined. The details of the development of specific navigational instruments are included in Chapter IV. Even in modern times, many of the instruments used at sea are direct refinements of those created by the inventors and instrument makers of Portugal, Spain, England, the Netherlands, Germany, Italy, and other countries. The problem of longitude, while well understood, was not adequately solved during the entire period under discussion due to the lack of accurate timekeeping devices.

The review of the history of navigation in Portugal, Spain, and England would be incomplete without a discussion of the development of four closely associated fields: mathematics, astronomy, cartography, and hydrography. These fields form a symbiotic relationship with navigation, being an integral part of a navigator’s activities, as well as fields that benefit from advances in the practice and professionalism of the navigator. Mathematics and astronomy will be discussed together, as the calculations first used by 13th century navigators involved measurements of the associations of celestial bodies and the earth, which were in turn used to compute mathematically the approximate latitude of the vessel. Cartography and hydrography will be discussed in a separate section as the land and sea maps, respectively, developed by navigators increased the accuracy of their positioning and, ultimately, the safety of the vessel. The chapter ends with a review of the difficulties of computing longitude in the period and its subsequent effect on accurate navigation.

Mathematics and Astronomy in Navigational History

Mathematics and astronomy were fundamental to the development and accurate use of navigational instruments. When a vessel is out of sight of land, only measurements of astronomical bodies, such as constellations, stars, and/or planets, can provide a reference point as to the ship's location. These astronomical measurements must be compared to mathematical tables or processed through a variety of computations to provide accurate latitude information. Therefore, without mathematics and astronomy, a navigator or captain would have no clue as to the vessel's northerly or southerly position on Earth. While latitude could be computed from celestial bodies, the longitude could not. The problem of longitude will be discussed later in this chapter.

In 1400, the lack of knowledge of mathematics throughout Europe, coupled with the belief that the Earth was the center of the universe, made scientifically precise navigation, as we know it today, impossible. The maritime societies of the Italian peninsula, such as Amalfi, Piza, Bari, Venice, Genoa, and others, were responsible for developing several early navigational instruments, including an early form of the compass. As early as the twelfth century, the Italian poet William of Puglia stated that Amalfi was famous for showing sailors the “paths of the sea and sky” (*nauta maris coelique vias aperire perifus*)(Taylor 1957:92). By 1485, teaching of mathematics flourished in Portugal, Germany, and Italy (Taylor 1954:7); however, mathematics were not generally taught or studied in England at this time. England had a long history of staunch prejudice against including mathematics in an academic course of study. Roger Bacon remarked that religious people put mathematics among the “black arts.” Pope Sylvester II was called a “magician” for his star-gazing and sun clock (Taylor 1957:90). Until the 16th century, navigation depended on experience, sound common sense, and good seamanship (Taylor 1954:ix), with science playing only a small role.

In 1547, there was still little evidence of mathematical use in civil, military, or nautical matters in England (Taylor 1954:17). By the early to mid-17th century, a small number of London practitioners taught advanced mathematics to individual students (Taylor 1954:x). However, basic arithmetic was not taught in schools and was generally considered suitable “only for clerks” (Taylor 1954:ix). After 1553, expertise in geometry and astronomical sciences was increasingly in demand due to the frequent naval wars in Europe, as well as global exploration and trade. Advances in surveying, horology, cartography, gunnery, and fortification sciences demanded more accurate measuring instruments, as well as academic training in mathematics (Taylor 1954:xi, 9). E.G.R. Taylor quotes one contemporary source, “The general level of technical competence among the rank and file must keep step with the advance of science, not only in order that new discoveries may be utilized, but so that a sufficient number of recruits into the higher ranks of scientists can be relied upon" (Taylor 1954:119).

By the 16th century, navigators relied heavily on mathematical calculations and tables (Waters 1958:196). Mathematical computations were performed on an abacus and noted in logbooks in Roman numerals (Waters 1958:94). The navigator sailed by "dead reckoning," a technique utilizing his best judgment and instruments to insure the safety of the vessel and crew. Often, fleets would have multiple pilots who would gather and compare notes to determine the position of the ship. The pilots often surrounded their calculations with secrecy, in case they had made an error, and admitted that they often approximated the correct position of the ship from discussions with other pilots (Peréz-Mallaína 1998:86). An example of the use of mathematics and astronomy would be the technique of taking a noon reading. The altitude of the sun was taken from the deck of a rolling ship, as near to midday as could be calculated. The cross staff required the navigator to stare directly into the sun and place the center of the staff across the central diameter of the sun as well. The measurement would be used as the basis of a complex calculation, then the resulting sum would be compared to a table. The number of the table, after being used in another series of computations, would tell the navigator the approximate latitude of the vessel. But, there were extensive errors inherent in taking the initial, vital reading. For example, wind could cause astrolabe and cross staff readings to be incorrect. One pilot, Engenio de Salazar, states that the pilots took their readings “a little more or less” and that a mistake “no bigger than the head of a pin on their instrument will cause them to make more than five hundred leagues of error in their estimate” (Peréz-Mallaína 1998:87).

Literature was produced to improve gunnery, surveying, astronomy, and almanac writing. The first English book on gunnery was published around 1578, a translation of a mainland European textbook. The break-up of church lands under Henry VIII gave surveying its momentum, leading to increased development of new instruments, many of which were adapted for navigational use. The first textbook on astronomical and practical surveying by Leonard Digges, *A Book named Tectonicon*, was published in 1556. Digges was also an almanac-writer and astrologer. He published the almanac, *Prognostication*, from 1555-1559 and his son, Thomas, continued publication from 1570 until 1635 (Waters 1958:96). *Prognostication* included tables of propitious days for various activities, as well as tide tables and instructions on how to make and use a sundial to tell time at night. This admixture of practical information, such as tidal tables, and superstitious ideas, such as “evil sailing days,” was common to the period (Waters 1958:97). From 1571, almanacs included, among other features, the ecclesiastical calendar, the phases of the moon, distances between English towns by road, and local fairs (Waters 1958:17).

In 1598, Gresham College was established and, for the first time in England, courses in arithmetic, theoretical and practical geometry, astronomy, geography, and navigation were publicly taught. Developed in accordance with Sir Thomas Gresham's will, the College was unique. Lectures were given in English, rather than Latin as was common at other universities. It was also common in the period for teachers to prepare their lectures word-for-word before class. At Gresham College, the practice was forbidden so teachers could better cater their teachings to the level and needs of their students (Waters 1958:243). The first scientific society in the English-speaking world, the Royal Society, developed out of the informal gatherings of the Gresham professors (Waters 1958:246). Both Gresham College and the Royal Society fostered the type of education needed for navigators to utilize more complex instruments and invent newer, more accurate position-finding techniques. Oxford established the Chair of Astronomy and Geometry in 1619; however, until mid-century, universities remained mainly ecclesiastical in purpose and outlook. Minimal teaching was available at either Oxford or Cambridge in arithmetic, geometry, or astronomy. Discoveries in mathematics in particular occurred after students left the university or by those who were self-taught (Waters 1958:244).

Advances in astronomy in the Jacobean period did not lead directly to improvements in navigation. This was due to the emphasis on academic astronomy, rather than practical, the devolution of the navigational profession, and the lack of academic interest in maritime issues. However, increasing accuracy in academic astronomy ultimately led to greater accuracy in observations and calculation in navigation in the coming decades (Waters

1958:297). For example, the telescope was originally developed for warfare, but came to be used for astronomy and navigation as well (Waters 1958:298). Refracting telescopes were first marketed in October 1608. By February 1610, telescopes were being made in London (Waters 1958:299). The widespread availability of telescopes made astronomical observation possible, confirming the then recent observations of Galileo, Kemper, Copernicus, and others that the Sun was at the center of the solar system. The rapid integration of this knowledge improved astronomical observations taken for navigation.

The development of logarithms, discoveries of new lands, and increased success in establishing colonies encouraged the application of mathematics and science to maritime questions. For example, Thomas Addison, a navigator with the East India Company, published the first solution of navigational problems using logarithmic tables in *Arithmetical Navigation* (1625). This is also the first English navigational manual exclusively on arithmetical navigation (Waters 1958:447). By 1642, seamen of all nations had the widest collection of precision instruments, as well as knowledge of math and science, in general use (Waters 1958:319).

During the 16th and 17th centuries, navigators and scholars developed an antagonistic relationship. In 1624, Sir William Monsor states in his text *Naval Tracts*, “It is a question whether a man shall attain to better knowledge by experience or by learning? ...The scholar accounts the other no better than a brute beast, that has no learning but bare experience to maintain the art he proposes. The mariner accounts the scholar but verbal, and that he is more able to speak than act" (Taylor 1954:4). This rivalry seriously delayed the advancement of navigation as a science. Academics had little idea as to the challenges and problems of mariners while mariners found academics aloof, uncaring, and unlearned in the arts needed for navigation. The lack of navigational skill, due to a combination of inadequate training, mistakes in reference tables, poorly made instruments, and superstition that ultimately led to losses of vessels and lives (Lamb 1995 [III]:48).

Both academics and mariners realized that there needed to be some interaction between the practical and theoretical aspects of navigation. For example, in a letter to the secretary of Christ's Hospital, Sir Isaac Newton (an academic) wrote, "I will add, that if instead of sending the Observations of Seamen to able Mathematicians at Land, the Land would send able Mathematicians to Sea, it would signify much more to the improvement of Navigation and safety of Men's lives and estates on that element" (Taylor 1954:119). By the beginning of the 18th century, these two rivals had begun to overcome their differences, largely due to the increasing emphasis on education among navigators and practicality among academics.

Cartography and Hydrography in Navigational History

Cartography, hydrography, and navigation became integrated during the first voyages of exploration in the 14th century. Italian and Catalan pilots taught the Portuguese how to make charts of the land-sea relationships they observed. By 1509, the Portuguese had charts of the Arabian Sea and Indian Ocean. The Portuguese pilots served Spain, teaching the Spanish the arts of pilotage, navigation, and hydrography. The Portuguese kept their chartings of the coast south of the Congo secret from 1504 until King Philip II of Spain usurped the throne in 1580, when the secrets of Portugal passed into Spanish possession (Waters 1958:62). Two years later, Spain conquered the Azores, thereby gaining a vital revictualing port.

In England, open war with Spain in the late 1580s served as the impetus to develop accurate position-finding techniques at sea. Northern exploration had focused attention on problems with the compass and chart projections in polar latitudes. Voyages of reprisal and naval operations in the Azores and Spain led to the development of the Mercator's projection map (Waters 1958:121). Also, during the war, England took as a prize the *San Felipe* (1587) and another Iberian vessel in 1592, gaining valuable charts and sailing directions to the Indies (Waters 1958:122-123) and thereby breaking the Portuguese/Spanish monopoly on hydrographic information about these areas.

By 1549, the study of classical geographers such as Mela, Pliny, Strabo, and Ptolemy had been included as a branch of mathematics in English universities (Waters 1958:95). The increasing availability of geographic literature, combined with improved mathematic training, led directly to enhancements in navigation by simplifying cartographic difficulties. William

Barlow, an archdeacon of the Anglican Church, improved the seaman's compass, making it more accurate. Edward Wright, a university scholar, solved the greatest cartographical problem of his age by developing a method to plot the earth's curved surface on a flat plane in such a manner that the course and distance of a voyage could be accurately plotted on a map (Waters 1958:98). In the 1580s, the protractor was invented, partially to make the old "rhumb and compass" method of chart correction easier (Waters 1958:64). These changes, and many more, decreased navigator error and simplified the complex computations that had been necessary until this time.

The 1590s to early 1600s saw significant improvements in plotting boards, protractors, trigonometrical tables, and the mariner's compass. These changes made finding and plotting course errors easier. The introduction of the log and line in this decade made it easier to measure distance (Waters 1958:122). In the 1620s, three types of slide rule were invented in England, primarily to facilitate nautical calculations. It was made in three forms: straight, circular, and spiral (Waters 1958:479). The slide rule became the tool of choice for gunners, surveyors, navigators, and others who needed to quickly and accurately perform a variety of mathematical computations.

Challenges regarding Spain's master chart (*Padrón Real*) continued to haunt the Casa into the 17th century. The *Padrón Real* consisted of a large wall map and a book of charts of "considerable size" covering specific routes. Pilots were compelled by law to submit charts to the Casa for review before sailing.

These charts were compared to the Padrón Real and only charts in accordance with the master chart were returned to the navigators. It was well known that pilots would throw these approved charts overboard at the first chance and sail with an older chart, if they could get it. After returning from a voyage, pilots were supposed to submit their data to the Casa so the Pilot Major could update the master chart. Alonso de Chaves states that the *Padrón Real* remained uncorrected because pilots did not, or could not, give the proper data to the cosmographers, due to several factors. First, the Casa became heavily politicized and data conflicting with the perception of those in control was not welcome. Also, pilots were not trained to collect the data, so there was to way to rationalize two conflicting charts. In the end, the *Padrón Real* remained hopelessly out of date. A contemporary text, the *Coloquio*, tells of three pilots asked to give their data who "made their points on the chart, one showing 100 leagues, the other giving 45, and the other appearing to have sailed over land" (Lamb 1995 [III]:51, 53, 57).

The Longitude Problem

By the early 15th century, the globe was divided into latitudes and these were charted on some maps (Waters 1958:43). Historically, it is not clear when finding latitude at sea was first accomplished. Although it was difficult to teach sailors the complex sciences using astronomy and the calendar, by the 15th century this was considered desirable (Diffie and Winius 1977:133). As long as latitude could be checked, differences between computed and actual measurements were considered a result of currents, winds, leeway, and compass errors. Because the length of a degree of latitude was counted the same, regardless of longitude, the problem became exacerbated on east-west voyages. The length of a degree of latitude never changes; however, the length of a degree of longitude does because meridians are not parallel (Waters 1958:65-66). This meant that navigators were often “short” in their reckoning; however, this was preferred, rather than making landfall unexpectedly (Waters 1958:66).

Until navigators began using astronomy, the length of a longitudinal degree did not really interfere with their calculations or charting. However, at the close of the 15th century, navigators began relating linear distance to angular distance on the earth’s surface. Portuguese and Spanish navigators estimated 70 miles (each of 5,000 feet) to a degree of latitude or 17.5 leagues. The English, when they eventually used degrees, counted 60 miles of 5,000 feet to a degree of latitude (Waters 1958:64). These measurements are between 66%-86% of the true measurement of a degree. These differences in measuring a degree led to violent skewing of landmasses in relation to their actual locations; however, no one could determine what was the correct measurement for standardizing the maps. While the variations in maps led to the losses of hundreds of ships and thousands of lives, the conflicting claims of bearing, distance, latitude, and longitude remained unresolved until celestial navigation improved in later centuries (Waters 1958:70).

The voyages of Columbus, de Gama, Drake and others highlighted the problem of longitude. It was vital to locate the vessel on the earth accurately and to correctly map explorations to enable return voyages to newly found lands and support new colonies (Waters 1958:39). Meridians of longitude were sometimes drawn on maps, but were usually based on conjecture (Waters 1958:43). Gemma Frisius' *De principiis astronomiae et cosmographiae* (1530) discussed the longitude problem, which was understood to relate directly to the accuracy of timepieces. The position of the vessel along a longitudinal meridian could be computed using information on time: the time at the vessel's position versus the time at the point of origin (Maddison 1969:41). At noon, the sun is directly overhead. At any point east of this, the time would be later than noon and any point west of this would be earlier. The earth rotates 360 degrees in 24 hours, so each hour it rotates 15 degrees. Using these figures, the exact position of a vessel can be calculated using an accurate timepiece and comparing the time onboard to the time at a longitudinal point of origin, for example the Meridian at Greenwich, England. So, if the time in Greenwich was noon and the time on the vessel was two hours later (2:00pm), the vessel was 30 degrees west of the point of origin (2 hours multiplied by 15 degrees = 30 degrees). Since it was clear that the longitude problem was directly related to timekeeping, clockmakers in particular felt pressure from navigators to produce a reliable marine chronometer in this period (Maddison 1969:56).

Explorers used a variety of methods, including solar eclipses and observing the conjunction of a moon and planet, to establish more accurate longitude lines, but to little or no avail (Waters 1958:58). Agreements such as Pope Alexander VI's bull, *Inter Caetera* (1493), which divided the New World between Spain and Portugal, and the Treaty of Tordesillas, the following year, exacerbated the longitude question. With the stroke of a pen, exploitation of the wealth of the New World became a matter of longitude. Spain and Portugal agreed to a line "370 leagues west of Cape Verde in Africa," a boundary which could not be accurately determined. While the wording of the treaty is not particularly clear, it appears to imply ownership "toward the south and east" of the latitudes of Lisbon and Madrid (Waters 1958:81, 119). It would be the early 18th century before a reliable timekeeper would be designed for the sea.

CHAPTER III

LITERATURE REVIEW

Before the 1560s, most information about navigating a vessel was transmitted orally from one navigator or pilot to an apprentice. After years of study, an apprentice could become licensed and, ultimately, his received wisdom along with his experience would be passed on to his apprentice. Around 1560, this wisdom and experience was first collected into navigational literature. The first navigation texts were produced in Spain and Portugal, but many of these works were in limited circulation due to national security concerns. Navigational texts were state secrets and divulging navigational information to other nations was treason. Economic and political rivalry between the sea-going nations of Europe led to constant wars, further limiting the exchange of information later in the 1500s. Many of the first works published about navigation in England were brought from Spain by Sebastian Cabot during his defection or acquired during privateering expeditions. The usefulness of the texts was also limited due to their academic, rather than practical, nature. Many of the Spanish and Portuguese works focused on cosmography and elaborate mathematical treatises, rather than the practical needs of seamen, thus reflecting distinctions in the period between scholars and navigators. The science of navigation was greatly hindered by the inability of scholars and navigators to work together to solve challenges. After translation and alteration, including shortening, clarifying, adding drawings, etc., many of these early Spanish and Portuguese works later became popular in England.

This chapter focuses specifically on the history of English literature developed to deal with navigational issues. Literature from Portugal and Spain are included where translations into English altered the development of the genre. This technique was used in this chapter to develop a practical method of dealing with the extensive amount to literature developed in all three countries between the mid-15th to mid-17th centuries. To further assist the reader, where possible, the translation(s) and publication details of the original texts have been included. For clarity, the abbreviated title of the works cited has been utilized in the text. It should be noted that the period draws little distinction between commanders, captains, pilots, navigators, and mariner's of other specializations. These texts were published for the edification of those interested in the problems involved in maritime activities, regardless of their official ranks and/or titles. The practical utility of a certain text cannot be determined given the present state of scholarship. However, demand for a certain title leading to continued re-publication of the text gives us some indication of the perception of the book by those interested in the topic. Clearly, printers would only reprint a book when there was public demand and a profit could be attained.

The 1560s saw the first national English literature on navigation, rather than translations of foreign texts. While seamen may not have used these books at the time, the marked increase in the rate and number of publications indicates that the public desired books on practical topics such as navigation and astronomy (Waters 1958:167). The 1570s and 1580s saw several important new works, as well as republications of popular earlier works. After 1590, England launched a "flood of publications on subjects mathematical, astronomical, and purely navigational" and the first public lectures on navigation were given at Gresham College (Waters 1958:176). Thomas Hood is widely credited with giving the first lecture on using mathematics in navigation on November 4, 1588 (Waters 1958:185). Publications in the mid- to late-17th century focused on refining the navigators' techniques and introducing ideas of magnetic variation that made course corrections so difficult.

Almanacs

English shipmasters mainly traveled between local ports, using a collection of detailed sailing directions, called a rutter. After 1503, masters could also use an English almanac, with a calendar of lunar phases, dark nights, and weather forecasts. The first almanac published in England was a translation of the French work, *The Kalendayr of shyppars* (1503). The anonymous Portuguese *Regimento do estrolabio e do quadrante* (1509) and Sacrobosco's *De Sphaera Mundi* were the first printed nautical almanacs and first printed manuals of navigation (Waters 1958:52-53). Until the Act of 1541 repealed the laws against sorcery, the English almanacs rarely contained prognostications, like other European almanacs, and generally confined their educated guessing to weather and disease possibilities (Waters 1958:16-17). Almanacs appear to be widely used in the period, but due to constant use, poor paper quality, damage due to exposure to sea winds, and other factors, few survive into the present in historical collections.

Brief Journals, Traverse Books, and Logbooks

In the mid-16th century, navigators began to keep three record books, such as a brief journal, traverse book, and logbook. While these books were for personal use at the time of the voyage, many of these were kept for reference purposes by later navigators and the more useful texts were later published. Additional study is needed to discover the prevalence of navigators keeping all three books, or only one or two. In practice, the three books tend to work together, but were not always kept permanently. The brief journal kept a basic list of each day's sailing, with reflections and observations on navigational and shipboard matters. The journal had been kept from the days of Sir Hugh Willoughby in the 1550s. The lieutenant, merchant, purser, pilots, and master's mates all kept journals, meeting periodically to compare notes. The traverse book was a more systematic, detailed record of the courses sailed and the natural phenomena, course made good, distance run, and observations of latitude. The final development was the logbook, which had a longitude column. The traverse book only kept course from day-to-day, whereas the logbook kept a mathematical point-to-point record to be used on paradoxal or Mercator's charts

(Waters 1958:282-283). Logbooks also kept wind, allowances for leeway, variation and dip observed, soundings made, and landfalls (Waters 1958:283-284, 287). Based on their logs, we know that Hudson, Baffin, and other Jacobean navigators were taking sights to within 5-10 minutes of accuracy. This was possible due to increasingly accurate ephemeredes, as well as corrections applied for parallax, height of eye, refraction, the sun's semi-diameter, and instrumental improvements (Waters 1958:300-301). Brief journals, traverse books, and logbooks are not found on shipwrecks, since being submerged destroys them. Examples from this period survive in a variety of libraries, museums, and archives across Europe.

Navigation Teaching Texts

The reign of Elizabeth I (1558-1603) saw the first English translations of navigational treatises written in other European languages (Leary 1926:4). For example, in 1561, Richard Eden translated Martin Cortes' 1551 treatise *Arte de Navigar* from Spanish into English (Leary 1926:50; Waters 1958:104). While this text could have been used to train navigators, it was long and difficult to read in translation (Taylor 1954:33). Martin Cortes's *Arte de navigar* (1551) was not the first manual of navigation published in Spain, but it was widely considered the best for fullness and clarity of exposition in its original Spanish (Waters 1958:62-63).

This period also saw the genesis of English navigational literature. In 1567, William Bourne published the first English manual on navigation, titled *An Almanack and Prognostication for iii years, with serten Rules of Navigation* (Waters 1958:127). His subsequent publication in 1573, *Regiment for the Sea*, contains the first mention of the log line. While based on Eden's translation of Cortes' *Arte de Navigar* (1551), the text is in a more readable style (Leary 1926:52; Taylor 1954:33). Four years later, Dr. Dee published the *Art of Navigation* (Leary 1926:87). In 1594, Thomas Blundeville published the massive, 350-page tome, titled *Exercises*, consisting of a series of treatises on the mathematical, astronomical, and navigational knowledge necessary to master navigation. The text was so popular it was republished in 1597, 1606, 1613, and 1638 (Leary 1926:96; Waters 1958:213). John Davis published *The Seamans Secrets* (1594), giving information on navigation and gunnery (Leary 1926:97). *The Seamans Secrets* provides the clearest description of the three types of sailing: plane, paradoxal/rhumb line, and great circle (Waters 1958:201-202). Edward Wright published *Certaine Errors in Navigation* (1599). This text served as a summary of all the contemporary practices of navigation in the period with critical examination of problems current in navigation. Wright enumerates the prevalent errors in navigation, as well as the ways to eliminate these in practice (Waters 1958:220). *The Pathway to Perfect Sayling* (1605, reprinted in 1613, 1644), discussed card, compass, tide, time, wind, and way. Its author, Richard Polter, a Trinity House official and expert navigator, understood each of these variables to correct sailing from personal experience (Waters 1958:307).

Astronomy and Mathematics Texts

By the late 1500s, writers were well aware of the need for astronomical and mathematical training textbooks for navigators. The increase in the number and type of instruments designed to utilize one or both of these fields had made it necessary for navigators to learn as much about astronomy and mathematics as they could. Charles Turnbull developed his text, *A Perfect and easie treatise of the use of the coelestiall globe…which be exercised in the art of navigation* (1585), to provide a pocket manual for any seamen wishing to know astronomy. Another text by Thomas Blundeville, *The Theoriques of the seven planets, shewing all their diurse motions…A booke most necessary for all…pilots and seamen* (1602), was also widely read.

Books on mathematics and navigation began to appear in the mid-16th century. In 1542, Dr. Robert Recorde published the first printed English work on mathematics, *The Ground of Arts*. He later also wrote *The Castle of Knowledge* (1556) for the Muscovy Company navigators and *The Whetstone of Witte* (1557), another elementary mathematical textbook (Waters 1958:94-95). Texts to teach mathematics continued to be printed into the 17th century. While there were many texts written, the work by Robert Tanner, *A Brief treatise of the use of the globe celestial and terrestriall: wherein is set downe the principles of the* *mathematicks, for all…navigators* (1616) in 8 volumes provided excellent training to navigators and was reprinted in 1620. Advances in cartography made rules of proportions and circles particularly necessary. The text by Edmund Wingate, *The Use of the rule of proportion: in arithmetique and geometrie: first published in Paris in the French tongue...* (1645, reprinted in 1658) and Henry Phillippes, *Advancement of the art of navigation…first, shewing by new canon of sines, tangents, and secants…* (1657, reprinted in 1685) both helped teach navigators how to use mathematics in sailing. In Spain, Pedro Porter y Casanate (1608-1662) wrote *Reparo a los errors de la navegación Española* (1634), showing a proficiency in spherical trigonometry and this text led to the introduction in Spain of the English log, invented 50 years before by William Bourne (Goodman 1997:234).

Geography and Hydrography Texts

Generally, there was no popular demand in England for geography works on the Orient or the New World, although a few scholars had advanced the idea of studying geography in the 1530s (Waters 1958:79). In conjunction with the voyage of the Merchant Adventurers, Richard Eden published an English translation of *A treatyse of the newe India, with other new founde landes…* in June 1553. This was the first English book to discuss at any length the areas of recent exploration. Two years later, Richard Eden also published *The Decades of the newe worlde or west India…Wrytten in the Latine tounge by Peter Martyr* *of Angleria and translated into Englysshe by Rycharde Eden*. This was the first narrative collection of voyages to be published in English and served as a major source book on geographical and navigational knowledge for the next 25 years (Waters 1958:86-87).

The authoritative works of Richard Hakluyt were published at this time, including *Divers Voyages Touching the Discovery of America* (1582) and *The Principal Navigations, Voyages, and Discoveries of the English Nation* (1589)(Leary 1926:85, 91). Works such as *Certaine Errors in Navigation Detected and Corrected* by Edward Wright sought to explain and render accurately Mercator's chart projection (Leary 1926:4). This text was the "most influential and oft-quoted treatise on nautical practice of the era" (Taylor 1954:44).

Richard Hakluyt published the contents of two Spanish rutters in the 1600 edition of *Principal Navigations*, making their knowledge common to most English seamen. These rutters revealed the closely held secrets of the winds, courses, and landmarks needed to sail to and within the New World. These rutters were so accurate and detailed that they were still in use two hundred years later. In 1805, when Admiral Nelson chased Villeneuve to the West Indies, he used Hakluyt's directions, confident that Villeneuve could have used no other course at that time of year (Waters 1958:262).

Dictionaries and Word Books

The need for basic teaching texts, including dictionaries and word books, became vital in the 16th and early 17th centuries, primarily due to the devolution of the navigation profession in England, as discussed in Chapter II. Both Portugal and Spain were active in writing the first textbooks to teach navigation in the early 16th century. The oldest Spanish nautical dictionary was written between 1520 and 1538 by Alonso de Chaves (*Capítulo que tacta de la nao e de sus partes y de los vocablos usitados en la navegación* in "*Quatri partitu encosmographia practica I por otro nombre llamado espeio de navegantes*") (Waters 1958:466 note 1). During the 16th century, the Spanish developed four influential nautical dictionaries. The earliest was Juan de Moya's *Arte de Marear* (1564). In 1585, Andres de Poza's published *Hydrographía*, including a chapter titled, "*Declinatión de algunos vocablos marítimos*," which was very helpful to mariners. Diego García de Palacio's *Instruction nauthica para navegar* (1587) included a chapter titled "*Vocabulario de los nombres que usa la gente de mar en todo lo que pertenesce à su arte*." Finally, about 1600, Eugenio de Salazar's produced a text titled *Navegación de el Alma por el discurso de todas las edades de el hombre*, including a chapter titled, "Vocabulario." Two additional Spanish nautical dictionaries appear in the early years of the 1600s. Thomé Cano's work titled *Arte para fabricar, fortificar, y apareiar naos de guerra y merchante* (1611) included a section titled, "Declaración de los vocablos que se usan en la fabrica de baxeles." In 1614, he published a further work titled

Derotero de mar mediterráneo, which included a section titled “Vocabulario de los nombres que usa la gente de mar en todo lo que perteneze a su arte por el horden alfabético” (Waters 1958:466-467).

In the 17th century, difficulties with untrained captains under James I soon became a serious problem, as discussed in Chapter II. Officers did not know the names of parts of the ship or what orders to use in relationship to them. In naval battles, commanders’ orders were ignored when seamen felt that the order was illogical or impossible to execute. Problems such as these had led to several English naval disasters and the deaths of hundreds of seamen from malnutrition, exposure, disease, and “the pride of their higher commanders.” This need for vocabulary dictionaries developed into a new form of navigational literature in England, later referred to as “Sailors’ Word Books” (Waters 1958:462-463). Sir Henry Mainwaring wrote a text titled, *Seamans Dictionary*, between 1620 and 1623, to help those commanding vessels with the terms, names, and words, the parts, qualities, and manner of doing things with ships. The text was widely copied, studied and carried at sea by naval commanders of the time (Waters 1958:465). Captain John Smith published, *An Accidence for Young Seamen: or, Their Path-way to Experience*, in 1626, and again in 1627 under the title, *A Sea Grammar*. This vital text listed the phrases, offices, and words of command for the building, rigging, and sailing of a man of war, managing a fight at sea, as well as the names, weights, charge, shot, and powder of ordinance (Waters 1958:462). These books went some way to helping commanders communicate with their crews.

Navigational Instrument Literature

A variety of teaching texts were developed to teach sailors how to use their instruments, specifically the astrolabe, cross staff, quadrant, log line, and globes. Many of these authors were concerned that navigators would be able to use their new instruments correctly. Many of these texts served as advertisements for newly designed, or redesigned instruments. A selection of instrument texts were chosen based on two factors: 1) the number of reprints and 2) the acclaim of the texts by contemporary experts. Many other texts were also available, but are not listed herein due to space limitations.

In the 16th century, a predominant proportion of the instrument texts focus on magnetism and improving the compass. These texts can be divided into those which assisted in making and using compasses, and those which tried to improve the directional power of the compass. Texts on the manufacture of the compass included Martin Cortes' *Arte de Navegar* (1551), which included a description of the dry compass. When Richard Eden translated the text in 1561, the explanation was finally available in English. Both Anthony Ashley's *The Mariner's Mirrour* (1588) and William Barlow's *The Navigator's Supply* (1597) included illustrations of compasses and needle design variations (Waters 1958:26-27).

By the 17th century, these texts had encouraged widespread discussion among mariners, academics, and instrument makers about optimal compass design and manufacture. Should the needle be long or short, thin or fat, blunt or sharp, brass or bronze or iron or steel? Should the container be round or square, wet or dry, all wood or wood with some metal components (hinges, corner mounts, etc.)? Should the compass rose show all 32 points, or just the main 8 directions, or perhaps even 64 points? Should the compass dangle above the deck or be nailed into a binnacle? How often should the compass needle be refreshed with a magnetizing lodestone (daily, weekly, bi-monthly, monthly, etc.)? Under what conditions and in which parts of the world did the compass reading skew and where was it true and how could a mariner tell the difference? These and other questions dominate the literature of the 17th century and their proposed answers formed the instrument making trends of the period. Further discussion is included in Chapter IV.

Several authors, some of whom were also scientists, worked to improve the power of the compass and understand magnetism. William Barlow's work, *Magneticall Aduertisements* (1609, reprinted in 1616) revealed a way to increase the directional power of the compass needle. It also recommended using a steel needle rather than an iron one. These modifications significantly increased the accuracy of the compass (Waters 1958:336-338). William Borough published his studies on magnetism in *Discourse of the magnet, Discourse of the variation of the compass* (1581), which was later republished in Robert Norman's text *The*

Newe Attractive (1581, 1585). These treatises contained the first analysis of Earth's magnetic variation, which caused compass error. Robert Norman's text explained how to use a dip compass, as well as a chart of the daily declination of the sun (Leary 1926:87; Taylor 1954:44).

Specialized instrument texts were also created to assist navigators in using the astrolabe, cross staff, log line, quadrant, and other instruments. For example, John Blagrave published *The Mathematical Jewel* (1585), describing fully how to make and use a planispheric astrolabe (Waters 1958:165), as well as publishing a text on using the cross staff titled, *Baculum familliaire, catholicon sive general. A booke of the making and use of the staffe…called the familiar staff* (1590). In 1578, William Bourne's *Inventions and Devices* and Hallowe's translation of Guevara's *Arte de Merear* were published (Leary 1926:87) taught sailors how to use the log line correctly.

Several authors discussed multiple navigational instruments in their texts. William Barlow published *The Navigators Supply* (1597), discussing the compass, the variation of the compass, the Traveller's Jewel, the pantometer, the hemisphere, and the traverse board (Waters 1958:216-217). Edmund Gunter published the *De sectore & radio. The description and use of the sector in three bookes. The description and use of the cross-staffe in another three books* (1623, 1624, 1630, 1636), which contained a description of a nocturnal timekeeping device using all the constellations near the North Pole, not just Ursa Major and Ursa Minor (Waters 1958:365). Edmund Gunter's works were so popular in the period that they were compiled into a 4 volume set, *The Works of Edmund Gunter: containing the destription and use of his sector, cross-staff, bow, quadrant and other instruments…with the use thereof in arithmetick, geometry, astronomy, navigation and dialling* in 1662. The complete set was republished in 1673 and 1680, long after Gunter's death.

Popular Reprints

A variety of treatises popular with navigators were reprinted from 1640 to1700. Many of them continued to be reprinted multiple times and occasionally edited long after the author's demise. The most common texts include the previously discussed texts: *Perpetuall Prognostication* (Digges), *Seamans Kalendar* (Tapp), *Tractatus de Globis* (Hues), *Safeguard of Sailors* (Norman), *Arte of Navigation* (Cortes), *Exercises* (Blundeville), and others (Waters 1958:319). Other important reprints include the second edition of Edward Wright's *Certaine Errors* (1610), which included a table of magnetic inclination with an illustration of a dip ring or "inclinometer". The text also included a translation of the Spanish navigation manual by Licenciado Rodrigo Zamorano, *Compendio del Arte de Navegar*. Written in 1588, this was the third Spanish navigation manual translated into English (Waters 1958:316-317). In 1630, John Tapp reprinted the English translation of Cortes's *Art of Navigation* and Handson's *Trigonometrie*, with its nautical appendix. In 1631, the last edition of Bourne's *Regiment* appeared (Waters 1958:477).

Secondary Sources

Secondary literature on the science of navigation during the Age of Exploration has remained scarce into the twentieth century. Advancements in instrumentation from the 18th century, which led to increased precision, have eclipsed the production and use of instruments in earlier times. Modern authors writing about navigation in the Age of Exploration focus predominately on historical issues, such as trade, war, statesmanship, colonization, piracy, and other subjects of interest to events on land, rather than on maritime issues. The lack of published, available site reports on shipwrecks and/or artifacts means that archaeology has been slow to fill in the details of the evolution of navigational science. Most modern navigation books hesitate to discuss the history of the field, leaving the evolution of navigation to the writers of scientific history. Modern navigation books will not be discussed here, as the evolution of the field in the intervening centuries makes them inapplicable to historical, pre-scientific navigation. Since navigational instruments form only a small percentage of the artifacts in museums or private collections, little literature on their evolution is available and then only from the perspective of collectors.

In spite of the variety of navigation instruments in the period, only a few texts focusing on instruments have been written, usually by historians. For example, Stimson and Daniel (1977) and Mörzer Bruyns (1994) wrote texts focusing on the history and evolution of the cross staff. The astrolabe has also attracted attention, with three inventories or catalogs written by Grenier (1976

[1932]), Stimson (1988), and Linton (1992). General works, such as Maya Hambly's 1988 work on drawing instruments, were utilized in this text to analyze dividers. Due to lack of source material, analyses of museum collections have been utilized in this thesis for historical and scientific information. Examples of museum collection information that have been utilized to develop this thesis include texts by Bensaude (1921), Taylor and Richey (1962), Cotter (1968), Daumas (1972), Bennett (1987), Turner (1987), and Bud and Warner (1998).

General historical works on the navigation in the period provided valuable context for the instruments and their use. Taylor (1954; 1957), Waters (1949; 1955; 1958; 1974; 1978), and G. L'E. Turner (1980; 1998; 2000) have written extensively about English navigation in this period from a historical viewpoint. Their information on the development of navigation, science, mathematics, cartography, and precision instruments was invaluable to writing this thesis. Historians of particular periods gave analysis of maritime matters in England (Innes 1932; Quinn and Ryan 1983; Coward 2003), Spain (Bertrand and Petrie 1952; Atkinson 1960; Goodman 1997; Peréz-Mallaína 1998; Carr 2000), and Portugal (Atkinson 1960; Diffie and Winius 1977). A bibliography compiled by Adams and Waters (1995) contained a section on the invention, innovation, and use of navigational instruments in England that was helpful in gaining an understanding of the literature of the period.

Archaeological information on the sites under discussion in Chapter V derived from encyclopedias and various on-line resources. The most comprehensive and helpful encyclopedia source utilized was Delgado's *Encyclopedia of Underwater and Maritime Archaeology* (1998). The historical material was useful; however, the encyclopedia has become somewhat dated. Also recommended are online resources, such as Houghton Mifflin's, *Ships of the World: An Historical Encyclopedia* (2005). The most recent material on artifacts and sites was available on the Internet. The Western Australia Maritime Museum and the Texas A & M University Ship Lab (Brigadier and Randolph 2002) provided the best-documented artifact and site information available on their respective sites. Treasure diver sites commonly publish only the most sensational and/or valuable finds and were rarely useful; however, sites such as Mel Fisher's Maritime Heritage Society and Museum's database (Motivation, Inc. 2004) gave the names and a few photos of artifacts, although no site data. Finally, databases compiled and edited by enthusiasts, such as the VOC Shipwrecks' on-line databases had minimum information on selected finds from sites excavated by treasure hunters.

CHAPTER IV

INSTRUMENT ANALYSIS

Throughout the 17th century, navigation increasingly relied on a number of specialized instruments specifically designed for use at sea. Before the 17th century, most navigational instruments were designed to be used on land and were not practical for maritime use. Over time, heavier, more practical designs were created for navigational instruments. These new designs could be reproduced economically and in quantity (Maddison 1969:4). The variety of instrument designs was a result of efforts to secure easier handling, simpler computing, finer reading, or a combination of all three (Taylor 1954:28). In short, the easier or simpler the instrument was to use accurately, the more common it appears to be in the archaeological record. In contrast, those instruments that were heavier, more awkward, or difficult to use accurately decline in use and, as a result, appear less frequently in the archaeological record.

The instruments have been divided into four categories based on purpose in this chapter. The first category contains instruments used to establish the vessel's position at sea using astronomical bodies. These positional instruments include cross staffs, back staffs (including quadrants), and astrolabes. The second category includes direction, depth, and speed instruments. This grouping includes compasses and binnacles, sounding weights, and log lines. The third category, course and timekeeping instruments, contains instruments to assist in the maintenance of a vessel's course and record keeping, such as traverse boards, nocturnes, and sandglasses. The final category, drafting instruments, contains instruments used to record the course on charts. The most prevalent, dividers, or "compasses" as they were called in the period, is discussed in this section. Of all the instruments found on shipwrecks, dividers are both the most common and the least archaeologically appreciated of the navigational toolkit.

Positional Instruments

Observing the sun, moon, and stars had been used for centuries to guide ships and keep time on both land and sea (Diffie and Winius 1977:125). In the early 15th century, the Portuguese discovered that the altitude of the sun at midday or the Pole Star at night could be converted, using simple mathematics, into a degree of latitude on earth. The latitude on earth equals the angular distance between the equator (0°) and the North Pole (90°). In 1415, astronomers advised the pilots sent out by Prince Henry the Navigator on how to use a quadrant (Turner 1980:30; Waters 1958:46-47). The altitude of the sun could also be taken with a sea astrolabe, a cross staff, or an octant (Turner 1980:30). The size of the instrument was important. The smaller the instrument, whether globe, astrolabe, or quadrant, the more approximate the reading obtained of the sun's true azimuth (Waters 1958:312). Sailors followed the premise that "latitude equals declination plus zenith distance" (Mörzer

Bruyns 1994:14). If, after the calculations, the vessel was found to be at the wrong latitude, the heading was adjusted to the north or south to correct the ship's course. Chapter II discusses the development of the mathematics and astronomy needed to calculate and estimate the course adjustment discussed here.

<u>The Cross Staff</u>

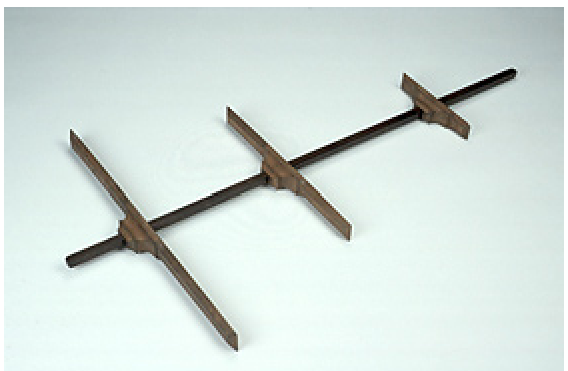

FIGURE 1. Cross staff replica. (Image 150591 ©Museum of the History of Science, Oxford. All Rights Reserved, Used with Permission.).

The cross staff (Figure 1), also called the fore-staff, Jacob's staff, *arbalestrille* (French) or *balestilna* (Spanish), was a popular device for making solar and celestial observations (Bud and Warner 1998:159). The cross staff was first described by Rabbi Levi ben Gerson in his *Sefer tekunah* (1328), which was translated, in part, from Hebrew to Latin by Peter of Alexandria in 1342. João of Lisboa in his text, *Livro de marinharia*, and André Pires, both writing before 1520, both mention the cross staff and the kamal, or the *tavoletas da Índia*, as it was called in Portuguese. The Portuguese pioneered the use of the cross staff at sea in the early 16th century. The Portuguese suggested that the cross staff be used to sight stars, as well as the sun (Diffie and Winius 1977:141-142; Maddison 1969:47, 50). John Dee introduced the cross staff to England in the 1550s (Turner 1980:33). In fact, English Captain John Davis claimed in his 1633 treatise on seafaring and navigation that he greatly preferred the cross-staff over the quadrant or the astrolabe (Seller 1633).

The instrument has a rectangular staff made of pear or boxwood about five to six feet long (1.5 to 1.8m). The staff was squared off lengthwise and graduated on one side in degrees and minutes. A perpendicular vane or crosspiece was placed over the staff and slid along the length of the staff to take measurements. The staff was graduated trigonometrically. Holding one end to the eye, the sliding vane was moved until the top end was on the center of the sighted star, such as the Pole Star or the Sun, and the bottom was even with the horizon (Turner 1980:33; Waters 1958:54). Originally the cross-staff carried only one vane; however, to shorten its length, some cross-staffs incorporated up to four vanes in graduating lengths. This allowed the staff to be shortened to approximately 2.5 feet (75cm). On English cross-staffs, the eye vane was called the 10° vane and the three longer vanes were called the 30°, 60°, and 90° vanes (Mörzer Bruyns 1994:28-30; Turner 1980:33).

The angle between the sun and the horizon could be measured in three ways using the cross-staff. The first technique, the "fore staff method," required placing the end of the central staff just under the eye for sighting. Then the navigator chose the correct vane, and slid it onto the staff. He then moved the vane until the top aligned with the middle of the sun (or star) and the bottom of the vane was even with the horizon. Upon completing the observation he lowered the cross-staff, carefully keeping the vane's position on the staff, and read the angle off the engraved scale. A few simple computations revealed the vessel's latitude.

Two other methods, commonly referred to as the "Dutch methods," required aligning the eye vane with the horizon and sighting from the vanes toward the eye vane. In one method, the bottom of the long vane was leveled to coincide with the fixed vane on the eyepiece end of the staff. The navigator then aligned the sliding vane so that the shadow at the top of the vane fell on the fixed eye vane. The other method involved sighting across the base of the fixed long vane toward the horizon and moving a sliding, smaller eye vane. As before, the shadow of the upper end of the long vane was aligned to coincide with the sliding eye vane. Both methods required additional computations, but were preferred to the fore staff method because they did not require the navigator to look directly into the sun and commonly provided more accurate readings (Stimson and Daniel 1977:6-7).

The cross staff suffered from several challenges which affected the accuracy of the readings. First, due to its length, it was difficult to hold steady during measurements, especially on the deck of a moving ship. However, this improved when the staff was shortened. Second, the observer had to position the cross staff exactly the same for each reading. The observer had to hold the staff so that the center of the staff sat on the cheekbone corresponding to the exact center of the eye. Some navigators pressed the cross staff to the cheek bone, others to the bridge of the nose or extremity of the eye socket, depending on the individual's facial construction. A reading that was off due to not holding it precisely was referred to as "parallax." Thomas Harriot (1560-1621), an English mathematician and friend of Sir Walter Raleigh, eventually showed how to correct parallax error (Maddison 1969:51). Third, the cross staff had to be held in place for several minutes to catch the highest point of the sun's meridian passage, which required the navigator to stare directly into the sun for some time. Many navigators lost their sight due to this problem. Fourth, it was difficult to accurately place the top of the crosspiece on the central diameter of the sun or star simultaneously with aligning the bottom of the crosspiece with the horizon. Finally, the cross staff could no be used if the sun or star was below 20˚ or above 60˚ altitude. This meant that the cross staff was useless between 20˚ north latitude and 20˚ south latitude any time of year due to the high altitude of the sun (Taylor 1954:43; Waters 1958:55).

The difficulties with using the cross staff led to a variety of modifications being rapidly developed. The cross staff with one sliding vane was described by Gemma Frisius around 1545 and both Bourne (1574) and Davis (1595) detail a cross staff with two movable vanes. A cross staff with three moveable vanes was described by Coignet (1584) and Blundeville (1594). These three-vane instruments remained in use into the 18th century (Waters 1958:297). Figure 1 is an example of this type of cross staff.

While taking the altitude of the pole star was relatively simple, trying to sight the sun at noon often proved difficult, and even painful. William Bourne advised using an astrolabe for taking observations of the sun rather than the cross-staff, as the pin-holes forming the site of the astrolabe protected the eye to some degree, "...for that the Sunne hurteth the eyes of a man...". If the navigator was faced with using the cross-staff for solar observations, he recommended either using smoked glass for protection, or aligning the upper end of the cross vane with the top of the sun, thereby blocking out much of the glare. As the sun’s apparent diameter from earth measures 30 minutes, the observer then simply deducted 15 minutes from the reading, equivalent to half the sun's apparent breadth (Bourne 1574:208-209).

A variety of methods to avoid eyestrain were developed in the 17th century. These included modification of the cross staff so that it could be sighted with the sun behind the observer. This instrument, and its many variations, came to collectively be called the back staff or quadrant, and will be discussed in more detail in the next section. In later periods, the cross staff came to be called the "fore staff" to set it apart from these back staff-type instruments (Turner 1980:33).

The addition of brass aperture disks to the end of the cross-staff vanes appears to be an invention of the 1650s (see Chapter VI, Figure on page 153). Pietersz, a Dutchman, was the first to describe the device in 1659 in his text, *Stuerman's Schoole* (Mörzer Bruyns 1994:41). It is believed that the disks were first used by the Dutch and eventually came to be known as "Dutch shoes," due to the similarity between putting a shoe on a person and putting a disk on the cross-staff vane. When attached to the end of a cross-staff vane, the disks allowed a thin ray of sunlight to pass through, enough for the navigator to make his observation while also affording a level of protection from the sun's rays.

An aperture disk was made using a small, half-circle of brass as a base. Two pieces were attached to the ends of the circular piece, then wrapped partly around to form the winged pieces that would hold the disk onto the end of the vane. Brass aperture disks could be attached to the bottom or top of the vane, depending on the user's preferences. A red or blue piece of glass could be added to further shield the user's eyes (Mörzer Bruyns 1994:40).

The aperture allowed an observer to look directly into the sun to take the reading or the observer could turn, so the sun was at his back and use the cross staff as a type of back staff. After turning, the aperture disk was attached to original eye end of the staff. A vane would be placed on the staff. The sun would show through the aperture and the sliver of light would land on the vane. The vane would be moved back and forth until the light was on the very top. The reading could be taken from the place where the vane crossed the staff. Often the shortest transom was cut in such a way that it could be transformed into a horizon vane to take readings in this manner (Waters 1958:306).

The cross staff is unlikely to survive well in the archaeological record. Due to its largely organic construction of pear wood or boxwood, this instrument would decay quickly if exposed to seawater. In fact, reports in the period noted that, over time, the cross staff tended to warp. In some cases, the cross staff aperture sights have been recovered. If one or more aperture disks are recovered, the excavator should look for a small piece of red or blue glass, which was commonly sold with the disks and used to protect the eye from the sun. On land, several complete and partial examples of the cross staff survive in historical and museum collections. Mörzer Bruyns notes that several central staves from antique cross staffs were recovered after being re-utilized to fold blankets in the Netherlands in modern times (see Mörzer Bruyns 1994 for additional details).

The Back Staff

As previously mentioned, the back staff was an evolution of the cross staff (Figure 2). The back staff was called the "Davis quadrant" by English seamen and the "English quadrant" by continental seamen (Turner 1980:33).

Werner of Nuremberg first described the back staff in 1514 (Leary 1926:11). Invention of the back staff is widely credited to John Davis, who depicted two forms of back staff and one quadrant in his text *The Seamans Secrets* in 1594 (Leary 1926:98; Turner 1980:33). The form of the back staff altered considerably in its first four decades and some instruments called a "back staff" or "quadrant" are actually hybrid, experimental tools.

FIGURE 2. Backstaff, by Edmund Culpeper, London, c. 1710. (Image 153182 ©Museum of the History of Science, Oxford. All Rights Reserved, Used with Permission.).

The evolution of the back staff or quadrant hybrids provides insight into instrument development in the period. In 1595, Davis depicted three instruments in his text *The Seamans Secrets*: a 45˚ back staff, a 90˚ back staff, and a sea quadrant. Davis' 45˚ back staff had a single octant arc on one side and the central staff was 3 feet 14 inches (1.35m) long. Degrees and minutes were clearly engraved along the arc. Davis' 90˚ back staff had a chord of a circle at 60˚ on one side of the staff and a 30˚ arc on the other side of the staff. The sea quadrant was a square, wooden frame with a 90˚ arc connecting the two opposing corners, graduated with degrees and minutes along the arc. A string was attached to the central corner and held up to be aligned with the sun or star being sighted. The place where the string crossed the arc provided an angular measurement. The navigator used two sighting vanes along the edge to make the observation, and a simple plumb-bob suspended from the apex of the instrument indicated the latitude.

In 1604, Davis improved his back staff by breaking up the 90˚ arc into two arcs on either end of the instrument. A 30˚ arc was placed on one end and a 60˚ arc was attached at the opposite end. Small sliding vanes with pinholes moved along the arcs and aligned with the sun or star. To take a reading with this revised instrument, the staff was placed at the approximate altitude of the sun. The sight vane arc measured 30˚ with a scale divided into 2˚, 5˚, or 6˚ increments. The shadow vane arc was 60˚ and divided into 1˚ or 5˚ increments. Sliding a sight vane up and down the lower arc, until the shadow cast by the upper arc was seen to coincide with the horizon, gave the final reading. The reading of the two portions of arcs was added together. The casting of the shadow was smaller and being close to the horizon vane, it gave a high definition shadow of consistent length. Observations were also easier because the arc movement of the sighting vane resulted in the same angular distance regardless of the position of the vane on the scale (Turner 1980:33; Waters 1958:46).

In the early 17th century, a variety of back staffs were in use at sea. Their size was limited by ease of handling to 3 feet (0.9m). There has been some confusion regarding the name of this instrument. This is due to the fact that the arc of the back staff is actually one-eighth of a circle or 45˚ (an "octant"), yet it is calibrated for a quarter of a circle, or 90˚. Also, when taking a sighting, the octant is the portion of the arc actually utilized (Turner 1980:34). The back staff remained in use with few structural modifications for two centuries and was not displaced until the 1730s with the development of the reflecting quadrant or octant (Waters 1958:206). The development of the back staff eliminated the possibility of parallax and the handicap of glare in sun sights, as well as the difficulty of sighting the sun and the horizon simultaneously (Waters 1958:205).

Instrument makers tried to increase the scale size without increasing the overall size and/or weight of the instrument, leading quickly to development of the quadrant (Waters 1958:302). The earliest known representation of the quadrant intended for use by mariners occurs in the 1563 (posthumous) edition of Valentim Fernandes' *Reportório dos tempos* (1518), first published in Lisbon (Maddison 1969:26). The quadrant was likely one of the earliest altitude-measuring devices adapted for use at sea, consisting of a quarter of a circle (hence its name), usually in wood or brass, with a radius of one to three feet.

Early users of the quadrant etched markings on their instruments corresponding to the latitude of important coastal positions. The navigator would take an observation of the Pole Star with the Guards of the Little Bear, nearby stars, in east-west relation to the star. A few days later, the navigator would take a second reading and compare the two readings, converting the distance on the basis of one degree on the quadrant equaling 16 and 2/3rds leagues traveled. As mathematical training in navigation increased, later quadrants included degrees engraved on their arcs from 0˚ to 90˚ (Cotter 1968:58-59; Maddison 1969:27). Mariners preferred smaller instruments and often took their readings from shore where the lack of a moving vessel led to greater accuracy (Bion 1709:189; McConnell 1992:2).

The back staff later evolved into two other instruments: the octant and the sextant. John Hadley developed the far more accurate octant in 1731. The octant came into general use after 1750. The sextant was developed after 1767 and modified for use at sea after 1770. As both of these instruments were developed in the 18th century, they fall outside the time period of this discussion.

Several portions of the back staff could, conceivably, survive in the archaeological record. While much of the instrument was constructed of wood, the measuring grids on the angles were often made of metal attached to the wooden structure. In addition, the screw used to hold the reading, the eye sight, and various connector and decoration pieces could be recovered. Unfortunately, in most cases, the archaeological record contains items that might, or might not, belong to the back staff, limiting the identification of such instruments. Fortunately, a large number of examples of many types of back staff, quadrant, and other related instruments survive in historical and museum collections for reference.

Astrolabes

The term "astrolabe" means "star-taking". There were two major types used on land: the spherical and planispheric. There is no evidence for either astrolabe being used at sea in the Medieval Period by European mariners (Taylor 1957:92). Around 1470, the planispheric astrolabe was modified to create the sea astrolabe, more commonly referred to as the "mariner's

FIGURE 3. Mariner's Astrolabe, Spanish, c. 1600. (Image 153468 ©Museum of the History of Science, Oxford. All Rights Reserved, Used with Permission.).

astrolabe" (Figure 3). Sea astrolabes have no stereographic projection of the celestial sphere, no zodiac or calendar scale, no shadow square, and no horary diagram on the back, as is common on earlier planispheric astrolabes (Maddison 1969:27).

By 1485, Portuguese mariners were using the sea astrolabe and had just begun to master using solar declination tables (Taylor 1954:10). Abraham Zacuto, the likely inventor of the sea astrolabe, made sea astrolabes specifically for Vasco da Gama's voyage in 1497. The earliest description of how to make and use a sea astrolabe comes from Martin Cortes' *Arte de Navegar* (1551). The navigator held the astrolabe on a string, then used the holes in the sighting vanes on the alidade to sight the star or the Sun. If he was sighting the Sun, the smaller hole was used. If sighting a star, the larger hole was used. The alidade would be shifted until the spot of light from the upper hole landed exactly on the lower hole. The sun's altitude could be read from the degree scale carved on the rim of the astrolabe (Turner 1980:31; Waters 1958:56-57).

The astrolabe was still in use in the early 17th century among English navigators, as evidenced by the logbooks of Waymouth's voyage (1605) and Hawkridge's voyage to Frobisher Sound (1625) (Waters 1958:301, 460-461). By the late 17th century, its use was in decline throughout Europe (Cotter 1968:62; Daumas 1972:14). While the use and manufacture of astrolabes during the 17th century declined in Europe, they continued to be manufactured in Islamic countries into the twentieth century (Taylor 1957:14).

Taking an accurate reading on an astrolabe was difficult. For example, on a smaller astrolabe, say 6 to 7 inches (12.5 to 15cm), a reading to 20' (minutes) of degrees accuracy was difficult. Even on the larger astrolabes it was impossible to take an observation to within 4˚ to 5˚. For comparison, today navigators are allowed no more or less than a quarter of a minute of error. The cast brass astrolabe developed in the mid-16th century was an improvement, but a navigator had to go ashore if he wanted accuracy to be within half a degree (Taylor 1954:29; Waters 1958:57). By about 1500, the Portuguese were using sea astrolabes graduated to measure either zenith distance, which eliminates one step in calculating latitude from a meridian observation of the Sun, or altitude or both.

By 1517, the sea astrolabe had undergone several innovative improvements. Astrolabes began to be made of cast brass or bronze, to prevent corrosion, replacing earlier wooden instruments. The instrument was pierced or fretted out to reduce wind resistance and the alidade was modified. The alidades were set closer together and indexes were tapered to fine points, enabling readings to within half a degree. A large pinhole was sometimes provided for taking star sights. Additional weight was added, especially at the base, to steady the instrument during readings. On some early astrolabes, it appears that only one lower quadrant of the outer circle was graduated, allowing the astrolabe to measure only 0° to 90°. Later in the century, the upper quadrants were graduated and finally, all four were graduated, though this was not done sometimes due to additional costliness. The Spanish, French, English, and Dutch made sea astrolabes; however, due to the expense in time and materials, there were never very many made.

The sea astrolabe varied from 5 inches (12.5cm) to 7 inches (17.5cm). Spanish seamen preferred astrolabes from 5 inches (12.5cm) to 6 inches (15cm) in diameter. Blundeville noted that the English liked larger astrolabes to take advantage of larger scales and wider spaced sighting vanes. By the time the English began using the astrolabe, a second scale had been added for accuracy. While this second scale was useful for an ill-defined horizon, some navigators still preferred to use the quadrant, which had the same dimensions, but a scale that was twice as large (Turner 1980:31; Waters 1958:55-56, 301). The sea astrolabe became obsolete by the mid-17th century, being supplanted by the back staff or Davis quadrant (National Maritime Museum 1989:42).

The astrolabe inspired the invention in the 17th century of the only form of sundial that was of much use to seamen. Called “the astronomical ring” or “universal equinoctial ring dial,” the instrument was improved by Gemma Frisius from an earlier design (Maddison 1969:43). Pedro Nuñez developed a similar instrument in his *De arte atque ratione navigandi libri duo* (1595) published in Coimbra, Portugal. The “sea ring” has a scale engraved on the broad, inner circumference of the ring onto which a spot of sunlight falls through a hole drilled opposite the ring. The scale was twice as large as an astrolabe scale of the same diameter and a reading could be taken by the mean of the extra swings of the spot caused by the motion of the ship (Maddison 1969:45-46; Taylor 1954:43).

Simão de Oliveira illustrated a related instrument, called a “nautical ring” (*armila náutica*), in his text *Arte de navegar* (1606), published in Lisbon, Portugal. The side of a flat ring, equipped with a suspension ring, bears a scale of 90°. A thin style is placed perpendicular to the plane of the ring, so as to cast a shadow on the scale when the ring is directed toward the sun. Such dials were popular in the later half of the 17th century and in the 18th century. Most English examples of the universal ring dial have a nautical ring engraved on the back, so there appears to have been some combination of these instruments (Maddison 1969:44).

Brass and bronze astrolabes survive excellently in the archaeological record. The heavy construction, circular form, and riveted center peg (which holds the instrument together) creates a heavy mass that sinks quickly into the seabed. These factors appear to help astrolabes survive in underwater environments. In many cases, it is the peg that deteriorates first, disconnecting the index arm from the central piece. Its large, metal construction also assists in its recovery, since it shows up well on a metal detection grid. Some 30 examples from 1540-1650 survive in museum collections (National Maritime Museum 1989:42), as well as many from treasure hunting activities that have, unfortunately, been sold into private ownership.

Direction, Depth, and Speed Instruments

A primary function of navigation is to get the ship from its port of departure to its intended port as quickly and safely as possible. In order to do this, the navigator needs to decide on a “course” or path for the ship to take. This course is developed to take advantage or avoid known landmarks, currents, winds, and seasonal events, such as hurricanes, typhoons, the monsoon, etc. The course consists of a heading or direction of travel. This direction of travel is established using the compass. To estimate the depth of the water and the speed of the vessel, sounding leads and loglines would be utilized. The readings from these instruments provided estimates, logged into journals, of the overall progress of the vessel toward its intended port. If these readings showed variation from the navigator’s plan, the course was altered and the vessel proceeded on its way. 16th century ships tended to be very “leewardly,” that is, they tended to slide off course to port or starboard, depending on the vessel. This made it difficult to “make good” or maintain an intended course (Waters 1958:60). These instruments were vital to making good the course, adjusting for leeward tendencies, avoiding hazards, and arriving safely at the correct port at the intended time.

Compasses and Binnacles

FIGURE 4. Compass, by Christoph Trechsler, Dresden, 1584. (Image 151103 ©Museum of the History of Science, Oxford. All Rights Reserved, Used with Permission.).

The instrument that came to be known as a “compass” began as a simple magnetized needle. The earliest literary reference to use of the magnetized needle at sea comes from a twelfth century source, Alexander Neckham’s publication, *De naturis rerum*, but it could have been in use earlier (Maddison 1969:15). By 1269, the dry compass was in use, having a base pin mounted at a right angle to a pivoting needle on top. The base pin and pivot needle were then placed in a bowl with an inscribed, graduated ring along the edge of the bowl (Figure 4)(Waters 1958:23). Magnetic compasses, with no cards, were found in some sundials of the 15th century (Turner 1980:38). Ocean navigators began using the magnetized needle in Europe in the 15th century. The first discussion of the “mariner’s needle” (*agulha de marear*) in Portugal dates to 1416. Three navigational needles, a clock (hourglass) and 2 sounding leads are listed in a ship’s stores (Diffie and Winius 1977:134-135). For Mediterranean navigators, the compass was the only instrument considered necessary well into the mid-16th century (Lane 1963:606). The Portuguese used Genoese, Catalan, and Flemish compasses. There is no evidence of a local compass or needle manufacturing workshop in Portugal (Diffie and Winius 1977:117).

During the 16th century, the navigator's compass evolved further. The magnetized needle was glued onto circular card or "fly". The needle was made of soft iron wire, the diameter of the fly, formed into an elongated hoop. At the center of the hoop, a brass cone, or "capital," was pushed and the fly would pivot on this cone. This assembly would be placed inside a circular box. Early compasses had a box of wood, but later brass was used. A glass cover would be placed on top of the assembly, sealed by resin, and fitted to the base (Turner 1980:38; Waters 1958:27). William Barlow in his text, *Magneticall Advertisements* (1616), gave detailed instructions for making a steel needle. He discusses three types of needle: the square needle, the loop (commonly an extended oval or diamond-shape loop), and the narrow straight plate needle. Also, he states the needle and fly should not be more than 6 inches (15cm) in diameter due to wear on the pin (Maddison 1969:36). From the inventories of Henry VIII, we know that the King's ships carried between two and four compasses, according to size of the vessel, at the end of the 15th century. Carrying multiple compasses on a single ship to act as spares and to cross-check the accuracy of the primary compass, appears to have continued throughout the 16th and early 17th centuries (Waters 1958:29).

	North	
North by west		North by east
North northwest		North northeast
Northwest by north		Northeast by north
Northwest		Northeast
Northwest by west		Northeast by east
Northwest west		Northeast east
West by north		East by north
West		**East**
West by south		East by south
Southwest west		Southeast east
Southwest by west		Southeast by east
Southwest		Southeast
Southwest by south		Southeast by south
South southwest		South southeast
South by west		South by east
	South	

FIGURE 5. Chart of wind directions.

The term “mariner’s compass” originally referred to the wind rose, the division of the circle into 32 directions. Figure 5 shows the divisions, in order from north to south, from the top to the bottom of the wind rose on right and left sides, respectively. These are wind directions or “rhumbs of the wind” as they were called. A related term, “rhumbline,” is a plot of the ship’s course direction on a chart. Angular distance between the directions of the wind rose is 11° 25’. The now familiar printed compass card, or “compass rose,” was adapted from the earlier wind rose (Turner 1980:36).

A compass would be of little value without a lodestone to magnetize the needle or a binnacle to keep it steady (Figure 6). Lodestones have not been recovered from an archaeological context, yet, according to historical sources, they were consistently utilized during this period. During use, the compass case needed to be partially disassembled so the needle could be stroked with a lodestone. Stroking the pin with a loadstone would help the pin maintain its magnetic properties. Lodestones were kept in a case or hung by a chain far from the compass (Waters 1958:27).

FIGURE 6. Lodestone, c.1700? (Image 149218 ©Museum of the History of Science, Oxford. All Rights Reserved, Used with Permission.).

Mariners realized that the compass needed to be placed where the helmsmen could easily see it, day or night. Also, the compass needed to be well-lit and protected from the elements and shipboard activities. So, a compass housing was devised called a “binnacle.” Essentially, this was a portable wooden chest, secured to the deck so that the compass fly was aligned with the fore-aft centerline of the vessel. A lamp or candle lit the compass at night (Waters 1958:24). In 1205, Guyot of Provins first mentions the binnacle, as well as the lantern used to light the needle (Taylor 1957:96). In 1269, Peter

Peregrinus described a compass placed on a pivot in a box and fastened in line with the keel of the ship to indicate the course (Lane 1963:616). Binnacles are mentioned in English ship inventories between 1410 and 1412 (Waters 1958:24). In this period, binnacles were usually rectangular and about 4 feet high (1.2m)(Turner 1980:38).

By the mid-16th century, gimbals were added on all compasses to steady the needles. These consisted of two brass rings, moving perpendicularly to each other. They suspended the compass and held it steady against the movement of the ship (Waters 1958:28). Gimbals were known to medieval technology and are depicted by Villard de Honnecourt around 1235. Leonardo da Vinci envisaged their use for a compass. Alternatively, the compass could also be hung on cords to protect it from the movement of the ship (Maddison 1969:39).

The extensive voyages of the Age of Exploration revealed that compasses would usually point to some angle, east or west, of true (geographic) north. The angle between true north and magnetic north varies depending upon the location of the compass on Earth. Also, this variation does not remain constant over time, due to complex fluid motion in the outer core of the Earth, which causes the magnetic fields to change over time (Canada Geological Survey 2004). Robert Hues remarked in his work, *Tractatus de Globis* (1594), “That the Needle touched with the Loadstone doth decline in divers places from the intersection of the Meridian and Horizon is a thing most certaine, and confirmed by daily experience…The cause of this deflexion, although hitherto in vaine sought after by many, hath yet been found by none…" (Leary 1926:95).

Navigators began to correct for the magnetic declination manually. Columbus had adjusted for a westward variation on his first voyage (Diffie and Winius 1977:140). An eastward variation was common in northwest Europe. From the latter half of the 15th century, compasses made in Flanders would mount the fly at an angle, so the needle pointed to true north in Europe (Waters 1958:24-25). It is likely that William Baffin used one of these compasses. Baffin notes that this sailing compass was "touched five degrees and a half to the eastward," giving him a faulty reading that had to be checked by using a quadrant on land (Waters 1958:276). Only long experience with the same compass, or using multiple compasses, could correct this type of error (Diffie and Winius 1977:140).

Two different instruments were designed to reveal the amount of magnetic variation: the azimuth compass (Figure 7) and the dip circle compass. Waters credits João de Lisboa as being the first inventor of an instrument for measuring compass variation (Maddison 1969:59). Francisco Falero developed a practical method to measure compass variation in his *Tractado del Esphera y del arte del marear* (1535). Felipe Guillen also devised an instrument, later improved by Pedro Nuñez, to measure the altitude of the sun. Nuñez described and illustrated his instrument, called *instrumento de sombras*, in his publication *Tratado da sphera* (1537)(Maddison 1969:36-37). The variation compasses designed by William Barlow (*Discours of the Variation of the Compass*, London 1581) and Robert Norman (*The Newe Attractive*, London 1581) are different

FIGURE 7. Azimuth Dial, style of Erasmus Habermel, c. 1600? (Image 148801 ©Museum of the History of Science, Oxford. All Rights Reserved, Used with Permission.).

from Nuñez' instrument because they use a string gnomon instead of a vertical style (Maddison 1969:36-37). These later azimuth compasses consisted of a brass case mounted on gimbals containing a rose, a sight, and strong gnomon on top of the case. The rule attached to the sight could move over a degree scale from 45° to 0° to -45° (Turner 1980:38).

Robert Norman invented the dip circle compass in 1576, a magnetic needle that moves in a vertical plane, rather than the horizontal plane of a compass. Explorers used the dip circle to study the way the earth's magnetic field fluctuated (Turner 1980:42). William Barlow modified the instrument for use at sea. He added a thumb ring for suspension and enclosed the sides of the case with disks of unbacked Venetian mirror glass. The dip circle had to be placed out of the weather in a binnacle or cabin. It could be read after being aligned north-south. William Gilbert made further improvements by adding a brass horizon line. He described the instrument in his book, *De Magnete* (1600) (Waters 1958:247). The dip circle compass was so effective it was carried for nearly two centuries. For example, in 1772, Captain Cook carried a dip circle on his second voyage (Turner 1980:42).

In spite of its almost universal use, the compass, in any form other than a dip circle, does not survive well in the archaeological record. The wooden case, in early examples, and the fly in particular are unlikely to survive due to being made of wood and paper, both of which self-destruct in marine environments. However, the pivot, needle, brass case, glass cover, and gimbals can and have been found in archaeological sites. Correctly identifying the needle seems to cause particular difficulty, due to the variety of shapes and metals used in the period. Needles can be of steel or iron, shaped as a long needle with a central hole, a long needle with an end hole, a triangular plate with a central hole, a figure-8 loop of wire, a long oval wire, or several other configurations. The pivot can also be a cone shape, shaped like a disk-headed nail, or a fat needle with no hole. While surviving portions of the compass are light and tend to be carried away by wave action, several have been located in sites from this period usually because the compass was quickly buried (see Chapter V).

Sounding Weights

Of all the tools in the navigator's kit, the sounding weight is likely the most ancient and simplest to use (for photo see Chapter VI, figure on page 146). Herodotus mentions the use of the sounding lead by ships approaching the Nile Delta and medieval portolan books describe its use in the upper Adriatic. However, the sounding weight was not utilized in the Mediterranean, which was too deep for effective use (Lane 1963:611). The sounding lead was first illustrated in Lucas Janszoon Wagenaer's publication *Spieghel der Zeevaerdt* (1584). A 1449 case illustrates the supreme importance of the sounding lead to navigation. A Danzig ship bound for Lisbon was arrested in Plymouth, England. To prevent it from trying to leave, the ship's sounding leads were taken (Lane 1963:612). Without their sounding leads, the ship was unable to sail and was effectively arrested.

There were two kinds of sounding lead, a shallow water lead and deepwater lead, called a "dipsie" in England. In the *Seamans Grammar* (1627), Captain John Smith states that the lead was "a long plummet, made hollow, wherein is put tallow," attached to a 150 fathom (900 feet/270m) line. The line is marked with strings knotted at 20 fathoms (120 feet/36m) intervals, then every 10 fathoms (60 feet/18m). In *Seamans Dictionary* (1644), Sir Henry Mainwaring states the dipsie lead had a line of 200 fathoms (1200 feet/360m) and weighed 14 pounds (6.36kg). The lead was "armed" by placing hard white tallow in a hollow at its base, unless the seabed was considered soft or "oozy." In that case, a white woolen cloth and a little tallow were used. A sounding could be taken from the deck of a moving or stopped ship. The lead was simply dropped into the water, allowed to rest on the seabed then brought to the surface. The sample of the seabed would be analyzed for contour, color, smell, taste and texture in order to determine the location of the ship (Waters 1958:18-20).

A coastal or ship's hand lead, sometimes called the "blue pigeon" in the British Navy, was used for sounding depths up to 20 fathoms (120 feet/36m) and typically weighed between seven and fourteen pounds (3.18-6.36kg). The shallow water lead had a thicker line than the dipsie lead and was variously marked. A piece of black leather was knotted at 2 fathoms (12 feet/3.6m) and 3 fathoms (18 feet/5.4m). A white cloth was placed at 5 fathoms (30 feet/9m) and 15 fathoms (90 feet/27m) and a red cloth at 7 fathoms (42 feet/12.6m). Leather would be tied at the 10 fathoms (60 feet/18m) mark. These tied pieces made it easier for the sailor to know the depth of line that had already been placed over the side of the vessel. So it would remain taut at greater depths, the dipsie lead often weighed up to 28 pounds (12.72kg) or more (Bennett 1987:28; McEwen and Lewis 1953:283; Waters 1958:20).

Of all the navigational instruments, this tends to be the most commonly recovered, perhaps due to its lead construction and heavy, solid design. Also, next to the astrolabes, the sounding weights appear to be the best preserved. While the lines are often gone, in whole or in part, the sounding lead is easily recognizable and, because it only comes in two types, usually enjoys some accuracy in the archaeological site literature. Additional examples survive in many maritime collections world wide for reference.

Log Lines

Before the 16th century development of the log line, mariners estimated the vessel's speed from the foam slipping past the vessel or the type of wake the ship made (i.e., fast, slow, wide, narrow, deep, shallow, etc.). Commonly, the faster, narrower, and deeper the foam and wake, the faster the vessel's speed. In the early 16th century, distance was recorded in "kennings," that is the distance a man could see, and days of sail (Waters 1958:435). In the late 1560s, the log line was invented, likely in England, to measure the distance sailed (Waters 1958:434). While many navigators and masters still estimated speed, the logline was used regularly. Some threw the line every two hours, others every hour (Waters 1958:283, 437).

The "English log", as it was called, had a log or lump of wood attached to a line. The line was usually on a reel held horizontally with handles. William Bourne's *Regiment for the Sea* (1573) contained the first description of the logline (Leary 1926:53-54). By the 1620s, the log line had come into general use by English sailors (Waters 1958:432). The English logline was adopted and improved by the Dutch. The "Dutch log" had the same long line, but used a different "log." Their log was in the form of a brass tobacco box, rectangular with rounded ends. Usually, the Dutch log also had a perpetual calendar and two engraved figures on the lid. Under the lid of the box were engraved the speed tables to convert time measured into speed. The Dutch seamen used this instrument from the 17th to the nineteenth centuries (Taylor 1980:39).

The technique to use the log and line was simple. The log as thrown over the transom into the water. The line, held on a reel, was played out in the ship's wake. The reel would be stopped at a particular time, either estimated from the time on the sandglass or when a number of words were spoken. The line and log would be brought back on board the vessel and the amount of line that had played out would be measured. This would tell the sailors the distance the ship had traveled in that time (Leary 1926:53-54). By counting the number of knots that went over the side, the ship could calculate miles per hour. A knot was tied every 7 fathoms (42 feet/12.6m). At the time, it was estimated that 60 miles equaled one degree of progress, although this was inaccurate (Turner 1980:39). Variations in the number and placement of the knots led to the development of a new technique. The knots were placed so the reading would be a direct proportion of the English mile. By using simple addition and subtraction, the average seaman could now use the log line to compute actual distance more quickly (Waters 1958:432).

The logline had a few problems that affected the accuracy of the readings. First, the navigator and his helper had to be very careful to let the logline out rapidly enough that the vessel would not drag the logline along the surface of the water. Also, if the ship was running before the wind or waves, the logline could drift alongside or even in front of the vessel, making readings difficult or impossible (Waters 1958:436-437). Lucas Janszoon Wagenaer in *Spieghel der Zeevaerdt* (1585 edition) suggested that a navigator could cast a line astern with a piece of lead weighted wood with a pole in it to discover the amount of leeway in a ship's course. The angle between the line cast astern and the centerline of the ship could be measured with a compass and added into the course (Waters 1958:60). Accounting for leeway led to more accurate course corrections and this leeway instrument was eventually added to the common log line.

Log lines rarely survive for any length of time in the archaeological record unless they have been stored in an enclosed container and completely covered by overburden during the intervening centuries. Since the English log line is made of rope and wood, the only surviving examples are most likely found in historical collections. The Dutch log, which is made of metal, would be more likely to survive in an archaeological site. In fact, it is likely that two have been recovered from the VOC wreck *Kennemerland* (1664).

Course and Timekeeping Instruments

During a voyage, timekeeping became vital. The ship's course needed to be maintained for a certain number of hours then reviewed for changes. The ship's watch served for four hours as estimated by the turning of the glasses, then changed with another watch crew. Timekeeping was needed to maintain accurate records of the voyage as well. When at sea, the navigator kept records using the "natural day" which lasted from noon to noon. On this cycle, the fifth day of the month became the sixth day of the month at 12:00 noon. When near or on land, the ship's day was considered to run from midnight to midnight (Waters 1958:76). So the fifth day of the month became the sixth day at midnight instead. The ship's records, such as brief journals, traverse books, and logbooks, were kept in the time format in use on that day either sea or land time. Until John Harrison developed the first marine chronometer in 1735 (Turner 1980:40), the only timekeeping instruments at sea were the nocturnal and the various glasses.

Traverse Boards

The traverse board was made of wood and commonly measured about 12 inches by 8 inches (30cm by 20cm). Due to wind, currents, pilot error, and other factors, the ship's course was rarely a straight line and a vessel often progressed by a series of tacks into the wind. In *Sea Grammar* (1627), Captain Smith describes the traverse board as, "a little round boord full of holes upon lines like the Compasse, upon which, by removing of a little sticke, they keep an account, how many glasses (which are but halfe hours) they steare upon every point" (Waters 1958:36-37). The traverse board would have holes for each of the 32 compass points. Each of the 32 compass points would each have 8 holes in a line, one for each 30 minutes of a four-hour watch. Pegs were attached to board by a string, then pushed into holes indicating the compass bearing and time steered on that bearing (Figure 8).

FIGURE 8. A traverse board with attached log board. (Image 150523 ©Museum of the History of Science, Oxford. All Rights Reserved, Used with Permission.).

The traverse board was mentioned in 1528 as part of the navigator's set of necessary instruments. During the 16th century, some mariners used the traverse board, but English pilots rarely did. English mariners preferred to use the Spanish and Portuguese "Rule to Raise or Lay a Degree of Latitude" tables. These tables provided the distance to sail on a given course. The distance equaled the difference of latitude divided by the cosine multiplied by the course (Waters 1958:37-38). Use of the traverse board survived into the nineteenth century and the few examples we have date from this period (Turner 1980:40).

The traverse board was augmented, in some cases, with an additional chart located at the base. This additional chart was referred to as the “log board.” Samuel de Champlain (1567-1635) mentioned using a wall-mounted board to keep records of the readings taken by the log lines, sounding lead, and other instruments.

Approximately 3 feet (0.9m) high by 15 inches (37.5cm) wide, including the traverse board section, the log board was ruled into 4 columns with 13 lines. The top line had the headings: hours, knots, fathoms, and courses with rhumbs. Under hours, the 12 lines listed the hours 12:00, 2:00, 4:00, 6:00, 8:00, and 10:00 twice. Every hour or two, the speed of the vessel would be taken by logline and written on the log board. Every two hours, the navigator or master would write the estimated mean course with his reckoning of the distance the ship had traveled. At the end of the watch, the estimates would be recorded in the traverse book and the board would be erased (Turner 1980:40; Waters 1958:37). The hourly distance would then be converted into leagues, with one knot equaling one mile and every three miles equaling a league. The distance would then be transferred into the log book (Waters 1958:283). The effect of wind, tide, waves, and waywardness of the vessel would also be estimated and recorded on the traverse board when out of sight of land (Waters 1958:36).

A traverse board, with or without the log board, in whole or in part, has never been recovered from an archaeological site to the best of the author’s knowledge. This instrument, being made entirely of wood and string, is a rare find in historical collections. Primary source materials in the period are unclear as to the prevalence of use of the traverse board. It is likely that the log board was detached and kept on a slate in a later period. The recovery of slates and pencils from *Kennemerland* (1664), *HMS Dartmouth* (1690), and the Jutholmen wreck, as well as contemporaneous historical documents, supports this hypothesis.

Nocturnals

A nocturnal, nocturne, or *nocturlabe* (in French) provides a rough indication of the time during the night. The immediate predecessor to the nocturnal is likely the medieval mnemonic diagrams which served the same purpose. Towards the end of the 13th century, Ramón Llull described an *astrolabium nocturnum* or *sphaera horarum noctis* in his *Opera omnia* (Maddison 1969:30-31). Duarte mentions a similar device in *Leal Conselheiro* (1428-1437)(Maddison 1969:30-31). Examples of nocturnals exist from about 1500 (Figure 9)(Turner 1980:18-19). Seamen from France, Spain, Portugal, and the Mediterranean more commonly used the nocturnal than their northern counterparts (Waters 1958:35). In the 16th and 17th centuries, nocturnals are fairly common instruments (Maddison 1969:33). Often, the nocturnal was included as an element of pocket compendia, a collection of timekeeping devices with various attachments sized to fit in a pocket. Seamen more often utilized the less expensive wooden version of the nocturnal (Turner 2000:249).

The nocturnal was designed to be easy to use at night. The nocturnal was commonly made of brass or wood (Turner 2000:249). The standard nocturnal consisted of three pieces: a central piece in a paddle shape with a handle, attached to a small disk, called a "volvelle," and a long piece, called the

FIGURE 9. Nocturnal and Regiomontanus-type dial by Caspar Vopel, Cologne, 1557 (obverse-left and reverse-right). (Images 150471 and 150472 ©Museum of the History of Science, Oxford. All Rights Reserved, Used with Permission.).

"arm". All these parts were held together by a nut and bolt, sometimes by a rivet, which is pierced by a hole. The edge of the disk was engraved with the names of the months and divided into twice 12 hours, with 12 at the top and 12 at the bottom. These hours correlated to the midnight positions of the Pole Star (β *Ursae minoris*) throughout the year (Maddison 1969:30-31). In the 16th century, the engraving often included a scale of the 12 signs of the Zodiac

(Turner 2000:249). Some nocturnals would only be engraved with the night hours, from 8:00pm to 8:00am. On some nocturnals, the hours are notched to be counted by feel, with 12:00am having a larger notch (Turner 1980:18-19).

In order to use the universal nocturnal, the navigator must be able to see the Pole Star and Ursa Major. The pointer on the volvelle is set to the date when the observation is made. The arm is turned to align with the star *Kochab* in *Ursa minor*. The handle is held vertically downwards and the Pole Star is observed through the central hole. The time is then read by the position of the extended arm over the volvelle (Turner 2000:249-250).

Although the process of using a nocturnal and planisphere appears to be rather simple, there were a few errors known to occur. It was difficult to align the long arm on the nocturnal and sight stars while on the deck of a rolling ship. Weather, wind, wave, and other factors could impede visibility or delay readings for several days or weeks. Polaris is a double star of the second magnitude, with –1 being the brightest and lower than 4 being nearly invisible to the naked eye. Sighting Polaris off-center through the central hole in the nocturnal resulted in a faulty time reading as well. Finally, the scales rendered on both sides of the instrument were incised using a double-pointed, divider type instrument. Misplacing a line could throw a reading off +/- 0.5° or more. Despite these challenges most trained pilots using a nocturnal could gauge the time to +/- 15 minutes.

The nocturnal evolved into a more universal version, able to be used globally, in either the Northern or Southern Hemispheres. This nocturnal had two pointers on the dial to align with the two stars *Dubhe* and *Merak* in *Ursa maior* (Turner 2000:249-250). Sometimes a second volvelle was attached to the back of the nocturnal to locate constellations like a planisphere. This type of nocturnal is discussed further in Chapter VI, as one was recovered from *LaBelle*. The nocturnal was only utilized at sea for a short time, as marine chronometers made it obsolete in the early 18th century.

A large number of nocturnals have survived in the historical record, but are rarely found in archaeological contexts. The nocturnals recovered usually date to the mid- to late-17th century. Some of them are wood, but more commonly the brass or bronze examples survive. In the wooden examples, only the central nut and bolt would likely be found. However, wooden examples have been found in archaeological sites (see Chapter V). In historical collections, the metal instruments are highly valued and some hundred or more can be found in museums throughout Europe.

Sandglasses

Sandglasses were likely developed in the western Mediterranean in the eleventh or twelfth centuries to keep time at sea (Waters 1958:308). The sandglass was also referred to as a “dyall,” a corruption of the Latin *diurnalis* meaning “relating to the day”. Glasses were used to keep track of the distance sailed, as well as run the ship’s routine (Figure 10)(Waters 1958:35-36).

FIGURE 10. Single sandglass clock, c. 1760 (left) and a set of sandglass clocks, 16th Century? (right). (Images 155162 and 151125 ©Museum of the History of Science, Oxford. All Rights Reserved, Used with Permission.).

The sandglass consisted of two pear-shaped bulbs of glass with flattened bases. The glass was heavy, thick, and greenish. One of the bulbs would be filled with iron filings, fine red sand, fine marble dust, or powdered eggshell. The angle of the cone of the bulb would be made equal to the angle of repose of the type of filling used. A filled and unfilled bulb would be placed neck-end to neck-end and connected. A paper thin, metal washer with a small regulating hole was placed between the join. Then, the join was sealed by putty or wax. In better quality glasses, the join was also bound by linen and finished with leather held by a strong thread. One or more of the glasses would be placed within a metal or wooden frame. The top and bottom plates of the frame, either square or round, were held together with four to eight oak legs. The sandglass would measure time by the action of gravity, giving a consistent rate of passage to the fall of the filling from one bulb of the glass to the other. Glasses were made in a variety of sizes. The four-hour watch glass was a foot (30cm) in diameter and two feet (60cm) in height, weighing several pounds and needing two hands to turn. The half-hour glass was half the size of the four hour glass and a half-minute glass, used with the logline, was 5 to 6 inches (12.5 to 15cm) high and 2 to 3 inches (5 to 7.5cm) in diameter (Waters 1958:308-309).

In order for the sandglass to work correctly, the filling had to perform properly, consistently. The use of sandglasses at sea was a challenge for manufacturing. In order to be accurate, the filling had to be of uniform size. To get just the right size and consistency, marble dust was ground fine in a mortar, then boiled in wine, dried, reground, and sifted nine or ten times. Iron filings ran freely when the glass was new, but over time, the action of the filings ground the central washer hole to a larger diameter, allowing the iron filings to drop too fast. Also, rust could cause the iron filings to stick together and run too slowly. Other filings also had problems. For example, powdered eggshell was affected by humidity. To try to maintain consistent timekeeping, two or three glasses would be turned at the same time and averaged (Waters 1958:309-310). João de

Castro notes that Portuguese pilots who did not know how to take the altitude correctly, placed the blame largely on the "clocks" which varied too much (Diffie and Winius 1977:139).

Several elements of the sandglass are likely to survive archaeologically. The glass globes, in whole or in part, as well as the central washer can and do survive. Unfortunately, these elements are commonly separated in collections and the sandglasses, although ubiquitous in the period, are rarely identified unless the wooden structure or complete bulbs are recovered. If a sandglass is suspected, the area around the glass should be excavated carefully to see if the filing can be identified. It should also be noted that the size of the bulbs is not a good indicator of the time the sandglass was designed to measure. Few examples survive for reference in historical collections and these are predominately smaller. For example, no four-hour glass is known to exist in either historical or archaeological collections, to the best of the author's knowledge.

Drafting Instruments

A variety of instruments were used in association with charts during the period. As mentioned in Chapter II, several new instruments were developed during the period, including the sector, a type of ruler, the slide rule, and the protractor (Waters 1958:64, 479). Mariners used globe-shaped charts at the beginning of the period. Edward Wright developed the first method the plot the earth's curved surface on a paper chart (Waters 1958:98), making charting easier. The development and use of many types of dividers and measuring instruments made charting a course easier and more accurate by the end of the 17th century.

Dividers

Dividers, called "compasses" in the period, are frequently found on shipwreck sites, testifying to their widespread use in maritime navigation. The design of dividers is fairly simple and can be traced to Babylonian times. Artisans, carpenters, engineers and navigators used plain compasses for marking off distances, measuring scales, dividing measurements into equal parts, and for copying drawings and charts. As part of a typical set of drafting instruments, dividers are used for measuring lengths (Turner 1980:55). A basic compass is easily described. Made of brass, the instrument consists of two long, straight pieces attached by a central joint. Due to later innovations, this basic type is commonly referred to as "simple" or "plain" dividers (Turner 1980:56).

Dividers or compasses were especially helpful if the navigator had to estimate the ship's position. When attempting to sail along a latitude, the navigator would take two sightings, 24 hours apart. Hopefully, the two readings were the same. If they were not, he could use two dividers to estimate the position of the vessel. He would place one leg on the point where he thought the ship was and the other on the course he thought he had sailed. The second compass would be placed as well, with one leg on the latitude scale of his observed latitude and the other leg on the east-west line where the course met the latitude scale. He would draw the two innermost legs of the compasses together and, where they crossed was his estimated position (Waters 1958:76).

By the 16th century, instrument makers had designed a wide variety of compasses for a variety of purposes. The first innovation involved cutting the ends off the legs and adding a joint so other attachments could be used. These bronze compasses with interchangeable steel legs often included extra steel points so the attachments could be changed. Some deluxe compass kits included Inking nibs or pencil holders. A compass using these attachments was called a “drawing compass.” Kits also included another attachment to append a wheel with small spikes radiating out to the end of a compass. This attachment, called a “dotting wheel,” was used to make punctuated lines on charts (Bion 1709:9; Hambly 1988:69).

In addition to the straight, plain steel legs, compasses came in other, non-straight leg designs for other purposes. A charting compass has legs that are curved. The legs begin closer together widen out into a near circle, then are bent back toward each other. The large, circular configuration allowed them to be easily used with one hand. A final type, called a “proportional compass,” was developed by Jost Bürgi about 1600. This type has two arms and a pivot part way down the leg so the ends open at different lengths, usually 2:1. This compass is used to create distances that are twice the length of the original distance (Turner 1980:56).

As previously mentioned, all types of compasses and their attachments have been recovered from archaeological contexts. Their metal construction and small size seems to assist in the survival of a large number of artifacts. Compasses are also widely collected by museums and private collectors, so all types and many variations not noted here exist. Also, if a compass is recovered without the ends of the legs, special care should be taken with the surrounding area, as the attachments are often small, soft metals (such as silver) and are easily overlooked.

CHAPTER V

ARCHAEOLOGICAL FINDS

For this analysis, a collection of vessels, considered to date between 1500 and 1700, were compiled from a variety of archaeological reports, web sites, and other information sources. Since dating is approximate on many of the wrecks, to be thorough vessels from before and after the period were included. Several Internet bibliographies for nautical and maritime archaeology in the period were utilized in an attempt to discover sites that might have produced navigational instruments of any kind. The Internet was especially helpful in cases of amateur excavation or treasure hunting, wherein official site reports are non-existent. Research into the sites varies considerably. Little is known about some sites beyond where it is located, usually based on historical accounts or modest survey attempts. In contrast, some sites have enjoyed full-scale excavation of most, or all, of the finds and official publication of these results. Each site will be discussed individually in the following section and the status of the site, according to latest public reports, will be noted.

The collection of sites reviewed for this analysis fall into three categories. In total, 160 vessel sites were evaluated for the recovery of navigational instruments (Appendix A and B). The distribution of these sites during the period is shown in Figure 11. Of the 160 sites, 72 sites were removed from the survey due to incomplete information (Appendix C). In many cases, a complete, or even partial, list of the number and type of recovered artifacts was not available. Some of the sites that were merely surveyed may prove to have navigational instruments in the future, but at this time there were no navigational instruments listed in the collections (Appendix D). Another 61 sites listed a variety of recovered artifacts, but no navigational instruments were listed in the published material. The remainder of this chapter will highlight the navigational artifacts recovered from the remaining 27 sites that list navigational instruments (Appendix E).

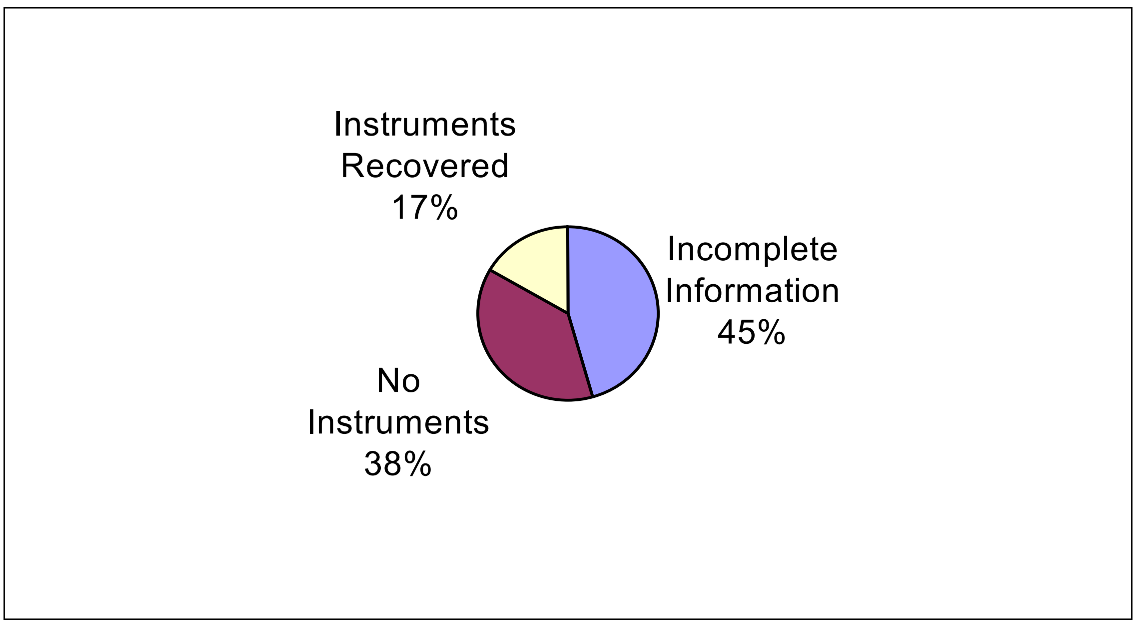

FIGURE 11. Percentage of sites yielding instruments.

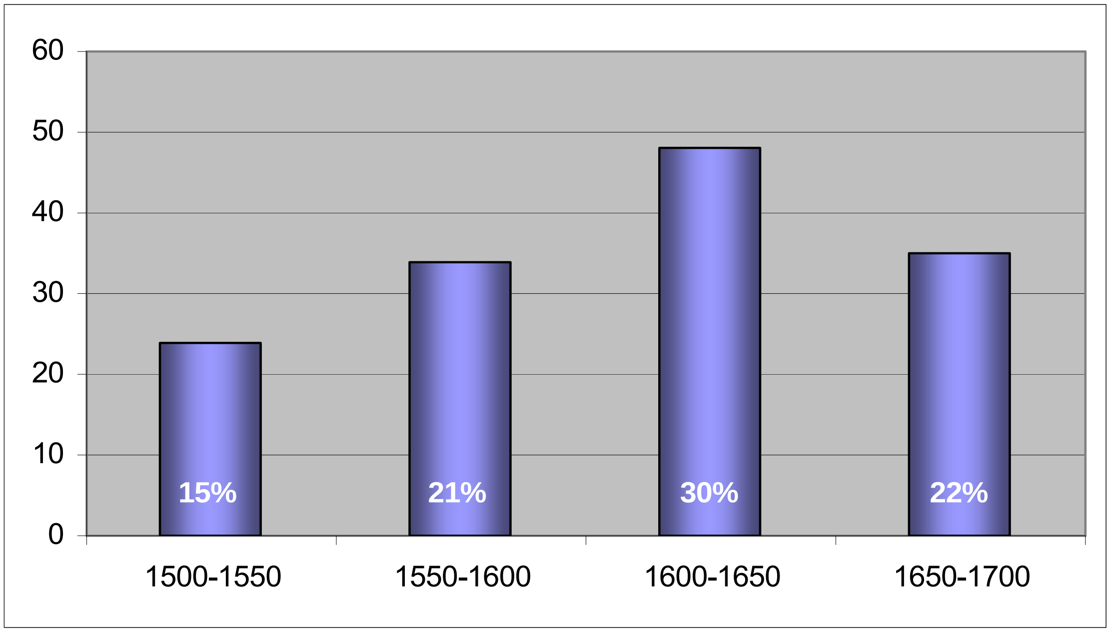

FIGURE 12. Site distribution by time period.

The distribution of these vessels over the 200 years between 1500 and 1700 provides additional data for analysis (Figure 12). The vessels have been divided into 50-year periods, based on the excavator's estimate of date of vessel destruction. Percentages shown reflect the proportion of sites within that period. Sites loosely dated by their excavators to be within the 16th and/or 17th century have been removed. Overall, this represents 12%, or 19 sites out of 160. Figure 12 shows a gradual increase in the number of sites until 1650 and a decrease after this time. This distribution could be the result of more widespread interest, among treasure divers in particular, in shipwrecks of Vereenigde Oost-Indische Compagnie (hereafter, "VOC") vessels, which largely date to the early 17th century. Another reason for this distribution could be an increased number of vessels destroyed during the period as a result of accelerating global commerce and naval wars.

Analysis of Finds by Archaeological Site

The incidence of navigational instrument recovery increases from the 16th century into the 17th century, as shown in Figure 13. While only 8% of the sites dated to the early 16th century yielded instruments, this increased to 18% of sites dated to between 1550-1600, 17% between 1600-1650, to a high of 34% (between 1650-1700). The increase in the number of instruments recovered could be due to differences in instrument survival in the archaeological record, as discussed in Chapter IV. The increases in recovery could also reflect increased use by navigators in the later periods.

Navigational instruments were reported among the artifacts in 27 vessels that will be discussed in this chapter. The vessels and their site excavation will be discussed individually in chronological order. It should be noted that vessels belonging to fleets appear to form a disproportionate number of the sites. Of the 27 sites under discussion, 16 sites (or 59%) consist of vessels belonging to fleets. This high percentage may be due to the increased historical documentation available when a fleet is lost, rather than a single vessel. Also, the number and type of instruments carried on a fleet vessel may exceed those

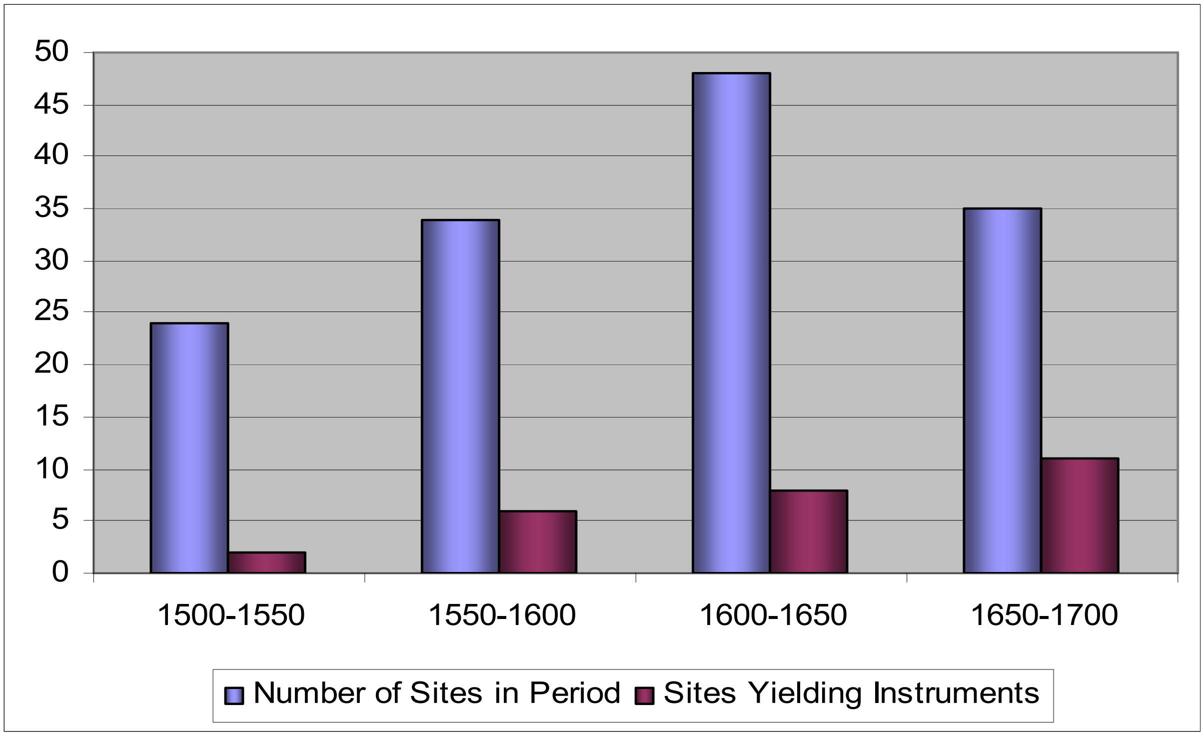

FIGURE 13. Comparative analysis of overall site distribution versus sites yielding instruments.

carried if the vessel is traveling alone, thereby increasing their incidence in the archaeological record. For instance, 80 dividers were recovered from *VOC Lastdragger*. As they were carried in boxes and unused, it is possible they were carried for trade, barter, or sale. In another example, 12 sounding leads were recovered from *VOC Batavia*, which may have been carried as spare leads or as a source of lead for other purposes (i.e., ship repair, making shot, etc.).

Lomellina, also known as the "Villefranche-sur-Mer wreck", was a Genoise nau shipwrecked in a French harbor during a hurricane in September 1516. Found on April 6, 1979, DRASM (Le Département des recherches archéologiques subaquatiques et sous-marines, a part of the French Government) surveyed the site shortly afterwards. Max Guérot excavated the site between 1982 and 1990. He recovered two compass arrows and a fragment of a sandglass. Historical records make it clear that multiple compasses were often carried in the period and the use of hourglasses was common among Mediterranean mariners (Guérout 2004).

Mary Rose, an English carrack, was wrecked on June 19, 1545 in Portsmouth Harbor, England. Excavated by Alexander McKee and Margaret Rule, and later under the Mary Rose Trust, the site has yielded a variety of navigational instruments. Due to the largely intact nature of the vessel, this is the only site discussed in this analysis where the instruments appear to have remained in-situ. Navigational instruments were recovered from three locations on the vessel: from the Pilot's Cabin, from a barrel in Area 8 on the Orlop Deck, and from Area U11 on the Upper Deck below the sterncastle. A piece of a chart, a nearly complete compass (still in its box and mounted on gimbals), and a pair of dividers were recovered from the Pilot's Cabin. A sounding weight was found in a barrel on the Orlop Deck and a chest containing 2 dividers, a sounding weight, and a compass was recovered from the Upper Deck (Marsden 2003:104, 118, 122). Again, these finds reflect the instruments used by navigators in the period, as discussed in the historical documents of the period.

San Esteban and *Esperitu Santo* formed part of the Spanish Plate Fleet of 1554 that shipwrecked on Padre Island, Texas on April 29, 1554. Both vessels were salvaged in the 1550s, re-discovered in 1967, and excavated from 1972 to 1973 by the Texas Historical Commission. *San Esteban* yielded 2 sounding weights and 2 dividers. The excavator mentions that the one set of dividers appears to resemble those found on the Armada wreck of the *Gerona* dated to 1588 (Martin and Wignall 1974:Plate 14) and the VOC wreck, *Lastdragger*, dated to 1653 (Sténuit 1974:232-233). The other pair resembles dividers recovered from the Swedish Jutholmen wreck dated to 1700 (Ingelman-Sundberg 1976:Figure 3). Three astrolabes and a screw that might be from a cross staff or quadrant were recovered from the *Esperitu Santo*. The U.S. Army Corps of Engineers probably destroyed a third vessel from the fleet, Santa Maria de Yciar, in the late 1940s during the opening of the Mansfield Cut. These instruments reflect the increasing complexity of the navigators' tool kit in comparison to earlier periods (Arnold and Weddle 1978:252-256).

A Basque whaler known as the "Red Bay" or "Basque" wreck, probably the *San Juan*, was destroyed near Saddle Island in Red Bay, Canada in 1565. Located in 1978 and excavated by Parks Canada between 1979 and 1984, a rare ship's binnacle was recovered, as well as a compass and "other navigational instruments" (Tuck 1985:50-57). Details on the specific instruments recovered were not available. Additional research on this site is recommended and the instruments would likely be very similar to those found on the vessels of the Plate Fleet of 1554.

Several vessels belonging to the Spanish Armada of 1588 wrecked on the shores of England, Scotland, and Ireland. Laurence Flanagan lists 14 known Armada wreck sites in Ireland, including two with navigational instruments: *LaGirona* (or *Girona*) and *Trinidad Valencera*. *LaGirona*, discovered in 1967, and excavated by Robert Stenuit (1968-1969), contained 2 incomplete astrolabes, 5 pair of brass or bronze dividers, and 2 sounding leads. Photos reveal that all 5 dividers were the straight type. *Trinidad Valencera*, found by sport divers in 1971. The site yielded an intact compass base (with intact pin) and an “elegant pair” of dividers (Flanagan 1988:26, 63-65). Comparison with the tools of the Plate Fleet of 1554 shows little change in the tools of navigation.

The first VOC wreck yielding instruments, *Nassau*, was part of Kornelis Matelieff’s fleet and was destroyed during a fierce naval battle with the Portuguese. The vessel came to rest on Bambeek Shoal in the Straits of Malacca on August 18, 1606. Found in 1993, the survey and excavation of *Nassau* was carried out for the National Museum of Malaysia by Transea (a salvage company), in association with Mensun Bound of Oxford University’s Maritime Archaeology Research Department (MARE) and the National University of Malaysia (UKM) in 1995. The survey found some “navigational instruments,” but failed to list exactly what was recovered (VOC Shipwrecks 2002b). Further analysis awaits the full publication of these finds.

Nossa Senhora dos Mártires, also known as the “Pepper Wreck” or the “São Julião da Barra 2 Wreck”, was found in 1993 in the Tagus River, near Lisbon, Portugal. Destroyed on September 15, 1606, this nau was excavated in 1996, 1997, 1999, and 2000 by the Museu Nacional de Arqueologia. A variety of navigational instruments, including 3 astrolabes, 3 sounding weights, 2 straight, or basic, dividers, and a possible fragment of a quadrant base were recovered. It is likely that additional artifacts were lost in the silt, since the vessel is in a coastal area near a river mouth, or carried away by tidal or river turbation. A number of artifacts are still concreted and these may also contain other instruments (Brigadier and Randolph 2002:6, 51, 93, 113, 122, 129, 184).

Lost off the Japanese city of Nagasaki in 1610, little is known of the *Nossa Senhora da Graça*, alternatively known as *Madre de Deus*. Two astrolabes and a few other artifacts were dredged from the wreck in 1928. A local carpenter, Matsumoto Shizuo, has partially excavated some finds since 1987 (Tomé 2000). The present location of these astrolabes is unknown and no further analysis is possible until they have been located.

In 1980, Patrick Lize and Jacques Dumas recovered an astrolabe from the VOC vessel, *Banda*, wrecked on a reef near Mauritius on March 6, 1615. Unfortunately, the recovered artifacts were sold at auction and no site report or photos are available (VOC Shipwrecks 2002a). If the astrolabe could be found, it would be interesting to compare it to those found on other VOC wrecks, as well as those recovered from ships of other countries.

The loss of the Spanish Treasure Fleet of 1622 in Dry Tortugas, Florida has become famous due to the wealth of finds recovered from two of the wrecks, *Nuestra Señora de Atocha* and *Santa Margarita*. Mel Fisher, a treasure diver, excavated these sites for profit. Later, archaeologist Duncan Mathewson supervised some of the excavation. While much archaeologically significant data has been lost, at least some photos of the artifacts have been made available in the artifact catalog on the Internet (Motivation Inc. 2004). Navigational instruments from *Nuestra Señora de Atocha* included 2 dividers, 3 or 4 lead sounding weights, and 5 astrolabes. Three astrolabes and a sounding lead were found on the *Santa Margarita*. This Internet site reported that a wooden cross staff was also found (Åkesson 2004); however, no photos are available. If this instrument was recovered, it is the only one of its type on any of the sites surveyed in this analysis. Its present location is assumed to be the Mel Fisher Maritime Heritage Society and Museum in Key West, Florida. The number of instruments recovered from these wrecks indicates a trend toward carrying multiple instruments of other types, not merely compasses and dividers, which was common previously.

The Royal warship, *Vasa*, sank in Stockholm Harbor, Sweden on August 10, 1628. *Vasa* was salvaged soon after sinking and again in 1663 and 1664. Excavated by the Government of Sweden, this vessel serves as a time capsule of the period. A number of navigational instruments have been recovered from this vessel; however, details were not available at the time of this analysis.

Further information about the instruments recovered would assist in the inclusion of more details in the future.

The VOC vessel, *Batavia*, was lost on June 4, 1629 on Morning Reef, Beacon Island, Western Australia. Found in 1963, the site suffered some deterioration from treasure hunters. Australia passed legislation protecting the site in 1964. The site was professionally excavated between 1972 and 1976 by the Western Australian Maritime Museum. According to the on-line database (Western Australia Maritime Museum 2004), an extensive navigational collection has been recovered. Concretions were used to make replicas of navigational instruments that had entirely corroded underwater. However, at least 5 astrolabes were recovered partially intact. Two screws were recovered. While the excavators did not state it, these screws might belong to either a cross staff or back staff instrument. Three items were recovered that might belong to one or more compasses. Two triangular needles and another piece with graduations on the edge were found. In addition, 12 sounding leads were recovered from the site (Western Australian Maritime Museum 2004). This incredible collection is the largest, next to that of *LaBelle*, of any surveyed for this analysis, likely due to the extensive length of the voyage and the inability of the vessel to gain replacement instruments until arriving in Jakarta, Indonesia, its intended port.

A vessel excavated from 1991 to 1996, called alternately the "Pipe Wreck" or the "Monti Christi Wreck," has been dated to between 1652 and 1665. The vessel was either English or Dutch and contained a pair of dividers. The site is located in the northwest corner of the Dominican Republic, churned by heavy seas and nearly completely encrusted in coral (Beshears 1993:123-129). No excavation appears to have been done in some time and no photo or description of the dividers is available for analysis.

The VOC vessel *Lastdragger* (or *Lastdrager*) was lost off Crooks Ayre, north of Cullivoe, Scotland on March 2, 1653. The site was found in 1971 and excavated by the Government of the Netherlands in association with the Zetland County Museum between 1971 and 1972. *Lastdragger* yielded what is believed to be the largest collection of navigational instruments from an archaeological site in the period with an impressive 88 artifacts, 80 of which are dividers in 4 types. Due to interest in collecting scientific instruments in the Far East, it appears that 72 of the dividers were being shipped as cargo. They were recovered concreted in a single block in the hold and have been stamped with a fleur-de-lis on one side. In addition, 6 portable sundials and a sounding weight were recovered. The most unique find was a *brachiolus* of brass and copper for a "Dutch mariner's astrolabe". This is an articulated arm with three joints used for calculations on an astrolabum catholicum. Sténuit believes that this was attached to a cheap, simplified variety of this instrument, based on "iconographic and printed documents" in the period. The inexpensive version of this instrument would have had a hardwood or cardboard backing, thus has not survived in the archaeological record (Sténuit 1974:226-235). This is the only instrument of its kind ever recovered from an archaeological site. The astrolabum catholicum was designed to be an astrolabe on one side and an adapted form of astrolabe that can be used at any latitude on the other side. A magnetic compass was included as part of the instrument (Morrison 2004). In this period, this is also the first mention of a pocket sundial found on an archaeological site, although they were likely in use earlier than this time.

A support vessel in Oliver Cromwell's fleet called the *Swan* was destroyed on September 13, 1653. Also called the "Duart Point Wreck," this vessel was located in Scotland in 1979 and excavated by the Scottish Maritime Studies Department at St. Andrews University under the direction of Colin Martin from 1993 to 1994. A nearly intact compass binnacle with two compasses, one with gimbal ring, was found on the site. Burn marks on the binnacle indicate that the lamp scorched the wood at some time. The damage was repaired using iron nails, which would have adversely affected the accuracy of the compass (Martin 2001). Since the binnacle found on *San Juan* was nearly a century older than that recovered from *Swan*, they provide valuable tools for analysis in the evolution of the binnacle.

Wrecked off Ledge Point, north of present day Perth, Australia, on April 28, 1656, the VOC vessel *Vergulde Draeche* (alternatively *Vergulde Draeck* or *Vergulde Draak*) contained a rich cargo. The *Vergulde Draeche* was found in 1963 and recovery of coins led to treasure hunters blasting on the site several times later that same year. The site was officially excavated by the Western Australian Maritime Museum in 1972. Records are incomplete and the site was heavily disturbed; however, a sounding lead and astrolabe were recovered (VOC Shipwrecks 2002c). Other navigational instruments may or may not have been recovered by treasure hunters.

The VOC vessel *Avondster* wrecked near Galle, Sri Lanka on July 2, 1659. The Maritime Archaeology Unit and conservation laboratory have been formed under the Mutual Heritage Centre, managed by the Central Cultural Fund in cooperation with the Amsterdam Historical Museum, the University of Amsterdam, and the Western Australian Museum. The site is partially buried in an area which receives fresh water after heavy rains. This has kept salinity in the water low at times and led to significantly slower degradation of the artifacts. The vessel is readily accessible, so it is assumed that some treasure hunting activities have disturbed the site integrity. A sounding lead with an arming hole was recovered from the site and several other sounding leads, of unknown antiquity, have been recovered in other areas of the Galle Harbor (Barnes, Parthesius, and van Duivenvoorde 2002; Maritime Lanka 2003). Should enough sounding leads be recovered, it might be possible to develop a typology for this generally overlooked instrument.

The VOC vessel *Kennemerland* wrecked on the Stura Stack, Outer Skerries, Scotland on December 20, 1664. While the wreck was scavenged in 1665, modern surveys and excavations were carried out in 1978-1979, 1984, 1987, and 1988. Navigational artifacts recovered include 3 sounding leads, one pair of dividers, and a sundial rim (Muckelroy and Price 1974:263-264;

1977:207). A pocket sundial in perfect condition was also recovered. It was preserved so well that the paper compass card was intact and able to be read. This complete sundial was similar to that found on the *Lastdragger* (Sténuit 1974:229, 231; Muckelroy and Price 1977:212). An extraordinary find was a sight vane transom of an early backstaff, the only one recovered from an archaeological site in the period. The transom predates those surviving on land by 40 years (Muckelroy and Price 1977:210). The survival of this portion of a backstaff highlights the vital ability of archaeology to provide information on practical use.

Often navigational items are misidentified due to lack of expertise. I believe that several instruments have been mislabeled in *Kennemerland* site reports due to these problems. While two “egg-shaped” tobacco boxes were recovered and could not be part of the navigational tool kit, it is possible that an additional two boxes recovered could be examples of Dutch logs, as discussed in Chapter IV. While the decoration on the top and rim of the boxes are described in the site report, any incised detail on the underside of the box lid was not included (Muckelroy and Price 1974:264). Without this information, it is impossible to conclude positively that these are Dutch logs; however, the possibility remains. Additional research should be performed because, if these are Dutch logs, they are the only ones surviving from the period.

In addition, slates and pencils recovered from the *Kennemerland* are likely part of the log board or boards. Parts of several slates and at least one complete, semi-circular slate have been found. In addition, 4 slate pencil pieces have been recovered. Muckelroy and Price state that they believe that these drawing slates are actually log boards (1974:266). Additional research on these artifacts, and other similar finds from *HMS Dartmouth* (1690) and the Jutholmen wreck (1700), both discussed below, could be very influential in correctly categorizing navigational artifacts of the period.

Santíssimo Sacramento, also known as *Sacramento* or *Galeão Sacramento*, served as *almiranta* of a fleet maintained by the General Commercial Company of Brazil. After sinking in All Saints Bay, Brazil, on May 5, 1668, the *Sacramento* was subject to some illegal scavenging. The Government of Brazil sponsored excavation between 1976 and 1978, and again from 1982 to 1983. A bronze astrolabe is inscribed with 16… and has a maker's mark …OVS. The last two digits and the first letter were undecipherable. Another astrolabe, 5 brass dividers, and several sounding weights of various sizes were also recovered (Mello 1979:218-219; Guedes 1981). It would be very helpful to compare these dividers and sounding leads to others in the period to discover what was actually being taken to sea in the period and what navigators could afford to purchase for use.

The Royal Ship, *Kronan*, capsized, exploded, and sank off the coast of Öland Island, Sweden on June 1, 1676. Anders Franzén found *Kronan* in 1980 and Kalmar Läns Museum began excavations in 1981. A nine-drawer cabinet was recovered the first year, containing a variety of drafting instruments, including a protractor, a set of straight or “basic” dividers with nib attachment, and a second style of dividers without attachments. It is likely that this cabinet belonged to one of the ship’s officers. Between the lower and orlop decks, 2 intact sandglasses were discovered. Their miraculous state of preservation was the result of being embedded in rope and cloth remains. The larger sandglass would have been used for keeping watches, whereas the smaller one could have been used with a logline. An officer’s pocket sundial was also recovered (Johansson 1985:80, 83, 105, 245; Kalmar Museum 2004a, 2004b). These are the only intact sandglasses recovered from this period.

The ill-fated La Salle expedition left several wrecks in Matagorda Bay, Texas, including the *LaBelle*, a naval barque wrecked sometime in January 1686. The Texas Historical Commission excavated the wreck in 1996-1997. The navigational instruments recovered included a compass gimbal, 2 sounding leads, portions of several sandglasses, 12 dividers, 2 cross staff aperture disks, and a nocturnal/ planisphere. The extensive collection of navigational artifacts may again be the result of an expedition to areas where replacement instruments could not be readily obtained (Texas Historical Commission 2005). Additional analysis of all navigational instruments recovered from *LaBelle* will be discussed in Chapter VI.

HMS Dartmouth, a fifth rate frigate, wrecked in the Sound of Mull, Scotland on October 9, 1690. Found in 1973, the site was excavated by Colin Martin of the Scottish Institute of Maritime Studies between 1974 and 1977

(Delgado 1998:121-122). Three intact log slates were recovered from this wreck. They were semi-circular and have a hanging hole on one edge (Adnams 1974:271). These slates could be compared to those portions recovered from *Kennemerland* to see if they are of similar types.

The shipwreck of the *HMS Sapphire* in the Bay Bulls Harbor of Newfoundland on September 11, 1696 provides an excellent example of the type of comparisons possible by the survey of navigational instruments. Due to the fact that both *HMS Sapphire* and *HMS Dartmouth* are fifth rate frigates, these sites have been excavated and analyzed together by the archaeologists involved. While no nocturnal was recovered from *HMS Dartmouth*, an exquisite nocturnal was recovered in excellent condition from *HMS Sapphire*, which wrecked only six years later. The paint used to highlight the incised numbers has survived, which is rare. This nocturnal is also the closest archaeological find comparable to the nocturnal face of the *LaBelle* nocturnal/planisphere discussed further in Chapter VI. A variety of other navigational instruments were recovered, but published sources do not list these individually, so further analysis is impossible at this time (Battcock 2004).

An unidentified three-masted, trading ship sank near Dalaro, Stockholm, Sweden around 1700. Known as the “Jutholmen Wreck,” this site forms the final wreck in this survey. The site was found in 1965 by Sven-Olof Johansson and excavated between 1970 and 1974. The lid of a brass pocket compass with engraved sundial was recovered along with 2 log slates. Five halves of sandglasses were found made of pale or dark green glass, one still containing its filling sand. A pocket sundial and 2 sounding leads were recovered in good condition. Two dividers were recovered that resemble those found on *Batavia* (Green 1975) and *Lastdrager* (Sténuit 1974)(Cederlund and Ingelman-Sundberg 1973:321; Ingelman-Sundberg 1976:57-58, Figure 3).

Archaeological Navigation Instrument Analysis

This survey has provided extensive information on the instruments actually utilized at sea between 1500 and 1700 as shown in the archaeological record. Tables 1 through 4 place the finds within the categories utilized in Chapter IV in order to present the data in a systematic order. Due to insufficient information, *Nassau* and *Vasa* have been removed from these tables. A comparison of instruments recovered on multiple sites dated to the same period has not previously been completed with regard to navigational instruments.

Table 1 is a compiliation of artifacts that are, or could be, part of positional instruments such as cross staffs, back staffs, quadrants, and/or astrolabes. As previously mentioned, cross staffs, back staffs, and quadrants do not survive well in the archaeological record because they are largely made of wood. Thus, in most cases all that has been recovered is a screw or the aperture disks. The number of astrolabes recovered may be a function of the increased suvivability of the instrument, due to its heavy, metallic construction. While several English and French vessels were surveyed, all the astrolabes were recovered from

Portuguese, Spanish, or Dutch vessels, which could be an indication of preferential use by mariners from these countries.

TABLE 1
POSITIONAL INSTRUMENTS LISTED CHRONOLOGICALLY BY TYPE

Date	**Number**	**Instrument**	**Site**
1554	1	Cross staff screw?	*Esperitu Santo*
1622	1	Cross Staff	*Nuestra Señora de Atocha*
1629	2	Cross staff screws?	*VOC Batavia*
1686	2	Cross Staff Aperture Disks	*LaBelle*
1686	1	Cross staff screw?	*LaBelle*
1664	1	Back staff Transom	*Kennemerland*
1606	1	Quadrant (partial)	*Nossa Senhora dos Mártires*
1554	3	Astrolabes	*Esperitu Santo*
1588	2	Astrolabes	*Gerona*
1606	3	Astrolabes	*Nossa Senhora dos Mártires*
1610	2	Astrolabes	*Nossa Senhora da Graça*
1615	1	Astrolabe	*VOC Banda*
1622	5	Astrolabes	*Nuestra Señora de Atocha*
1622	3	Astrolabes	*Santa Margarita*
1629	5	Astrolabes	*VOC Batavia*
1653	1	Astrolabum Catholicum brachiolus	*VOC Lastdragger*
1656	1	Astrolabe	*VOC Vergulde Draeche*
1668	2	Astrolabes	*Santíssimo Sacramento*

Table 2 is a compiliation of navigational instruments used to determine direction, depth, or speed. This category includes compasses, with their associated binnacles and gimbals, as well as sounding leads. The final two sections of the table contain instruments that, in my opinion, should be included in this category and have been misidentified by excavators. The number of compasses and sounding leads recovered dating thoughout the period indicates the widespread use of these instruments by mariners of all countries. No log lines have been recovered from archaeological contexts, likely due to its light-weight construction and organic materials. However, the probable recovery of two Dutch logs from the *Kennemerland* indicates that it is possible for the more sturdy, Dutch version of this instrument to survive. Perhaps further research will discover additional Dutch logs in collections. Finally, *Kennemerland*, *HMS Dartmouth*, and the Jutholmen Wreck all contain slates. Historical documents state that slate was used to keep the daily record of the vessel's speed, course, and other information before being transferred into the permanent log book. The slates all date to between 1664 and 1700, which may indicate increased use in this period. Again, these items have been consistantly misidentified by excavators and it is likely that further research will reveal these on other sites.

TABLE 2
DIRECTION, DEPTH, AND SPEED INSTRUMENTS LISTED CHRONOLOGICALLY BY TYPE

Date	**Number**	**Instrument**	**Site**
1516	2	Compass arrows	*Lomellina*
1545	2	Compasses	*Mary Rose*
1565	1	Compass	*San Juan*
1565	1	Compass Binnacle	*San Juan*
1588	1	Compass	*Trinidad Valencera*
1629	1	Compass edge?	*VOC Batavia*
1629	2	Compass needle	*VOC Batavia*
1653	1	Compass Binnacle	*HMS Swan*
1653	2	Compasses	*HMS Swan*
1653	1	Gimbal Ring	*HMS Swan*
1686	1 or 2	Gimbal Ring(s)	*LaBelle*
1545	1	Sounding Lead	*Mary Rose*
1554	2	Sounding Leads	*San Esteban*
1588	2	Sounding Leads	*Gerona*
1606	3	Sounding Leads	*Nossa Senhora dos Mártires*
1622	1	Sounding Lead	*Santa Margarita*
1622	3 or 4	Sounding Leads	*Nuestra Señora de Atocha*
1629	12	Sounding Leads	*VOC Batavia*
1653	1	Sounding Lead	*VOC Lastdragger*
1656	1	Sounding Lead	*VOC Vergulde Draeche*
1659	1	Sounding Lead	*VOC Avondster*
1664	3	Sounding Leads	*Kennemerland*
1668	several	Sounding Leads	*Santíssimo Sacramento*
1686	2	Sounding Leads	*LaBelle*
1664	2	Dutch logs?	*Kennemerland*
1664	several	Log Boards/Slates?	*Kennemerland*
1664	1	Log Board/Slate	*Kennemerland*
1664	4	Slate Pencil pieces	*Kennemerland*
1690	3	Log Boards/Slates	*HMS Dartmouth*
1700	2	Log Boards/Slates	Jutholmen Wreck

Table 3 includes all the course and timekeeping instruments, such as nocturnals, sandglasses, and pocket sundials. Historical records show that the nocturnal fell out of use as other instruments with greater accuracy, such as the marine chronometer, came into use. The fact that no nocturnals have been recovered from Dutch, Spanish, or Portuguese vessels, although many have been excavated from this period, could indicate that predominately English and French mariners used the nocturnal. Mariners of all nations used sandglasses, according to contemporaneous records; however, sandglasses have only been recovered from French and Swedish vessels in this survey. In the cases of the *Kronan*, *LaBelle*, and Jutholmen Wreck, the survivals of the sandglasses appear to be fortunate happenstances of the disposition of artifacts. Records of the *Lomellina* are incomplete and the actual location of the sandglass on the site is unknown. The popularity of pocket sundials in the mid- to late-17th century is reflected in the archaeological record in this survey. The recovery of a pocket compass and sundial from the Jutholmen Wreck provides additional evidence of the use of the pocket compendium at sea. The development of the marine chronometer in the early 18th century superseded all three instruments, due to its accuracy.

TABLE 3
COURSE AND TIMEKEEPING INSTRUMENTS LISTED CHRONOLOGICALLY BY TYPE

Date	**Number**	**Instrument**	**Site**
1686	1	Nocturnal/Planisphere	*LaBelle*
1696	1	Nocturnal	*HMS Sapphire*
1516	Fragments	Sandglass(es)	*Lomellina*
1676	2	Sandglasses	*Kronan*
1686	Fragments	Sandglass(es)	*LaBelle*
1700	5 halves	Sandglass(es)	Jutholmen Wreck
1653	6	Pocket Sundials	*VOC Lastdragger*
1664	1	Pocket Sundial rim	*Kennemerland*
1664	1	Pocket Sundial	*Kennemerland*
1676	1	Pocket Sundial	*Kronan*
1700	1	Pocket Sundial	Jutholmen Wreck
1700	1	Pocket Compass with Sundial	Jutholmen Wreck

The final table, Table 4, includes all the drafting instruments recovered from a variety of sites between 1545 and 1700. The widespread use of dividers, as well as the tendency for navigators to carry spare pairs, has lead to a plethora of these instruments surviving in the archaeological record. The popularity of dividers in the East as trade items led to the shipping and archaeological recovery of 80 dividers from a single vessel, the VOC *Lastdragger*. The protractor recovered from *Kronan* was unique, in that it is the only one recovered from an underwater site. Commonly, protractors and other charting tools only survive as sets in historical collections on land. While charts rarely survive due to their organic nature, the rare find of charts aboard *Mary*

Rose indicates that charts, and other organic materials, can survive if they are protected enough and inundated quickly after being immersed.

TABLE 4
DRAFTING INSTRUMENTS LISTED CHRONOLOGICALLY BY TYPE

Date	**Number**	**Instrument**	**Site**
1545	2	Dividers	*Mary Rose*
1554	2	Dividers	*San Esteban*
1588	1	Dividers	*Trinidad Valencera*
1588	5	Dividers	*Gerona*
1606	2	Dividers	*Nossa Senhora dos Mártires*
1622	2	Dividers	*Nuestra Señora de Atocha*
1652-1665	1	Dividers	Pipe Wreck
1653	80	Dividers	*VOC Lastdragger*
1664	1	Dividers	*Kennemerland*
1668	5	Dividers	*Santíssimo Sacramento*
1676	2	Dividers	*Kronan*
1676	1	Protractor	*Kronan*
1686	12	Dividers	*LaBelle*
1700	2	Dividers	Jutholmen Wreck
1545	Fragments	Chart(s)	*Mary Rose*

Cederlund and Ingelmen-Sundburg (1973:325) mention that navigational instruments, in general, lack typological and chronological classification. Archaeologists have believed that these instruments have not undergone enough change to be analyzed in this manner. In fact, using only the instruments listed in this survey, a basic typology is possible, as the form, design, materials, and other factors do alter over time in an appreciable way. A compendium of information, and perhaps photographs, of the artifacts listed in

Tables 1 through 4 would assist future archaeologists in developing a chronological classification system. This system would provide the basic types needed for archaeologists to compare new finds to old finds, thereby more closely dating the artifacts.

CHAPTER VI

LABELLE CASE STUDY: NAVIGATION INSTRUMENTS AND NAVIGATORS

In order to demonstrate the avenues of research available on navigational instruments, a closer look will be taken at the artifacts recovered from the *LaBelle* excavation. This chapter will follow the artifacts from France with the LaSalle expedition through their deposition, excavation, and conservation. Each artifact will be considered in turn. The artifacts are divided into two sections. The first section contains those artifacts that were correctly identified by excavators and placed in the navigational tool kit. A separate section details the investigations into other artifacts that later proved to be part of the navigational instruments. The chapter will conclude with a look at the captains and navigators of the LaSalle expedition and their expertise in navigation, as reflected in historical and archaeological records.

Introduction to the LaSalle Expedition

The expedition of René Robert Cavelier, Sieur de LaSalle, left France on August 1, 1684 with 4 vessels and 280 people to start a colony near the mouth of the Mississippi River (Weddle 2001). According to survivors, in January 1686, six of the crew of *LaBelle* took the ship's boat to get water, but the men were attacked by animals and killed. The ship's master on *LaBelle* became drunk and could not navigate. Driven by thirst and desperation, the remaining crew tried to sail for LaSalle's base at Ft. St. Louis. A hard, northerly wind drove the ship onto Matagorda Peninsula. The wreck of the *Belle* in January 1686 doomed the colony, since most of the stores were destroyed (Weddle 2001:12).

Site Deposition and Excavation

The deposition and excavation of the site are difficult to analyze due to several factors. The vessel appears to have been quickly inundated by the dense clay and silt sediment, as evidenced by the recovery of organic remains in good condition. During the years between deposition and excavation, the site was exposed by wave action on several occasions. Evidence for this exposure is derived from encrustations of oyster shells in layers on parts of the site. The shells were one-half inch to 3 or 4 inches in diameter, meaning that the site was exposed for a 6 month to 3, 4, or 5 year period at various times. The site had virtually no overburden or corals at the time of excavation. Records from the excavation of *LaBelle* were compromised by confusion in record keeping during the project. Information is different, even conflicting, for specific artifacts and no information is available on the predominant area of the navigational instrument finds. The known wave action likely moved instruments, making this information of negligible value even if it was available. Lack of information could also be due to the cofferdam excavation technique utilized to recover *LaBelle* artifacts, which required draining the site.

Artifacts Identified During Excavation

The Texas Historical Commission recovered 19 navigational instruments during the excavation of *LaBelle* between 1996 and 1997. The artifacts related to the navigation of *LaBelle* comprise one of the most specialized categories of materials recovered during excavation. These artifacts not only provide insight into navigational tools and techniques used during the voyage, but also reflect the art of navigation as practiced in the late 17th century. This section presents detailed analyses of the compass gimbal or gimbals, sounding leads, sandglasses, and dividers recovered from *LaBelle*.

Compass Gimbal or Gimbals {Artifact #7795}

In order to insure that the compass remained level despite the movement of the ship, two large brass rings, called “gimbals” supported the compass. These were particularly common for steering compasses in the binnacle as discussed in Chapters IV and V. Excavators recovered portions of a collection of objects that could have formed a gimbal (Figure 14), but the association of these artifacts is unclear. Since it was smaller and poorly preserved, it is unclear whether this was another compass gimbal, since other items onboard, such as lamps, utilized gimbals as well in the period.

The intact gimbal (Figure 15) exhibits five holes and a peg; when the peg is connected with the fifth hole, the remaining four align perpendicularly to each other. The gimbal’s diameter measures 8 inches (20cm) and it averages 0.28

FIGURE 14. A partial gimbal? (Photo taken by author. Used with permission of Texas Historical Commission, Austin, TX.).

FIGURE 15. A complete gimbal. (Photo taken by author. Used with permission of Texas Historical Commission, Austin, TX.).

inches (7mm) wide. Considering that the compass would have been slightly smaller than the diameter of the gimbal, an estimated diameter of the compass would be in the 4.8-6.4 inches (12-16cm) range. Excavators failed to locate any lodestones, needles, boxes, covers, cards, or pivot pins for this compass.

As previously mentioned, multiple compasses were commonly carried on board, so this lack could be due to the lightness of the objects and the history of the site being exposed. Unfortunately, evidence for the binnacle has not survived, if it was used at all.

Sounding Leads {Artifact #3419-21}

FIGURE 16. Large sounding lead (abraded rope hole-inset left; arming tallow hole-inset right). (Photo taken by author. Used with permission of Texas Historical Commission, Austin, TX.).

Conservators discovered two sounding leads inside containers recovered intact from the site as encrusted features and excavated in the laboratory. The largest sounding lead (Figure 16) measures 13.25 inches (33.1cm) in length and weighs 11.65 pounds (5.3 kg). The lead exhibits crude manufacture and heavy use, with some bending along its shank. It also shows extensive wear and additional augmentation of lead at its top where the line attached. The application of additional lead is not even. Several gouges are apparent along its side and faint angles along the body of the artifact suggest that it initially may have been octagonal. Unfortunately extensive wear obscures much of the surface detail. A nearly 1 inch (2.45cm) arming hole in its base allowed the insertion of wax or tallow for sampling of the seafloor, see inset lower right.

The second, smaller sounding lead (no photo or catalog number available) was recovered from a chest found in the boatswain's locker. This chest also contained a broken sword hilt, axes, knives, and other tools. Little information is available pertaining to the artifact other than it appears octagonal and is smaller. It also contains a void in its base for the insertion of tallow or wax and fragments of the line attached to its head appear to be preserved. Both leads are coastal sounding leads, primarily useful in shallower depths. The fact that both were found enclosed in containers suggests that they may have been consigned for scrap, rather than serving as the primary instruments for depth sounding during the voyage. The fact that heavier, deep sea leads were not found could indicate that these were previously salvaged or lost. It is likely that these leads were being kept for use if the more valuable leads were lost or for later melting down for another use.

Sandglasses {Artifact #11660}

Archaeologists recovered fragments of at least three different sandglasses from the site. No photos or drawings of these are available. The best preserved fragment is a nearly complete bulb measuring 4.48 inches (11.2cm) in length with a maximum diameter of 3 inches (7.5cm). None of the supporting wooden structure survived. The size of the sandglass generally provides a poor indication of its running time, as the diameter of the hole in the metal piece joining the two bulbs, the grain size and the volume of the filling all factored in the amount of time the glass measured (Turner 1998:13-14). With a reconstructed total length approximating 8.8 inches (22cm) and a maximum diameter of 3 inches (7.5cm), based on reproduction sandglasses, it is estimated that the *LaBelle* sandglass could have regulated a range of ten to thirty minutes of time. The other sandglass pieces found are too fragmentary for speculation.

Dividers

Archaeologists recovered ten dividers from the site, in three general types: chart compasses (Figure 17:2370), straight compasses (Figure 17:13207), and straight compasses incorporating a ring for ease of opening (Figure 17:11746 and 1588). By the mid-16th century instrument makers

FIGURE 17. Selection of dividers, from left to right (2370 with attachments-lower left, 13207, 11746-top right, and 1588-lower right). (Photo taken by author. Used with permission of Texas Historical Commission, Austin, TX.).

designed variations made of bronze with interchangeable steel legs (Hambly 1988:69). Thus the fine steel points could be changed if dropped or bent, or other types of legs could be attached, such as inking nibs (Figure 17:lower left) or pencil-holders. Five of the compasses incorporate removable points. One example, artifact number 2370, exhibits the letters "TP" on one leg. The chart compasses are easily identifiable by the hemispherical curves in the legs where they attach to the hinge. Table 5 lists the dividers recovered from *LaBelle*, with type, dimensions, and leg type included for comparison purposes.

TABLE 5
DETAILS OF DIVIDERS RECOVERED FROM *LABELLE*

Artifact No.	Type	Length	Width (max.)	Leg Type
2370	straight	5.0in. (12.5cm.)	0.6in. (1.5cm.)	Removable (Intact)
1640	straight	3.1in. (7.75cm.)	0.6in. (1.5cm.)	Removable (Missing)
13207	straight	4.1in. (10.25cm.)	0.2in. (0.6cm.)	Permanent
3794.5	straight	6.3in. (15.8cm.)	0.6in. (1.5cm.)	Permanent
3099	straight/ring	3.5in. (8.75cm.)	0.8in. (2.0cm.)	Removable (Missing)
11746	straight/ring	3.5in. (8.75cm.)	0.8in. (2.0cm.)	Removable (Missing)
1588	chart	3.3in. (8.35cm.)	1.3in. (3.25cm.)	Removable (Missing)
4953	chart	4.2in. (10.6cm.)	1.4in. (3.4cm.)	Permanent
5817.2	chart	3.0in. (7.6cm.)	1.4in. (3.5cm.)	Permanent (Broken)
11232	chart	4.1in. (10.25 cm.)	1.4in. (3.5cm.)	Permanent

Artifacts Identified During Conservation

As previously mentioned, navigational instrument collection remained incomplete until after conservation due to two main factors. First, *LaBelle* artifacts were divided by material, so composite artifacts (items made of more than one material) were not conserved or presented to experts as a group. For example, a compass is mainly comprised of wood, glass, and brass. Each of these materials, when recovered, was separated from the other items for processing and analysis. Several items were found in the conservation lab that, if put together, might have comprised one or more compasses. A circular wooden box was recovered and placed in the wood collection. This artifact could have formed the case for a clock or compass, or could have been used for holding small items on a dresser. It was approximately the correct size for the complete gimbal, but this is inconclusive. A glass, concave lens, which might have fit the box, was placed in the glass collection. Again, this glass lens could have been the face of a clock or compass, the cover for the binnacle light, or some other item. Large numbers of brass and bronze pins, which could have served as orientation needles and/or pivots, of varying dimensions were also found, but placed together regardless of location of the find. Each of these artifacts was conserved separately and analyzed by a different expert. Generally, if a composite artifact is suspected, reference to the site notes regarding the original artifact location is helpful. However, in the case of *LaBelle*, the extensive number of recording errors on site, in regard to location and artifact numbers, makes original association of artifacts impossible to reconstruct. Thus, items that might have led to a greater understanding of the site, but were composite artifacts, remain mere pieces in the conservation lab.

Second, some navigational items were placed in a collection of unknown artifacts. For example, the two brass aperture disks were recovered from a collection of unidentified brass objects at the conservation lab. The expert analyzing the brass collection could not identify their function. Few brass aperture disks survive in historical collections, so their recovery from *LaBelle* provided valuable examples of the instrument. These disks were used in association with a colored piece of glass to shield the eyes. According to the expert analyzing the glass collection, no colored glass of the correct color or size was recovered; however, an uninformed excavator might have considered a colored piece of glass an intrusion into the site. Since only two colored lenses survive worldwide, the loss of this lens is unfortunate. Increased appreciation of the value of navigational instruments to reconstructing the history of the period, as well as increased education on the evolution of science among archaeologists, would increase the chance of correct identification in the future. The general consensus that the instruments have not altered over time has led to a situation where, if a specialist does not review all the wood, cupreous, ferrous, glass, and stone finds, often these instruments are classified as "unknown" or misidentified by excavators. Even when the instrument is identified in part, as the nocturnal was, only someone familiar with other contemporaneous artifacts might pursue additional relevant research.

<u>Cross Staff Aperture Disks and Screw {Artifacts #7482, #1591, and #5819-2}</u>

The cross staff aperture disks and screw are all integral to the use of a cross staff. As discussed in Chapter IV, the cross staff does not survive well in the archaeological record due to its mostly organic construction. Thus, evidence for one or more cross staff instruments being used relies on identification of metal components. Archaeologists recovered 2 brass cross staff aperture discs

(Figure 18) used to reduce glare when making solar observations. Unfortunately no references are made in historical documentation about the use of this instrument during the voyage.

FIGURE 18. Cross staff aperture disks (1591-top, 7482-bottom) (Photo taken by author. Used with permission of Texas Historical Commission, Austin, TX.).

FIGURE 19. Cross staff screw. (Photo taken by author. Used with permission of Texas Historical Commission, Austin, TX.).

The use of these brass apertures is more fully discussed in Chapter IV. The two disks recovered from *LaBelle* are of differing sizes. The larger piece (#1591) measures 1.97 inches (4.93cm) across the base, 1.66 inches (4.14cm) tall, and the aperture is 0.9 inches (2.33cm) wide. The smaller piece (#7482) is 1.65 inches (4.14cm) across the base, 1.56 inches (3.9cm) tall, and the aperture is 0.65 inches (1.62cm) wide. It could not be conclusively determined if these disks were designed for two different cross-staffs of differing size or two vanes of the same cross-staff, but of different widths.

Some doubt remains about the purpose of the screw (Figure 19) recovered from *LaBelle*. As noted in Chapter V, screws were also recovered from *Esperitu Santo* (1554) and the VOC vessel *Batavia* (1629). Arnold and Weddle suggest that such screws might have been part of a cross staff or perhaps a quadrant (1978:256). Overall the screw measures 2.2cm long and 0.9cm in maximum width. The head is small, cube shaped, and unslotted, measuring 0.4cm by 0.45cm in size. The threaded section is 1.5cm long.

Nocturnal/Planisphere {Artifact #11393}

The nocturnal/planisphere recovered from the site proved to be both unique and a source of extensive research. When *LaBelle* wrecked, the instrument fell serendipitously between the hull and a cannon, where it rapidly became encrusted (Helen DeWolf 2004, pers. comm.). Because the instrument was conserved in silicone oil, it could be easily handled and a variety of techniques were employed to complete the cleaning of the back dial, which had suffered from heavy concretions.

The instrument has been fabricated from small, straight-grained boxwood. The main plate is carved out of a single piece of wood and two dials are held onto the main plate by a brass bolt and nut (Figure 20). An index arm is attached above the obverse dial. The bolt is made of a sheet of brass, rolled into a cylinder. The cylinder appears to be carved externally with threads and on the obverse and reverse of the instrument these threads have been used to attach nuts. The overall length is approximately 23.8cm. The round area of the main plate measures approximately 13cm in diameter, but is not perfectly circular. The handle is approximately 10.8cm long. The obverse dial is 9.8cm in diameter and the reverse dial is 9.6cm in diameter. The index arm is 3.3cm wide, narrowing toward the end. Both obverse and reverse dials move freely. The obverse dial cracked and, during conservation, a third of the dial detached. This does not affect the analysis of the instrument as both pieces match well. The handle and the index arm have suffered some deterioration.

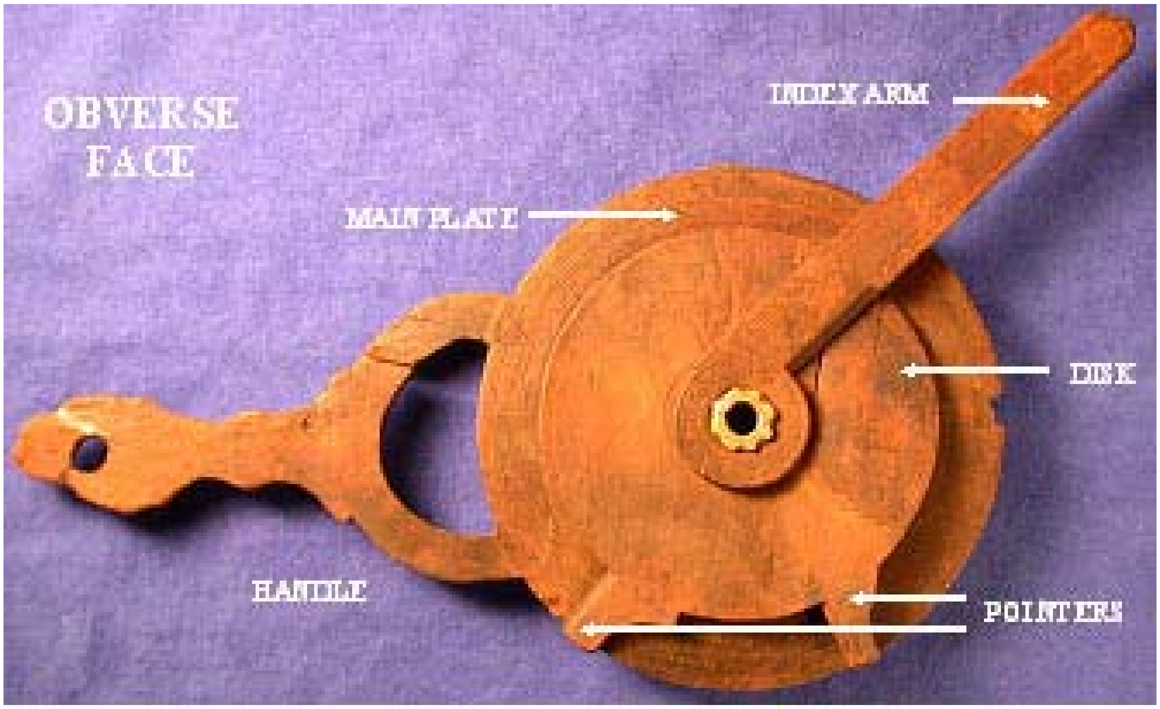

FIGURE 20. Nocturnal (obverse face). (Photo taken by author. Used with permission of Texas Historical Commission, Austin, TX.).

Though the instrument exhibits excellent preservation, some damage occurred during the shipwreck, recovery, and conservation process. A piece of the central plate snapped off before excavation. This was indicated by the encrustations found in the break (Helen DeWolf 2004, pers. comm.). The break impacted the scales directly across from the handle and a long crack runs toward the center of the instrument. Based on other instruments from the period, the broken piece was likely triangular. The ends of the handle and index arm were both broken, which probably occurred during the wrecking event. The handle end piece was recovered and will be reattached. The right side of the arch, looking at the face, also shows a serious crack, which has separated

FIGURE 21. Detail of nocturnal (obverse face). (Photo taken by author. Used with permission of Texas Historical Commission, Austin, TX.).

slightly. The instrument has been heavily inscribed on both sides of the main plate and both dials (Figure 21). The writing has been punched into the wood using hammered dies. The obverse side of the instrument is a universal nocturnal. The two pointers attached to the dial are stamped “LB” and “GB,” standing for “Little Bear” and “Great Bear”. A 32-point wind rose is inscribed in the center of the dial, surrounded by a Roman numeral scale (1-12 printed twice). Half of the points of the wind rose are scored as well.

On the outer scales, the zodiac and the calendar year are inscribed counter-clockwise (Figure 22). Both calendars are carefully cut into the individual

FIGURE 22. Edge detail of nocturnal (obverse face). (Photo taken by author. Used with permission of Texas Historical Commission, Austin, TX.).

days of the month. February, which is shown on the left side, is marked for 28 days. The other months have the appropriate number of days. The zodiac is marked with 30 days for each sign. The zodiac on the nocturnal is not for navigation purposes, but for astrological purposes. This combination of science and superstition is common in the Renaissance period. For example, two 16th century, French nocturnals were found to have charts of “lucky” and “unlucky” days.

The reverse side of the instrument is a type of planisphere (Figure 23). Three scales are written counter-clockwise on the edge of the reverse of the instrument (Figure 24). The inner-most scale shows 360° at the top, with the numbers decreasing by 10° counter-clockwise. Then, a Roman numerical scale, marked in fourths indicating 15-minute intervals, is inscribed. It should be noted

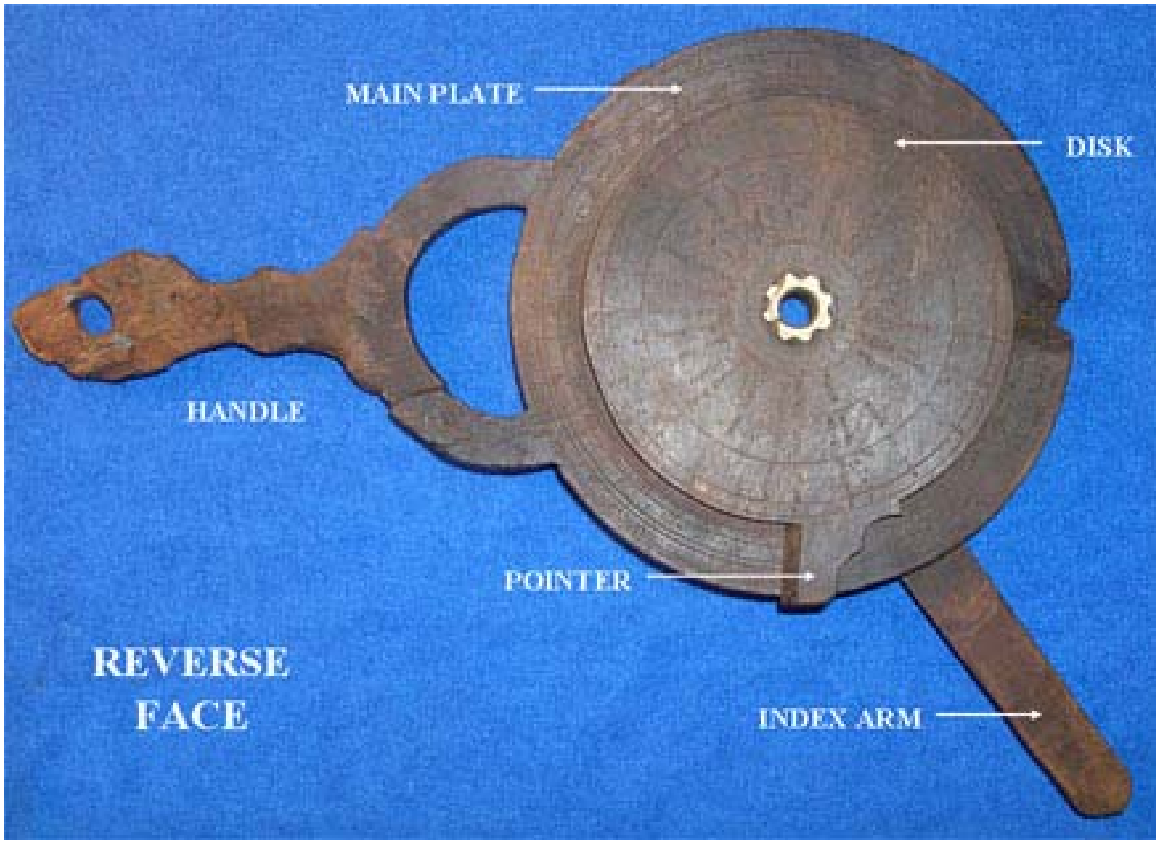

FIGURE 23. Detail of planisphere (reverse face). (Photo taken by author. Used with permission of Texas Historical Commission, Austin, TX.).

FIGURE 24. Edge detail of planisphere (reverse face). (Photo taken by author. Used with permission of Texas Historical Commission, Austin, TX.).

that this scale serves as a 24-hour clock such that 0 is Midnight and 12 is Noon. The edge of the main plate has another calendrical year, nearly identical to that on the obverse. The months of the year are written in their complete, modern, English spellings, with the common substitutions present in the printing of the era. For example, the upper case "V" has been substituted for "U" and "I" for "J" and, at least one lower case "s" has been rendered "f" (a long "s"). The number four has been rendered "IIII" rather than the modern "IV." This is common on clocks of the period and found on dials when Arabic numerals are not utilized.

The dial attached to the reverse side has only one pointer. The dial contains a list of stars and constellations used for navigation, listed spoke-wise around the center of the dial (Figure 25). Two numbers are listed next to each star, separated from the name by a line that forms a circle around the dial. The

FIGURE 25. Detail of constellation layout on planisphere (reverse face). (Photo taken by author. Used with permission of Texas Historical Commission, Austin, TX.).

first number represents the angle of ascension in degrees of the constellation or the star itself. The use of the second number listed is unknown, but it is possible that it corresponds to a text, now lost, that gave further information about the constellation or star. Then, another vertical line is drawn and an “N” (northern latitude) or an “S” (southern latitude) is listed on the edge of the dial (Don Corona 2003, pers. comm.).

Table 6 lists all the constellations on the planisphere, in order clockwise, with the modern star name and modern designation. Of the 27 constellations inscribed on this planisphere, only 4 were undecipherable and one of these was partially discernable. The stars suggested in the 3 remaining constellations can be estimated with fair accuracy, given the standardized nature of the instrument. Gerard L.E. Turner’s text, *Elizabethan Instrument Makers* (2000), shows that all of the constellations on the planisphere were commonly used in England for navigation at least 100 years before *LaBelle* sailed. Also, the stars are listed in order of rising, by season, giving the largest portion of the dial to 13 constellations most readily visible during the spring months (48%). This is likely because of the large number of ships leaving Europe for the New World colonies during the spring months. Constellations rising in autumn, winter, and summer are nearly equal in number, listing 7, 5, and 6, respectively.

Some of the constellations in Table 6 are located in the southern latitudes, while others are located in the northern latitudes. This would have been necessary because moving below 20° north latitude would make some constellations, like the Crab, difficult to locate for navigational purposes. Also, traveling into northern latitudes would make some of the more southern constellations, such as Scorpius and Sagittarius, difficult to use. Sighting these constellations and stars helped determine correct course through the night.

TABLE 6
CONSTELLATIONS INSCRIBED ON THE PLANISPHERE

Planisphere Text	**Star Name**	**Designation**
Pegas Mouth	Enif	ε Peg
Pegas Neck	Scheat	β Peg
Pegas Wing	Algenib	γ Peg
Androm Head	Alpheratz	α And
Whails Tail	Dipheda	β Cet
Androm Feet	Almach A	γ1 And
Perfeus (side?)	Marfak	α Per
Pleiades[a]	---	o Per, β Cas, or ξ Per
Buls Eye	Aldebaran	α Tau
Orions Foot	Rigel	β Ori
Orions Shoulder	Betelgeuse	α Ori
Orions Belt[b]	Alnitak A or Mintaka	ζ1 Ori or δ Ori
Lit Dog Thigh	Procyon	α CMi
The Crab	Asellus Australis	δ Cnc
Heirs Heart	Alphard	α Hya
Lions Heart	Regulus	α Leo
---[c]	(likely) Spica	α Vir
---[d]	(likely) Vindemiatrix	ε Vir
Lions Tail	Denebola	β Leo
M___ea Tail[e]	---	---
---[f]	Zubeneschmali	β Lib
South Balance	Zubenelgenubi	α2 Lib
Bright Guard	Arcturus	α Boo
Scorpio Head	Dschubba	δ Sco
Hercules Head	Rasalgethi	α Her
The Harp	Vega	α Lyr
Swans Bil	Albireo	β1 Cyg
Eagles Heart	Altair	α Aql
Dolphin Tail	Deneb	ε Del

(Dolan 2004; Lesikar 2004; Wright 2004).

[a] The Pleiades is a group of seven stars, so the specific star is uncertain. These are the three most commonly used for navigation.

[b] Three stars form Orion's Belt. These two stars, on the left and right side, both carry the idea of "belt" in their Arabic names. The middle star, Alnilam (ε Ori), does not.

[c,d] Both stars are in the same constellation, Virgo. If so, these stars are most likely candidates.

[e] The central line refers to a group of three stars in or near the constellation of Draco; however, the original writing remains too blurred to know which stars for certain.

[f] Unable to be deciphered. The star is in Libra, likely the northern pan star, which is noted.

The names used to refer to the constellations and stars (Table 6: Column 1) were not the academic names utilized in observatories across Europe, but more colloquial terms familiar to sailors. Often what is inscribed is actually an English translation of names used as far back as Classical times, and perhaps even before, when men first went to sea. Each of the names is associated with a nearly direct translation from Latin, Greek, or Arabic. Another example, termed on the instrument the “L-I-T Dog Thigh” derives from all three languages. The star today, known as Alpha Canis Minoris, was sometimes called “Procyon” in Greek, “Antecanis” in Latin, or “Al Shi'ra Shamiyyah” in Arabic, all referring to the before or front of a dog. Thus, this planisphere is among the rarest of finds, one that gives us insight into the received oral traditions of sailors in a time when few literary references survive.

Don Corona, a teacher in the Texas A&M University Department of Physics performed a variety of experiments to determine the accuracy of the instrument. Researchers have noted that misplacing even one line on the dial could cause an error in the reading of +/- 1/2° or more, thereby adversely affecting the navigation of the vessel. After using the instrument for several nights at the Texas A&M University Observatory, Corona reported that the instrument is extremely accurate. This nocturnal is unusual in that no attempt has been made to show the equinoxes, tides, lunar calendar, or seasonal delineations, which is common on other nocturnals of this period (Don Corona 2003, pers. comm.).

The two sides of the instrument were designed to be used in tandem. First, the navigator read the time indicated on the nocturnal or obverse side. Then, using this information, the navigator turned the instrument over and read the planisphere side. The pointer was then moved to coincide with the date and time of the nocturnal observation. Using the Roman numeral scale, the navigator could read which constellation or stars were directly overhead at any given hour. The inscriptions are in order of appearance directly overhead year-round.

A variety of celestial projections survive from the 16th century, including the nautical hemisphere by Charles Witwell (c. 1597), a horary quadrant by William Senior (1600), and two compendiums by Elias Allen (c. 1610-1615). The nautical hemisphere, horary quadrant, and one of the compendiums use many of the same constellations; however, these instruments are pictorial, rather than written as on the *LaBelle* planisphere. The other compendium by Elias Allen is more similar to the *LaBelle* planisphere. While the spoke-like listing and meridian use are similar, the *LaBelle* planisphere contains 27 constellations and stars, whereas Allen's compendium only lists twelve. This could be due to size constraints, as the compendium is about half the size of the instrument recovered from *LaBelle.*

Markings on the nocturnal (obverse) face of the instrument provide an example of the type of information that can be gleaned from an object only after conservation. The top arrow shows some of the wear marks on the face of the obverse dial (Figure 26). The marks could be from a buckle on a carrying case or could derive from readings taken between four and five, when the navigator could have marked the dial with a sharp tool, like a divider, to hold his place. It is clear that the navigator liked to make marks, since a small "X" can be clearly seen, written between V and VI on the rim of the dial. This mark could be from a final reading taken on *LaBelle*. While there is no conclusive evidence, tantalizing clues are available for further research.

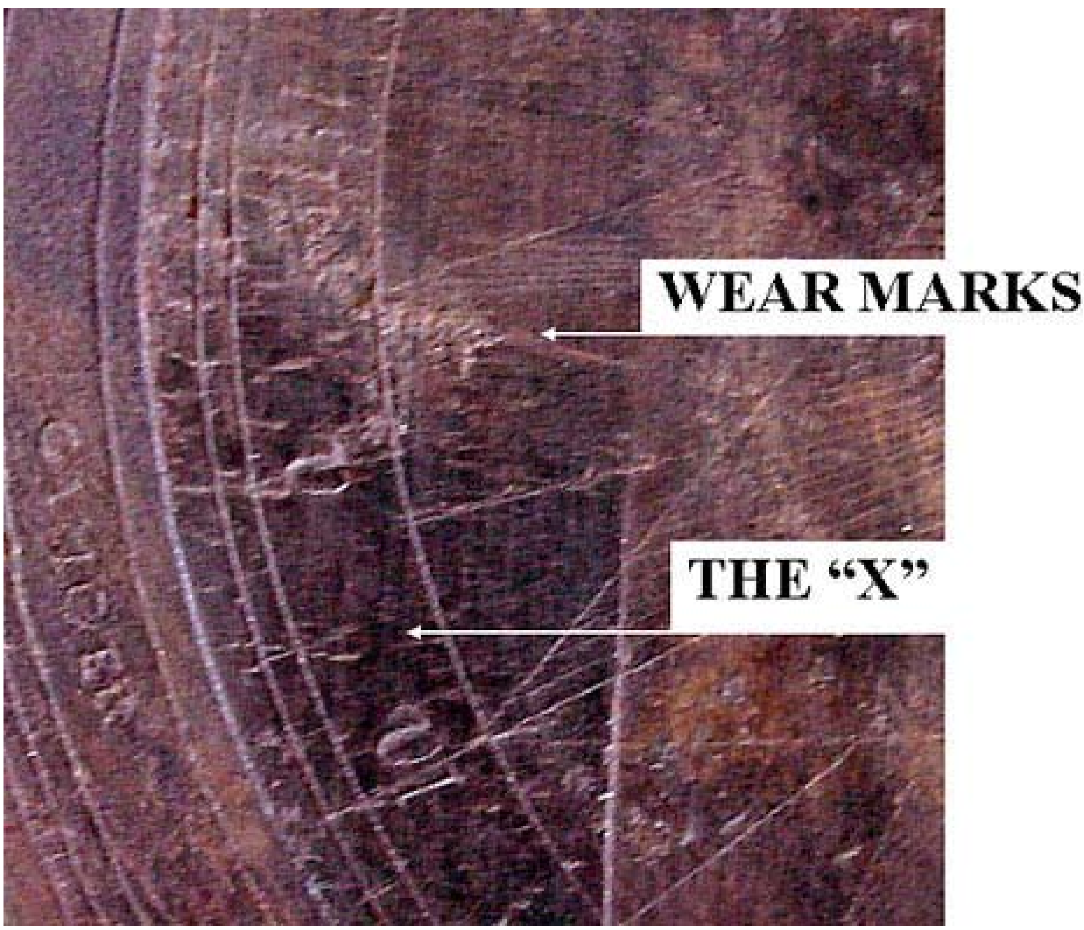

FIGURE 26. Detail of wear marks and the mysterious "X" on the nocturnal (obverse face). (Photo taken by author. Used with permission of Texas Historical Commission, Austin, TX.).

The vessel arrived in Matagorda Bay on February 18, 1685. This would have been the last time that the nocturnal was used for navigation. According to historical documents (Weddle 2001), only three people on *LaBelle* could have owned or used the instrument: LaSalle, Captain Daniel Moraud, and Head Pilot Elie Richaud. We know that LaSalle took his instruments on exploration and, as the nocturnal was also used on land, he would not have left it behind on the ship. Captain Moraud died soon after arriving and Head Pilot Richaud died on a shore expedition in November or December 1685. So after arriving, the only person who could have taken a reading was Head Pilot Elie Richaud. He was killed during a shore expedition in January 1686.

For example, if we suppose that this small "X" was written when *LaBelle* arrived on February 18th, we might even discover if it was the morning or evening. First, we know the star had to be high enough in the sky to take a reading and, second, the sky had to be dark enough to see Polaris. Regressed star charts reveal that Polaris was visible both in the morning and the evening, but it was not high enough at 5:30pm to take an accurate sighting. Also, the United States Naval Observatory reports that the sky was not dark enough to see Polaris until after 6:39pm on the 18th, so the reading was likely taken in the morning.

In conclusion, research has confirmed that this unique instrument is a precise, 24-hour timepiece created by an astronomical master with extensive knowledge of the celestial sphere. The instrument was almost certainly made by someone who was an astronomer himself or in close association with a person fully and fluently conversant in astronomy. In many ways, the research has shown that this unique instrument highlights the pivotal role navigation played in the exploration and colonization of the New World, as well as the value of interdisciplinary analysis in artifact conservation.

Navigator's Tool Kit and Expertise

Historical documents, such as diaries, letter, ship manifests, and state documents, related to LaSalle's voyage have survived and those involved are known. The archaeological record at *LaBelle* and Fort St. Louis confirms that the captains, pilots, and navigators of the expedition were armed with some of the best tools, knowledge, and techniques available in their time. LaSalle had significant skills in navigation, as did the captain of the *Joly*, Tanguy Le Galois de Beaujeau. François Guitton and Christopher Gabaret served as navigators on the *Joly*. Claude Aigron captained *l'Aimable*, with Zacharie Mengaud serving as his navigator. Daniel Moraud was captain of *LaBelle*, with 20 year old Elie (Hélie) Richaud as navigator, and perhaps another pilot only referred to as Sellié. Finally, the ketch *Saint-François* carried a nine-man crew led by Captain Paul Giraud or Girault (Weddle 2001:5-6, 166).

Two crew members whose records of the voyage survive, Henri Joutel and Jean-Baptiste Minet, make frequent navigational references in their journals. The fleet's position was often an issue of intense debate between LaSalle and his navigators over the course of the voyage. Elie Richaud even went so far as to keep a secret record containing his own computations, as he was convinced (rightly so) that they had passed their intended landfall during the search for the Mississippi River (Weddle 2001:7).

The journals of Henri Joutel and Jean-Baptiste Minet frequently provide both latitude and longitude figures; the former determined by observations of the sun or pole star, the latter estimated based on direction and speed of the vessels. One of the few exceptions occurred on December 21, 1684, when, during an eclipse of the moon Minet noted their longitude based on the difference between the anticipated time of the eclipse in Paris compared with the local time of the event.

Minet writes:

> The 21st calm. At noon a little wind. Latitude 25º 09'. Eclipse of the moon. Its largest blackout at 5:20. Its end, which I most noticed, at 6:20 in the evening We were here, according to the altitude at the time of the eclipse, at 25º 16'. Having made four leagues NNW since noon, at Paris, according to the reckoning of time, it should end at 12:27. Thus, the longitude from here to Paris is six hours and seven minutes, which are 91º 45' (Weddle 1987:92).

The journals refer to particular navigational instruments being used on all the vessels of the expedition. A variety of instruments existed for making the celestial observations required for determining latitude in the late 17th century and there is evidence that navigators utilized different devices on the voyage. Minet used a quadrant belonging to the captain of the *Joly* for determining latitude, mentioning in his journal that the instrument's radius measured a foot and a half (Weddle 1987:92). The size of the quadrant bore a direct relationship to its accuracy: the larger the instrument, the more accurate its reading. The need for accuracy was tempered by the restrictive space restrictions onboard a ship. The relatively small dimensions of Beaujeau's quadrant would likely have been an attractive feature for ocean navigation, where a degree of precision was sacrificed for portability and ease of use at sea. Operating the instrument on land increased its accuracy somewhat, and in fact, most navigators preferred making their observations ashore whenever possible. The Spanish sailors who conducted searches for the French colony employed a quadrant with a radius of "three spans" as well as an astrolabe for determining their latitude (Weddle 1987:135).

The journals of the expedition also record the expertise of the navigators, as well as, in some cases, their deaths. Captain Moraud was 30 years old when he became captain and readings taken by him indicate that he was skilled in navigation. He died soon after arriving in Matagorda Bay. Elie Richaud became navigator of *LaBelle* at 20 years of age. His log book excerpts, recorded in Joutel's journal, indicate a well-educated, well-spoken man, with a careful eye for weather and climate conditions. His notes indicate that he took his position seriously. Richaud was well respected by LaSalle and was made captain of *LaBelle* after Captain Moraud's death. Richaud was attacked and killed by wild animals during a shore expedition after serving only 15 or 16 months (Joutel 1962:5, 11-12, 151).

Navigational instruments played a central role in the narrative of LaSalle's final voyage, from celestial observations in determining latitude to the soundings of coastal waters and bays in the quest for exploration. Debate over the mariners' positions relative to the Mississippi River abound in both Joutel's and Minet's journals. Disagreements regarding the water depth at the mouth of Matagorda Bay factored into the grounding of *l'Aimable* and the loss of a large portion of the supplies the colony depended upon for survival. The navigational artifacts recovered from *LaBelle* provide mute testimony not only of the tragic tale of LaSalle's final voyage, but of the developments and limitations of navigational science at the waning of the 17th century.

CHAPTER VII

CONCLUSION

After reviewing the history, literature, instruments, and artifacts from 1550 to 1700, several important points can be made. The invention and innovation of navigational instruments, begun under the Italians, was adopted by the Portuguese and later acquired by the Spaniards. England was able to build upon this rich heritage, developing new and more accurate instruments. The independence of England's scholars and craftsmen from direct royal control so evident in Portugal and Spain led to a situation wherein commerce, business, and science could work in tandem on the problems faced by navigators. England also benefited from the advances in metallurgy, technology, and scientific philosophy of the later period in which it was most active. The interactions between mathematics, astronomy, and cartography/hydrography, and advances made in each of these disciplines, directly affected the practice and precision of navigation.

A wide variety of literature was available for navigators during this period. Early literature consisted of almanacs and navigation teaching texts. These texts were first compiled by the Portuguese, and then translated into Spanish. A number of teaching texts, as well as nautical dictionaries, were first published in Spain and later translated into English. Teaching in astronomy and mathematics played a vital role in improving the ability of navigators to correctly determine their position at sea. Nearly all navigation literature in the period contained some reference to astronomy and mathematics for this reason. Two later forms of literature emerged: the journals and books related to maintain a course, as well as “word books”. The combination of brief journals, traverse books, and logbooks provide a systematic, detailed record of many voyages, allowing the re-creation of the course today. Word books were fundamental to training new captains, especially in the late 17th century. In the early 18th century, the sustained popularity of navigation as a field of study is shown by extensive reprinting of earlier texts. Additional research is needed to determine the utility of these texts in educating navigators as well as their prevalence at sea, as they do not survive in the archaeological record.

The instruments used by navigators became more specialized, precise, and varied between 1500 and 1700. Until the 16th century, navigation depended on experience, sound common sense, and good seamanship. Using only a compass, lead, and line, navigators estimated the direction and speed of winds, tides, and currents, using these to estimate the vessel’s position by “dead reckoning.” By 1700, a navigator needed to possess and operate some or all of the following instruments: mariner’s astrolabe, ring-dial or pocket sun-dial, nocturnal, a tide-computer, a lodestone and compass, an azimuth compass, back staff or Davis quadrant, sounding leads and lines, a traverse board, a log and line, log board, and running glasses. His drafting instruments could include dividers, rulers, protractor, terrestrial globe, plain-scale, Sector or Gunter’s

Scale, as well as plane, circumpolar, and/or Mercator chart projections. He might also have a telescope and or a six-inch dial watch. By this time, navigators relied heavily on mathematical calculations and tables. Navigators were also required to be literate, as well as proficient in geometry, calculus, astronomy, geography, and cartography. Clearly, the profession of navigator had undergone a fundamental revolution, leaving behind its superstitious roots for the realm of scientific endeavor.

While history records many instruments that were developed and/or utilized at sea, actual popularity and usefulness are difficult to determine given the enthusiasm of the makers, whose books form our primary source material. Archaeology provides the a valuable quantifier of which instruments were preferred and of the most practical use. The archaeological finds on the 27 vessels analyzed in Chapter V begin to shed light on this quandary. At least 230 instruments, in whole or in part, are represented by this survey. The lack of a typological system hinders further analysis of these instruments, but the mere number involved indicates that such a classification system is possible.

The case study of the instruments recovered from *LaBelle* shows that navigation, as practiced aboard this French naval vessel, was consistent with that used on ships of other nations in the period. The presence of the compass (or compasses), as represented by the gimbals, the sounding leads, the sandglass (or sandglasses), and the dividers demonstrate their value, as understood and derived from centuries of use at sea. In contrast, the presence of highly specialized instruments, such as the cross staff aperture disks and the nocturnal/planisphere, point to navigation experts, trained to utilize more recent inventions. Taken together, the navigation collection represents both traditional customs and more contemporary training among the French pilots and captains on LaSalle's expedition. Unfortunately, their combined training and expertise did not compensate for the lack of knowledge on the subject of longitude in the period.

Overall, the analysis of the navigator's toolkit would be greatly improved if archaeologists would begin understand the relevance of navigation to the overall analysis of their sites. Voyages of exploration, trade, colonization, and conquest would have been difficult without transoceanic navigation techniques. The improvements in the science and technology of navigation led to safer, faster, more economical voyages, leading to greater global interaction. Precision in vessel location caused fundamental changes in the way that Europe engaged in naval conflicts in the period, giving rise to highly organized naval tactics called "line-of-battle." This required large vessels to be arrayed in specific locations in relation to each other, to move precisely, and to interact without damage. Pilots and navigators in such a situation would have had to be amply trained to excel in such a situation.

Further investigation is needed in many areas to attain a more complete picture of the development of knowledge and instruments in navigation. For example, the historical record is clear that navigational knowledge was passed from English prisoners to their captors, the Barbary pirates. Too little is known about how navigational knowledge spread between peoples, from Arabs to Europeans, from Europeans to Japanese, etc. Second, the factors leading to the increase in the number and mobility of merchants and craftsmen in the pivotal Renaissance period of European history is largely unstudied. Another area that has received little attention is the history of the Portuguese instrument making trade. While exploration, history, politics, and economics of the burgeoning Portuguese involvement is well known, where they made or purchased their instruments and how they learned to use them has not been studied.

The training of pilots and navigators deserves further research as well. Obviously the size of the vessel has a direct impact on both its use and, by extension, the training required of the navigator or pilot. A 1,000 ton vessel handles very differently from a 30 ton one. Also, how were pilots and navigators trained in naval tactics or naval gunnery? Finally, during the course of exploration, pilots and navigators encountered a variety of climates, fauna, winds, currents, instrument variations, charting problems, and other challenges. How were they taught to deal with these dangers? Piloting a ship through polar ice has particular difficulties not encountered in dodging reefs in the South Pacific. Perhaps in the future these and other related subjects will receive academic attention and answers will be discovered.

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APPENDIX A

COMPLETE ALPHABETICAL LIST OF VESSELS INVESTIGATED

Ship Name	**Wreck Date**
Alderney Elizabethan Wreck (Alderney Wreck)	before 1588
Angra D	1575
Bahía Mujeres	Early 16th century
Beurtschip Wreck (Oost Flevoland B 71, the Lelystad Buertschip)	late 16th century/1619
Blackfriars Wreck II	17th century
Blessing	July 10, 1633
Brouwershavensche Gat. Wreck	exact date unknown
BZN-10 Wreck	c. 1650
Calvi I Wreck	1500s
Cape Canaveral Wreck	17c
Cattewater Wreck	1495-1530
Cayo Nuevo (Bajo Nuevo)	Early 16th century
Dry Tortugas Wreck (Deep Water Wreck)	1622
Dubrovnik Galleon	exact date unknown
El Gran Grifon	September 27, 1588
Emanuel Point Wreck (El Jesus?)	1559
Esperitu Santo	April 29, 1554
Esselholm Wreck	exact date unknown
Flevoland Barge	16th century
Flor de la Mar	1512
Girona (La Girona)	October 26, 1588
Hasten Wrecks (Stockholm)	c.16th century
Heartscove Wreck	exact date unknown
Henrietta Marie (The English Wreck)	1700
Highborn Cay	Early 16th century
HMS Anne	1690
HMS Dartmouth	October 9, 1690
HMS Kronan	June 1st, 1676
HMS Sapphire	September 11, 1696
HMS Sussex	February 19, 1694
HMS Swan (Duart Point Wreck)	September 13, 1653
HMS Swan (Port Royal Shipwreck)	1692
HMS Winchester	September 24, 1695
Hollandia	1627
IDM-002 (Fort San Sebastian Wreck)	c.1610

Ship Name	**Wreck Date**
Inês de Soto	c. 1556 or 1572
Jesús María de la Limpia Concepción de Nuestra Señora la Capitana (La Capitana)	1654
Jupiter Wreck (San Miguel el Arcangel?)	1659/1660
Jutholmen Wreck	1700
Ketelhaven	16th century
Kravel Wreck (Possibly "Swan"?)	1522/1525
LaBelle	January 1686
La Capitana	1503-04
La Condesa	1555
La Gallega	1503
La Nicolasa	1526
La Rondinara	1500s-1600s
La Therese	1600s
Lake Garda Galley	1509
Langesund Fjord Wrecks	exact date unknown
L'Anse aux Bouleaux Wreck (Sir William Phip's Wreck, "Elizabeth and Mary," or "Hannah and Mary")	July 1690
L'Assure Wreck (Santa Catalina Wreck)	1692
Lomellina (Villefranche-ser-mer Wreck)	September 1516
Lossen Frigate Wreck	1679
Lundeborg	1600
Maasilinn Wreck	1568
Margam Wreck	1500s
Mariposa Wrecks	exact date unknown
Mary (royal yacht)	March 25, 1675
Mary Rose	July 19, 1545
Molasses Reef Wreck (Turks Caicos Wreck)	1518 (?)
Mukran Wreck	May 21, 1565
Mulan Wreck	1611/1612 (?)
Mullion Cove Wreck (San Salvador?)	1600s
New Old Spaniard Wreck	exact date unknown
Noordoostpolder Wreck	17th Century
Nossa Sanhora da Atalaia do Pinheiro	1647
Nossa Senhora da Conceição	1621
Nossa Senhora da Graça (Madre de Deus)	1610
Nossa Senhora da Luz	1615
Nossa Senhora dos Mártires (Pepper Wreck, São Julião da Barra 2)	September 15, 1606
Nuestra Senhora de Maravillas	1656
Nuestra Señora de Atocha	1622

Ship Name	**Wreck Date**
Nuestra Señora de la Concepción (Almirante Wreck)	October 31, 1641
Nuestra Señora de la Concepción	September 20, 1638
Nuestra Señora del Pilar de Saragoza y Santiago	June 2, 1690
Nuestra Señora del Rosario (Fuxa Shipwreck, FOJE-UW-9)	1622
Pipe Wreck (Monti Christi Wreck)	1652-1665
Pwll Fanog (Slate Wreck)	1500s
Rill Cove	1616 (?)
Rye A	exact date unknown
Saint John’s Bahamas	1555-1575
Sainte Dorothéa	1693
San Agustin	November 1595
San Antonio	1621
San António	1527
San Diego	1600
San Esteban	1554
San Juan (Red Bay Whaler, Basque Whaler)	1565
San Juan de Sicilia (St. John, Tobermory Treasure Wreck)	May 11, 1588
San Martin (Green Cabin Wreck)	1618
Santa Catarina de Ribamar	1636
Santa Christo de Castillo (Pin Wreck, Mullion Cove Wreck)	exact date unknown
Santa Helena	1626
Santa Lucia (Yarmouth Roads Wreck)	1567
Santa Margarita	1622
Santa Maria de la Rosa	1588
Santa Maria de Yciar	1554
Santa Maria Madre de Deus	1643
Santiago	1585
Santiago de Palos	1503-04
Santíssimo Sacramento	1647
Santíssimo Sacramento (Sacramento, Galeão Sacramento)	May 5, 1668
Santo Alberto	1593
Santo António	1589
Santo Antonio de Tanna (Mombasa Wreck)	1697
Santo Espiritu	1608
Santo Inácio de Loiola	1633
São Bartolomeu	1626
São Bento	1554

Ship Name	**Wreck Date**
São Gonçalo (Plettenberg Bay Wreck)	1630
São João	1552
São João Baptista	1622
São Lesmes	exact date unknown
São Pedro	1596
Scheurrak SO1	December 24, 1593
Scheurrak T24 (Inschot, Zuidoostrak)	1655
Sea Venture (Bermuda Wreck, Sea Adventure, Seaventure, or Seaventer)	July 1609
Seahawk (Buen Jesus y Nuestra Senora del Rosario)	exact date unknown
Seychelles Wreck	1550s
Sharm-el-Sheik Mercury Wreck	exact date unknown
Shot Wreck	exact date unknown
Solon Wreck	1627
South Hole Sound Wreck	exact date unknown
Sovereign of the Seas	1637
Sparrow Hawk	1626
St. Anthony	exact date unknown
Stinesminde Wreck	1600
Stonewall Wreck	1650
Streedagh Bay Wrecks	1588
Studland Bay	1520s
Sunchi Reef Wreck	Early 17^{th} century
Texel Wreck	exact date unknown
Triall (Ritchies Reef Wreck)	1622
Trinidad Valencera (Balenzara)	September 16, 1588
Urca la Viga	1639
Utrecht	March 26, 1648
Vasa	August 10, 1628
Virginia Merchant	1660
VOC Avondster (De Avondster)	July 2, 1659
VOC Banda	March 6, 1615
VOC Batavia	June 4, 1629
VOC Campen (Needles Wreck)	1627
VOC Kennemerland	December 20, 1664
VOC Lastdragger (VOC Lastdrager)	March 2, 1653
VOC Mauritius	March 19, 1609
VOC Meresteyn/Merestein	April 4, 1702
VOC Nassau	August 18, 1606
VOC Oosterland	May 23, 1697
VOC Prinses Maria	1686

Ship Name	Wreck Date
VOC Tyjer/Tiger	1613
VOC Vergulde Draeche	April 28, 1656
VOC Witte-Leeuw	June 1, 1613
VOC Zeerobbe	1640s
Warwick Wreck (Burgzand Noord III)	1619
Waterschip	exact date unknown
Western Ledge Reef Wreck (Western Ledge Wreck)	1500s
Yassi Ada Wreck	1566-1590
Zuidelijk Peat Boat	exact date unknown
Zuider Zee Wreck	exact date unknown

APPENDIX B

COMPLETE CHRONOLOGICAL LIST OF VESSELS INVESTIGATED

Wreck Date	Ship Name
1495-1530	Cattewater Wreck
1500s	Calvi I Wreck
1500s	Pwll Fanog (Slate Wreck)
1500s	Western Ledge Reef Wreck (Western Ledge Wreck)
1500s	Margam Wreck
c.16th century	Hasten Wrecks (Stockholm)
16th century	Flevoland Barge
16th century	Ketelhaven
Early 16th century	Bahía Mujeres
Early 16th century	Highborn Cay
Early 16th century	Cayo Nuevo (Bajo Nuevo)
1503	La Gallega
1503-04	La Capitana
1503-04	Santiago de Palos
1509	Lake Garda Galley
1512	Flor de la Mar
September 1516	Lomellina (Villefranche-ser-mer Wreck)
1518 (?)	Molasses Reef Wreck (Turks Caicos Wreck)
1520s	Studland Bay
1522/1525	Kravel Wreck (Possibly “Swan”?)
1526	La Nicolasa
1527	San António
July 19, 1545	Mary Rose
1550s	Seychelles Wreck
1552	São João
April 29, 1554	Esperitu Santo
1554	San Esteban
1554	Santa Maria de Yciar
1554	São Bento
1555	La Condesa
1555-1575	Saint John’s Bahamas
c. 1556 or 1572	Inês de Soto
1559	Emanuel Point Wreck (El Jesus?)
1565	San Juan (Red Bay Whaler, Basque Whaler)
May 21, 1565	Mukran Wreck

Wreck Date	Ship Name
1566-1590	Yassi Ada Wreck
1567	Santa Lucia (Yarmouth Roads Wreck)
1568	Maasilinn Wreck
1575	Angra D
1585	Santiago
before 1588	Alderney Elizabethan Wreck (Alderney Wreck)
1588	Santa Maria de la Rosa
1588	Streedagh Bay Wrecks
May 11, 1588	San Juan de Sicilia (St. John, Tobermory Treasure Wreck)
September 16, 1588	Trinidad Valencera (Balenzara)
September 27, 1588	El Gran Grifon
October 26, 1588	Girona (La Girona)
1589	Santo António
1593	Santo Alberto
December 24, 1593	Scheurrak SO1
November 1595	San Agustin
1596	São Pedro
1500s-1600s	La Rondinara
1600s	La Therese
1600s	Mullion Cove Wreck (San Salvador?)
late 16th century/1619	Beurtschip Wreck (Oost Flevoland B 71, the Lelystad Buertschip)
17^{th} century	Cape Canaveral Wreck
17^{th} century	Blackfriars Wreck II
17^{th} century	Noordoostpolder Wreck
early 17^{th} century	Sunchi Reef Wreck
1600	Lundeborg
1600	San Diego
1600	Stinesminde Wreck
August 18, 1606	VOC Nassau
September 15, 1606	Nossa Senhora dos Mártires (Pepper Wreck, São Julião da Barra 2)
1608	Santo Espiritu
March 19, 1609	VOC Mauritius
July 1609	Sea Venture (Bermuda Wreck, Sea Adventure, Seaventure, or Seaventer)
c.1610	IDM-002 (Fort San Sebastian Wreck)
1610	Nossa Senhora da Graça (Madre de Deus)
1611/1612 (?)	Mulan Wreck
1613	VOC Tyjer/Tiger

Wreck Date	Ship Name
June 1, 1613	VOC Witte-Leeuw
1615	Nossa Senhora da Luz
March 6, 1615	VOC Banda
1616 (?)	Rill Cove
1618	San Martin (Green Cabin Wreck)
1619	Warwick Wreck (Burgzand Noord III)
1621	Nossa Senhora da Conceição
1621	San Antonio
1622	Dry Tortugas Wreck (Deep Water Wreck)
1622	Nuestra Señora de Atocha
1622	Nuestra Señora del Rosario (Fuxa Shipwreck, FOJE-UW-9)
1622	Santa Margarita
1622	São João Baptista
1622	Triall (Ritchies Reef Wreck)
1626	Santa Helena
1626	São Bartolomeu
1626	Sparrow Hawk
1627	Hollandia
1627	Solon Wreck
1627	VOC Campen (Needles Wreck)
August 10, 1628	Vasa
June 4, 1629	VOC Batavia
1630	São Gonçalo (Plettenberg Bay Wreck)
1633	Santo Inácio de Loiola
July 10, 1633	Blessing
1636	Santa Catarina de Ribamar
1637	Sovereign of the Seas
September 20, 1638	Nuestra Señora de la Concepción
1639	Urca la Viga
1640s	VOC Zeerobbe
October 31, 1641	Nuestra Señora de la Concepción (Almirante Wreck)
1643	Santa Maria Madre de Deus
1647	Nossa Sanhora da Atalaia do Pinheiro
1647	Santíssimo Sacramento
March 26, 1648	Utrecht
c. 1650	BZN-10 Wreck
1650	Stonewall Wreck
1652-1665	Pipe Wreck (Monti Christi Wreck)
March 2, 1653	VOC Lastdragger (VOC Lastdrager)
September 13, 1653	HMS Swan (Duart Point Wreck)

Wreck Date	Ship Name
1654	Jesús María de la Limpia Concepción de Nuestra Señora la Capitana (La Capitana)
1655	Scheurrak T24 (Inschot, Zuidoostrak)
1656	Nuestra Senhora de Maravillas
April 28, 1656	VOC Vergulde Draeche
July 2, 1659	VOC Avondster (De Avondster)
1660	Virginia Merchant
1659/1660	Jupiter Wreck (San Miguel el Arcangel?)
December 20, 1664	VOC Kennemerland
May 5, 1668	Santíssimo Sacramento (Sacramento, Galeão Sacramento)
March 25, 1675	Mary (royal yacht)
June 1st, 1676	HMS Kronan
1679	Lossen Frigate Wreck
1686	VOC Prinses Maria
January 1686	LaBelle
1690	HMS Anne
June 2, 1690	Nuestra Señora del Pilar de Saragoza y Santiago
July 1690	L'Anse aux Bouleaux Wreck (Sir William Phip's Wreck, "Elizabeth and Mary," or "Hannah and Mary")
October 9, 1690	HMS Dartmouth
1692	HMS Swan (Port Royal Shipwreck)
1692	L'Assure Wreck (Santa Catalina Wreck)
1693	Sainte Dorothéa
February 19, 1694	HMS Sussex
September 24, 1695	HMS Winchester
September 11, 1696	HMS Sapphire
1697	Santo Antonio de Tanna (Mombasa Wreck)
May 23, 1697	VOC Oosterland
1700	Henrietta Marie (The English Wreck)
1700	Jutholmen Wreck
April 4, 1702	VOC Meresteyn/Merestein
exact date unknown	Brouwershavensche Gat. Wreck
exact date unknown	Dubrovnik Galleon
exact date unknown	Esselholm Wreck
exact date unknown	Heartscove Wreck
exact date unknown	Langesund Fjord Wrecks
exact date unknown	Mariposa Wrecks
exact date unknown	New Old Spaniard Wreck
exact date unknown	Rye A

Wreck Date	Ship Name
exact date unknown	Santa Christo de Castillo (Pin Wreck, Mullion Cove Wreck)
exact date unknown	São Lesmes
exact date unknown	Seahawk (Buen Jesus y Nuestra Senora del Rosario)
exact date unknown	Sharm-el-Sheik Mercury Wreck
exact date unknown	Shot Wreck
exact date unknown	South Hole Sound Wreck
exact date unknown	St. Anthony
exact date unknown	Texel Wreck
exact date unknown	Waterschip
exact date unknown	Zuidelijk Peat Boat
exact date unknown	Zuider Zee Wreck

APPENDIX C

ALPHABETICAL TABLE OF VESSELS REMOVED FROM INVESTIGATION

Ship Name	**Wreck Date**
Beurtschip Wreck (Oost Flevoland B 71, the Lelystad Buertschip)	late 16^{th} century/1619
Calvi I Wreck	1500s
Cape Canaveral Wreck	17c
Cayo Nuevo (Bajo Nuevo)	Early 16^{th} century
Dry Tortugas Wreck (Deep Water Wreck)	1622
Dubrovnik Galleon	exact date unknown
Esselholm Wreck	exact date unknown
Flevoland Barge	16th century
Hasten Wrecks (Stockholm)	c.16^{th} century
Heartscove Wreck	exact date unknown
HMS Swan (Port Royal Shipwreck)	1692
Hollandia	1627
IDM-002 (Fort San Sebastian Wreck)	c.1610
Jupiter Wreck (San Miguel el Arcangel?)	1659/1660
Ketelhaven	16^{th} century
Kravel Wreck (Possibly "Swan"?)	1522/1525
La Condesa	1555
La Rondinara	1500s-1600s
La Therese	1600s
Langesund Fjord Wrecks	exact date unknown
L'Assure Wreck (Santa Catalina Wreck)	1692
Lossen Frigate Wreck	1679
Lundeborg	1600
Maasilinn Wreck	1568
Margam Wreck	1500s
Mariposa Wrecks	exact date unknown
Mullion Cove Wreck (San Salvador?)	1600s
New Old Spaniard Wreck	exact date unknown
Noordoostpolder Wreck	17^{th} Century
Nossa Senhora da Luz	1615
Nuestra Senhora de Maravillas	1656
Nuestra Señora del Rosario (Fuxa Shipwreck, FOJE-UW-9)	1622
Rye A	exact date unknown
Sainte Dorothéa	1693

Ship Name	Wreck Date
San Antonio	1621
San António	1527
San Martin (Green Cabin Wreck)	1618
Santa Catarina de Ribamar	1636
Santa Christo de Castillo (Pin Wreck, Mullion Cove Wreck)	exact date unknown
Santa Helena	1626
Santiago	1585
Santíssimo Sacramento	1647
Santo António	1589
São Bartolomeu	1626
São Bento	1554
São Lesmes	exact date unknown
São Pedro	1596
Scheurrak T24 (Inschot, Zuidoostrak)	1655
Seahawk (Buen Jesus y Nuestra Senora del Rosario)	exact date unknown
Seychelles Wreck	1550s
Sharm-el-Sheik Mercury Wreck	exact date unknown
Shot Wreck	exact date unknown
Solon Wreck	1627
South Hole Sound Wreck	exact date unknown
Sovereign of the Seas	1637
Sparrow Hawk	1626
St. Anthony	exact date unknown
Stinesminde Wreck	1600
Stonewall Wreck	1650
Streedagh Bay Wrecks	1588
Sunchi Reef Wreck	Early 17th century
Texel Wreck	exact date unknown
Urca la Viga	1639
Virginia Merchant	1660
VOC Prinses Maria	1686
VOC Tyjer/Tiger	1613
Warwick Wreck (Burgzand Noord III)	1619
Waterschip	exact date unknown
Western Ledge Reef Wreck (Western Ledge Wreck)	1500s
Yassi Ada Wreck	1566-1590
Zuidelijk Peat Boat	exact date unknown
Zuider Zee Wreck	exact date unknown

APPENDIX D

ALPHABETICAL TABLE OF VESSELS WITHOUT NAVIGATIONAL INSTRUMENTS

Ship Name	**Wreck Date**
Alderney Elizabethan Wreck (Alderney Wreck)	before 1588
Angra D	1575
Bahía Mujeres	Early 16th century
Blackfriars Wreck II	17th century
Blessing	July 10, 1633
Brouwershavensche Gat. Wreck	exact date unknown
BZN-10 Wreck	c. 1650
Cattewater Wreck	1495-1530
El Gran Grifon	September 27, 1588
Emanuel Point Wreck (El Jesus?)	1559
Flor de la Mar	1512
Henrietta Marie (The English Wreck)	1700
Highborn Cay	Early 16th century
HMS Anne	1690
HMS Sussex	February 19, 1694
HMS Winchester	September 24, 1695
Inês de Soto	c. 1556 or 1572
Jesús María de la Limpia Concepción de Nuestra Señora la Capitana (La Capitana)	1654
La Capitana	1503-04
La Gallega	1503
La Nicolasa	1526
Lake Garda Galley	1509
L'Anse aux Bouleaux Wreck (Sir William Phip’s Wreck, "Elizabeth and Mary," or "Hannah and Mary")	July 1690
Mary (royal yacht)	March 25, 1675
Molasses Reef Wreck (Turks Caicos Wreck)	1518 (?)
Mukran Wreck	May 21, 1565
Mulan Wreck	1611/1612 (?)
Nossa Sanhora da Atalaia do Pinheiro	1647
Nossa Senhora da Conceição	1621
Nuestra Señora de la Concepción (Almirante Wreck)	October 31, 1641
Nuestra Señora de la Concepción	September 20, 1638
Nuestra Señora del Pilar de Saragoza y Santiago	June 2, 1690

Ship Name	Wreck Date
Pwll Fanog (Slate Wreck)	1500s
Rill Cove	1616 (?)
Saint John's Bahamas	1555-1575
San Agustin	November 1595
San Diego	1600
San Juan de Sicilia (St. John, Tobermory Treasure Wreck)	May 11, 1588
Santa Lucia (Yarmouth Roads Wreck)	1567
Santa Maria de Yciar	1554
Santa Maria Madre de Deus	1643
Santiago de Palos	1503-04
Santo Alberto	1593
Santo Antonio de Tanna (Mombasa Wreck)	1697
Santo Espiritu	1608
Santo Inácio de Loiola	1633
São Gonçalo (Plettenberg Bay Wreck)	1630
São João	1552
São João Baptista	1622
Scheurrak SO1	December 24, 1593
Sea Venture (Bermuda Wreck, Sea Adventure, Seaventure, or Seaventer)	July 1609
Studland Bay	1520s
Triall (Ritchies Reef Wreck)	1622
Utrecht	March 26, 1648
VOC Campen (Needles Wreck)	1627
VOC Kennemerland	December 20, 1664
VOC Mauritius	March 19, 1609
VOC Meresteyn/Merestein	April 4, 1702
VOC Oosterland	May 23, 1697
VOC Witte-Leeuw	June 1, 1613
VOC Zeerobbe	1640s

APPENDIX E

ALPHABETICAL LIST OF VESSELS WITH NAVIGATIONAL INSTRUMENTS

Ship Name	**Wreck Date**
Esperitu Santo	April 29, 1554
Girona (La Girona)	October 26, 1588
HMS Dartmouth	October 9, 1690
HMS Kronan	June 1st, 1676
HMS Sapphire	September 11, 1696
HMS Swan (Duart Point Wreck)	September 13, 1653
Jutholmen Wreck	1700
LaBelle	January 1686
Lomellina (Villefranche-ser-mer Wreck)	September 1516
Mary Rose	July 19, 1545
Nossa Senhora da Graça (Madre de Deus)	1610
Nossa Senhora dos Mártires (Pepper Wreck, São Julião da Barra 2)	September 15, 1606
Nuestra Señora de Atocha	1622
Pipe Wreck (Monti Christi Wreck)	1652-1665
San Esteban	1554
San Juan (Red Bay Whaler, Basque Whaler)	1565
Santa Margarita	1622
Santa Maria de la Rosa	1588
Santíssimo Sacramento (Sacramento, Galeão Sacramento)	May 5, 1668
Trinidad Valencera (Balenzara)	September 16, 1588
Vasa	August 10, 1628
VOC Avondster (De Avondster)	July 2, 1659
VOC Banda	March 6, 1615
VOC Batavia	June 4, 1629
VOC Lastdragger (VOC Lastdrager)	March 2, 1653
VOC Nassau	August 18, 1606
VOC Vergulde Draeche	April 28, 1656

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2000 Who's Who in the World
National Dean's List
1999 Graduating Leadership Honors
Student Appreciation Citation for Leadership
Letter of Commendation from University Chancellor
Who's Who Among Students in America's Universities & Colleges

Selected Presentations and Publications:
2004 "Beyond Conservation: The Analysis of a Unique Instrument," presentation at the Annual Meeting of the Society for Historical Archaeology, St. Louis, Missouri, January 7-11, 2004.
2003 "Navigational Instruments," *LaBelle* Site Report, co-authored with Greg Cook, Texas Historical Commission, publication expected 2005.
"Maritime Research in the United Kingdom," *The INA Quarterly*, No. 3, Fall 2003.
Contributing Author, *Monarchies and Dynasties*. Book Builders, NY, NY (18 articles).
2002 Contributing Author, *Peoples of North America*. Brown Partworks, London, UK (26 articles).
Contributing Author, *United States-Mexico Border Encyclopedia*. Brown Partworks, London, UK (7 articles).
2000 "Maritime Transport of Slaves during the Islamic Classical Period", co-authored with Dr. Hassan Khalilieh, accepted for publication in *Studia Islamica.*