

Abstract

The Evolutionary Development of Floating Dry Docks

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The floating dry dock represents one of the most technologically advanced structures ever designed to operate in a maritime environment. These indispensable repair facilities provided necessary maintenance to commercial and naval fleets operating in waters where traditional graving dry docks were impractical or impossible to erect. As technological development allowed for construction of larger sailing and steam vessels, a corresponding progression ensued within the floating dry docks contracted to service and maintain all vessels, up to the largest ships of the day. By analyzing various models of technological evolution as they apply to developments within floating dry docks, the author asks whether their historical advancements qualify as evolutionary, or if individual docks developed solely in response to specific environmental constraints.

The Evolutionary Development of Floating Dry Docks

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By

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TABLE OF CONTENTS

LIST OF FIGURES.....	vii
CHAPTER 1: INTRODUCTION.....	1
Research Questions.....	4
Sources, Methodology, and Previous Research.....	5
Thesis Structure.....	6
CHAPTER 2: METHODOLOGY OF FLOATING DRY DOCK RESEARCH.....	8
Sources.....	8
Data Collection.....	11
Comparative Analysis.....	15
CHAPTER 3: APPLICATIONS OF TECHNOLOGICAL CHANGE THEORY TO THE EVOLUTION OF FLOATING DRY DOCKS.....	18
Introduction.....	18
Invention, Innovation, and Technological Change.....	20
Novelty and Acts of Insight.....	25
Diffusion and Adoption of Technology.....	28
CHAPTER 4: HISTORICAL DRY DOCKING TECHNOLOGIES.....	35
Introduction.....	35
Ancient Vessel Extraction.....	36
The Earliest Verified Graving Dry Dock.....	45
Careening.....	48
The Camel.....	53
CHAPTER 5: THE HISTORY OF FLOATING DRY DOCKS.....	57
Introduction.....	57

Arrival of the Floating Dock.....	59
Patents and the Early Floating Docks of the United States.....	66
The First Floating Docks of the United States Navy.....	75
Iron Floating Docks.....	81
Depositing, Off-Shore, and Double Power Docks.....	88
Early 20th Century Floating Docks.....	93
United States Naval Floating Docks and the Second World War.....	104
Floating Docks through Today.....	114
CHAPTER 6: ANALYSIS OF FLOATING DRY DOCK DEVELOPMENT.....	120
Introduction.....	120
Impetus for Change: Floating versus Graving Docks.....	121
The Cumulative Synthesis of Floating Dry Docks.....	128
Evolution and the First Bermuda Dock.....	131
Adoption and Diffusion of Floating Dock Technology.....	135
CHAPTER 7: CONCLUSION.....	143
Floating Docks as Evolutionary Technologies.....	143
The Significance of Floating Dock Evolution to Maritime History.....	146
Potential for Future Studies.....	150
Final Thoughts.....	152
REFERENCES.....	154

LIST OF FIGURES

FIGURE 1: The Cumulative Synthesis Approach to Technological Change.....	24
FIGURE 2: Market Forces of Technology Push and Market Pull.....	33
FIGURE 3: Cothon of Mahida.....	39
FIGURE 4: Satellite view of San Pantaleo Cothon.....	39
FIGURE 5: Loading and Unloading a Beached Vessel.....	41
FIGURE 6: T. W. Ward Shipbreaking Gridiron.....	43
FIGURE 7: Sketches Illustrating the Process of Careening.....	49
FIGURE 8: Breaming a Ship.....	51
FIGURE 9: Camel for Floating Ships.....	55
FIGURE 10: Lock Alternative designed by Meijer.....	60
FIGURE 11: Camel Dock.....	63
FIGURE 12: Watson Floating Dock.....	64
FIGURE 13: Adamson Floating Dock Patent Sketch.....	66
FIGURE 14: Covenhoven Patent Drawing.....	67
FIGURE 15: Clark Hydraulic Lift.....	69
FIGURE 16: Floating Graving Dock of Commodore Barron.....	70
FIGURE 17: Basic Operation of Floating Graving Dock.....	71
FIGURE 18: Patent Drawing of Thomas Sectional Floating Dock.....	73
FIGURE 19: Perspective view of Gilbert Balance Dock.....	76
FIGURE 20: Depiction of Joggled Frame Construction of Gilbert Dock.....	77
FIGURE 21: Charles Johnson Pneumatic Lift Dock.....	78
FIGURE 22: Perspective View of Sectional Floating Dock and Railways.....	79

FIGURE 23: Plan and Elevation Views of Sectional Floating Dock.....	80
FIGURE 24: Perspective View of Gilbert Balance Dock with Basin and Railways.....	80
FIGURE 25: Launching of the Callao Iron Sectional Dock.....	82
FIGURE 26: Scale Model of Bermuda Floating Dry Dock.....	85
FIGURE 27: Towing Bermuda Dock from England to Bermuda, 1868.....	85
FIGURE 28: Sketches of Standfield Self-Docking Design.....	87
FIGURE 29: Standfield Depositing Dock.....	90
FIGURE 30: Staging Area for Depositing Dock.....	90
FIGURE 31: Depiction of Potential Harbor Operation of Depositing Dock and Stage....	91
FIGURE 32: Self Docking of Barrow-in-Furness Depositing Dock.....	92
FIGURE 33: Havana Floating Dock.....	95
FIGURE 34: New Orleans Floating Dock lifting Battleship <i>Illinois</i>	97
FIGURE 35: Plan and Profile Views of New Orleans Dock Sketch.....	98
FIGURE 36: Cavite Floating Dock lifting <i>Maryland</i>	100
FIGURE 37: Standard Arrangement of Center and End pontoons of <i>Dewey</i>	100
FIGURE 38: Reinforced Concrete Hulled Floating Dock.....	103
FIGURE 39: <i>Dewey</i> Floating Dock Under Tow to Philippines.....	105
FIGURE 40: <i>ARD-1</i> Passing through Panama Canal Locks.....	106
FIGURE 41: Sketch of Proposed but Never Constructed <i>ARD-3</i>	107
FIGURE 42: USS <i>Shaw</i> On Fire in <i>YFD-2</i>	110
FIGURE 43: Magazine of USS <i>Shaw</i> Exploding while docked in <i>YFD-2</i>	110
FIGURE 44: <i>YFD-2</i> Capsized with Bow of USS <i>Shaw</i> still Afloat.....	111
FIGURE 45: <i>ABSD-1</i> with <i>Antelope</i> and <i>LST-120</i> in Dock.....	112

FIGURE 46: Side to Side Connection of ABSD sections.....	113
FIGURE 47: Using Hydraulic Jacks to Raise Section of Wing Wall of ABSD.....	113
FIGURE 48: Table of United States Naval Floating Docks in the Second World War....	114
FIGURE 49: Modern 300,00 ton lift caisson floating dock.....	116
FIGURE 50: Commercial Heavy Lift Ship MV <i>Blue Marlin</i>	117
FIGURE 51: Satellite View of Mort Dock, Sydney, Australia.....	150

CHAPTER 1: INTRODUCTION TO THE HISTORICAL ANALYSIS OF FLOATING DOCK EVOLUTION

Without exception, all vessels operating in a maritime environment eventually require maintenance stemming from their constant interaction with the destructive properties of navigable waterways. Marine borers, corrosion, fouling, leaking seams, and running aground represent a few of these deleterious actors directly affecting the vessel hull, which often necessitate the conducting of physical inspections and repairs, a challenging proposition for any craft while still afloat. In many cases involving small boats, operators simply hauled their vessel ashore or positioned it above shallow water during spring tides, beaching the vessel and exposing the lower strakes as the water slowly receded. This describes the generally accepted practice of docking for the greater part of human maritimistic endeavors. As the dimensions of vessels grew in response to various commercial and naval stimuli, ship carpenters desired a more effective means of accessing the hull, leading to construction of temporary brushwood and puddled clay coffer dams around a beached vessel at low tide, prolonging repair time by excluding water from the space immediately surrounding the craft (Goldingham 1918:489). From these simple excavations, an unnamed Phoenician living in Ptolemaic Egypt concocted a new method for launching a ship by increasing the size of the excavation and adding a wooden frame to support the vessel when drained, essentially designing the first historically documented graving dock during the 3rd century B.C. (Athenaeus 1854:325). Their crude construction and operation continued virtually unchanged until 1495 with construction of the large stone graving dock at Portsmouth, England (Oppenheim 1896a:39).

Beginning with a detailed look at some of the earliest docking systems employed throughout antiquity, including cothons and ship sheds dating back hundreds of years B.C., the

author attempts to uncover the means of servicing vessels employed by early seafarers, beyond simply beaching. The historical appearance of docking structures indicates people recognized quite early the need for frequent maintenance and repairs, if their craft were to remain operational in the long term. Though not necessarily qualifying as docks, ship sheds performed a similar function by hauling vessels above the tidal line, up an inclined ramp on a series of greased timber ways, with the intention of prolonging the operational life of a vessel through dry storage. Another early form of dock, Cothons, were square or rectangular excavations connected to a larger body of water, functioning essentially as wet docks but possessing a narrow entrance channel that, if potentially obstructed, could permit draining of the interior space in a fashion similar to graving docks. Whether individuals actually conducted repairs from within these nascent docking systems remains to this point unknown, though the capacity to do so certainly existed.

Historical records indicate similar early docking structures also existed in the Far East as early as the 11th century A.D., where the Song Dynasty Chinese constructed a graving dock for the storage and service of two large ceremonial ships, the description of which reads strikingly similar to the recorded construction methods employed in Ptolemaic Egypt during the 3rd century B.C. (Needham 1971:660). Approximately 1,200 years elapsed between these two early docks, and another 400 before construction of the first generally recognized graving dock at Portsmouth, England in 1495, potentially indicating a pattern technological development through of interactive diffusion or independent invention, as discussed in the following chapters.

The 15th and 16th centuries A.D. marked a period of significant expansion in the size of merchant vessels and warships in Northern Europe, both in dimensions and displacement, prompting the beginning of an increase in the appearance of graving docks required for their

service (Hocker 2004:79). Despite the early establishment of these basin dry docks, people sought simpler alternatives to this rather cumbersome system, particularly for conducting simple visual inspections or re-caulkings, leading to the practice of careening or heaving-down, first referenced historically in 1666 (Pepys 1666:190). Unfortunately, very few careenages or ancient graving docks survive in the archaeological record, owing to their often-temporary construction and necessary occupation of valuable shorefront land, placing an increased reliance upon historical documents and anecdotes for their information.

Nearly 200 years after construction of the 1495 Portsmouth dock, a British merchant captain operating in the Baltic Sea built the first crude floating dry dock from the body of a derelict hulk by removing the stern and replacing it with an improvised gate, mimicking the general operation of graving docks (Maxton 1899:66). With the hulk ballasted to a point of negative buoyancy, the stricken ship warped through the entrance, the gate closed and the interior space pumped dry, exposing the hull for repairs. In the process of pumping, the captain found the increased buoyancy created by draining the impounded space caused the hulk and dock to lift free from the bottom, spawning the term floating dry dock. Whether the captain intended for this or it occurred by sheer accident remains unknown, but this innovative rearrangement of existing technologies represented the beginning of a divergent lineage of new docking structures, directly descendent from the graving docks prevailing contemporaneously. An overview of observed developementary processes within the subsequent development and expansion of floating docks, in addition to a reconstruction of their chronological improvements, comprise the bulk of this thesis.

Research Questions

The primary research question preempting this study, “does the development of floating dry docks over time represent an evolutionary development,” stems from a statement made by Dr. Richard Gould regarding the categorization of a particular floating dock as a “unique, one-off technological development designed to operate under special conditions imposed by Bermudian geography,” and that “it should not be viewed as a stage within a linear progression in floating dock technology, but was more a response to local conditions” (Gould 2000:315). With little knowledge of the subject, the author elected to pursue the history of floating dry docks and attempt to discern whether they developed as individual responses to local conditions, as Gould implies, or if they comprised a discernible pattern, analogous to a technological evolution.

Over the course of many months, the author amassed an extensive collection of historic sources citing any mention of floating docks, attempting to create the most complete historical account of their development yet compiled. The interpretation of this historical account relies on the application of an existing theoretical foundation of technological evolution, most notably the cumulative synthesis model of Abbot Payson Usher (Usher 1954:10-13). Specific factors, such as the continuous and cumulative nature of technology, the role of various adopter categories, diffusionary characteristics, novelty, acts of insight, and the Great Man theory all contribute to the elucidation of floating dry dock development within the greater scheme of technological evolution. Using this database, the author attempts to identify technological characteristics common among many floating dock designs at various points in their history, compare them with similar component technologies in graving docks, and establish whether the results of this evaluation fit the accepted definitions of technological evolution.

Sources, Methodology and Previous Research

The general discontinuity of information regarding dry docks greatly hindered the acquisition of evidence, requiring exhaustive investigations into many obscure sources to acquire the data necessary for creating a unified and comprehensive history of floating dry docks. The available historical documentation chronicles the development of these structures in an intermittent, though substantively complete array, through science, engineering, and historical journals, as well as governmental documents, patent applications, and newspaper articles. Many of these addressed floating docks in a highly selective manner, typically providing only small pieces of general information about a specific dock, most often upon the launching or construction of a new design, omitting technical data beyond that of basic dimensions and lift capacity. However, a handful of articles written by individuals directly responsible for designing floating docks provided much more thorough descriptions and discussions of their new technology, particularly as it grew in scale and complexity (Clark 1828; Gilbert 1843; Stuart 1852; Rennie 1869; Standfield 1881; Clark 1897; Clark 1905; Donnelly 1911). Their work stimulated an increased focus on examination of the physical properties and laws dictating structural limitations of docks.

Given the lack of floating dock remains in the archaeological record, this thesis necessarily relied on historical documentation to a greater degree than artifactual remains for assessing the development of floating dry docks. Without the option for field examination of a wrecked or abandoned floating dock, the thesis instead focused on locating and exploiting available repositories, including the state and national archives of Bermuda and the United States. The interlibrary loan department of the Joyner library at East Carolina University also

acted as an intermediary with many other partner institutions, acquiring many antique (and sometimes fragile) documents that were otherwise unobtainable. Without question, the examination of engineering journals and societal transactions proved the greatest boon to this research, where multi-volume indices often steered research to pertinent issues and articles.

Despite the preponderance of information existing in the historical record, very few documents reflect a concerted effort to identify a pattern of development amongst floating dry docks, and those that do lack the specificity desired for drawing apt analytic interpretations (Thatcher 1978; Hepburn 2003). Several individuals published documents around the turn of the 20th century that outlined significant docks of the day, and briefly discussed their developmental history, though often providing the best source for imagery used in this thesis (Courtney 1897; Staples 1898; Cunningham 1903; Ford 1903; Cox 1906; Anderson 1907). While some are relatively complete in their assessment of early developments, none span past the Second World War, despite the continued presence of floating docks in modern shipping, where they occupy roughly 42% of the global vessel repair market (Nippon Kaiji Kyokai 2011).

Thesis Structure

Using the cumulative synthesis theoretical models and the assembled historical database, this author argues for inclusion of all floating docks within a unified theory of technological evolution. Though standing in opposition to theories purported by respected individuals in the field of maritime history, analysis of available resources suggests that every floating dock drew influence (to varying degrees) from previous floating and graving docks designs. Following this introduction, Chapter Two outlines the methodological procedures guiding the direction and focus of research. Chapter Three provides a review of the relevant technological change theories employed in this thesis, forming a basis for understanding the causes of principal changes in

floating dock design and operation. Following description of this theoretical framework, Chapter Four provides a detailed historical account of docks and docking systems existing around the world prior to construction of the first floating dock around 1685. Chapter Five forms the material basis of this investigation, historically chronicling the inception and proliferation of floating dry docks through modernity, paying special attention to those examples substantially affecting the overall direction of technological advancement. In Chapter Six, the author applies cumulative synthesis theories directly to the development of floating dry docks, attempting to discern the relative applicability of technological change modeling to the study of floating dry docks, and if these theories elucidate or confound floating dock developments as evolutionary.

CHAPTER 2: METHODOLOGY OF FLOATING DRY DOCK RESEARCH

The construction and operation of floating dry docks draws influence from a wide array of disciplines, primarily naval architecture, civil engineering, mechanical engineering, shipbuilding, carpentry, iron working, and the merchant marine. The sum of these groups provides a collection of material available for historical interpretation and analysis. Unfortunately, that material covers an extremely wide swath, often lacking a unifying feature giving cause for general assimilation and dissemination, significantly limiting availability. Historically, the proceedings of meetings and journals such as The Institute of Civil Engineers, The American Society of Civil Engineers, The Institute of Mechanical Engineers, The Institute of Naval Architects, and the Franklin Institute devoted considerable print space to the issue of floating dry dock designs and improvements. Most dealt only with specifics and technical information regarding the physical forces acting on floating dry docks, providing little in the way of historical background or influence. This is not surprising, as the intended audience likely possessed ample knowledge of floating dry dock operations and history, given that the floating dry dock was a relatively recent invention that rose to prominence during the industrial age. This thesis aspires to assemble a meaningful account and description of the floating dry dock, including a survey of all known precursor technologies employed to achieve a similar end as the floating dry dock, and determine if the development of floating docks qualifies as evolutionary.

Sources

As with most subjects, the historical record of floating dry docks decreases rapidly when looking back in time, subsequently diminishing the reliability of sources devoid of independent verification (Howell and Prevenier 2001:2). Given that the bulk of floating dry docks existed after 1800, the increasing availability of printed texts and manuscripts acted to preserve the

existence of early docking structures through literature, sketches, and photographs. Of these texts, engineering journals and transactions of societal meetings provided the most apposite information. Many of these contained articles written by individuals intimately associated with floating docks, such as the engineers who produced their designs, naval officers who handled and worked with the docks, government officials tasked with overseeing construction of federally purchased naval docks. At one point, they proved so popular that academic societies such as the Franklin Institute conducted a full-scale review of floating dry docks, featuring a multidisciplinary committee designed to understand the issue from a variety of perspectives (Humphreys et al. 1827:3). These reviews often included response letters published in subsequent editions, and in many cases provided invaluable constructive criticisms that often prompted the designer to incorporate into future projects (Clark 1827:425).

In some cases, the publications originally served as a speech or lecture given at a professional meeting or conference to an audience of peers, containing a high degree of technical information or a discussion of the relative merits of floating and graving docks, placing little emphasis on historical background. Following these disseminations, the author typically held a discussion to address questions, a transcript of which sometimes accompanied the paper into publishing (Rennie 1869:26). Information gleaned from these discussions is of crucial importance to the study of floating dry docks, as it reveals the thoughts and opinions of other professions towards the design in question and can shed light on the general disposition of the public. For example, following the review conducted by Franklin Institute, the committee recommended implementation of a marine railway before a floating dry dock, owing to apprehensions over stability and operational safety (Clark 1827:425). This shows the floating dry dock was in a phase of early adoption at the time of the article, where, as discussed in the theory

chapter, a few enterprising individuals accept the risk and embrace the new technology before society as a whole comes to grips with it.

Another valuable source of information includes the proceedings of various governmental agencies or groups, as funding for dry docks typically derives from tax revenue, usually through a naval appropriations bill or act voted upon by representatives within the government (United States Government 1843:480). Records of these bills, or discussions pertaining to these bills, often prove difficult to ascertain, but when available serve to illustrate the perspective of lay government representatives regarding the legitimacy of floating dry docks (Hinds 1907:493). When resources are allocated and new construction of dry docks ordered, it typically indicates the state of technology has advanced to such a degree it receives enough governmental support to warrant funding. In other cases, documents produced by the government reveal underhanded support for a certain dry dock design simply because members of an opposing political party supported a different one (United States Government 1843:1). Government documents therefore provide contextual information germane to social causes within the parameters of the relevant exchange in which they participate.

Another form of government document paramount to this research is that of the patent application. These act as chronological markers, often indicative of new trends in design or construction of floating dry docks. Coupled with the drawings and schematics included with the patents, these constitute the richest primary source material available for inclusion in this work. In fact, patent records are sometimes the only source of information regarding floating dry dock structure and design (Covenhoven 1821:1). Studying the patents alone proves insufficient to understand wholly the changes taking place in floating dry docks, as not all designers sought or received patents, and patent records from other countries are difficult or altogether impossible to

acquire. Additionally, the patents cannot fully describe the functioning of the dock without having constructed or operated it within a real world setting, as there is no guarantee the patent will work as designed.

Data Collection

The research questions for this thesis arose during research conducted regarding the first Bermuda floating dry dock. The lack of source material readily available prompted interest in other floating dry docks, of which a similar dearth of information existed. A wide scouring of available repositories resulted in the conclusion that history as a whole generally overlooked the development of floating dry docks. A marine structure, intimately linked to the successful management of an expanding navy and merchant marine, received but a passing mention in the most prominent monographs on maritime history. The question then arose, why have maritime historians glossed over this major facet of the global maritime landscape? The answer, to the extent one can extract an answer from the available literature, lies primarily with the general sense of apathy expressed towards mundane historical features. Maritime historians did not necessarily take this approach directly; rather, the inordinate amount of literature devoted to treasure fleets, lost cities, and famous vessels guided the scope of research during the formative years of the discipline. History comprises an infinitely wide range of people, places and events that must be uncovered one step at a time, with deference regrettably given to those drawing interest from financiers. Dry docks and later floating docks represented to historians mere utilitarian structures, less worthy of attention than the vessels for which they provided service. Few people long to hear tales of the infamous floating dry dock that essentially made the Bermuda Royal Naval Dockyard, or the 150 floating dry docks built during the Second World War to sustain the United States fleet while abroad. They want to hear about the HMS *Victory*,

USS *Constitution* or HMS *Bounty*, for which heroism and mystery created a universal sentiment of intrigue forever associated with their names.

The next step involved conducted deeper layers of research into fields connected with the design and construction of floating dry docks. One of the first places to consult was the journals of various branches of engineering. Utilizing the resources of the Joyner library at East Carolina University, the author identified for many journals a subject index covering many years of journal publication, such as *The Engineering Index* comprised by the Association of Engineering Societies, and the *Index of the Technical Press* by the International Institute of Bibliography, among others. These limited indices guided the way to many of the articles used extensively within this paper, forming a baseline from which subsequent research flowed. Once established, the research forged its own path from the citations used within the articles, leading to new repositories previously unexplored. Comprehensive research went into all lines of source material, though many remain impossible to locate today due to logistical limitations. In some cases, the physical historical documents themselves no longer exist, as was the case with the early records destroyed in the great patent fire of 1836, leaving only secondary accounts and descriptions of the lost works. Additionally, the author consulted monographs devoted to the practice of dry dock and harbor engineering, typically locating anywhere from a handful of paragraphs to a handful of pages in each, merely summarizing the general development of floating dry docks and brief description of their operation (Mazurkiewicz 1980:9; Gaythwaite 2004:443-453). Even this limited amount of information offered insight towards the historical undervaluation of floating dry docks. While only allowing a few paragraphs for discussion, these books included barely the most basic of information; however, the information they contained attempted to chronicle the progression of floating dry dock forms and materials over time,

creating a partial developmental map of these structures (Gaythwaite 2004:444). Obviously incomplete and in some cases utterly lacking in detail, each example still referenced in some form of chronological development of floating dry docks, a fact not lost on the author while researching.

In addition to material obtained through the Joyner library, a good portion of the information used in this study derived from Google Books. Many of the engineering works unavailable through the library existed in digitized format online. While hardly exhaustive, the collection offered a considerable supplement of primary source material from the 19th and early 20th centuries onward, conveniently coinciding with the period floating dry docks reached their zenith in the United States. One of the advantages to working with texts digitized through Google is the ability to search the document using the Google search engine. Most documents acquired were merely digitized scans of original documents, which are typically not searchable in .pdf format. Some of the engineering works obtained comprise over 1,000 pages of text and plates, often with only a minimal index or table of contents, making the locating of pertinent information tedious and time consuming. However, when a digitized document appears on Google, the engine analyzes the text of the document, allowing users to search any document located within their collection for any keyword they choose, essentially acting as an index to publications that otherwise lack one. For example, the *Proceedings of the American Society of Civil Engineers* for 1907 spans over eight hundred pages with no index and a paltry table of contents at the beginning of each undifferentiated section. If reading this publication in text form, an individual must sift through 482 pages before discovering whether the volume contained pertinent information. With the Google search engine, keywords appear highlighted with containing pages marked, allowing the user to quickly discern the presence of any valuable

information without flipping through hundreds of pages. While this function is certainly not a necessity for successful perusal of documents, it greatly increases search efficiency and proved of immense benefit in researching this relatively obscure subject matter.

Having now located the bulk of available information, the next step involved making meaningful comparisons with developmental trends in shipping, shipbuilding, and raw materials production and refinement. To do so involved utilization of the same set of resources, this time focused on major developments in ship design and construction, and plotting those against the major developments in dry docks. The most significant links identified between ship and floating dry dock design are the utilization of iron and later steel in lieu of wood, and the development of steam engines for powering pumps and related apparatuses. One area of major concern in this comparison involves avoiding adherence to a ruling theory. As discussed above, historians have established a well-developed account of ships and shipping, in which a general pattern of ship enlargement and increased complexity develop over time, often in response to increased payload demands or a desire for higher profits (Gilfillan 1935:21). Because of the necessarily intertwined relationship between ship and dry dock, early hypotheses suggest floating dry docks follow a path most similar to that of ship construction. This opens the door to bias on the part of the author as they seek to determine whether such a discernible pattern exists, or rather floating docks developed as one-off responses to regional geographical constraints. The only acceptable means of tackling this issue is to address the concerns upfront and recognize where the vulnerabilities lay in the theory. This approach, coupled with the impartial task of merely recounting the historical facts before drawing comparative conclusions, can achieve a satisfactory result in spite of the perceived bias.

Another repository consulted warranting a brief description is the National Archives in Washington, DC. The author made a trip there in October of the past year and spent the better part of three days pouring over material with relatively little success. At the time of visit, the archives were very crowded and access to an archivist was limited, though when consulted could only suggest searching the Bureau of Yards and Docks, targeted by the author for investigation prior to arrival. Using a general index of holdings, the author managed to explore a significant portion of naval records relating to the Bureau, and discovered very little referencing floating dry docks, though some did contain valuable comparative data regarding the operational expenses of the timber naval graving docks in New York during the early 1800s. Eventually, the author procured the more focused assistance of an archivist, who echoed the earlier sentiment that further exploration into records from the Bureau of Yards of Docks offered the best chance of containing relative material. Most information contained in the record group existed in the form of memoranda and letters between naval officers regarding acquisition of resources for maintenance and upkeep of facilities, including graving docks, with scarcely any information regarding floating docks. The author hoped to find information describing the impetus for constructing the first United States naval floating dry docks in 1848, but the limited research time failed to uncover any during the years searched. Navigating through the boxes of previously identified “key” years yielded only scant pertinent information, though some key data regarding the cost and maintenance of graving docks clearly support the argument that floating dry docks represented the less expensive option versus their timber graving counterparts.

Comparative Analysis

Utilizing information gleaned regarding the evolution of ships, the author conducted a qualitative and quantitative comparison of ships and docks during various periods of United

States and global history. These comparisons, made using photographs, descriptions, sketches and drawings identified the development of floating dry docks as following a discernible evolutionary path, where each new form features an improvement or adaptation, making it better suited to operate in a given environment. Further issues regarding the societal influence upon floating dry dock development contributed to the chronological scope of research conducted; more specifically, the impact raw materials refinement and availability made in facilitating or hindering floating dry dock development, and the overall receptiveness of various adopter categories to new floating dry dock designs. The existence of alternative means for laying up ships, such as depositing docks and hydraulic lifts, reveals many individuals desired options other than graving and floating dry docks. The comparative analysis hopes to address the desire for choice in dry dock options, and the root causes for the general approval of one type and disapproval of another.

Many of these issues seek to identify the cause of human preference, drawing inspiration for their choice from a set of beliefs intrinsic to each shipwright, naval architect and sea captain, originating from their life experience with floating dry docks. For example, a captain may prefer a graving dock simply because that is the only type with which they have experience; their beliefs unjustly shaping their stance in the debate over the validity and efficacy of other dock forms. While these may prove impossible to identify in some individuals, clues exist in the wording of their discussion that indicate the direction to which they lean, adding to the general interpretation of the floating dry dock and the response elicited from those directly or indirectly connected to it.

The greatest challenge in effecting this research occurred at the very beginning. No single monograph chronicling the advancement and change of floating dry docks existed from inception

to modernity. Instead, their discontinuous story resided in the multitude of loosely related journal and society publications, creating a daunting proposition for the amalgamation of their comprehensive history. Through extensive research and creative alternatives to traditional channels, a complete picture began to work its way into focus with the addition of each piece of information, often seemingly immaterial. Using the resources available in this manner, the author made a genuine effort to exhaust all historical leads and all manner of repository within the grasp of practicability. The task of assembling by piecemeal a complete history of anything is forever developing, as heretofore unknown information frequently reveals itself, potentially altering the historical perception of events. The only way to counter is by accepting change as the only historical constant and making a concerted effort to verify factually all sources to the greatest extent possible.

CHAPTER 3: APPLICATIONS OF TECHNOLOGICAL CHANGE THEORY PERTAINING TO THE EVOLUTION OF FLOATING DRY DOCKS

Introduction

This chapter sets forth the theoretical framework used for guiding the analysis of floating dry dock evolution, focusing on the technological change theory literature regarding invention, innovation, adoption, diffusion, and their applicability to ships and docks. The sociological, economic, and political studies of technology change provide a vast wealth of theory on the topic, yielding the cumulative synthesis theory of technological development paramount to the study of evolution within floating dry docks. The incorporation of various aspects of broad categories, such as the social valuations of a technology, the degree to which market demands govern innovation, and the role of necessity in dictating progress fill out the overarching theory of technological evolution in a manner applicable to the rationalized development that took place in the history of floating dry docks.

In a fashion similar to the growth and development of shipbuilding, docking technology progressed from rather humble origins to become the most essential service of any modern vessel repair facility. This thesis seeks to identify the complete developmental path of floating dry dock structures, from graving dry docks and camels to the reconditioned hulls of ships to crude wooden dry docks and beyond, adding that all vessel extraction techniques operating in a similar historical context directly influenced variation within the process. This development closely reflects that of ship design and construction, as both factions began with simple vernacular designs that gradually developed into complex and intricate mathematical undertakings intended to maximize load (Fincham 1851:xxxii). Additionally, floating dry docks operate in the same environment as the ships they service, and therefore must employ manipulations of similar physical properties to maintain positive buoyancy, creating valuable overlaps between the two.

While the degree of refinement of raw materials is often the mitigating agent governing technological advancement, floating dry dock technology diffused slowly even as the material production became more sophisticated and readily available. The reason stemmed from the long-held conservative tenant of shipbuilding that experimentation with new vessel designs is dangerous, expensive, and for the most part unnecessary, as previous designs are proven to function as-advertised (McBride 2000:34). New designs meant increased risk for investors and builders, one often deemed unnecessary due to the “unchanging” nature of the sea and the knowledge that techniques demonstrated as successful in the past were likely to work again (Unger 1980:25). In order for engineers to embrace design changes in maritime-based fields, a new technology must demonstrate that it substantially improves operations without simultaneously increasing risk. Unger states that “it is commonplace of the history of medieval technology that developments occurred at least 50 years before the date of the earliest known device...for changes in ship design the time span is even greater” (Unger 1980:22). The loss of an investment the magnitude of a fully laden cargo ship could result in financial ruin for a small shipping company, but it is interesting to consider whether some large firms used their ability to absorb such losses and actively sought to create new ship types through research and development. In any event, the investment often includes more than one concerned party, with a fundamental economic split existing between the interests of the shipbuilder and the ship owner, which as a result places different demands on the ship design. The shipbuilder is concerned with constructing the ship to given specifications at the lowest cost possible, while the ship owner seeks to make the best possible financial return on their investment, often creating a divergence in preferred designs (Sarder et al. 2010:2-4).

As an alternative to reducing building cost, owners often sought to increase the earning potential of the ship as a whole, which meant “adapting them to the needs of the market,” and more specifically to the product they transported (Wijnolst 1995:43-44). With dry docks the situation was a bit different, as “the size of great ships today are in general limited by the size of the dry docks of yesterday,” meaning the modern civil engineer is “estimating the size of the ships of tomorrow and designing and building dry docks to accommodate them” (Angas 1937:82-83). The market directly influenced the size of ships, which directly influenced the size of graving and floating dry docks. This economic interplay steered floating dry dock engineers towards designs that permitted flexibility, undoubtedly contributing to the adoption of sectional dry dock designs as an early standard for the industry.

Invention, Innovation and Technological Change

Inventions are fundamental building blocks of technological change, functioning as the point from which innovation stems (Wijnolst 1995:50). Three interrelated factors typically contribute to the manifestation of an invention: the mental ability of the individual as dictated by their having a penchant for greatness, the cultural material available to the individual, and the desires of society, or “social valuations” (Ogburn 1926:228). Ogburn argues that the potentialities of greatness amongst individuals is common throughout all societies, but that potential is controlled by social conditions, claiming people “become engineers, monks, shepherds, or soldiers according to different cultural conditions, which vary from time to time and from group to group” (Ogburn 1926:226). Additionally, he argues social valuations guide potential greatness by stimulating inventive effort along lines relevant to local society, noting how research in commerce is socially valued in the United States, leading to more rapid development in that sector than compared to others receiving a decreased social valuation

(Ogburn 1926:228). This focus on commercial activity yielded an intricately developed shipping industry capable of moving a large volume of goods, and a formidable navy to protect the merchant marine as they conduct business around the globe.

Prior to the invention of railways and automobiles, virtually no advancements in land transportation technology existed apart from the wheel and the horse, while water-borne transportation experienced a slow but relatively steady increase in vessel size and capacity. Wijnolst explains this disparity by noting that water acts as a universal road that does not require construction or upkeep, whose reduced friction and infinite source of wind and current power permitted construction of larger craft than were previously possible on land (Wijnolst 1995:50). Similar to mutations found in biological evolution, technological breakthroughs in raw material processing (some potentially by accident) created new avenues for maritime related inventive activity to flourish. The successful models utilizing the new technology often became widely adopted, or selected for, while the inferior designs faded to obsolescence, though some later experienced periods of resurgence as improved materials arose. Also in the vein of biological adaptation, no one model or design ever dominates indefinitely, with variables like new construction methods or increased payload demands shaping subsequent versions of the original concept (Mokyr 1990:278). In order to deduce a sound theory of floating dry dock development, one must first relate the biological concept of species diversity to technology, which is done by identifying the wide range of different docking alternatives employed throughout humanity, such as beaching, careening, tidal docking, basin dry docking, floating dry docking, hydraulic lifting, and so forth. To explain this observed diversity, one must demonstrate continuities between the artifacts (in this case any graving, floating, wet, alternative form of dock), implying each manifestation of artifact is not unique, but related in some fashion to those built before. Many

factors exist veiling the continuity of docking technology, foremost among them the dearth of extant historical records, but external factors such as the advent of the patent system, the desire for nationalistic pride, or “a tendency to equate technological change with social, scientific, and economic revolutions” also heavily contributed to a seemingly discontinuous pattern of development (Basalla 1988:208).

Taking the evolutionary perspective of technological change a step further, David Kingery proposed that “in the beginning of every design process there is in the designers’ mind a normal configuration that is an essential constituent of his/her basic design concepts,” and that these visions “come from school, from experience, from observation, from apprenticeship, much of which is tacit” (Kingery 2001:127). In other words, the unnamed Phoenician who constructed the first historically recognized dry dock at Alexandria unequivocally drew influence for their design from similar structures already employed elsewhere in the world, or they merely expanded upon a prevalent but unrecorded form of simple brushwood and puddled clay dock already in use for small vessels. In either case, the general concept of dry docking already existed to provide inspiration for the Phoenician design. In this same vein, Unger argues that the period from 600-1600 AD brought about minimal changes in the construction of ships, and claims the “change usually came in the form of new combinations of existing features or greater emphasis on already known features” (Unger 1980:22). As demonstrated over the following pages, much of floating dry dock development occurred in the same fashion, where combinations of improvements in component features resulted in the creation of new dock types.

Many authors categorize technological change theory by its relationship with specific sectors of global society, typically economic, social and political systems, though this study incorporates facets from each sector into a comprehensive historical amalgamation. A current

accepted model for technological change, and one relevant for evaluating the interplay of external stimuli in the development of floating docks, states that inventive activity is continuous (though not necessarily constant) and cumulative over time (Loch and Huberman 1999:163). The primary theoretical structure guiding this thesis centers on the “cumulative synthesis” theory proposed by Usher and elaborated upon by Basalla as discussed above (Usher 1954:10-13). The theory consists of four steps leading to the creation of an individual invention, beginning with “the perception of an unsatisfactory pattern in the current method” of solving a problem. In the case of dry docks, they proved effective enough in laying up ships for repairs, but possessed certain unsatisfactory characteristics hindering or preventing altogether their use in specific locations, leading to the development of the floating dry dock. In the next step, the individual with potential for greatness sets the stage by incorporating and manipulating data, often in a novel manner, leading to the essential solution of the problem referred to as “the act of insight.” Finally, the solution goes through a series of critical revisions, “in which the newly perceived relations become fully understood and effectively worked into the entire context to which they belong” as demonstrated in Figure 1 (Ruttan 1959:602). Thirtle and Ruttan state that “major inventions are visualized as emerging from the cumulative synthesis of relatively simple inventions,” implying previous models play a quantifiable role in the modern, finalized product (Thirtle and Ruttan 1987:4). When applied to floating dry docks, the high degree of variation present in early designs indicates a multitude of individual attempts to improve dry dock functionality, lifting capacity, size and efficiency. After trial and error in real-life environments, more commonly referred to as the theory of “learning by doing,” naval architects deemed certain features, such as the ability to self-dock or self-careen, of particular importance and made a point to incorporate those features into future dry dock designs (Rosenberg 1982:12). The result is the

“major invention” or sophisticated modern floating dry dock structures capable of lifting 300,000 ton vessels.

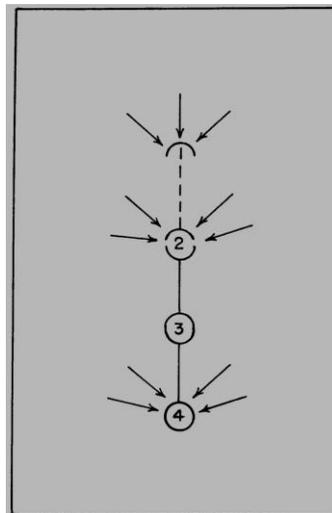


FIGURE 1. Flow chart conveying the four steps of the Cumulative Synthesis approach to technological change: 1) perception of an incomplete pattern; 2) the setting of the stage; 3) the act of insight; and (4) critical revision and full mastery of the new pattern (Ruttan 1959:603).

Thus, it follows that each individual floating dry dock contributed something, whether positive or negative, to the evolution of floating docks; a point neglected by Dr. Richard Gould in his report of the HM Floating Dock *Bermuda*. Gould claims “historical and archaeological evidence shows that the Bermuda floating dock was a unique, one-off technological development designed to operate under special conditions imposed by Bermudian geography” and that “it should not be viewed as a stage within a linear progression in floating dock technology but was more a response to local conditions” (Gould 2000:315). In actuality, the local geographic conditions found in Bermuda only precluded construction of a graving dock, and did not favor use of a specific floating dry dock design, as evidenced by the structural differences amongst the subsequent docks utilized there (Mazurkiewicz 1980:87; Select Committee on Dockyards 1864:39). Several pioneering innovations employed by the HM Floating Dock *Bermuda* (the extensive use of wrought iron and self-careening ability among others) became seminal features

of later floating dry dock designs, significantly influencing the design of all future floating dry docks, including those operating today (Gaythwaite 2004:444). A more substantive discussion of this topic appears later in the Analysis chapter of this text.

Novelty and Acts of Insight

The concepts of novelty and acts of insight are of critical importance to the theory of technological change, though the extent of their function remains hotly contested. The “Great Man Theory” argument attributes novelty to works of inspired genius, who solely through the exercise of intuition achieves direct knowledge of an essential truth (Usher 1954:60). Novel technological breakthroughs hardly ever constitute a complete innovation, as they are constantly refined and re-invented, but they create a new vista from which future designers contemplate the objects they create (Rosenberg 1976:533). Conversely, the “Social Forces” argument paints novelty as the emergence of many individual items over a long duration of time, claiming that the small magnitude of a vast number of individual items inevitably leads to creation of all potential forms over time, greatly reducing the impact of the individual inventor (Ogburn 1926:225; Usher 1954:60). In the annals of floating dry dock engineering, there exist both great individual engineers, like Sir George Rennie, responsible for significant advances in sectional pontoon floating dry docks, as well as immense social forces, like global wars, guiding the hand of engineers. Ogburn attempts subtle mediation by offering:

Great men are thus the product of their times. They in turn influence their times, that is, their achievement influences the times. The great man is thus a medium in social change. But certain extended observations indicate that the production of great men and their influence are strongly conditioned and determined by the particular existing stage of historical development. The great man and his work appear therefore as only a step in a process, largely dependent upon other factors (Ogburn 1926:230).

Progress brought about by the Industrial Revolution created a niche for inventive activity, with the inventors who filled it treated “like military or political leaders...who battled social inertial

and confronted powerful natural forces in order to bestow the gifts of technology upon humankind” (Ghose 2007:215). The patent system also contributes bias to the debate, as ownership of a patent grants rights solely to the inventor for their own monetary gain. A key argument against the patent system is that it rewards a single individual while often ignoring their influences: “a patent bestows societal recognition on an inventor and distorts the extent of the debt owed to the past by encouraging the concealment of the network of ties that lead from earlier related artifacts” (Ghose 2007:216).

Both arguments solely use necessity as the driving force of this innovation, however Basalla attempts to strike a balance by incorporating Gestalt psychological analysis, which permits the achievements of great individuals as a special class of acts of insight, while also defining the synthesis of existing items as the product of prior acts of insight, allowing varying degrees of importance depending on social valuations (Basalla 1988:24). The crux of this approach, defined by Usher as “cumulative synthesis” rests on four major premises: perception of a problem, setting the stage, acts of insight, and critical revision (Ogburn 1926:225;Usher 1954:66). Although this theory assumes that the process of invention is predetermined and automatic, where the vast number of inventions inherently guarantees a technological change, this thesis argues that “Great Inventors” are responsible for reassembly of component technology in unique fashions, therefore circumventing the deterministic and unilinear view of technology development (Basalla 1988:24). This Gestalt or social process of innovation places the importance of acts of insight between that of the two sides discussed above, but still identifies the catalyzing factor for change as increased necessity (Ruttan 1959:603). Only after the ship increased to a considerable size did people begin searching out new methods of laying them up for cleaning and repairs; obviously, this does not imply a human necessity. Surely the people

who created early dry dock structures did so not because their lives were in danger, but because it made a considerable improvement in their ability to generate capital (by facilitating maintenance of vessels used to engage in commerce), thereby improving their livelihood. Logic revealed to humanity long ago that a larger vessel meant increased carrying capacity, whether the cargo is people or commercial goods, but the physical restrictions imposed by limited construction materials technological development kept vessels relatively small and more easily worked. Once material technology became available for larger ships, it necessitated creation of alternative methods to repair and clean. While the creation of dry docks was not a fundamental human need, in many areas it became a fundamental shipping need, which fits within a more broadly applied definition of necessity.

Another popular theory purported by Karl Marx, known as the materialistic theory, cites pecuniary gains as the chief motivator of invention, “either through the spur of competition among capitalists or through the monetary reward system” (Ghose 2007:218). This theory, which underlies the Communist social philosophy, builds upon social determinism by proclaiming all major inventions draw influence directly from economic motives (Russell 1921:119). Determinism stresses the importance of necessity, fundamentally believing it to be the mother of invention, though many examples of technological advances, such as the automobile, demonstrate the inverse to be true (Ghose 2007:218). While early floating dry docks designs remained limited, a great expansion took place during the nineteenth century, where some unscrupulous inventors clearly drew inspiration from the prospect of financial gains, to the extent they lobbied their inadequate designs before congress in an attempt to win government contracts (Gilbert 1841:69). During this time, companies developed with the sole purpose of cultivating, manufacturing, and selling specific inventions, leading to an exceptionally high failure rate

(Wijnolst 1995:89). Following the transition from wood to iron and steel floating dry docks, most construction took place at mills and iron works of sufficient capacity, as the size of these firms likely permitted their taking added risk in the hope of creating a successful design capable of garnering future contracts.

Diffusion and Adoption of Technology

Diffusion, as defined by Rogers, is the process by which “an innovation is communicated through certain channels over time among members of a social system,” the four key elements being the innovation, communication channels, time, and the social system (Rogers 1995:11). Rosenberg adds to this measured notion of development by stating technological diffusion is likely to be a “gradual process” depending on the pace at which secondary improvements refine the original invention (Rosenberg 1972:7). Two main components contribute to the rate of diffusion of a certain technology, understood as a “hardware aspect” defining the material or physical object that embodies the tool, and a “software aspect” acting as an information base for the tool (Rogers 1995:12). In the early development of graving dry docks, the concept or idea of the dry dock clearly permeated throughout the ancient world, representing the diffusion of software. In this instance the software existed long before the advent of the physical dry dock structure, the hardware, first established at Portsmouth, England in 1495. However, tracing the path of software diffusion often presents significant methodological problems, as it is not readily observable and thus has a slower rate of adoption once the idea has diffused (Rogers 1995:13).

Another factor affecting the diffusion is the factor of newness. Whether the technology is objectively new as measured by the lapse of time since its first use or discovery, or perceived new after a technical retrogression in which knowledge of design is lost, is irrelevant for the individual; if an idea seems new to them, it is an innovation (Unger 1980:24; Rogers 1995:12).

These technical retrogressions result when builders abandoned certain construction techniques or features, initially losing familiarity with them and then after a period of extended disuse, forgetting about them entirely. The technical retrogression theory also suggests sociopolitical and economic forces directly contributed to this loss of knowledge by altering the shape of demand over time (Unger 1980:24).

In addition to diffusion rates, adoption rates are of vital importance to technological change theory. Individuals often perceive certain characteristics of innovations through opposing perspectives, greatly varying the rate of adoption between communities, towns, and countries. The most significant of these are the relative advantages ascribed to the innovation as being better than the one it supersedes, measured in economic, social prestige, convenience, and satisfaction factors. One important distinction made by Rogers is the notion that an innovation does not necessarily imply an objective advantage over previous designs; rather the important factor is whether or not an individual perceives an innovation as advantageous, and thus the greater the perceived relative advantage the faster the rate of adoption. Conversely, the more persons involved in making an innovation decision, the slower the rate of adoption, as introducing more people introduces more opinions. After the relative advantage, other major factors include compatibility with existing values and needs of adopters, complexity and ease of understanding, trialability of new technology with gradual exposure, and observability of many individuals within a given community (Rogers 1995:15-16,221). Graving, and especially floating dry docks both gained advantage in the court of public opinion due to reactions evoked from their observability. Large floating dry docks towered above sea level when pumped dry and exposed portions of ships seldom observed above water, generating quizzical interest amongst the general population.

Another key factor at work is the element of time, affecting the innovation-decision process, innovativeness, and adoption rate. The innovation-decision process encompasses five elements that quantify the transition from first knowledge of an innovation to its adoption or rejection. The individual will spend varying amounts of time during this process seeking information in an attempt to reduce uncertainty, and during the decision stage will either adopt and make full use of an innovation or reject part or all of it. Rogers defines innovativeness as “the degree to which an individual or other unit of adoption is relatively earlier in adopting new ideas than other members of a social system” and breaks down all members of a social system into five specific adopter categories based on their innovativeness: innovators, early adopters, early majority, late majority, and laggards (Rogers 1995:37). Socioeconomic status, personality values, and communication behavior influenced adoption rates to varying degrees depending on the individual or decision-making group, and Rogers sets forth certain generalizations that help to identify characteristics of different adopters. Early adopters tend to have more years of formal education, though age does not play a factor, and are more likely literate and representing a higher social class. From this stems the innovativeness/needs paradox, which claims individuals who most need the benefits of an innovation are generally the last to adopt it, while those of higher social standing and less need first utilize the new technology (Rogers 1995:295-299).

Modern interest in technological change seems to focus on the growth of total productivity as the marker of an innovative process, possibly due to quantifiable nature of economic activity. Karl Marx firmly believed the exploits of industrial capitalism brought about the great technological achievements of his time, claiming within a century the industrial class surpassed all accomplishments of all past civilizations (Marx and Engels 1906:17). One of the great successes of capitalism was the rejection of a static society by the ruling class and adoption

of dynamic one “driven by unceasing technological change” (Basalla 1988:110). An original and widely referenced theory of capitalist development stems from the work of Schumpeter, who considers uncertainty and risk key factors in the diffusion of technology. For Joseph Schumpeter, economic life begins as a circular flow, with consumers and producers in equilibrium with one another (Schumpeter 2004:64). Once an innovation enters into the flow, the entrepreneurial response to a new profit prospect generates a sequence of alterations in the behavior of economic actors (Rosenberg 1976:524). In many cases, entrepreneurs went bankrupt from premature investments in technological alternatives that never panned out: “expected profitability will not only be affected negatively by expected improvements in substitute technologies; it will also be affected positively by expected technological improvements in complementary technologies” (Rosenberg 1976:533). Therefore, improvements in floating dry dock alternatives, such as railway docks, graving dry docks, and hydraulic lifts directly reduced the profit margin of entrepreneurs working with floating docks, but the subsequent expansion of steam and combustion engine technology and the refinement of steel opened new realms of technological possibility and therefore increased the expected profitability. It is because of this risk that “decisions to adopt an innovation are often postponed in situations which might otherwise appear to constitute irrationality, excessive caution, or over-attachment to traditional practices in the eyes of uninformed observers” (Rosenberg 1976:533).

One of the interesting developments in the economics of technological change is the shifting interpretation of their relationship. Technological change was long believed to be an exogenous phenomenon, “moving along without any direct influence by economic forces,” but now economists argue it can be entirely explained by economic forces (Rosenberg 1974:92). One such theory divides innovative impulses of society in two factions: the technology push and

market pull/demand pull/need pull theories. Technology push refers to a situation where an individual or group identifies a technological opportunity, whether through a new invention or the reapplication of an existing one, to overcome an existing limitation or obstacle and capitalize on it (Morris et al. 2008:206-207). Market pull/demand pull/need pull approaches begin with the needs of the consumer, where marketing agents source new product ideas from the customers themselves. Technology push models rely heavily on research and development to identify the next major breakthrough, but can suffer from perfection syndrome, where engineers overdevelop an innovation by adding extraneous features or making it excessively complex, to a point beyond what the consumer desires or is willing to pay (Morris et al. 2008:207). Increased research and development does not correlate directly to increased innovation, while overemphasis on market pull approaches “can result in a regime of technological incrementalism and lack of radical innovation” (Wijnolst 1995:83). Market pull approaches often incorrectly assume the customer “knows their needs and can describe them in a way that results in new products” (Morris et al. 2008:207). Following the chart below in Figure 2, trends in floating dry dock development during the transition from wood to iron seem to incorporate aspects of both the Market Pull and Technology Push approaches. For example, uncertainty with the new technology was high, but little capital went towards research and development. Market research for floating dry docks gathered information from qualitative discovery and quantitative verification, while also not requiring a significant change in customer behavior. Given its large scale and multidisciplinary nature, both Technology Push and Market Pull approaches help to classify the nature of technological development and underscore the essential factors contributing to the rapid ascension of floating dry docks.

Description/attribute	Technology push	Market pull
Technological uncertainty	High	Low
R&D expenses	High	Low
R&D duration	Long	Short
Sales market related uncertainty	High	Low
Time to market	Uncertain/unknown	Certain/known
R&D customer integration	Difficult	Easy
Kind of market research	Qualitative discovering	Quantitative verifying
Need for change of customer behavior	Extensive	Barely
Kind of innovation process	Trial and error'/learning	Structured milestones

FIGURE 2. Chart depicting the difference between Technology Push and Market Pull theories on driving forces within technological change (Morris et al. 2008:208).

Floating dry docks emerged as indispensable components of dockyards only after engineers determined certain geological substrata could not support the weight imposed by graving dry docks (Mazurkiewicz 1980:87; Select Committee on Dockyards 1864:39). Following a period of early adoption in the beginning of the nineteenth century, people began to discern that floating dry docks possessed favorable attributes for operation in yards not limited by porous or unstable substrate. As more repair yards incorporated floating dry docks into their facilities, they began to utilize them for alternative purposes, such as vessel construction, launching or transportation across a shoal in addition to performing repair lifts (Mazurkiewicz 1980:9). This repurposing and early adoption opened the door to new inventive activity, inundating the market with a flood of new floating dry docks designs.

Given the limited scope of this chapter, the arguments set forth herein only manage to scratch the surface of technological change theory, and their application to floating dry dock evolution is not always immediately clear. But the basic components of cumulative synthesis theory, in addition to theories of diffusion and adoption rates, the Great Man/Social Forces

debate, Technology Push/Market Pull approaches, profitability, and materialistic theory adds invaluable context to the changes taking place in the design of floating dry docks. While necessity (in the form of increasing ship dimensions and expanded use of iron) promulgated the rapid advancement of floating dry dock innovations in the nineteenth century, people viewed them in the preceding years as novelties, devoting precious little research and development into their creation. It was only after their invention and early innovation that people embraced the potential this new method of docking possessed, which proved to be one of many social/cultural factors affecting technological invention, innovation, diffusion and adoption.

CHAPTER 4: HISTORICAL DRY DOCKING TECHNOLOGIES

Introduction

Like most trends in maritime history, the refinement of the floating dry dock represents the culmination of various preliminary attempts to overcome a common obstacle (such as increasing payload capacity, or utilizing steam propulsion). In this instance, shipwrights and naval architects grappled with the dilemma of performing necessary maintenance and repairs to vessels that grew ever larger and more difficult to physically extract from the water. Other factors compounded the problem, such as the scarcity of shore-based facilities capable of handling large vessels, or unstable sedimentary compositions precluding the construction of shore-based facilities altogether. Over time, solutions ranged from simple careenages to extraordinarily complex floating dry docks, determined by factors such as vessel size, available resources, and the current state of technological development. This chapter introduces the various methods employed to maintain and repair craft before and after the introduction of the floating dry dock and the litany of factors directly contributing to the advancement and proliferation of floating dry docks around the world.

The method by which one extracts a vessel from the water depends primarily on the dimensions of the craft. Throughout history, human labor alone proved sufficient to haul out small vessels, but servicing large vessels required additional mechanical assistance. Size is only the beginning of the equation though, as shoreline composition plays a pivotal role in the viability of a proposed repair facility, regardless of the size of vessels serviced there. It is easy to imagine a single individual dragging a canoe onto a sandy beach to mend a hole, but the same situation becomes much more tenuous on a tumultuous coastline comprised primarily of rock outcroppings or a steep riverbank. The same holds true for larger facilities, most notably basin

dry docks, where the sediment beneath the dock must possess a certain level of watertightness in order to limit the hydrostatic pressure acting upon the basin. A recent Unified Facilities Criteria publication released by the United States Department of Defense regarding the design of graving dry docks lists a variety of soil types potentially encountered in proposed dry dock locations, including “soft and hard rock, hardpans and shales, sand and/or gravel, soft and hard clay, marl, soft and hard mud, and certain types of coral. Extremely cavernous coral, through which water flows in such quantities as to preclude even grouting, cannot be used as a site support” (Department of Defense 2002:2-4).

Ancient Vessel Extraction

Throughout history, the word “dock” appears in various forms and meaning a variety of things, and warrants a brief discussion. The word derives from the Low Latin word *diga*, meaning ditch, and adequately describes some of the earliest forms of docks (Oppenheim 1896a:29). In 1434 AD, William Soper used the word dock in reference to the vessel *Grace Dieu*, describing the means by which the vessel “was got as high up on the mud as possible, at high tide, allowed to bed herself in the mud, and then surrounded by a fence of brushwood” (Oppenheim 1896b:xxxv). Oppenheim also notes the process “was always called docking” and the enclosed ground referred to as a “dok.” (Oppenheim 1896b:xxxv). The *Oxford Companion to Ships and the Sea* lists dock as “the area of water in a port or harbor enclosed by piers or wharves” describing the wet dock (Dear and Kemp 2006:170). The wet dock is generally “an area of impounded water within which vessels can remain afloat at a uniform level, independent of external tidal action,” intended for temporary storage of vessels away from navigable waterways (Cunningham 1904:1). In the *Nomenclator Navalis* of 1625 AD, the author describes a wet dock is described as “any creek or place where we may cast in a ship out of the tideway in the ooze, and then when a ship hath made herself (as it were) a place to lie in we say the ship

hath docked herself” (Oppenheim 1896a:29). Conversely, a dry dock is a basin “from which water can be temporarily excluded, in order that repairs...may be effected;” while floating dry docks are structures “capable, by reason of their own floating, of raising ships completely above water, and of maintaining them in that position during the execution of repairs” (Cunningham 1904:1). Prior to the creation of floating dry docks, the term floating dock was synonymous with wet dock, referring to the means by which the vessels remained in dock, rather than a structure designed to float the vessel out of the water (Colson 1894:2). With technological advances came further delineation of docks based on a particular specialized method of operating, such as the railway dock, sectional dry dock, lift dock, depositing dock and screw dock among a handful of others addressed in the following pages.

Some of the earliest archaeological evidence of organized vessel extraction derives from the various “ship sheds” prevalent along the Mediterranean coast. These structures, dating to at least the fourteenth century BC, housed ancient warships during times of peace to prevent unnecessary decay from prolonged interaction with the marine environment (Rutter 2008:13). Ship sheds are comprised of two structural criteria: a superstructure of load-bearing elements, such as pillars, columns and masonry or rock-cut walls supporting a roof, and the slipway used to haul the vessel beneath the superstructure (Loven 2006:1). Though common throughout the ancient Mediterranean after the fifth century BC, there remains little evidence about the hauling mechanisms required to move the ships onto the ways. Blackman argues that it “now seems generally accepted that on most slipways, ships could not have been man-handled, and that a combination of hauling gear and greased timber ground-ways was needed” (Blackman 2000:87). Archaeological excavations from Oeniadae, Greece uncovered numerous ship sheds whose rear wall showed evidence of projections, which may have once held large bronze rings used in some

fashion to assist in drawing the triremes up the graded slipway (Sears 1906: 232). A similar feature exists at the ancient Phoenician city of Kition (modern day Larnaca) on the south coast of Cyprus, though it remains unclear whether these rings saw use for anything more than securing the vessels in place within the shed (Blackman 2000:87). Archaeological evidence at the ancient Greek colony Thurii, situated on the Gulf of Taranto in southern Italy, possibly indicates the earliest presence of capstans employed to assist with hauling the vessel into the shed, dating to the fifth century BC or later (Blackman 1987:37). These early designs set the groundwork for the slip dock, first introduced by Thomas Morton in 1820, which utilized a rail and hauling mechanism to pull a vessel onto a slip (Lightfoot and Thompson 1883:136).

Presumably, the dry and covered environment provided by the ship sheds acted as a favorable location for maintenance and repairs, in addition to long-term storage, although no available evidence indicated such operations actually took place. However, evidence does suggest the early Greeks employed their own form of docking by “making foreshore excavations into which the ship was floated during the relatively small high tide [of the Mediterranean]” after which “an earth dam was then constructed across the entrance and the water pumped out, leaving the ship on the bottom” (Mazurkiewicz 1980:23-24). Similar archaeological finds from sites in the ancient Mediterranean dating to the Punic period reveal widespread use of “cothons,” or rock-cut basins accessible by means of a narrow canal or channel for the holding of ships as seen in Figures 3 and 4 (Markoe 2000:70). The term cothon originally referred to the major port of ancient Carthage, but as they began appearing throughout the Mediterranean, the term eventually encompassed all similar rock-cut basins of Phoenician origin (Muckelroy 1978:81). Markoe appears to use the term dry dock in reference to what he subsequently describes as a wet dock, so it is unclear if these structures were capable of excluding and pumping off the water inside the

basins, as no evidence exists to substantiate this hypothesis. However, the entry for cothon in the glossary refers to it as an “artificially constructed dry dock used for the building or repairing of ships” so it seems plausible they functioned as precursors to modern graving docks as well as wet docks (Markoe 2000:218).



Figure 3. Cothon of Mahida. (Carayon 2005:8).



Figure 4. Satellite view of Phoenician Cothon on Island of San Pantaleo (Google Maps 2011).

Throughout history, people often found it sufficient to dock their vessels by maneuvering them above a shallow spit of submerged land during high tide and waiting for the tide to recede, beaching the vessel (Mazurkiewicz 1980:23). The result of this primitive docking is an exposed hull, briefly accessible for repairs, maintenance, cleaning or loading/unloading. The duration clearly depended on the frequency and amplitude of the tides, but even the longest low tide provided only a handful of dry hours during which work occurred, making significant repairs to larger vessels a time consuming and expensive endeavor. While not an ideal technique, and one easily improved upon with the addition of brushwood walls, it proved sufficient to accommodate repairs to smaller craft (which dominated early seafaring cultures), and effective enough that its use permeated through the twentieth century and undoubtedly still takes place today (Cornick 1968:185). To cope with the frequent beaching, ancient Egyptian and Phoenician seafarers utilized relatively small vessels with “short and stout” hulls whose “thick and strong” side construction withstood the stresses incurred when grounded (Cornick 1968:20). Indeed, little space existed between the framing components of vessels that docked in this fashion, and shipwrights took care to give their vessels a relatively flat bottom that rested more evenly when beached. The port of Bristol, England earned a favorable reputation during the eighteenth century as a preferable stop due the soft river bed there, which permitted vessels to “take the ground” securely during low tide along the quayside for ease of unloading, much like the scenario taking place in Figure 5 below (Cornick 1968:20). Occasionally, ships foundered because of this method of docking, as mud and silt tended to create such a suction against the hull of the vessel that the rising tide alone proved insufficient to dislodge the craft without assistance from the crew (Kenealy 1905:20).



Figure 5. Typical unloading of an intentionally beached vessel. (Jackson 1983:13).

The earliest historical record of a structure resembling a dry dock comes from the third century BC and the reign of Egyptian Pharaoh Ptolemy IV Philopater. During this time, the Pharaoh contracted for construction of the largest known ancient oared warship, “tesserakonteres,” meaning “forty-fitted” in reference to the purported number of ranks of oarsman used to power the vessel (Chaffin 2010:213). Despite the disagreement surrounding the positioning of four thousand oarsman, little discrepancy exists when referencing the immense size of this craft, for in this case the historian Callixenos (retold by Athenaeus) included dimensions in cubits accompanying his description of the vessel. In his *Account of Alexandria*, Callixenos provided original dimensions for the craft as 238 cubits long, 38 cubits wide, 48 cubits from keel to gunwale, and 53 cubits from the highest part of the stern to the water line (Athenaeus 1854:324). Using the generally accepted conversion factor of .523 meters to 1 cubit

identified by Nora Scott, the dimensions translate to a craft of roughly 406 feet long, 65 feet wide and 82 feet from keel to gunwale (Scott 1942:70).

Athenaeus reports the original launching of this ancient behemoth took place on an unidentified wooden framework, in all likelihood a simple greased railway on a ramp, similar to those utilized in the ship sheds discussed above, and “was launched by the multitude with great acclamations and blowing of trumpets” (Athenaeus 1854:325). Despite the use of a framework said to require the wood of fifty ships, one can presume the launching process still presented a serious physical challenge that required a crowd of people (potentially with the aid of beasts of burden) to overcome. Following the original launching, Athenaeus writes that an unknown Phoenician devised a new method of launching the great vessel. Though Athenaeus does not explicitly recount the circumstances surrounding the derivation of the new method, it stands to reason that difficulties encountered due to the scale of the ship prompted the exploration of alternative launching methods. Athenaeus states:

But after that a Phoenician devised a new method of launching it, having dug a trench under it, equal to the ship itself in length, which he dug close to the harbor. And in the trench he built props of solid stone five cubits deep, and across them he laid beams crosswise, running the whole width of the trench, at four cubit's distance from one another; and then making a channel from the sea he filled all the space which he had excavated with water, out of which he easily brought the ship by the aid of whatever men happened to be at hand; then closing the entrance which had been originally made, he drained the water off again by means of engines; and when this had been done the vessel rested securely on the before-mentioned cross-beams (Athenaeus 1854:325).

Clearly, the description represents an early dry dock, as the controlled flow of water into and out of the basin allowed for positioning of the ship above a preconceived framework designed to support the vessel after draining the water, and seems very similar to the cothons discussed above. The preconceived crossbeam framework functioned as a precursor to the “gridiron,” which was a series of beams arranged as a platform exposed above the water during low tide, as

seen in Figure 6 (Dear and Kemp 2006:249). The gridiron proved effective for minor repairs, and its simplicity made it a mainstay in docks around the world through the twentieth century (Lloyd's Register Committee 1890:459).



Figure 6. T.W. Ward Shipbreaking Gridiron. Barrow, England circa 1900 (Preston Digital Archive 2011).

Despite the seemingly revolutionary nature of dry docks, no further account of a dock of any sort exists in the historical or archaeological record for another 1,200 years. This is not to imply people ceased to employ similar technologies during this span solely because there is no evidence. One possible explanation lies in the theory of technical retrogression, which states, “knowledge of design could be lost over time as builders, having abandoned a certain method or approach, would first lose familiarity with a technique and then forget about it,” adding “the loss may have been aided by the shape of demand...over time” (Unger 1980:24). This and other theories of technology received a thorough discussion in the preceding Theory chapter. It is likely that these structures do not appear in the records because vessels during the time were, on

average, small enough that massive structures for servicing and maintenance, like the one built for Ptolemy IV Philopater, were simply not in demand. It is equally plausible that such structures did exist, perhaps on a smaller scale, or utilized by merchant vessels for which little or no documentation remains. Either way, one can say with relative certainty that throughout the history of docking, including modern times, the most cost effective method remained beaching or mud docking, with modifications such as “walls of brushwood and puddled clay” and the use of buckets or pumps to drain the interior space, simulating the functionality of a dry dock (Goldingham 1918:489).

A similar situation to that in Alexandria occurred 1,200 years later during the Song dynasty in China, recounted by the renowned scientist and mathematician Shen Kua, where the two Chê provinces presented two dragon ships to the throne as a gift, each over two hundred feet in length (Needham 1971:660). By the Hsi-Ning reign of 1068-1077 AD, the vessels deteriorated to such an extent that major repairs were necessary, prompting palace official Huang Huai-Hsin to create a plan to remove the ships:

A large basin was excavated at the North end of the Chin-ming Lake capable of containing the dragon ships, and in it heavy crosswise beams were laid down upon a foundation of pillars. Then (a breach was made) so that the basin quickly filled with water, after which the ships were towed in above the beams. The (breach now being closed) the water was pumped out by wheels so that the ships rested quite in the air. When the repairs were complete, the water was let in again, so that the ships were afloat once more (and could leave the dock). Finally the beams and pillars were taken away, and the whole basin covered over with a great roof to form a hanger in which the ships could be protected from the elements and avoid the damage caused by undue exposure (Needham 1971:660).

Owing to its specialized construction specifically to service these dragon ships, no other available information indicated dry docks of this fashion existed elsewhere in China during the Song dynasty. While this potentially diminishes the impact these early graving dry docks made on vessel repair elsewhere around the world, it demonstrates the general existence of this

knowledge in over various periods and multiple regions throughout history. The possibility exists that the technology developed independently in these various locations, or that it diffused across populations with early seafarers as they began traveling to distant lands, with further historical and archaeological investigation required to determine which occurred.

The Earliest Verified Graving Dry Dock

It is not until the reign of Henry VII in 1495 that the Royal Navy constructed one of the earliest modern dry docks in Portsmouth, England. Prior to this time, a dock referred to a temporary structure situated in a convenient location along a shore or bank as discussed above. N.A.M. Rodger argues the Portsmouth dock actually existed as early as 1492, and the only feature separating it from the mud docks in use there before was the introduction of a wooden dockhead, basically an inner and outer cofferdam filled with earth to form a barrier between the basin and the channel. The process of building up and tearing down the dockhead required a significant amount of labor and time, meaning ships that entered a medieval dry dock stayed there for a considerable duration beyond what was often necessary (Rodger 1998:71). The prevailing notion of the time suggested keeping a vessel in dock or out of the water prolonged its useful life, and given the dearth of other ships vying for space in the dry dock, they often remained there until needed (Oppenheim 1896b:x1). For instance, the first vessel docked in Portsmouth dock of 1495, *Sovereign*, stayed for eight months, leaving only after receiving conscription from the crown to conduct a trading mission in the Levant. However, the next vessel to dock, *Regent*, stayed only seven weeks, as England was actively involved in military engagements with Scotland and required the services of the vessel in combat (Oppenheim 1896b:xlii). Rodger also suggests that widespread use of pumping devices on ships for many

years prior to 1495 AD reduced the novelty of their use in dry docks, though no evidence exists to corroborate this claim (Rodger 1998:71).

From a historical perspective, construction of the Portsmouth dry dock appeared out of thin air. No evidence currently exists regarding the source of influence for this dry dock, despite a considerable amount of information pertaining to its construction. Oppenheim states, “if one existed previously no reference to it has survived, and we may suppose that the new departure was the result of foreign superiority in such matters rather than of native enterprise” (Oppenheim 1896a:39). However, Portsmouth existed as a strategic location of naval importance since 1212 AD, when the “Sheriff of Southampton was directed to cause the ‘exclusa’ at Portsmouth to be enclosed with a strong wall, in the manner which the Archdeacon of Tauton would indicate, for the preservation of the king’s ships and galleys” (Clowes 1897b:117). Given the extensive history of naval involvement at Portsmouth prior to 1495 AD, and the presumed repeated use of primitive docking technology at that location for well over 250 years, it is reasonable to suggest English naval architects created the first graving dry dock by their own accord, despite historical evidence suggesting they previously existed elsewhere in the world. Interestingly, construction of the structure “seems to have been undertaken as a matter of routine, without any difficulties having been experienced, so far as we can tell, just as though such works were familiar to those in charge” (White and Moorhouse 1905:224).

In nineteenth century AD India, and potentially many centuries before, simple mud docks serviced vessels up to five hundred tons burthen, and did so with a unique twist (Harrington 1873:318). In much the same fashion as the Phoenician and Chinese examples discussed thus far, workers dug a trench in the mud slightly larger than the dimensions of the craft and at a right angle to the waterway. Two parallel rows of strong stakes lined with bamboo

mats formed a dam (called a “bund”) made watertight by filling with sand and mud, in a fashion similar to the wooden dockhead first employed at Portsmouth in 1495 (Colson 1894:167). Once the bund is completed, workers raise the level of water within the dock by adding mud, thus raising the vessel inside to a level higher than that of the surrounding water (Harrington 1873:318). Workers then dig three or more tunnels into the mud below the dock, through which they pull large beams, forming a series of floor timbers upon which the dock rests (Colson 1894:168). The mud side walls are torn down to the height of the floor and the surrounding water drained away, leaving the vessel high and dry, supported by several stumps of Palmyra trees to prevent rolling. To lower the ship, four or more hawsers shaped into cones and filled with mud replace the timbers, allowing for slow, simultaneous uncoiling of the hawsers that safely returns the vessel back afloat (Harrington 1873:318-319).

These examples represent novel inventions within geographically distinct locations, though there are many obvious similarities. It is within the realm of possibility that primitive dry dock technology diffused from a single originating idea, given the cultural exposure resulting from overseas explorations. However, early dry docking technology possessed many simple characteristics that easily could arise through novel invention as the need within each culture occurred. Not enough historical information exists to proclaim a single originator of dry dock technology, and the promise of locating remains of early dry docks through archaeological excavation remains slim, given the temporary design of early docks. Timber and stone/masonry graving docking facilities existed centuries before transitioning into mainstream vessel extraction techniques, prompting questions of their efficacy in societies with moderate to small sized crafts, especially given the available alternative methods to dry docking.

Careening

The next major development in the evolution of floating dry docks takes a different approach to servicing vessels, foregoing removal of the entire craft in favor of partial exposure. The practice, referred to as “careening” or “heaving down,” developed primarily to remove marine fouling or conduct minor repairs to the underside of the hull, such as replacing sheathing or providing a fresh coat of paint (Bramwell 1867:80). In general, careening works by first maneuvering a vessel parallel to a steeply sloping shoreline, then heaving the ship down using tackles attached to the masthead of the vessel, thereby exposing the lower strakes on the opposite side of the hull (Dear and Kemp 2006:88). After servicing the exposed section, the crew reversed the orientation of the ship and repeated the process for the opposite side of the hull. In some cases, the protruding length of the yardarms required the digging of careening pits ashore to permit a greater angle of heel and expose hull planking nearer to the keel (Gwyn 2004:322). Alternatively, another vessel could carry the heaving down tackle allowing the “operation to be performed independent of the rise and fall of the tide” as depicted in Figure 7 (Bramwell 1867:80). Built in 1685 AD, the Swedish Navy possesses the oldest known careening wharves at the naval town of Karlskrona, though the existence of dedicated wharves implies the procedure occurred at other convenient locations prior to the construction of careening wharves, with the earliest historical mention from 1666 (Pepys 1666:190; Stenholm 2008:4). Similar facilities, consisting primarily of a careening wharf, capstan, and capstan house, gradually began appearing in naval bases such as Halifax, Nova Scotia, Port Mahon in Minorca, Spain, and English Harbor in Antigua, British West Indies in the early 18th century (Lavery 1989:238; Gregory 1990:3; Gwyn 2004:3).

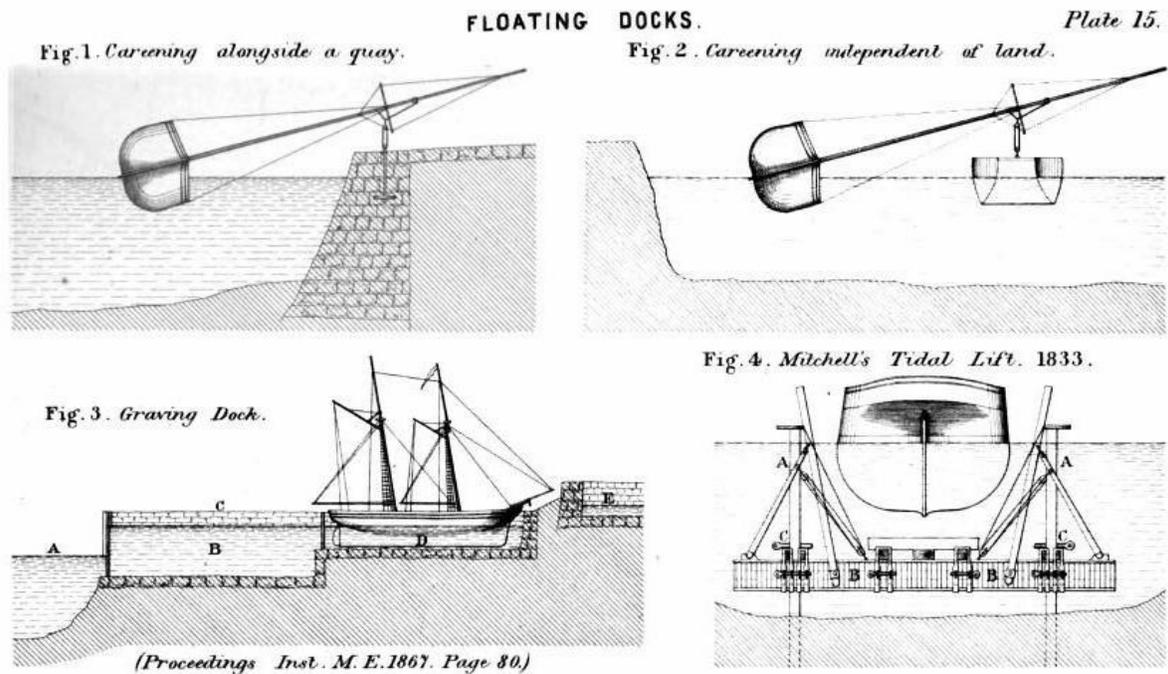


Figure 7. Depictions of careening alongside a quay and independent of land, as well as a graving and tidal lift dock (Bramwell 1867:Plate 15).

Despite the seemingly universal adoption of careening for accessing the hull of ships after the advent of proper dry docking facilities, a multitude of different applications of careening, along with subsequent cleaning and repairing, existed during this time. One variation, known as a parliament or parliamentary heel, careened a vessel by running ballast, cargo, or the ships guns to one side of the vessel, unevenly distributing weight and creating a list (Jeans 2004:195). This practice occurred frequently during the age of sail, potentially originating during the Parliamentary period when Oliver Cromwell controlled the English Navy (Dear and Kemp 2006:417). The oldest reference to a parliament heel comes from the *Universal Dictionary of the Marine* by William Falconer (1780), though he describes the procedure as merely another method of careening, without providing details regarding the means by which the ship achieves the heel (Falconer 1780:931). People often elected to pursue this type of procedure in situations

where “the defects to be repaired are not extensive, or where...it is desirable to avoid the delay of going into dock” (Alden and Beardsley 1857:146). Careening proved problematic though for many vessels, as it “was frequently attended by a distortion of the shape of the ship, caused by unequal stress on the exposed side during operation, rendered permanent by the driving of caulk into the seams,” making it nearly obsolete by 1874 (New South Wales Legislative Council 1874:719). The serious danger inherent to performing an operation of this sort seems obvious, but some sources reveal the officers and crew thought so lightly of situation that they usually remained on the vessel throughout the process, and in some cases even brought women aboard (Alden and Beardsley 1857:332). This practice resulted in one of the worst maritime catastrophes of the time when the twenty-six year old first-rate ship *Royal George* capsized during a parliamentary heel in 1782, killing over a thousand people on board (McCauley 1902:230). The disaster occurred in part because the gun ports on the lower decks remained open during the procedure, but the situation became exacerbated when the sloop *Lark* lashed alongside *Royal George* and began loading rum into the low side of the hold while the heel took place (Kingston 1876:32).

Once the ship achieved the desired list during careening, the crew then removed the accumulated fouling using a variety of methods. One of the oldest, known as “breaming,” utilized controlled fires to burn and loosen the marine growth before or in lieu of scraping, as seen in Figure 7 (Dear and Kemp 2006:65). Similar to the inherent danger of parliamentary heels, breaming could easily engulf an entire ship in flames with the smallest of miscues, as was the case of the fifth HMS *Victory* in 1721 (Goodwin 2000:10). Many nations feared the spread of fire from breaming within a port, leading to the establishment of approved breaming locations as well as steep fines and penalties for those caught breaming in an illegal location. By 1869,

French harbor regulations required breaming conducted only by a master caulker, under the superintendence of port officers, and with men stationed fore and aft “with buckets of water to besprinkle the lanyards and moorings, and to watch the fire” (Urquhart 1869:9). Once the burning ceased, the crew used a device known as a “hog” to scrape any remaining marine fouling from the hull. Sailors securely bound and enclosed a number of birch twigs between two planks and severed the tops of the branches to form a stiff broom. The hog was then made fast against the hull by means of a staff (typically from the ships’ boat) while men onboard the vessel drew up the hog along the hull using ropes fixed to either end of the tool. Once the crew completed scraping, a fresh coat of pitch, tar, hair, resin or paint covered the freshly charred timber and temporarily sealed the hull from marine growth (Dear and Kemp 2006:265). Sailors referred to the entire process of cleaning and re-sealing the ships hull in this manner as graving, eventually lending its name to the graving dry dock (Fincham 1851:95).

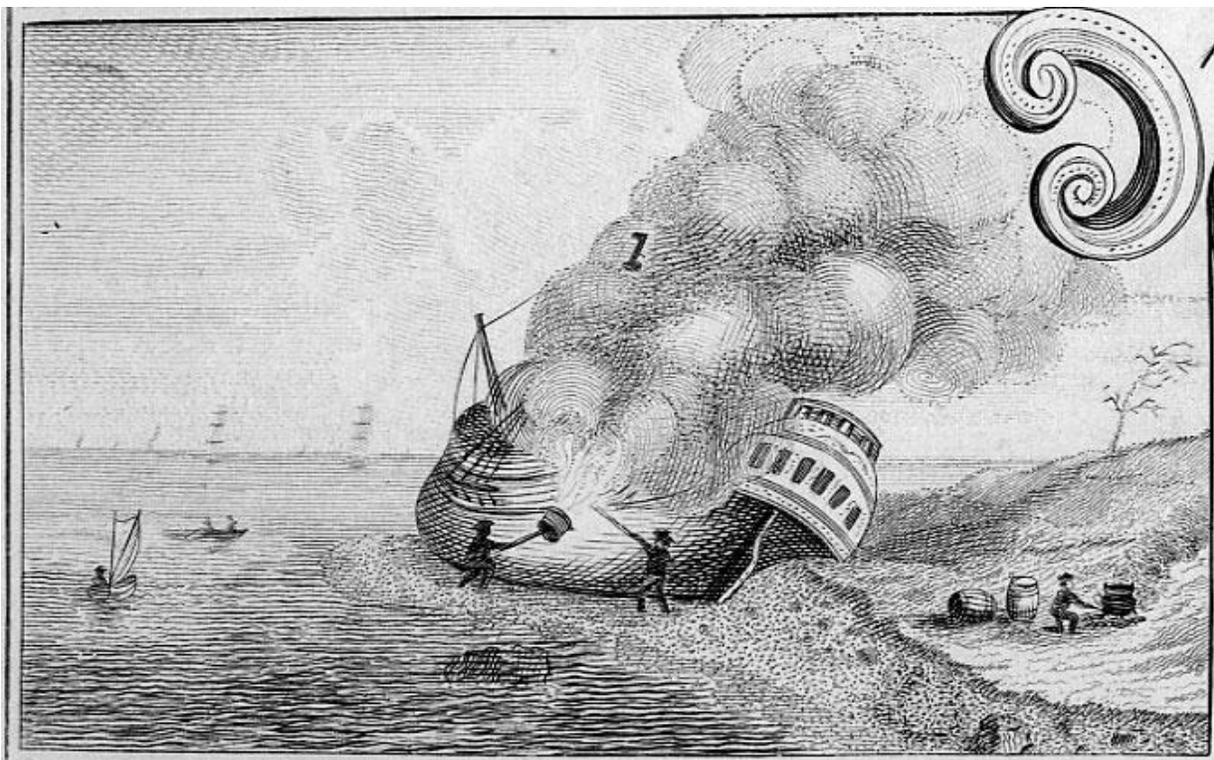


Figure 8. Breaming a Ship, from the Salem Maritime National Historic Site, National Parks Service Featured Object (National Parks Service 2011).

Careening represented the simplest, most cost-effective method of accessing the hull of vessels of any appreciable size for several hundred years, but remained an imperfect system. The procedure could only expose half of the hull, thereby limiting repairs to one side at a time and increasing the duration a ship stayed in port. Should the ship require replacement of any frames or major structural components, performing such repairs on a careened vessel proved very problematic, especially where the framing element spanned both sides of the keel. It is reasonable to suggest ship construction began incorporating half frames and futtock designs to facilitate repairs conducted while a vessel is under careen, though no evidence directly supports this supposition.

The significance of careening as the dominant method of hull cleaning and repair during the age of sail cannot be overstated, for no other method of accessing the underside of a ship existed anywhere in the world. The graving dry dock described by Athenaeus in the third century BC failed to take hold, and it seemed the quandary of extracting a vessel from the water remained a mere inconvenience for ancient and medieval mariners, who found careening and beaching sufficient for their relatively limited needs. Through the end of the seventeenth century AD, well after the advent of dry dock technology in England, vessels routinely performed careening procedures while abroad, where dry docking technology was unavailable (Dampier 1699:363). In his book *A New Voyage Round the World*, Captain William Dampier provides an account of his travels from London to various parts of the world between the years 1679-1691. During his exploits, the author diligently referenced each instance the vessel upon which he traveled stopped to careen, and described searching for a suitable patch of shoreline for careening in virtually all of the remote locations he encountered (Dampier 1699:3). During a stop on the island of Mindanao in the Philippines, Captain Dampier discusses the prevalence of

shipworm around the world, and claims the people of Mindanao “immediately hale their Ship into a dry Dock” when returning from the sea, and “burn her bottom, and there let her lye dry till they are ready to go to Sea again. The Canoas or Proes they hale up dry, and never suffer them to be long in the water” (Dampier 1699:363). Though the exact type remains unidentified, the fact that a dry dock existed in a remote location such as Mindanao and not at any other location visited by Captain Dampier epitomizes the infantile nature of the technology, but also suggests knowledge of such structures diffused rather broadly before experiencing a significant level of refinement. As Captain Dampier mentions, the teredo worm plagued the people of Mindanao in an extreme fashion, creating a situation where the people eagerly and openly accepted new ideas to alleviate the hardship imparted upon them by the shipworm, placing them in the technological category of early adopters.

The Camel

Through the nineteenth and early twentieth centuries, servicing merchant vessels by means of beaching and careening, a common and effective practice, limited the necessity for civilian enterprises to invest in expensive dry docking facilities (Greenhill 1970:103). Unfortunately, limited information exists pertaining to merchant repair tendencies, meaning most of the available information derives from naval records and refers to the practices of maintaining and repairing naval ships. Further, much of the documented support stems from English Naval records, as they are the most readily available and require no translation. This invariably introduces a level of bias that requires consideration during analyses, but still yields valuable information that is otherwise unobtainable.

As shipbuilding technology advanced in Europe during the Renaissance, nations began to develop larger ships for increased military and economic gains. By the middle of the seventeenth

century, shipbuilding in the Netherlands occurred at a rate of two thousand per year, giving them by far the largest shipping fleet in Europe (Dawson 2009:220). The early eighteenth century saw France and England begin to challenge the Netherlands sea prowess, due in large part to the morphology of their respective ports. England and France possessed deep and wide harbors, permitting admittance of large one hundred-gun, three-deck warships of fifteen hundred tons (Dawson 2009:221). In Holland, the largest harbor of Amsterdam could only admit ships up to seven hundred tons due to a preponderance of sand bars and shoals, made worse by intense silting and dumping of ballast, effectively obstructing navigation (van Loon 1989:217). Gaining access to the harbor proved the most difficult problem, for once in the Zuider Zee, the depth easily accommodated the largest vessels of the time (Jackson 1849:4). By 1672 AD, the Dutch overcame the problem by utilizing marine camels, defined as a rudimentary floatation device in the form of “large rectangular chests” filled with water and affixed to the hull, then pumped dry to provide extra buoyancy and lift the ship over the shallows (Dawson 2009:222). German historian of technology Jacob Leupold credits Cornelius Meijer with the first use of the camel, and was perhaps the first person to coin the term in print (Dawson 2009:222). Use of the camel flourished during the seventeenth and eighteenth centuries in Holland, but virtually disappeared following the completion of the North Holland Canal in 1824 AD (Jackson 1849:5).

Use of the camel during the eighteenth century spread to other countries with shallow, difficult to access harbors similar to those in the Netherlands. Russia, during the reign of Peter the Great, sought to expand their empire by gaining access to the Baltic Sea, founding the city of St. Petersburg on the shores of the Gulf of Finland (Dawson 2009:227). Due to the shoal waters separating the St. Petersburg from Kronstadt and access to the open waters of the Baltic Sea, the Russian Navy readily employed camels to transport vessels over this twenty-seven mile expanse

(Leslie 1856:145). Further, “all ships built at Nicholaieff and Kherson were floated to Sebastopol, where they took in their armaments and stores, and were fitted for the service,” as shown in Figure 9 (Leslie 1856:145). The concept for these camels stemmed from a visit Peter the Great and English Captain John Perry made to Amsterdam in 1698 AD, in which they observed their operation first hand and sought to adapt this new technology to their respective waterways (Dawson 2009:227). Use of the camel in Russia continued at least through 1819 when the American paddlewheel steamship *Savannah* made its revolutionary journey across the Atlantic, requiring camels to enter the harbor of Kronstadt (Braynard 1963:171).

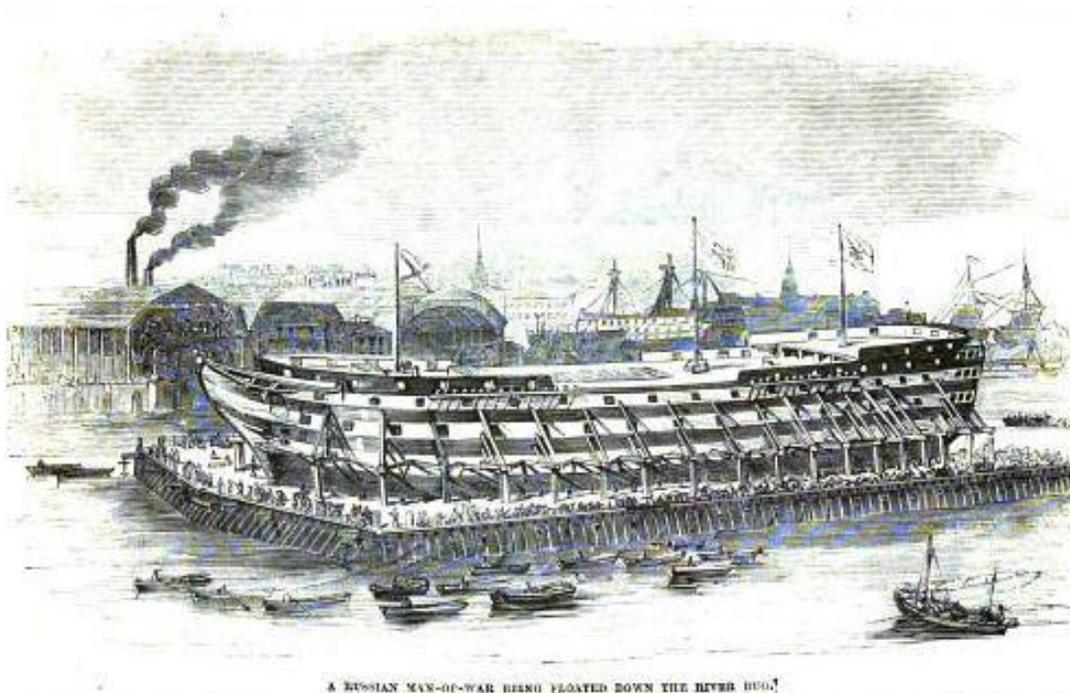


Figure 9. Depiction of hull constructed inland and floated to deeper water for fitting out by camels. *Frank Leslie's New York Journal* 3(I):145.

The term camel has a second maritime meaning that requires attention for the purpose of disambiguation. In addition to the camels intended to increase buoyancy, camel can also describe a “floating separator placed between a vessel and quay or between two vessels in order to maintain a safe standoff distance” (Gaythwaite 2004:365). The origin of this term is unclear.

Available historical and archaeological data reveals only a handful of structures utilized in a fashion similar to dry docks before 1495 AD. Many factors account for this, such as vessel size not necessitating use of massive dry docks, or the existence of less expensive yet adequate alternatives such as beaching and careening. The knowledge or software aspect of dry dock technology diffused throughout most, if not all seafaring people of the Old World, as evidenced by its appearance in the Ancient Mediterranean, Indus Valley, China and throughout much of Europe. The simplicity of early dry dock designs allows for the potential that independent technological development occurred throughout the world, but the interconnected nature of trade and shipping provided many opportunities for cultural overlap, especially among shipwrights.

The graving dry dock reached its zenith in early to middle nineteenth century AD, where it served as the primary means of extracting a vessel from the water around the world (Navy Department 1892:86). Graving dry docks performed satisfactorily, but incurred high initial construction and maintenance costs, occupied valuable shoreline, and took years to build. This imperfect solution opened the door to alternatives, foremost of which became the floating dry dock, discussed at length in the following chapter.

CHAPTER 5: THE HISTORY OF FLOATING DRY DOCKS

Introduction

Shipping and water-borne transportation represented the primary means of moving goods and people around the world for the better part of civilized existence, but technological limitations in the production of raw materials and a perceived lack of necessity effectively restricted development within the shipbuilding industry (Pollock 1905:170). That changed significantly with the onset of the Industrial Age and refinement of iron and steel during the nineteenth century AD, where utilization of new materials allowed for construction of larger, stronger, and lighter vessels than ever before (Fremdling 1993:39). Compared with the sluggish development previously noted of graving dry dock technology, floating dry docks evolved briskly, joining graving dry docks as the preferred methods of laying up ships around the turn of the twentieth century AD, despite their relatively recent inception 250 years prior (Maxton 1899:73). Historical evidence suggests graving dry dock technology existed as early as the third century BC but failed to proliferate in earnest until the latter fifteenth and early sixteenth centuries AD, beginning with construction of the first dedicated basin dock at Portsmouth, England in 1496 (Athenaeus 1854:324; Oppenheim 1896b:xxxiv-xxxvi).

The greatest improvements in design, construction, and operation of graving dry docks occurred during the industrial revolution, where revolutionary applications of burgeoning technologies (such as the implementation of steam mechanization for pumping) reduced the “abundance of unskilled civilian workers” previously required to operate the docks (Thiesen 2006:74). The basic form and operation of graving dry docks remained largely unchanged, even as their dimensions increased and the use of iron became more prevalent in maritime applications, with the lone exception lying in the graving dock gates (Gaythwaite 2004:414).

Early graving dry docks excluded water by essentially utilizing a coffer dam as a gate, developing later into caissons and hinged gates of wood, drained either through a sluice door in the gate (if a tidal dock) or by pumping. Eventually, engineers began to experiment with composite and completely iron gates, finding them lighter, easier to work and much stronger than previous wooden gates (Colson 1894:220-221). The gates represented the only portion of the structure constructed of iron, as the walls and floor consisted of masonry, excavated bedrock, or concrete, occasionally lined with timber (Cornick 1958:190).

The history of the floating dry dock stands in stark contrast to that of their graving counterpart, where seemingly from commencement floating docks experienced a flurry of variations in design, form and function. Between 1790 and 1847, the United States administered twenty-seven patents related to improvements in floating dry docks, compared with eighteen patents associated with basin dry docks, of which many referenced alternative dry dock structures, such as screw docks or hydraulic lifts (United States Government 1847:193-194). While these numbers suggest both forms witnessed significant improvement during this period, the floating dry dock developed to a near-modern design in only a couple hundred years, while graving docks existed for a millennium before experiencing a similar level of refinement. Advances in raw materials production and the implementation of steam power during the industrial revolution likely accounted for the time discrepancy, rather than an overarching societal need for a new form of marine repair facility.

Most seafaring nations maintained the capacity to construct graving docks of sufficient size to service any vessel in their fleet, despite the enormous cost, but found them not without complications. The greater problem rested with the physical requirements of large basin dry docks, such as their occupying an exorbitant amount of valuable shoreline, requiring multiple

years to construct, and extended time and energy employed in draining and filling (Cox 1907:99). The outright cost inhibited widespread construction of large graving docks, effectively limiting the available ports of call for many naval and shipping vessels should they experience damage or problems at sea, often forcing them to return home for repairs, significantly reducing the time an asset spent in action. Additionally, deplorable working conditions existed inside graving docks, consisting of very little light, no air circulation, noxious odors emitting from the dying biofoul, and an overall dampness (Humphreys et al. 1827:258). These deleterious factors primed the environment for early adopters to embrace any docking alternative, based on the promise of reduced cost and increased efficiency, flooding the market with a range of inventions heretofore unseen in the history of seafaring. This chapter chronicles the history of floating dry docks and similar dry docking alternatives, from their humble beginnings through the early twentieth century, highlighting the morphologies of floating dry dock that significantly affected the overall path of technological development.

Arrival of the Floating Dry Dock

Much of the information surrounding the earliest known floating dry dock stems from secondary sources, where limited available resources and language barriers hinder factual verification and corroboration. This does not render it necessarily erroneous or inutile, but requires the caveat that some sources purport information regarding the first floating dry dock as a story, rather than in a mechanical, governmental, or scientific report like those found in later texts on the subject.

Given the amazing human propensity displayed towards mechanized advancement, it was likely a small mental leap from the established camels found operating in Holland during the seventeenth century AD to creation of a floating dry dock. People associated with maritime

trades recognized the need for regular maintenance of vessels and the challenges inherent in employing graving dry docks, beaching, or careening. At some point in time, an individual or individuals likely suggested utilizing the camels to scrape a hull or check for damage, logically developing that concept into a pontoon dock, or rudimentary floating dry dock (Gaythwaite 2004:442). The reputed author S.P. L'Honoré Naber disagrees with this assessment, claiming Dutch engineer Cornelius Meijer invented the floating dock in 1685, prior to the introduction of camels, stating, "the time for those docks was not yet ripe, as long as ships could be careened easily" (Lemmers 1998:65). In 1685, Meijer published an engineering work entitled, *L'Arte di Restituire a Roma la tralasciata navigazione del suo Tevere*, in which he described a method for hauling a ship up through locks, as depicted in Figure 10 below (Meijer 1685:103). Though revolutionary in concept, this structure more closely represents a patent slip or early version of a marine railway than an early floating dry dock. As with many of his inventions, the city of Rome never followed through with its construction, prompting Meijer to publish his engineering treatise to prevent the theft of his ideas.

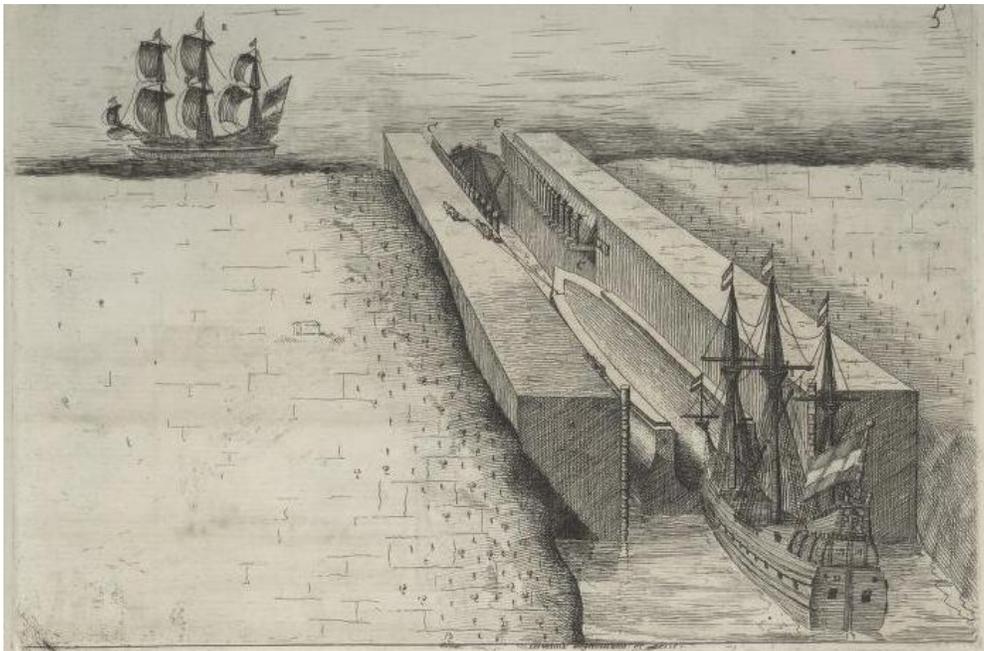


Figure 10. Lock alternative designed by Cornelius Meijer in 1685 (Meijer 1685:103).

Occurring contemporaneously in Russia, people began concocting alternatives to graving docks for servicing their vessels. According to an article published in the 1897 *Annual Report of the Belfast Natural History and Philosophical Society*, the captain of a British merchant ship conducting business in the Baltic Sea during the reign of Peter the Great of Russia (1672-1725) experienced trouble adequately careening his ship in the Bay of Kronstadt, outside of St. Petersburg, Russia (Maxton 1899:66). The exact problem affecting the ship is unclear, as sources differ slightly in their interpretation of events, but it appears either the hull required fresh caulking, or the copper sheathing necessitated some sort of repair (Maxton 1899:66; Clark 1905:2). To overcome his lack of adequate carenage or dry dock, the captain purchased and gutted an available hulk, removed the stern and replaced it with a gate, similar to that used in a lock. He then filled the hulk with ballast, causing it to rest on the bottom, exposing only the upper works above the surface. After warping his ship between the works, he closed the gate and pumped out the water from within the hulk, creating a type of coffer dam dry dock known colloquially as a camel dock (Staples 1922:647). As the interior water level receded through pumping, the vessel came to rest atop the hulk and the entire structure began floating free of the bottom. The sources remain very vague regarding the actual operation of this process, specifically whether or not the captain intended the hulk to float once drained. Despite the hulk resting on the bottom and not remaining constantly buoyant, it represents an integral step in the path towards floating dry dock technology, as discussed in the following chapter. Additionally, sources cite Peter the Great as the person responsible for bringing floating dry dock technology to Russia, and claim he conceived the idea while working as a shipwright in Holland (Schuyler 1995:275).

Interestingly, and perhaps lending some credence to the story, the hulk employed by the captain apparently operated under the name *Camel*, which as discussed in the previous chapter is the term still used today for a lifting pontoon (Staples 1922:647). In Holland, a man by the name Menves Meindertssoon Bakker of Amsterdam receives credit for the first camel used as a lifting pontoon around 1688, which coincides with the timeframe established for construction of the first camel dock (Knight 1874:432-433). To reiterate, the camel lifting pontoon and the camel dock are two different technologies that both influenced floating dry dock evolution and are easily confused. The camel lifting pontoon used the controlled buoyancy of a hollow trunk to reduce draft and physically lift a vessel higher in the water column (as described Chapter 4). The camel dock is also known as a floating graving dock, as it functions under the same principles as a graving dry dock, namely by forming a watertight barrier that permits the exclusion of water from the interior space through pumps or sluices. These two main principles guided the design of all future floating dry docks.

Nearly a century passed before in 1774 or 1776, depending on the source, a shipwright named Aldersley built the earliest recorded camel dry dock in England, constructed entirely of wood and operating in the city of Devonport, just outside Plymouth (Maxton 1899:66; Clark 1905:2). Sydney Staples claims docks of this original camel type existed in “other ports,” but notes, “their action must have been somewhat unsatisfactory, owing to the absence of means of regulating their descent, or of ensuring their stability during lifting and lowering” (Staples 1898:338). Technological innovations such as the camel dock tend to diffuse more readily when displayed in prominent locations, and the crowded river banks of eighteenth century England fit that mold nicely, so it is reasonable to suggest nearby ports experimented with them as well (Rosenberg 1972:8). It is also a reasonable assumption that these camel docks preformed at least

somewhat satisfactorily, especially for smaller craft, as the United States continued to employ them through 1893 on the Mississippi River, even in tandem with a floating dry dock (Secretary of War 1893:3810). Figure 11 shows a colloquial version of a camel dock at Wivenhoe, fifty miles northeast of London, England.



Figure 11. Camel dock employed in the port of Wivenhoe, England, 1898 (Staples 1898:339).

In 1785, Christopher Watson built and received a patent for the first true wooden floating dry dock at the port of Rotherhithe, outside of London, along the Thames River, illustrated in Figure 12. This dock measured 245 feet long, 58 feet wide and 23 feet deep on the blocks, roughly in the shape of a ship or hulk, with the stern removed and replaced with a closable gate (Smith 1868:99). The primary advantage separating the Watson dock from that of Aldersley was the ability of the Watson dock to sink only to the required depth without contacting the river or sea bed, earning it the reputation as the first true floating graving dock. This structure operates in the same manner as a camel dock, with a moveable gate or caisson creating a watertight interior space, relying on the natural buoyancy of the timber frame to remain only partially sunk while flooded for the accepting of ships. Once sunk, an individual or crew warped the vessel into dock

and closed the gate, enabling the interior space to be pumped dry, the floor of the dock remaining below the surrounding waterline. At the completion of docking, the gate is simply removed and the vessel floats out with minimum assistance. The only major vessel docking on record performed by the Watson dock is that of the HMS *Mercury*, a sixth-rate *Enterprise*-class Royal Navy frigate, which apparently took place with great success (Smith 1868:99). Bramwell reaffirms the point made earlier by Staples that similar docks existed elsewhere in England (outside of the historical record), but recapitulates that those were actually camel docks, as “in order to ensure stability they have been sunk between guiding piles upon a level bed” and were therefore not “independent of the land” like the Watson dock (Bramwell 1867:90). The 1789 *Parliamentary Register for the House of Commons in Ireland* makes mention of a petition and subsequent debate started by Nicholas Le Favre, regarding construction of both graving and floating docks on the south side of the River Liffey in Dublin, exemplifying the comparatively rapid progress made by floating dock technology into mainstream ship repair culture (Irish Parliament 1789:390).

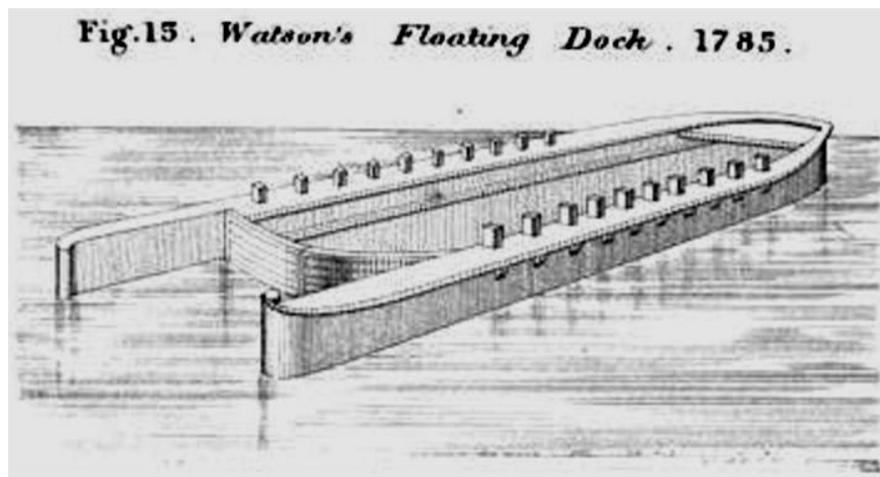


Figure 12. Sketch of first floating dry dock, built by Watson in 1785 (Bramwell 1867:Plate 18).

Despite the scant record of early designs, the conceptualization of a floating dry dock permeated nautical communities around the world by the year 1800, though they remained

largely unrefined and seldom documented for another quarter century. During this interim period, the legitimacy of floating dry docks began to take hold, prompting new designs with considerable variation, especially in the United States. Though it is clear the first floating dry docks operated in Northern Europe, the United States most fully embraced the concept and set about actively engaging in a debate over the relative merits of graving docks versus floating docks, as well as amongst varying types of floating dry docks themselves. One interesting floating dry dock precursor is that proposed in 1810 by R. Trevithick, constructed entirely of half-inch thick wrought iron and measuring 210 feet long by 54 feet wide and 30 feet deep, displacing 350 tons (Trevithick 1810:52). While likely the first dock designed completely of wrought iron, it lacked the capability to lift a vessel completely above the waterline, functioning more as a camel lifting pontoon than floating dry dock (Trevithick 1872:302). In this design, the side walls rise twelve feet above the waterline when docking, “to prevent the sea from breaking over” (Trevithick 1810:53). The reasons this design never came to fruition lies in part with the skeptical perspective felt by many in the industry towards the new technology, principally due to a lack of understanding. For example, a reviewer of the article by Trevithick objected to the design solely because the investment cost of 20,000 pounds was, in his eyes, better spent on a graving dock that lasts “ten times as long,” expressing trepidation over the risk “without more certainty of advantage than what these caissons promise” (Trevithick 1810:55). At this point, the European nations remained ahead of the United States in working with iron and steam in nautical applications, a continuing trend reflected in the design of floating dry docks on both sides of the Atlantic.

Patents and Early Floating Dry Docks in the United States

The United States issued the first patent for a floating dry dock on 16 May 1808 to William Rhodes of New York, NY (Burke 1847:193). No other available information exists regarding this patent, and it remains unclear whether anyone built the dock he described. In all likelihood, the dock operated as a floating graving dock similar that of Watson above, as that remained the type of floating dock in existence for another thirty years (Burke 1847:193-194). A similar situation exists with the second patent awarded for “a floating dry dock” in the United States on 15 June 1812 by Samuel Rose, also of New York City, where the historical record indicates it was never constructed. The third patent, issued to John Adamson of Boston, Massachusetts on 13 December 1816, received a considerable amount more notoriety than the first two, and various sources confirm construction of a dock in New Jersey based on the patent of Adamson for the dry docking and repair of canal boats, as seen in Figure 13 (Donnelly 1905:61). Mr. Adamson must have experienced some measure of success with his dock, as the United States Congress agreed to extend his patent for an additional period of fourteen years, beginning on 12 December 1830 (United States Government 1843:75).

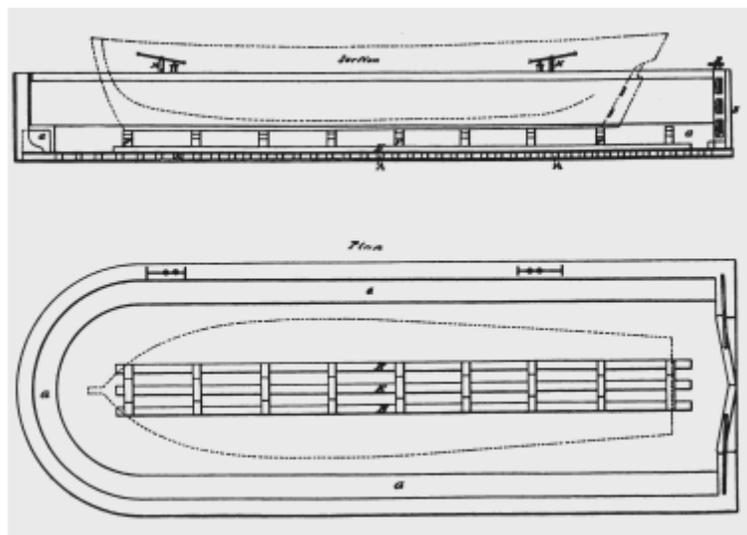


Figure 13. Adamson Floating dry dock patent sketch, with outline of vessel positioning (Donnelly 1906:Plate 3).

Over the following decade, the United States only awarded four new patents for inventions related to floating dry docks: Albert Brux in 1818, Edward Covenhoven in 1821, William Loweree in 1825 and John Floyd in 1826 (Burke 1847:193-194). Only one image exists of these four designs, belonging to Covenhoven from his 1821 patent, depicted in Figure 14. The low resolution and lack of accompanying description presents challenges for identifying certain salient features, most notably the two rows of vertical cylindrical structures flanking the sides of the ship in dock. Based on the utilization of piers as apparent guide ways, this structure employed a watertight pontoon beneath the floor of the dock for buoyancy and lift, similar to the camel lifting pontoons discussed in the previous chapter. Attempting to determine any other operational information from this image proves impossible; however, the general design appears a few years later in a new type of dry dock alternative, known as a hydraulic lift dock.

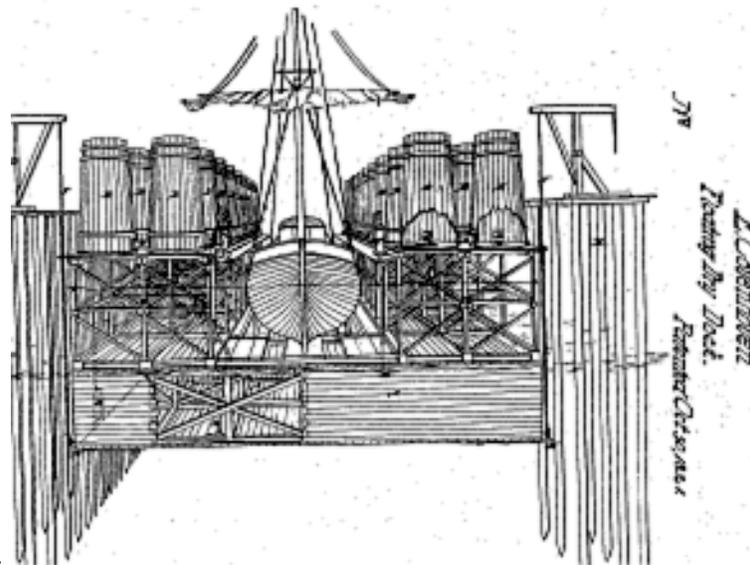


Figure 14. Patent administered to Edward Covenhoven of Greenburgh, NJ on 30 October 1821. (Covenhoven 1821:1).

In late 1826, the Franklin Institute launched an investigative committee to evaluate the new dry dock designs appearing on desks in patent offices and shipbuilding companies around

the country. One of the earliest designs reviewed was that of New York Civil Engineer Edward Clark, who designed a unique method of raising vessels dubbed the hydraulic lift dock. His dock, seen in Figure 15, qualified as a pontoon dock, in that a hollow, compartmentalized box provides the necessary buoyancy when pumped out to lift both the platform and vessel (Clark 1828:120). The incorporation of piers (b,b) with vertical guide-ways (d,d) and rollers (e,e) clearly represents a departure from the camel style docks previously employed, though it appears similar in function to the dock of Covenhoven above. Members of the Franklin Institute reviewed the design, objecting only to the “unequal pressure to which their bottoms must be subjected, by the weight of the vessel upon them, and the upward pressure of the water” (Clark 1828:121). Stability remained the foremost concern of all types of floating docks around this time, prompting the committee to recommend marine railways over floating dry docks where possible. However, they were inclined to recommend floating dry docks for specific applications in the same sentence:

In such situations, and when the vessels to be repaired are not of the larger class, the floating dock may be found advantageous; and they believe that under such circumstances, the plan before them presents considerable advantages above those floating docks from which the water must be excluded by flood gates (Clark 1828:122).

These events transpired in the early part of 1827, less than twenty years removed from the first patent awarded to Rhodes, illustrating the truly rapid proliferation of alternative structures for docking, primarily floating dry docks.

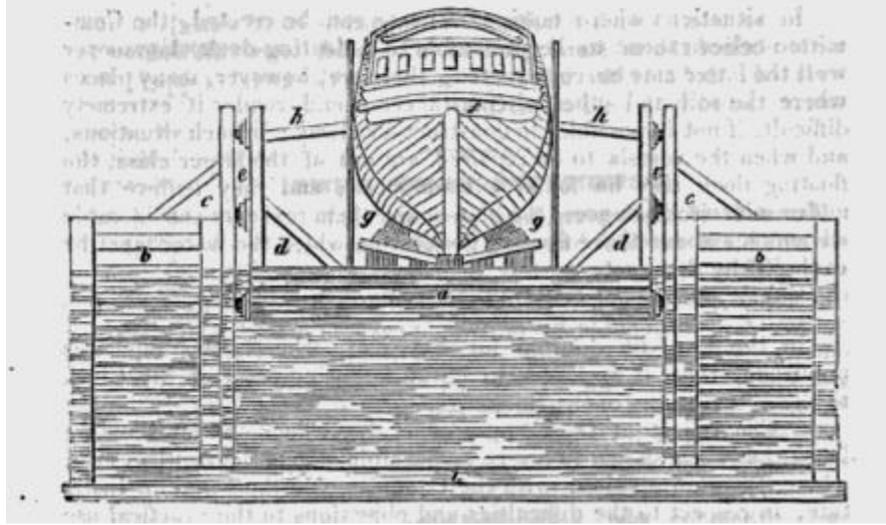


Figure 15. Sketch of proposed hydraulic lift dock of Edward Clark, 1827 (Clark 1828:121).

In 1826, Commodore James Barron, USN, received a patent for a “Dock, Carrying and Lifting Trunk” that sparked the interest of engineers around the country, as seen in Figure 16 (Burke 1847:193). This dock functioned much like graving and camel docks, except it possessed sufficient buoyancy to remain afloat at all times, never encountering the bottom. The dock operated by opening a gate at one end to admit water and sink the structure below the surface. Once the crew positioned the vessel over the blocks, they fasten closed the gate and pump water out from the interior space, causing the natural buoyancy of the timber frame to lift the dock until the vessel sufficiently clears the surface. One of the great advantages ascribed to this dock (and floating dry docks in general) over comparable basin docks is the reduced amount of energy required to pump the interior space dry. The following passage describes pumping in a basin dry dock:

At the commencement of the operation of pumping, as the level of the water in the dock and harbor is the same, no power is requisite to remove the water from the dock; as the pumping proceeds, the surface of the water in the dock sinks below the level of water in the harbor; of course, power is now required to elevate the water. The difference between the height of these two surfaces continually increases, until the last portion of water in the bottom of the dock is to be

removed, when the elevation to which the water must be raised is the greatest (Humphreys et al 1827:8).

This states that pumps in graving dry docks must work harder to expel water as the level decreases within the dock. The opposite holds true for floating graving docks:

At the commencement of pumping of the water from the floating dock, it resembles the common dock in not requiring any power to exhaust; but as the pumping proceeds, the dock becomes lighter, and of course the bottom does not remain in the same relative position to the surface of the water in the harbor, but rises in proportion to its buoyancy (Humphreys et al 1827:9).

Floating graving docks designed with an aperture in the bottom for discharging water therefore require one-fourth the pumping power of a comparable basin dry dock; however, docks that pump water up and over the sides require the same power as basin dry dock (Humphreys et al. 1827:9). Figure 17 provides a sketch of the fundamental concepts guiding the operation of floating graving docks.

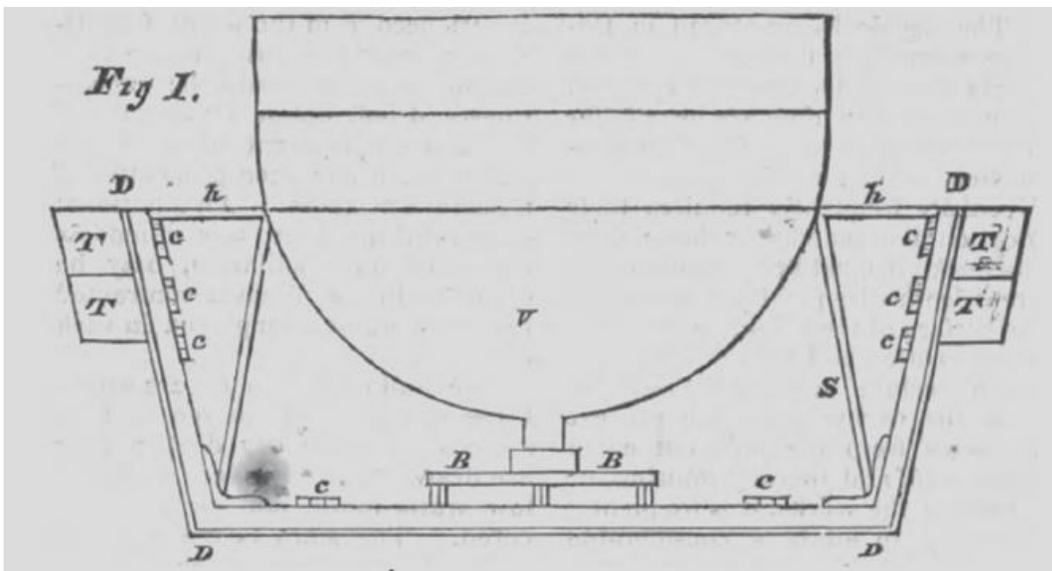


Figure 16. Profile view, floating graving dock of Commodore Barron. Note lifting trunks T,T (Humphreys 1827:7).

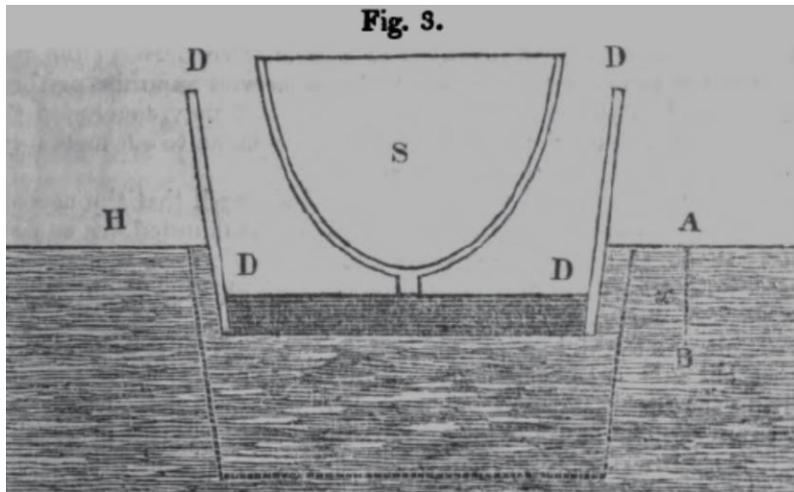


Figure 17. Basic operation of floating graving dock, with submerged position indicated with dotted line (Humphreys 1827:9).

As floating dry dock technology improved, designers raved of potential long term cost savings versus construction and operational costs of a basin dock, prompting debates and discussions in engineering circles around the country that lasted well into the twentieth century. As late as 1907 many still held the belief that basin docks were superior to floating, claiming “there are few situations in which a graving dock could be built in fairly good ground, where the writer would recommend a floating dock,” though simultaneously accepting the notion that in some locations floating dry docks proved advantageous (Cox 1907:153). Curiously, the United States awarded a patent to John Floyd for an “Improvement in Floating Dock” (referred to as Floyd’s Floating Machine) fifteen days after Barron, with virtually no interest from any engineering texts, though his name does appear in a lawsuit regarding a dock of which he owned a one-ninth stake (Burke 1847:193; Gray 1867:115).

The debate between the merits of graving and floating dry docks warrants a brief synopsis of advantages and disadvantages from both a commercial and naval perspective. Relative to commercial shipping, basin dry docks operate in shallow harbors and allow complete safety of a ship when seated in the dock. General disadvantages for commercial shipping are a

higher initial cost, lack of adequate ventilation and lighting, and amount of land required. Conversely, floating docks offered a reduced initial cost, did not occupy any land, could adapt to damaged craft while afloat, and were by nature portable. Commercial floating dock limitations resided in their “necessary occupation of useful waterfront,” as well requiring greater water depth to operate and marginally higher risk of accident owing to human error (Cox 1907:99). For naval purposes, deference towards safe handling of ships prompted overly conservative approaches to dry docking, in large part due to the intricate and fragile hulls present in early twentieth century warships, as well as the large sums of money invested in them (United States Senate 1847:62-73).

The years following the design of the dock by Barron showed little in the way of new patents, with only one awarded between 1826 and 1834, to Thomas Cunningham of Pittsburgh, PA (Burke 1847:193). His patent of 1830 laid the basis for the 1835 construction of the Folger Floating Dry Dock in Pittsburgh. Despite receiving a great deal of press in the *Pittsburgh Gazette*, *New York Times*, *New York American*, and various journals, the invention operated on the same principle as a floating graving dock. A lack of available schematics or description by the patentee preclude accurate classification of the dock, but there appears little novel about it warranting the praise and attention it received. Shipwrights, naval architects, and engineers recognized the value of the floating dry dock three decades prior, demonstrating how the rapid floating dry dock expansion outpaced the awareness of the lay public.

In 1834, the future of floating docks forever changed with the design of a sectional floating dry dock by John Thomas, illustrated in Figure 18. This dock differed significantly from earlier floating graving docks by dividing the structure into nine equal sections constructed entirely of timber, each containing their own strengthened bulkhead pontoons that link together

to form a desired length, measuring sixty feet long by four feet wide and four feet six inches deep (Jones 1834:253). The following year, the United States awarded patents to Jonathan Hawes for a pontoon floating dry dock, Rufus Porter for an obscure sectional type dock utilizing a platform sunk beneath two scows, and Campbell and Withington for a manner of raising vessels using casks or floats (Burke 1847:193-194). No information exists regarding the construction or operation of these docks however.

Following the establishment of his initial 1834 patent, John Thomas revised his design in 1837 to move the floating pontoons from the sides of the dock to the ends, improving stability and support while obviating the need for additional ballast (Stuart 1852:11). Sectional dry docks were the first to offer the advantage of self-docking, where workers disconnected single sections and lifted them on the remaining portions of the structure in order to facilitate their cleaning. Additionally, the independent operation of each section within a sectional dry dock permits their splitting into multiple smaller docks of varying sizes to accommodate any size vessel and increase overall productivity. Although the sectional aspect proved novel and valuable, the exclusive use of lifting pontoons independent of piers or guide ways separated this dock from all previous designs, acting as the template from which future floating dry docks drew inspiration.

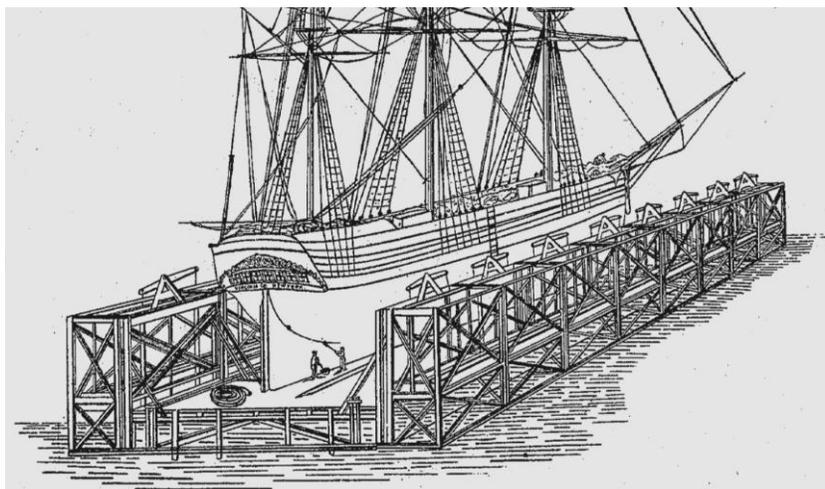


Figure 18. Patent drawing of early sectional floating dry dock by John Thomas (Thomas 1837:1).

This dock also contained the earliest recorded use of iron fastenings for strengthening connections at various points throughout the structure (Thomas 1837:3). While revolutionary for the construction of floating docks, iron bolts and nails existed in shipbuilding as early as the fifth century BC in Slovenia, where archaeologists discovered a Celtic riverboat employing ferrous nails as part of its fastening scheme (McCarthy 2005:30). Over two millennia passed before erection of the first iron-hulled vessel in 1787 AD, when J. Wilkinson constructed an eight-ton, seventy-foot long canal boat for hauling iron in Birmingham, England (Grantham 1868:6). Many factors contributed to the tentative adoption of iron as an acceptable construction material in shipbuilding, such as general maritime conservatism, the low quality and quantity of available iron, the relative abundance of wood and knowledge of its properties, and the interests of investors and commercial firms with a stake in the wood trade (Goodwin 1997:1). Floating docks emerged at a time when wooden vessels still dominated the maritime landscape, so logically builders used wood for their new docks. As iron vessels permeated into the mainstream, wooden floating docks lacked the necessary lifting capacity to service them, prompting a reevaluation of iron as a potential building material for new docks. Similarly, vessel size continued increasing, causing an increase in the size of floating docks to a point where timber docks of such magnitude became unfeasible (Donnelly 1910:71). Thus, the evolution of floating docks necessarily responded to a similar evolution occurring simultaneously in the evolution of ships.

Similar to the Adamson dock, the apparent effectiveness of the John Thomas sectional dock prompted the United States Government to extend the patent for an additional fourteen-year period in 1849 (Burke 1897:194). In 1840, William Thomas (relation to John Thomas unknown) patented improvements upon this design, most significantly making the bulkheads watertight and controlling the passage of water between them using a series of pipes controlled by cocks

(Thomas 1840:4). As with so many others already listed, William Thomas failed to receive any appreciable notoriety for his improvements in floating dry docks, though his contributions undoubtedly affected future designs.

After introduction of the sectional dock in 1837, Commodore Barron reemerges with an improved version of his 1826 floating graving dock to counter the dock of Thomas. The major improvement noted in this design is the incorporation of air into chambers within the widened sidewalls, acting as to improve stability and provide extra lift. Even Barron, who championed the floating graving dock, recognized that pontoons and air chambers provided greater lift and stability than relying solely on the buoyancy produced by the drained, watertight hull of the dock. The basic operation of his design remains unchanged however: excluding water and attaining buoyant lift by pumping out the interior space of the dock (Barron 1837:1).

The First Floating Dry Docks of the United States Navy

The next major developments begin with a series of floating dry docks patented in 1840. The first, of Joseph T. Martin, improved working of the ballast tanks with racks and pawls and addition of cisterns designed to catch leakage and pump it out along with water accumulating in the main reservoirs (Martin 1840:4). One year later, John Gilbert of New York received a patent for his “floating balance dry-dock;” a combination graving and pontoon dock using compartmented air chambers in tandem with the natural buoyancy of the structure to provide the necessary lifting power, as seen in Figure 19 (Gilbert 1841:1). Gilbert revolutionized floating dock construction with his innovative relocation of the pontoons, moving them from beneath the floor of the dock to within the wing walls, significantly reducing the water depth required to sink the dock below a vessel requiring service, effectively eliminating one of the early objections to floating dry docks (Gilbert 1841:2).

The reason Gilbert referred to his dock as a “balance” dock stems from his use of moveable carts on rails, filled with ballast, to aid in sinking the dock, while also adjusting the overall center of gravity as needed (*k,k* in the perspective drawing of Figure 19). Additionally, the design of this dock reduced the amount of pumping required to achieve the desired buoyancy, while also implementing a new method of construction designed to tighten seams and simplify caulking by joggling the timber frames together, depicted in Figure 20 (Gilbert 1841:2-4). Gilbert explicitly stated he designed his balance dock in such a fashion as to permit its construction of wood or iron, despite no other iron floating docks existing at that point in history, showing a shrewd anticipation that iron would eventually supersede wood as the primary construction material for floating docks (Gilbert 1841:3).

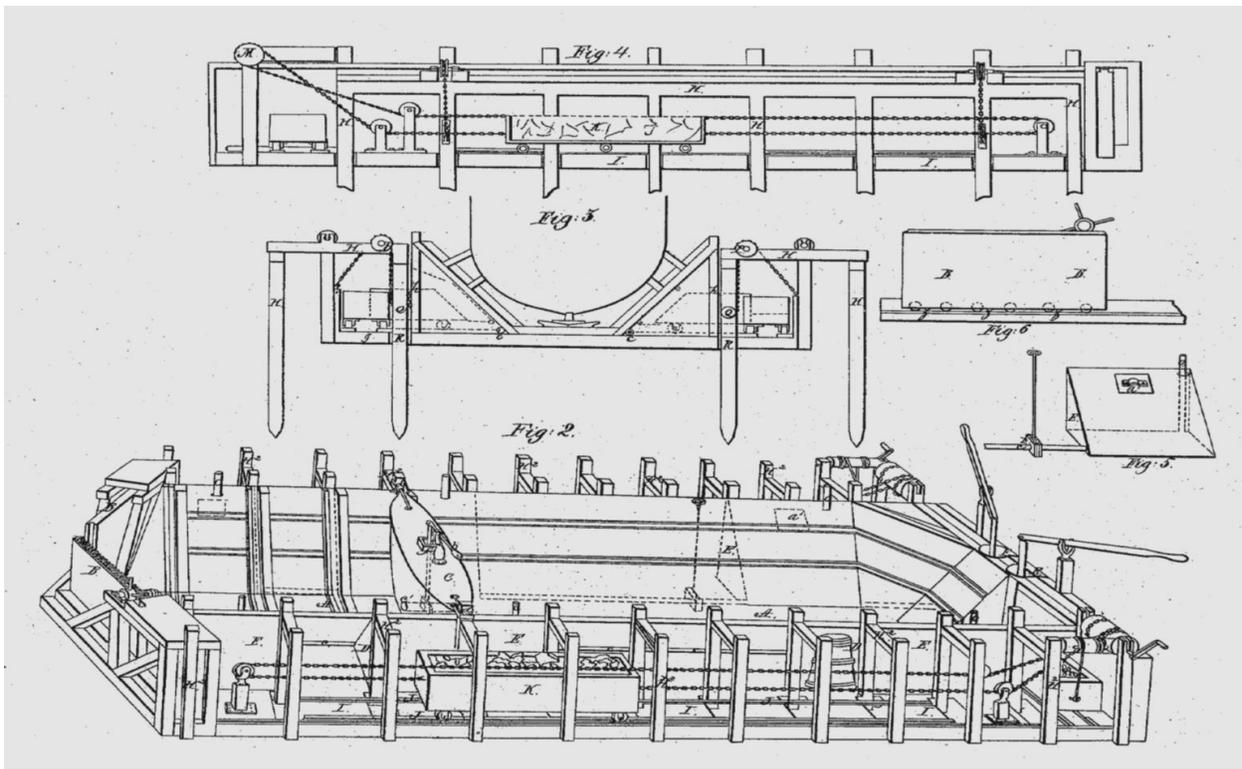


Figure 19. Perspective view of floating balance dock showing compartmentalized pontoon and machinery (Gilbert 1841:Plate 2).

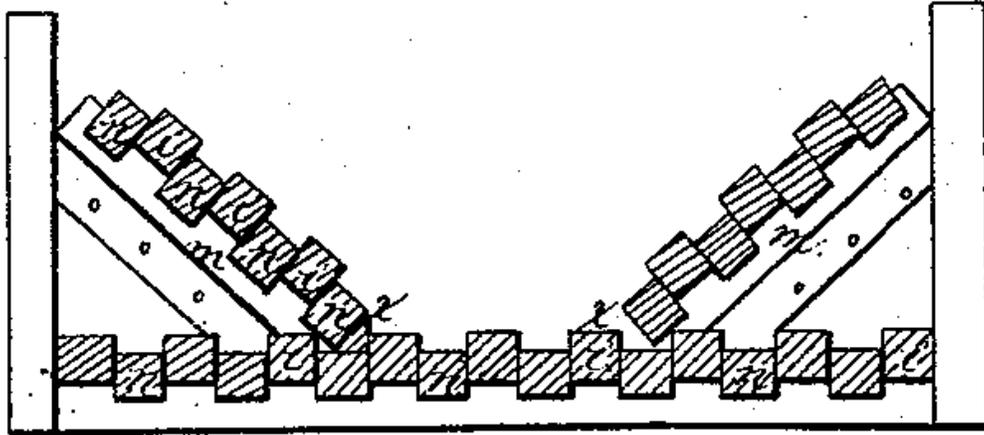


Figure 20. Depiction of improved joggled framing construction (Gilbert 1841:Plate1).

Capitalizing on the recent success of pontoons in floating docks, Charles Johnson created the pneumatic lift dock, which operated by “placing inverted boxes or air chests beneath a cradle for receiving the vessel and giving them buoyancy by forcing air into or under them” seen in Figure 21 (Johnson 1840:2). This dock operated under the same premise of that proposed of Edward Clark in 1826 and depicted above in Figure 15, though it does not appear this dock, or any dock operating in this manner, achieved any great significance. In 1841, Dodge and Burgess acquired a patent for their version of a floating sectional dock, only slightly disambiguated from the sectional docks conceived of by Thomas a year earlier in that they further regulated the admission of water into the end floats. They also moved all pumping machinery into the wing walls, allowing for simultaneous submersion and producing the least possible strain on the hull of the ship during the transfer of weight onto the keel and bilge blocks (Donnelly 1906:63). Even from this early juncture, engineers realized the promise of the sectional design, primarily in an attempt to increase the longevity of floating docks to reflect more closely that of long-term excavated basin docks through frequently maintenance and cleaning.

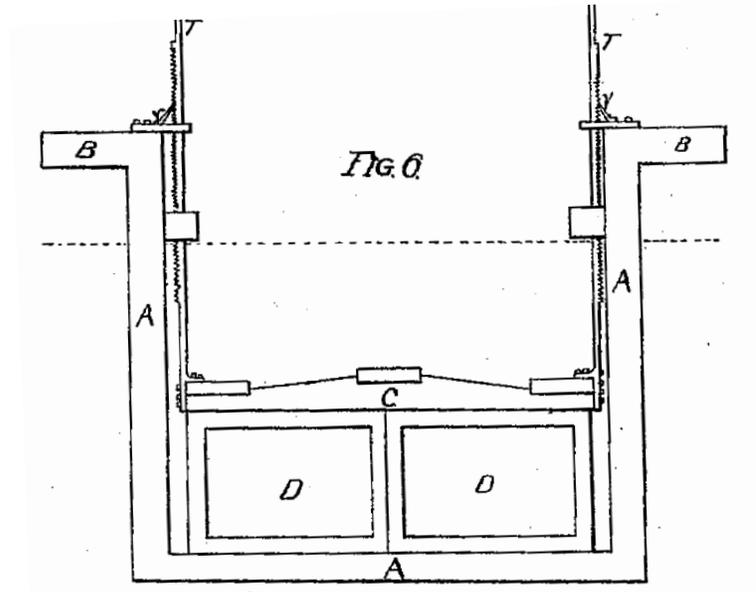


Figure 21. Pneumatic lift dock invented by Charles Johnson, similar in form and function to floating dock designed by Clark in Figure 5 (Johnson 1840:1).

For the better part of the early nineteenth century, and beginning with remarks made by Thomas Jefferson in 1802, the United States government considered adding a floating dry dock and marine railway to the Philadelphia dockyard in order to lay up ships of the line when not in service, as a means of enacting their preservation (Dakin 1844:11). The movement increased momentum in 1820, following a report by Navy Commissioners indicating the life of a ship lasts longest when provided a dry, covered facility free of direct sunlight and harsh winds, but open enough to admit the exchange of air (Stuart 1852:9). Citizens so eagerly embraced the idea that they held a rally pronouncing their support for improved docking facilities in Philadelphia in 1837 (Dorwart 1837:76). Following the rally, politicians became involved, with one faction, led by U.S. representative Levin of Philadelphia stumping for the design of a sectional dry dock, basin, and railway system devised by Dakin and Moody in 1843, depicted in Figures 22 and 23 (Levin 1846:2). The Democratic Party within the house took up the opposing side and supported a plan incorporating the balance dock of John Gilbert, also intended to operate in conjunction

with a basin and railway system, as illustrated by Figure 24. After considerable posturing and propagandizing by both parties, the United States Congress appropriated the necessary funds to contract the design of Dakin and Moody in 1847 (Stuart 1852:7). Despite failing to win the contract for the Philadelphia Navy yard, the United States went ahead with construction of the Gilbert balance dock for the Navy yard at Portsmouth, Maine (formerly known as Kittery) and Pensacola, Florida (Stuart 1852:219). Dakin and Moody also won the contract for a the California floating dock on San Francisco Bay, though the contract changed shortly after the announcement to only include the sectional floating dry dock, and not the additional basin or marine railways (Stuart 1852:226). As an interesting side note, Rebel forces captured the Pensacola dry dock in 1861 and burnt it within the channel to obstruct the waters opposite Fort McRae (Moore 1862:117).

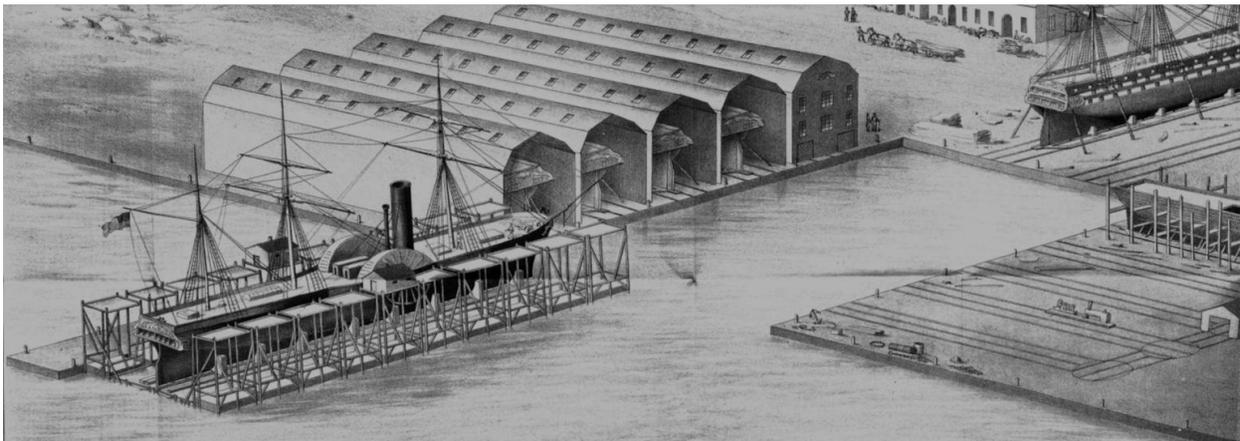


Figure 22. Perspective view of sectional floating dry dock and corresponding railways designed for Philadelphia (United States Government 1849:1).

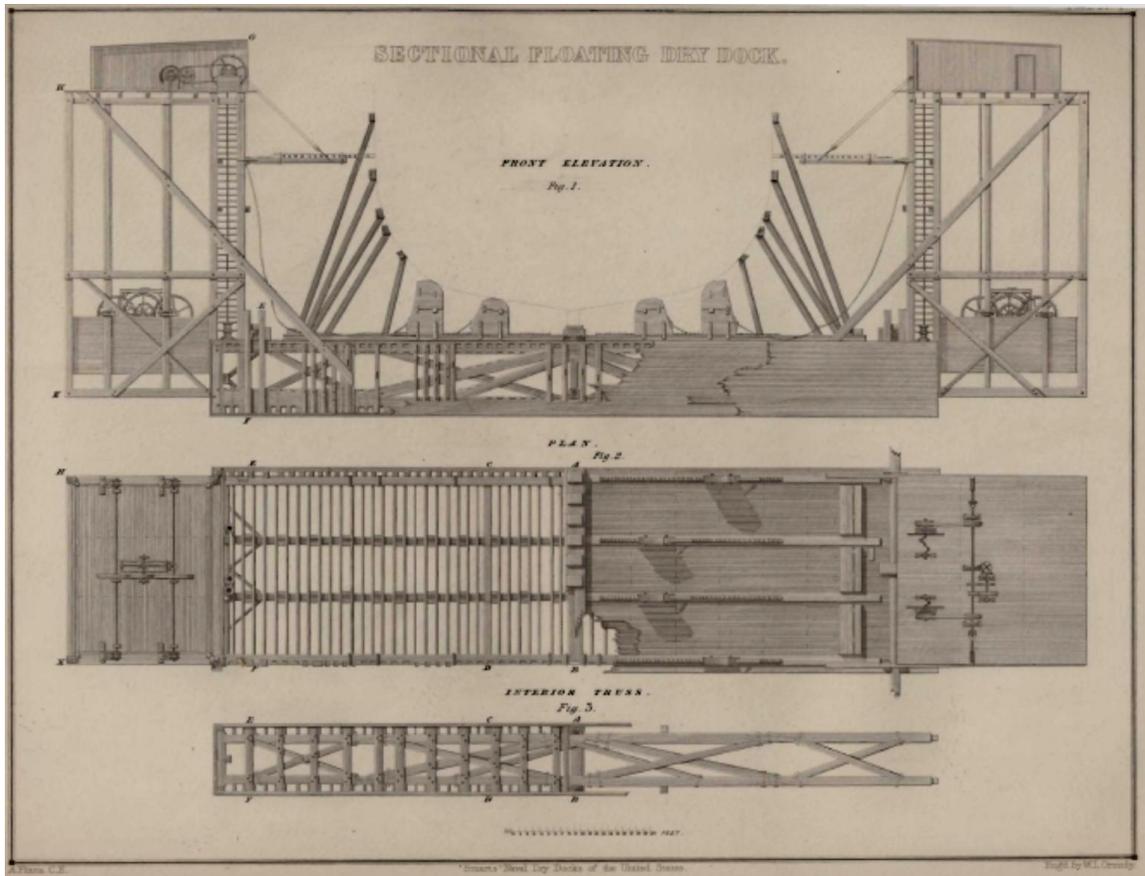


Figure 23. Plan and elevation views of sectional floating dock (Stuart 1852:113).

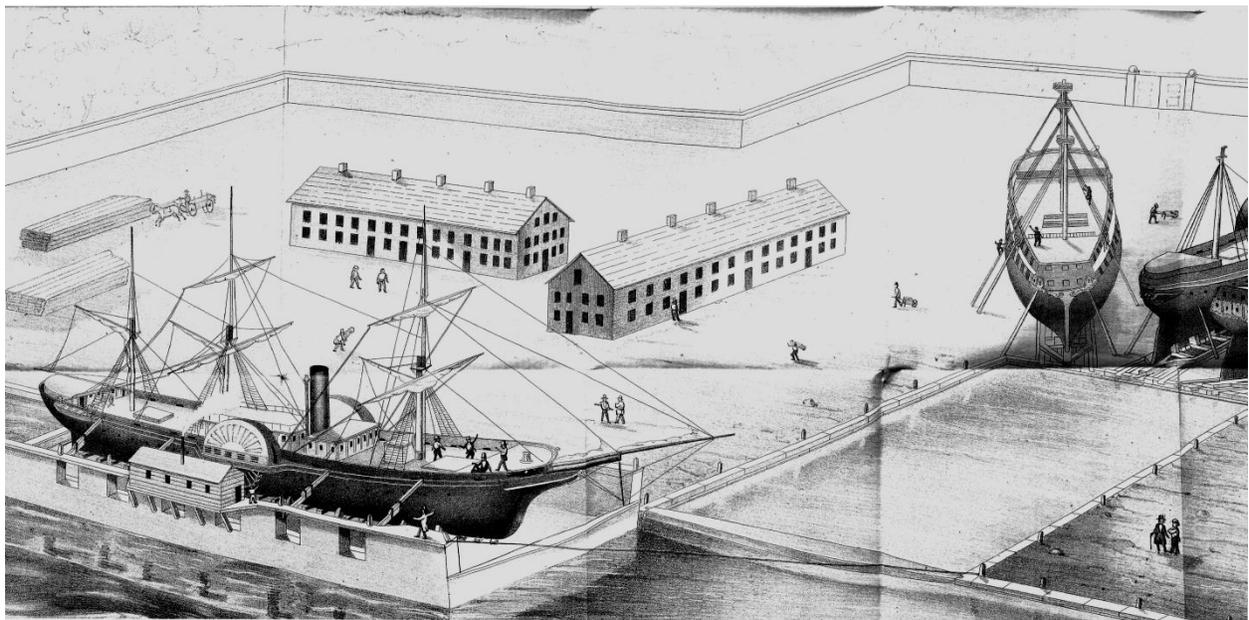


Figure 24. Perspective view of the Gilbert Balance Dock with basin and railways, proposed for Philadelphia (United States Navy Department 1849:2).

Iron Floating Docks

Despite the relative advances found in the pre-modern floating dry docks, the specter of iron and steam ships eventually overcame the wooden frames employed ubiquitously to this point. Notwithstanding the rapid advances made by iron in the United States in the decades prior, wood maintained its hold as the primary material for construction there because it was cheap, abundant, easily manipulated, and proven sufficiently strong to support the largest vessels in their fleet through the middle of the century. In the United Kingdom, engineers worked at an early stage with iron as a medium of primary construction, and in 1859 R. W. Thomson of Edinburgh, Scotland, designed the first completely iron sectional floating dock for Royal Naval operation in Surabaya, Java (Chambers 1870:524). An article from the *Otego Witness* dated 26 January 1867 describes the unusual manner of construction that won Mr. Thomson the contract:

Hitherto the plan followed was to build up the structure in this country, fastening all the parts together by means of screw bolts, putting on each individual piece in its place a mark indicative of its special position, pulling the whole down again, and re-erecting it abroad. In fact, the entire work had to be done twice over. Mr. Thomson determined to make every separate piece of the Surabaya Dock from drawings, and to dispense altogether with the costly operation of building it up in this country (*Otego Witness* 1867:2).

The piecemeal approach succeeded in reducing the overall cost, while also increasing the uniformity of the pieces used for construction (Greene 1890:52). Workers at the iron mills rolled out the steel plates, cut them to the appropriate size, punched holes in them and sent them for assembly as is, requiring no shaping or bending of any pieces at the assembly site (Greene 1890:52). As novel and industrial as this method was, the first practical application of it resulted in a complete failure when the dock lost control and sank during its maiden lift (Smith 1863:185). The purported low quality of the workmanship resulted in hundreds of rivets capable of being “shaken by the fingers,” with plentiful “gaping seams filled with wooden wedges”

directly contributing to the operational failure (Smith 1863:185). Similar iron docks designed by Mr. Thomas operated in Callao, Peru (depicted in Figure 25) and Saigon, Cochinchina, with a better, though still imperfect record of success, as on 17 December 1860, the Callao dock malfunctioned while lifting the 44 gun Peruvian frigate *Callao* (*Sacramento Daily Union* 1860). Thomas pioneered a rather ingenious method of maintaining control during docking, one repeated in the St. Thomas floating dock and the floating dock of Janicki, by situating within the wing walls three hollow pontoons per side (*Engineering* 1871:185). While performing a lift, operators raised and lowered the permanently watertight air chests within the wing walls to adjust trim and maintain buoyancy as needed (Greene 1890:52). The only available description of the specific malfunction states the keel of the ship slid off the blocks and heeled over “in consequence of some of the boxes being lowered too quickly,” killing 100 and injuring 88 (Moriarty 1874:723). The dock sustained only minor damage when the masts of *Callao* struck the side of the dock and broke off, remaining in service at least through 1902 when the oil tanker *Bakuin* caught fire while inside the dock (Forbes and O’Beirne 1957:527).

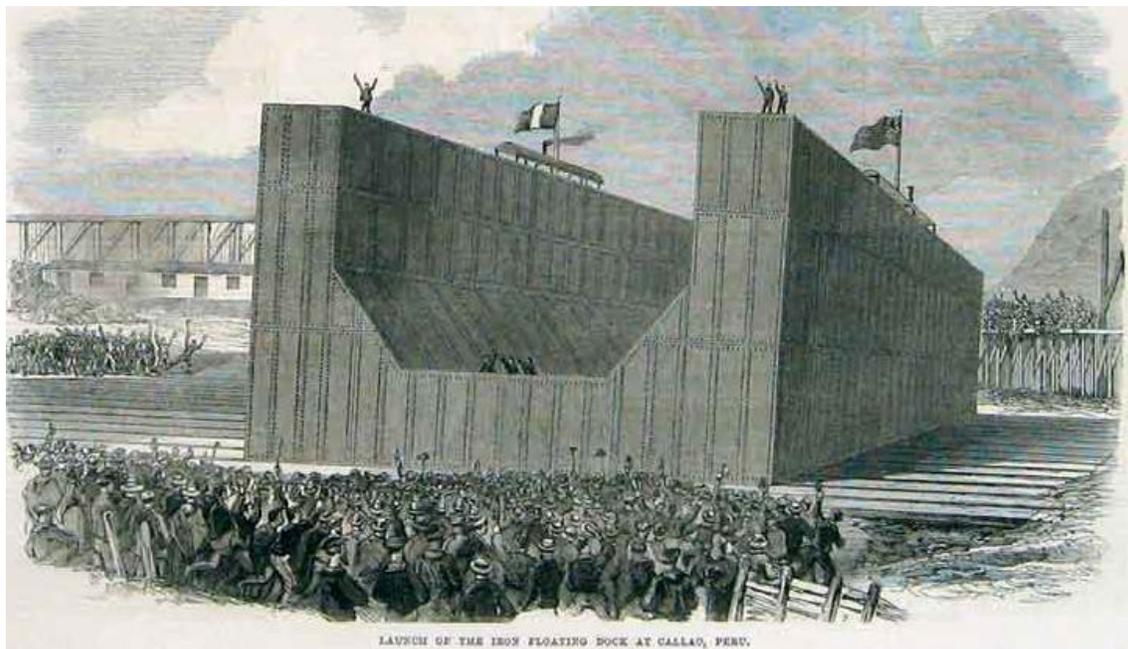


Figure 25. Launching of the Callao iron sectional dock (*London Illustrated News* 1866).

Two years later, in 1862, an intrepid engineer by the name of George Rennie designed an iron floating dock in the same fashion as Mr. Thomas, shipped in pieces and assembled in Cartagena, Spain for use by the Spanish Navy. The entire dock consisted of wrought iron, except for the decks, shoring steps (or altars) and fenders, which were all of timber (Rennie 1869:18). The feature separating this design from previous sectional docks was the single-piece side walls situated atop a series of sectional pontoons, an efficient design universally referred to as the Rennie type. Maintaining the side walls in one piece essentially formed continuous girders running longitudinally down both sides, increasing stiffness to that of comparable balance docks (Cox 1907:165). Shortly after construction of the Cartagena dock, Rennie designed a similar dock for the Spanish port of Ferrol 50 feet longer and capable of lifting 1,000 tons more than said dock, only to see the revolution in that country use the prefabricated iron sections for other purposes (Rennie et al. 1906:1026). Floating dry docks constructed prior to these typically lacked adequate longitudinal support, and subsequently possessed limited supports for shoring timbers, contributing to the general disapproval of floating dry docks for naval applications prior to 1869 (United States Senate 1847:62-68).

Following the introduction of iron floating dry docks around 1859, all the requisite components existed for what essentially comprises a modern floating dry dock: compartmentalized air chambers, self-docking capability, steam power for mechanized pumping, and a ferrous hull. During this watershed period, engineers no longer strived to invent new methods of docking vessels; rather, they devoted their energy to maximizing the existing methods with improved construction materials and manufacturing techniques, often incorporating many structural variations into a single dock. Civil engineer A. C. Cunningham, responsible for designing the steel floating dry dock *Dewey*, based at Cavite, Philippines, claims

“general perfection in floating dry docks was reached with the type first and still known as the ‘balance dock’ which is also called the ‘solid dock’ since the introduction of sectional and self-docking docks” (Cunningham 1907:266).

In 1868, the Campbell and Johnston shipyard launched the first iron hulled floating balance dock for operation at the Royal Naval Dockyard, Bermuda. Following the recent European trend of utilizing entirely wrought-iron materials for construction, and given the success of early wrought iron floating docks, the designers selected it for use in their balance dock, as seen in Figures 26 and 27. Conceptually, the design represents an oversized pontoon curved in the shape of a capital U, employing compartmentalized chambers through the turn of the bilge and up the wing walls, granting it unparalleled maneuverability during the self-careening process while also allowing manipulation of the dock to conform to any list encountered with damaged vessels. At a length of 339 feet and breadth of 84 feet, the HM Floating Dock *Bermuda* boasted a lifting capacity of 11,000 tons displacement, heavy enough for any ship in existence at the time of construction (Navy Department 1892:180). This dock incorporated all the hallmark features of early balance docks, with only the hull a significant departure; but despite the hefty lifting capacity and successful record of operations, the U shaped hull design never took hold as a viable design. The excessive amount of construction material required versus a rectangular box dock proved the ultimate drawback of the Bermuda design. When compared with the dock built for Cartagena, Rennie claims:

It will be seen that a dock of the rectangular form of the same proportions as that of Carthage, will have the same total stability as the U form of dock, require about one-fifth less material for its construction, and be capable of supporting a longer ship of one quarter greater weight, and with a less draught of water (Rennie 1869:20).



Figure 26. Scale model of 1868 Bermuda floating dry dock (Gould and Souza 1996:6; Fletcher 1910:356).

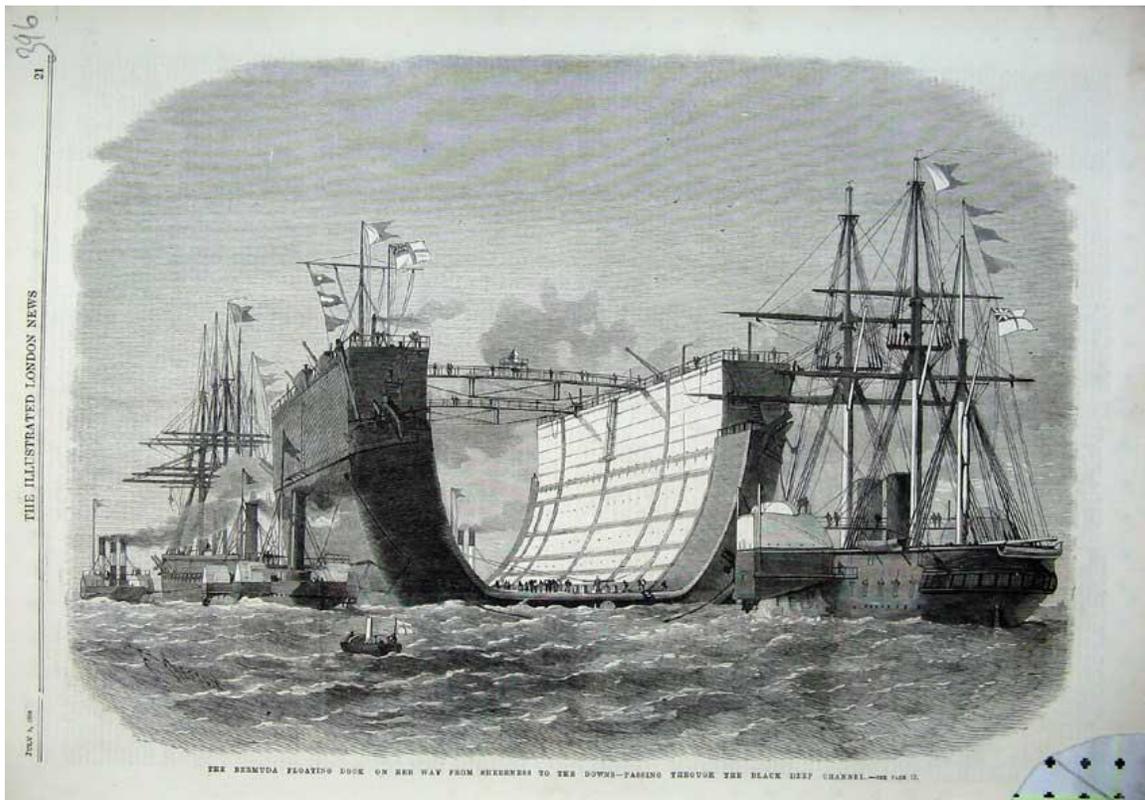


Figure 27. Towing Floating Dock *Bermuda* from England to Bermuda, 1868 (*Illustrated London News* 1869:21).

Around the world, iron rectangular sectional docks took over as the primary floating dry dock structure through the latter 19th century, though they never completely supplanted graving dry docks as the preferred method of laying up ships, all conditions being equal. Their successful construction of iron in St. Thomas, Dutch West Indies, Callao, Peru, and Cartagena, Spain, set the stage for a class of floating docks constructed around the turn of the twentieth that closely represent the primary form of floating dry docks in use today. However, even as the rest of the world embraced iron, the United States expanded their fleet to include timber floating dry docks at the ports in Savannah, Georgia, New Orleans, Louisiana, and Mobile Alabama. By 1886, the United States Navy operated a combination of twelve balance and sectional timber floating dry docks, each with a breadth greater than 58 feet (Supplement 1886:294). Despite an increase in the number of large ships plying waters around the world, the number of large floating dry docks increased only marginally; however, their size necessarily increased in direct proportion to the largest ships coming off the ways (Clark 1907:238).

Although iron clearly represented the future of floating docks, building with it proved problematic for individuals or small firms lacking the immense facilities and expertise required to work with iron. Patents regarding construction of timber floating dry docks continued appearing in the United States through 1900, as wood remained abundant, easily manipulated, and inexpensive there. On this premise, Charles Brown and Thomas Biddlecombe patented a floating balance dock in 1889, which assimilated newly developed features of floating docks into a consolidated and improved design (Brown and Biddlecombe 1889:3). They received a patent for their structure by claiming to incorporate a compartmentalized buoyant caisson with a series of improved valves for controlling the admission of water into the dock, between the watertight bulkheads, and within the trimming compartments located in the upper portion of the wing walls.

Additionally, they added new scaffolding of the caisson, an inclined anchoring-brace, and relocated the pump apparatus to the top of the scaffolds (Brown and Biddlecombe 1889:3). Despite no historical evidence suggesting construction of a dock based on the Brown and Biddlecombe patent ever occurred, the designers recognized the potential these structures possessed for operation colloquially around the United States:

Our construction can be carried out at a minimum of cost, and is intended to solve the difficulty of building such a structure with the ordinary materials and workmen at command of any place equipped for building ordinary wooden vessels, and, furthermore, its construction is specifically adapted to the conditions of the coast along our great northern lakes (Brown and Biddlecombe 1893:3).

In the same year, John Standfield received a patent for a self-docking floating sectional dock whose pontoon extended considerably beyond the wing walls. The intended construction material remains unknown due to the tersely worded accompanying description. The patent only claims to reference a new method of self-docking, where the extended pontoon end of one section fits between the wing walls of the other, allowing for lifting one section completely free from the water, as depicted in Figure 28 (Standfield 1889:1).

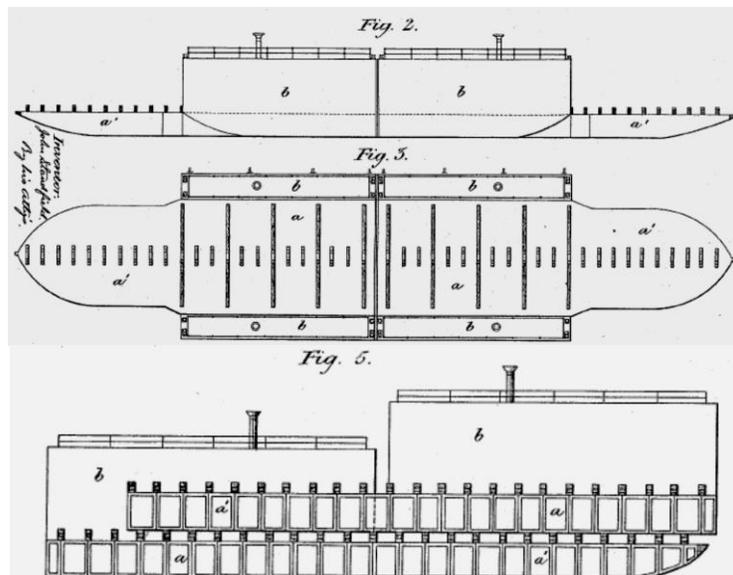


Figure 28. Fig 2 and 3 represent sketches of dock in operational form, while Fig 5 depicts them self-docking upon one another (Standfield 1889:Plates 1 and 2).

Depositing, Off-Shore, and Double-Power Docks

In addition to the various types of floating docks discussed thus far, a handful of floating dock offshoots developed during this period, as experimentation with alternative applications of lifts, hydraulics, and pneumatics for docking skyrocketed. As previously described, the hydraulic lift dock continued to provide service around the world, most notably in the Victoria Docks of London from 1857-1896 (Cherry et al 2005:295). Similar structures existed in Bombay, India in 1872 and San Francisco, California in 1887, Valetta, Malta in 1891 as well as never completed lifts in Tidnish and Amherst, Nova Scotia (Navy Department 1892:160-278). Despite possessing considerable advantages over basin graving docks, such as greater exposure of the hull to wind and sun to expedite drying, hydraulic lifts initially failed to catch on for servicing large vessels, particularly due to the considerable depth of excavation required to set the hydraulic rams, in some cases upwards of fifty feet (Select Committee on Dockyards 1864:16). By 1909, all major ports in the world ceased operating hydraulic lift docks of appreciable size, preferring floating docks, excavated docks, marine railways, or patent slips (Office of Naval Intelligence 1909:87-213). Despite their waning approval for large vessels, lift-style docking systems remained effective and efficient for use in small private or commercial yards before resurging in the 1960s with the improved Syncrolift dock, discussed later in the chapter.

Prior to inventing his self-docking floating dry dock in 1889, Standfield developed an interesting derivative of the floating dock in 1881 known as a depositing dry dock. These docks essentially resemble a traditional floating dock with only a single wing wall, forming an L-shape, as shown in Figure 29. To compensate for the loss of a wing, a broad and shallow outrigger connected to the exterior of the remaining side, also compartmentalized, and ballasted in such a fashion as to remain permanently half submerged. This outrigger merely provided support for the

dock and did not aid in lifting, though it created a useful storage platform for the location of boilers, spare parts, and auxiliary equipment. The compartmentalized vertical wing section houses all the pumping machinery and connective piping, possessing only the necessary buoyancy to support its own weight and therefore not affecting lift. The floor of the depositing dock consists of a series of parallel, compartmentalized pontoons that provide all the necessary lifting power (as in a pontoon dock), spaced equidistantly apart and resembling fingers. In addition to the dock, a corresponding staging area existed within the harbor consisting of floor supports, resembling a gridiron, situated to remain above the water level as illustrated by Figures 30 and 31. The floor supports were spaced in such a manner to allow the fingers of the depositing dock to interlock with the staging area, allowing for simple transfer from dock to stage without rails or ways. The dock lifts in the same fashion as traditional floating docks, where water fills the air chambers to a point of negative buoyancy below the hull of a vessel, pumps removing the water sufficiently to raise the dock and vessel together. Once raised, workers haul the dock towards shore using capstans, move the dock into the interlocking position between the fingers of the staging area, and deposit the vessel onto blocks positioned atop the supports. Thus, the depositing dock can lift and deposit many vessels in a short amount of time within a harbor, limited only by the available staging space, a scene depicted by Standfield in Figure 31 (Standfield 1881:81-89). While the inspiration for this particular arrangement of technologies remains obscured, the scenario seems highly unlikely for another individual to create the same assemblage had Standfield never developed floating docks.

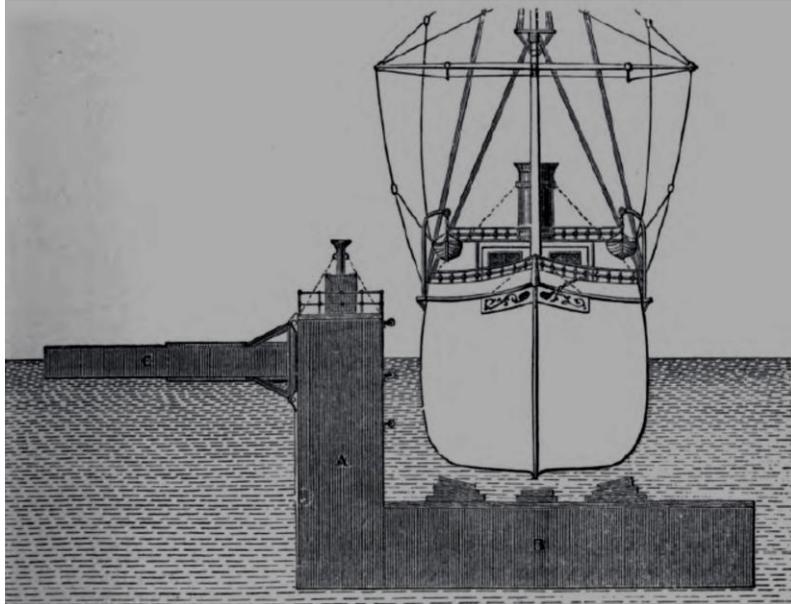


Figure 29. Deposing Dock showing wing wall (A), pontoon (B) and outrigger (C) with outline of vessel in position before lifting (Standfield 1881:83)

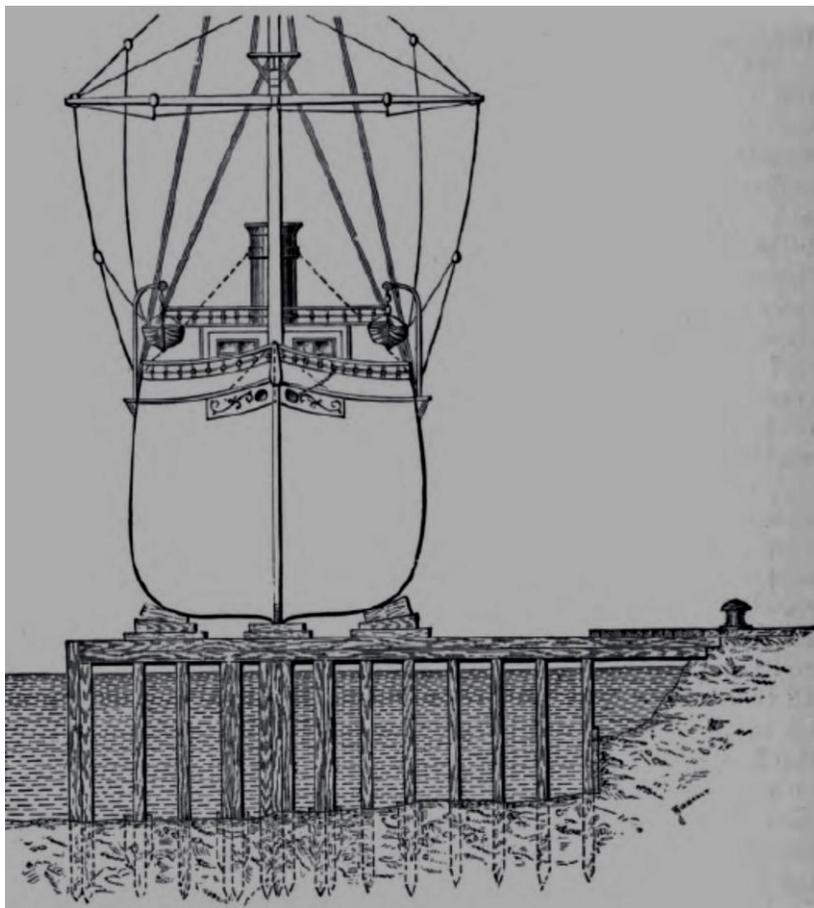


Figure 30. Elevation view of staging area with outline of ship on blocks. (Standfield 1881:86).

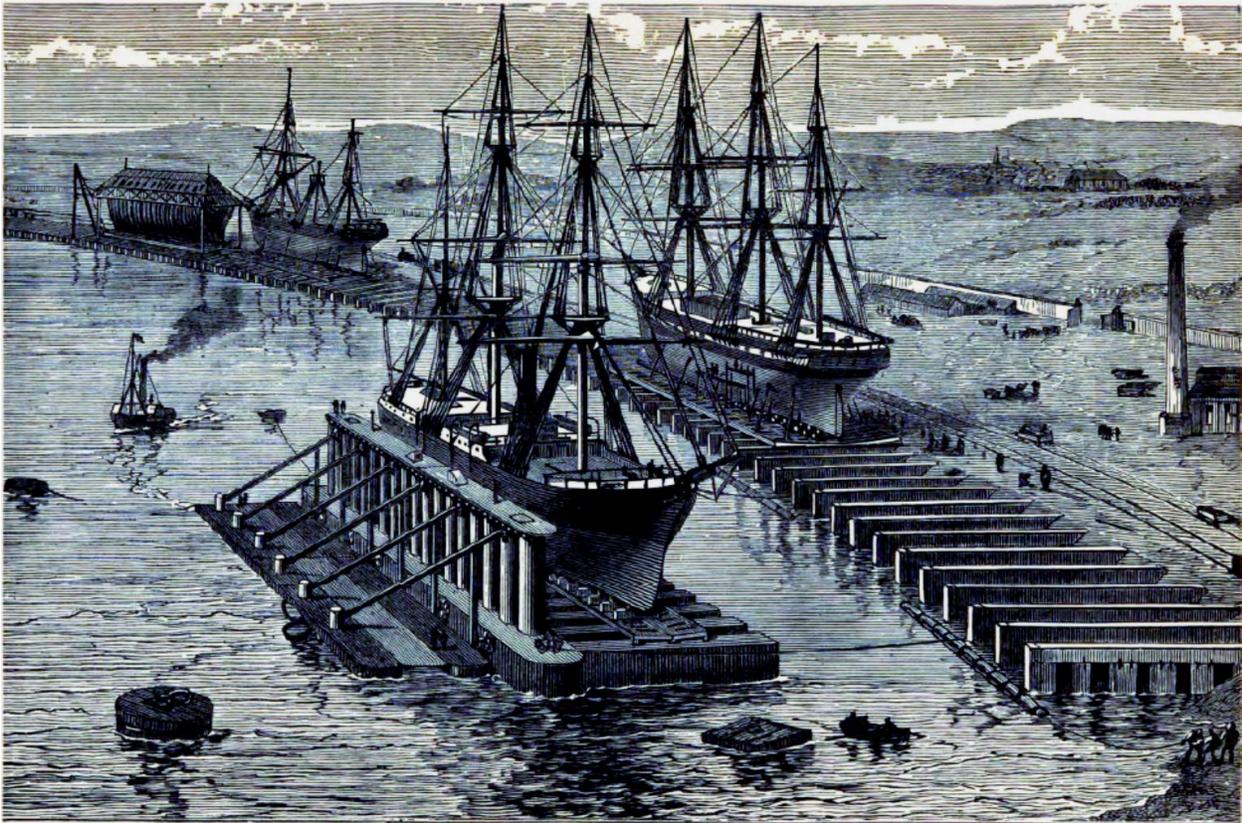


Figure 31. Depiction of potential operation of depositing dock and gridiron stage within a harbor (Standfield 1881:89).

In 1874, accomplished engineer Latimer Clark, brother of aforementioned engineer Edwin Clark, and John Standfield merged their collective talents into one of the most formidable docking design firms in history, which designed and implemented an impressive 41 docks in less than 30 years, and an additional 52 docks between 1904 and 1926 (Clark 1905:39-40; Amirikian 1957:351). They designed the first depositing dock for operation in Nicholaieff, Russia in 1877, leading to similar contracts for Vladivostok, Russia, and Barrow-in-Furness, England before the turn of the twentieth century (American Society of Naval Engineers 1898:679). One of the major features separating these docks from hydraulic lifts was the ability to self-dock in a fashion similar to floating dry docks. The hydraulic lift necessarily contained many parts constantly submerged without an easily accessible means for cleaning and painting, whereas the depositing

dock operated sectionally, permitting the self-docking procedure of Figure 32. Coincidentally, the Russian Navy decided to adopt the depositing dock concurrent with their 1876 decision to construct an experimental class of circular ironclads 120 feet in diameter, known as “Popoffkas,” which were far too wide to fit in any type of graving or floating dock in the world (Staples 1898:344). To overcome the problem, Clark and Standfield devised a method of removing the end pontoons of the depositing dock and bolting them to the remaining center ones, taking a dock that was 280 feet long by 72 wide and rearranging it into a dock 155 feet long by 144 feet wide (Clark 1905:13). In 1887, the company modified their depositing dock by replacing the floating outrigger with a series of rigid columns excavated into the foreshore, maintaining the use of booms for connecting the dock to the columns (Clark 1905:14). Clark and Standfield first implemented this type of dock, known as an off-shore dock, in Hamburg, Austria in 1888, where its immediate success prompted construction of similar structures in Cardiff, Wales, Flensburg, Austria, Stockholm, Sweden, Astrakhan, Russia, Copenhagen, Denmark, Genoa, Italy, Aberdeen, Scotland, and North Shields, England (Clark 1905:39-40).

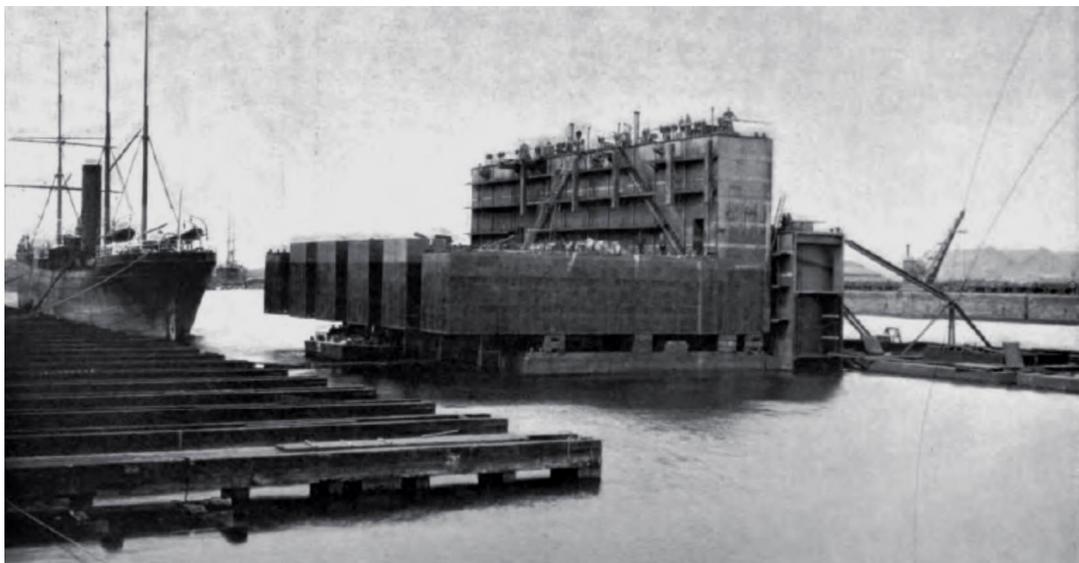


Figure 32. Self-docking of depositing dock at Barrow-in-Furness, England (Staples 1898:346).

One final offshoot dock designed by Clark and Standfield was that of the 1879 double-power dock, resembling a typical floating dry dock in design but incorporating elements of pontoons and camels to provide lift. In the standard floating dock operating during this time, the compartmentalized wing walls provided more stability while docking than lift, in effect contributing to the overall weight of the structure and increasing the load placed upon the pontoons once raised above water. In the double-power dock, the wing walls float independently of the pontoon, resembling a normal floating dock shape when pumped dry. When a vessel required docking, the pontoon lowered beneath the keel of the ship in the normal fashion, but the wing walls remained afloat, disconnected from the rest of the dock. Workers then pumped out the pontoons, effecting the maximum lift available from the continuous dock, independent of the wing walls. If not sufficient to raise the vessel above the waterline, the wing walls were then flooded and made fast to the dock, quite similar to the operation of early camels. Once pumped dry, the added buoyancy of the wing walls lifted the dock and vessel together to the required height. Like sectional docks, the double-power dock possessed the desirable ability to dock parts of itself for cleaning and repair, and did so in an easier and more efficient fashion than previous designs (Standfield 1881:90-97). The primary drawbacks of this design are the necessary use of separate pumps for the pontoon and wing walls, as well as the significantly increased depth required of the wing walls to provide lift for the pontoon and vessel. Thus, for all the promise this new design offered, a large dock of this structure proved impractical, and only one small double-power dock was ever built, that of Vera Cruz in 1893 (Clark 1905:7)

Early 20th Century Floating Docks

Around the turn of the century, the company experienced a notable change in the types of docks contracted for construction, shifting from predominantly off-shore and depositing docks to

exclusively floating docks of both box and sectional form, designing only one of each depositing and off-shore dock after 1900. This shift occurred following establishment of the first Clark and Standfield floating docks for Havana, Cuba, Amsterdam, Holland, and Stettin, Germany in 1897. The record of successful lifts performed by these docks paved the way for their receipt of a contract from the United States for construction of a steel naval floating dry dock in New Orleans, Louisiana. Their reputation for exceptional floating dock construction permeated throughout ports of the world, and while their earlier depositing and off-shore docks proved effective, they required a more specialized hand to operate and lacked the longitudinal stability required of for larger vessels, affecting their switch to designing floating dry docks (Clark 1905:15-40).

The greatest improvement found in the design of 20th century large floating docks lies in the implementation of steel as the primary construction material. The Havana dock, also designed by Clark and Standfield, first employed the new steel technology for the Spanish government in 1897. Classified as a sectional floating graving dock, this dock consisted of five pontoons responsible for lifting, but also possessed light caissons capable of impounding and pumping out the water surrounding the dock in the same manner as the early floating graving docks (Clark 1905:7). Though similar to the Rennie dock described previously, the main advantage afforded by the Havana style is the relocation of the pontoons between the side walls, rather than below them, providing an increase in the depth of the wing walls that granted greater longitudinal stiffness (Cunningham 1906:361). Comparable in many regards to its predecessors, the Havana dock employed a few additional unique traits that became mainstays of the Havana type dock, such as the pointed, projecting end pontoons, reminiscent of the 1889 self-docking sectional dock of Standfield, and the stepped terminal ends of the wing wall. The Havana dock

represented one of the largest floating docks of any type in the world at the time of construction 450 feet long with a lifting capacity of 10,000 tons, depicted in Figure 33 (Staples 1898:351). However, this dock pales in comparison to the 624 foot floating dock built for Hamburg, Germany in 1897, capable of lifting vessels over 17,000 tons displacement (Robertson 1897:386). Unfortunately, available resources only mention the dock cursorily, limiting the extent of feasible comparative analysis, though clearly this dock capitalized on the dimensional capabilities newly obtainable with steel as a primary construction material.

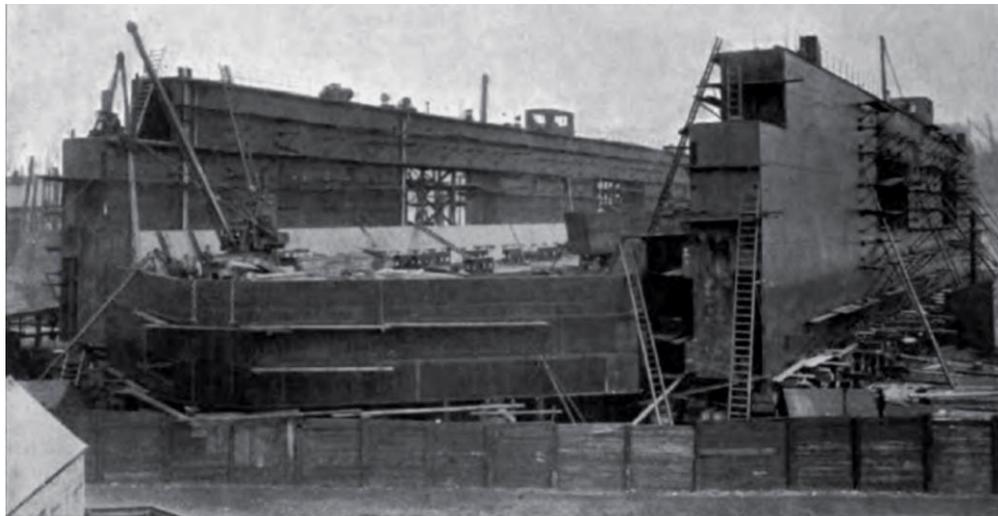


Figure 33. Havana floating dock under construction. Note depth of wing walls and pointed pontoon (Staples 1898:352).

Recognizing the need for improved docking facilities in the Gulf of Mexico, the United States seized an opportunity to demonstrate their newfound friendship with Spain (following conclusion of the Spanish-American War) by purchasing the Havana floating dock in 1901. The dock, however, rapidly fell into to disrepair while operating in Havana, and suffered a serious accident during the first self-docking conducted by the United States, potentially because it was the first such action preformed since its initial tests. While lifting the end pontoons, a valve responsible for draining the pontoon as it rose above the water become stuck, tremendously increasing the weight placed upon the center pontoons. The engineers decided to raise the

sections anyway, planning to remove a few rivets from the end pontoons once accessible as an alternate means of draining them. Unable to withstand the overloaded weight, the center pontoons buckled, opening a large gash along the top and interior face of the wing wall (*Marine Engineering* 1903:599). The U.S. Navy elected to tow the two sections to Pensacola for repairs, where the dock remained once returned to working order for many years of successful lifts (Clark 1905:63).

Shortly after acquiring the Havana dock, the United States completed construction of a second steel sectional dry dock, this one for use at the mouth of the Mississippi River in the navy yard at Algiers, opposite New Orleans. The firm of Clark and Standfield won the contract in 1899 and elected to construct the dock on the same principle design as the Havana dock, enlarging the dimensions to 525 feet long and increasing the lifting capacity to 18,000 tons, the most in the world (Clark 1905:40). The specifications for this dock called for increases in longitudinal stiffness over the original design, prompting the engineers to reduce the number of pontoons from five to three, making the center pontoon as long as possible to still permit its docking by the two ends (Clark 1905:83). Other significant improvements involved deepening of the pontoons by two feet and stiffening their decks, allowing universal placement of blocks and greater freeboard, further improving the overall longitudinal stiffness (Ford 1903:13).

Though for all the improvements, some questionable design components remained that appear to exist only for the slight economy of construction material, and possibly the fancy of the designers, at the expense of a stronger and more sturdy dock. These features are the pointed end pontoons, whose extension beyond the wing walls give the appearance of a longer working platform, and stepped side walls that terminate before the ends of the pontoons, both illustrated in Figures 34 and 35, making it impossible to dock a vessel on the extreme end (Ford 1903:12).

Still, Clark and Standfield won additional contracts for this highly effective type of dock, launching one for the Royal Naval Dockyard in Bermuda the same year as the New Orleans dock (1902) to replace the 1869 iron U-shaped dock that continued successful operation over 30 years after construction (Clark 1905:40). The new Bermuda dock eclipsed the length of the New Orleans by 20 feet and surpassed it in weight by 650 tons, though it was only able to lift 16,500 tons, or 1,500 fewer than the New Orleans. Following construction of these massive docks, Clark and Standfield designed smaller Havana type floating graving docks for Venice, Italy (365 feet long) and Durban, South Africa (325 feet long), both of which could lift a vessel of 4,500 tons (Clark 1905:40).

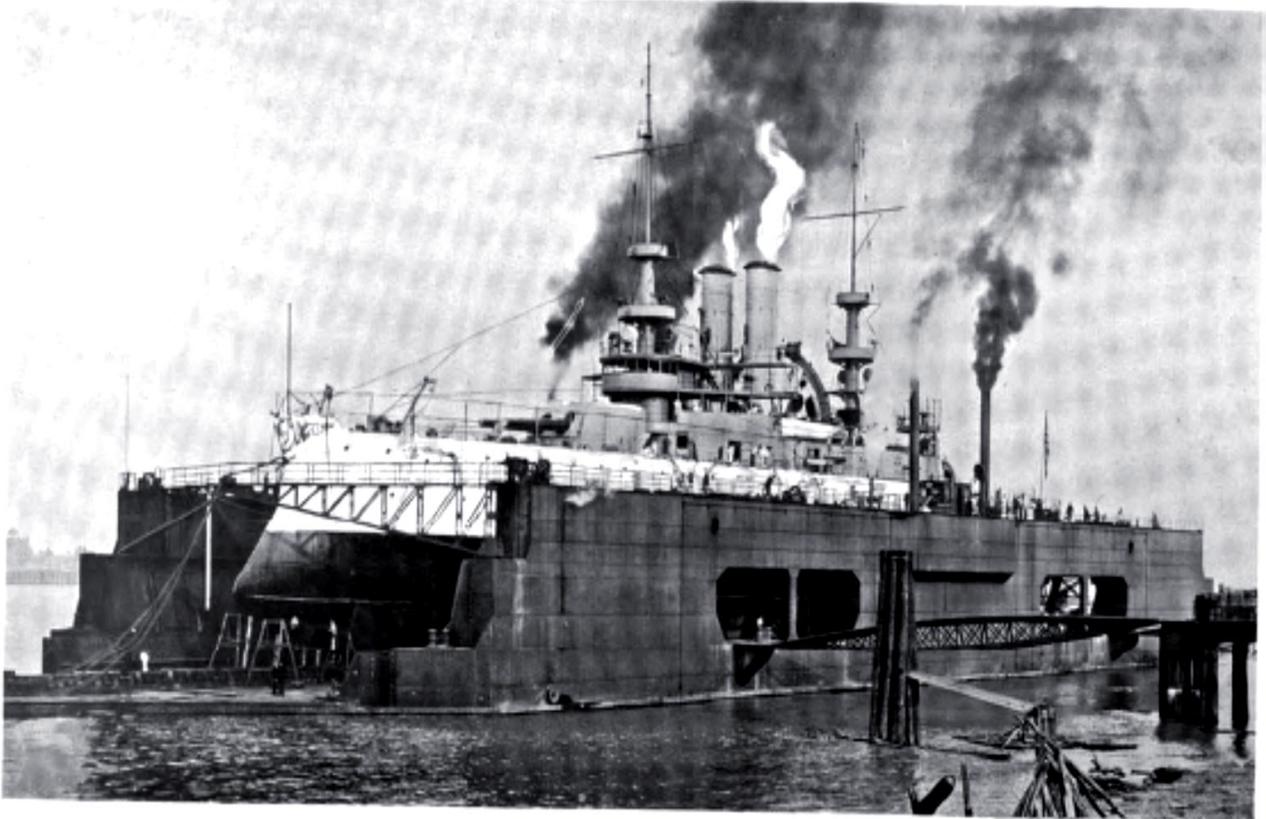


Figure 34. New Orleans floating dock, with American battleship *Illinois* lifted (Talbot 1906:480).

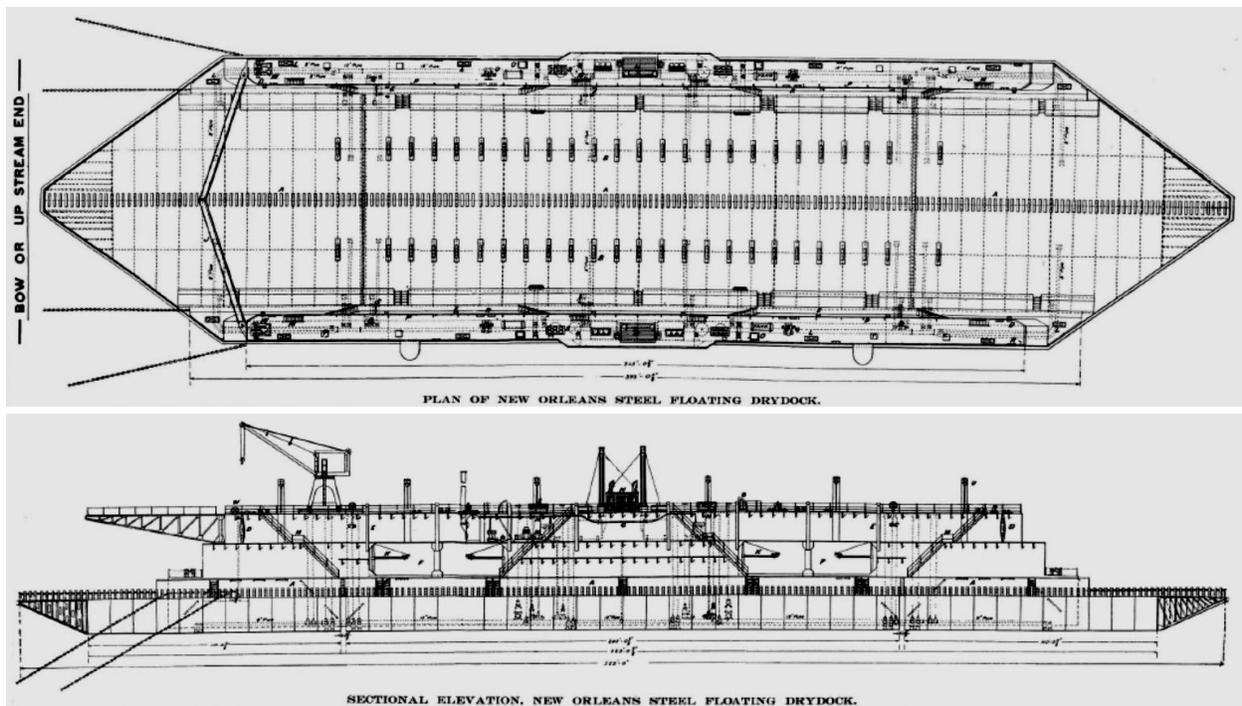


Figure 35. Plan (top) and profile (bottom) views of the New Orleans steel floating graving dock. Note pointed end pontoons in plan and stepped wing walls in profile (Ford 1903:Plates 1-2).

Though ultimately satisfied with the performance of the New Orleans dock, the United States Navy further increased the strength and convenience requirements of the next contracted floating dock, intended for operation in the recently acquired Philippine Islands (Cunningham 1903:475). The Maryland Steel Company won the contract for construction in 1902, based on designs submitted of a new type of sectional self-docking floating dock. The contract stipulated the most stringent operational requirements yet witnessed in the design of floating dry docks, most notably requiring uniform support of any size or shape vessel within the established lifting capacity, uniformly pumping of all compartments, and positioning “all self-docking and strain transmission connections” above the waterline at light-draft (Cunningham 1903:481-485). These new features called for a stronger, faster lifting dock that required less technical expertise to operate, could hog or sag a vessel if needed, and could dock a ship near the end of the dock (Cunningham 1906:371). This penchant for increased longitudinal stiffness derived from a

perception held by the U. S. Navy that earlier floating dry docks relied too heavily on commercial concerns and not those of appropriate of a progressive naval fleet. A. C. Cunningham, the chief U. S. naval architect appointed by the Bureau of Yards and Docks to oversee design and construction of the New Orleans dock, and who submitted a bid for the Philippine dock of his own design, claimed:

There has been an effort to secure the greatest possible dimensions and displacement with the least amount of material and call this result battleship lifting power. The design of a military floating drydock should differ as much from that of a commercial floating drydock as the design of an armored cruiser differs from that of a transatlantic liner [...] The commercial dock deals with ships having strong bottoms, much inherent stiffness, and weights of fairly uniform distribution. The military dock deals with ships having tender bottoms, less stiffness, and great weights unevenly distributed (Cunningham 1903:483).

The Maryland Steel Company submitted bids for three separate types of floating dry dock: a Havana or Clark type like the New Orleans dock, a Cunningham or bolted sectional type similar to the dock built for Pola, Austria, and a new Maryland Steel Company type designed by assistant engineer Henrik Hansson to meet the specifications of the contract (Cunningham 1903:486; Cunningham 1906:366). Costing \$9,000 more than the Havana type but \$40,000 less than the Cunningham type, the U. S. government awarded the contract to the Maryland Steel Company type with a bid of \$1,124,000 (Cunningham 1903:486).

The design of the dock, known as the “Dewey” after legendary Admiral George Dewey, depicted in Figures 36 and 37, reveals a three-piece sectional design where the sidewalls and center pontoon form a single structure, providing the greatest available rigidity in a sectional dock. The walls of the center pontoon are continuous and run the entire 500-foot length of the dock, though the pontoon itself only measures 316 feet. The overhanging sidewalls rest atop the deck of the adjacent end pontoons, enabling the positioning of connecting joints above the light-

draft waterline as stipulated in the contract (Clark 1905:11). The length of the center section allowed for self-docking the two smaller end sections at the same time, while the two end sections could cooperatively lift the center pontoon by utilizing a special set of secondary sidewalls, designed for securing the center pontoon during this procedure. Unfortunately, the negative extra weight of the secondary sidewalls cost the dock some lifting power, as this newest design only lifted vessels up to 16,000 tons, 2,000 less than the comparable Havana type New Orleans dock of 545 feet, built three years prior (Cunningham 1903:506-508).

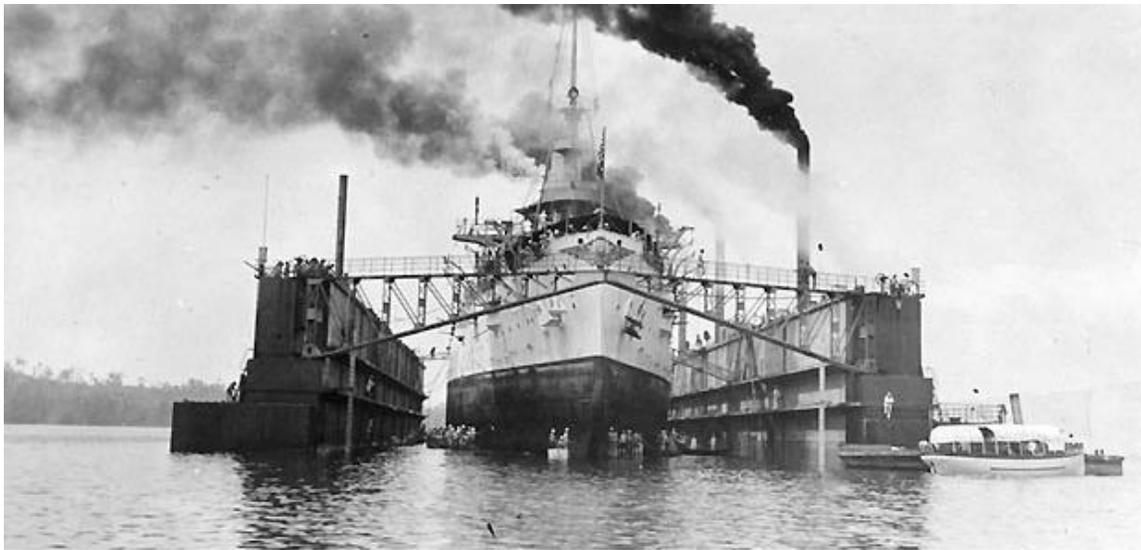


Figure 36. *Maryland* in Dewey floating dock. (U. S. Navy Historical Center 1907:NH 50360)

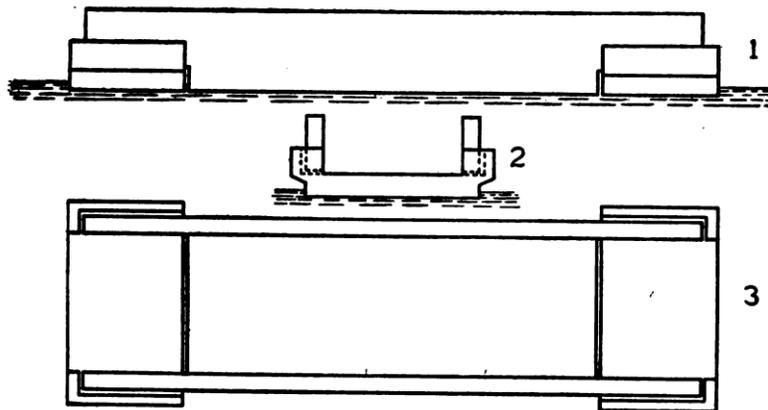


Figure 37. Standard arrangement of Dewey floating dock. Note continuous wing walls overhanging end pontoons in (1) and secondary walls on end pontoons of (2) and (3) (Cunningham 1906:367).

Following their design of the New Orleans dock, Clark and Standfield endeavored to construct a stronger Havana type dock, capable of meeting the contract requirements for the Philippine floating dock. Their solution involved securely affixing the wing walls to the pontoons, forming three sections (each maintaining their own wing walls and pontoon) using fishplate connectors similar to those used for strengthening the connections in the one-sided depositing and off-shore docks of a few years earlier (Clark 1905:10). While providing some improvement in rigidity, the U. S. Navy rejected this design in large part because the connections between sections occurred below the light-draft waterline, which weaken if not properly maintained, particularly in the tropical climate of the Philippines (Cunningham 1903:511). Despite losing the bid for the Philippine dock, Clark and Standfield in 1905 designed a 450 foot bolted commercial sectional dock of 4,000 tons lift for operation in Detroit, Michigan, and in 1907 a 723 foot long bolted section sectional dock of 36,000 tons lift for Hamburg, Germany (Clark 1907:243). These docks operated exceedingly well in the respective locations, as the fresh waters of Lake Michigan and the Elbe River acted less aggressively upon the submerged joints than would salt water, and their capacity for extension by additional sections appealed to commercial interests (Clark 1907:243). Though not meeting the standards of the U. S. Navy, the bolted sectional design became the accepted type of floating dock for servicing the largest class of vessels in the years before the Second World War.

Not only did the corrosive properties of salt water create serious problems the submerged connections of bolted sectional docks, it wreaked havoc on every steel scantling below the water line, especially in the interior of the pontoons. In a little over five years, the neglected interior of the Havana dock pontoons corroded to such an extent they required nearly \$100,000 in repairs before returning to working order (*New York Times*: 19 September 1902). Conversely, the steel

portions of dock that remain above the waterline, namely the upper wing walls, showed comparatively little corrosive deterioration. In wooden docks, like those dominating the American floating dry dock landscape, the exact opposite situation occurred, with the submerged pontoons preserved while the exposed upper wing walls deteriorated considerably. Owing to the increased amount of construction material required in wooden docks compared with a steel dock of similar dimension, timber wing walls “are not practical for the largest size of dock,” though “they are applicable for docks up to 10,000 tons” (Donnelly 1910:62). Provided the dock master took appropriate steps to repel marine borers, and kept the timbers wet through occasional use, wooden floating docks could last almost indefinitely (Gaythwaite 2004:445). In 1909, Civil Engineer William Donnelly designed the first composite dock incorporating steel wing walls and wooden pontoons, a modest sized 364 feet long and capable of lifting 6,500 tons (Donnelly 1909:294). Each pontoon comprised 31 feet of the overall length of the dock, and provided 100 tons of lift even when completely flooded, ballasted only by the weight of the steel wing walls resting upon them (Donnelly 1909:295). After experiencing great success with this initial dock employed at the John Robbins yard in New York, Donnelly designed larger versions for the Federal Shipbuilding company in New Jersey and the Sun Shipbuilding Company of Pennsylvania in 1920 and 1921. These docks were 522 and 468 feet long respectively, capable of lifting vessels of 10,000 and 8,000 tons when assembled into a single dock. In the case of the Sun Company dock, Donnelly utilized the sectional design of the pontoons and designed the dock to operate as a single 522-foot long dock or as two independent smaller docks of 197 and 323 feet length each (Barnes 1922:238). This type of composite dock became the standard for small to moderate sized commercial floating docks before the Second World War, and as late as

1960 many yards replaced the dilapidated wooden walls of older floating docks with new steel wing walls, considerably extending their workable lifespan (Toppan 2002:105).

In addition to the design by Donnelly, another innovation in floating dry dock technology occurred in 1917, with construction of the first reinforced concrete dock in Christiania, Norway by A. S. Maritim, depicted in Figure 38 (Fougner 1922:56). Designed to dock only light pleasure craft, the dimensions and lifting power remain comparatively quite small, at only 80 feet long and able to lift 75 tons. Due to the high price of steel and the rising cost of lumber, people sought alternative construction materials for building dry docks. Several countries, especially the United States, pursued the feasibility of reinforced concrete between 1920 and 1940, discovering that they required considerably more material to produce the same strength as steel. To build a steel dry dock of 4,000 tons lift would require 450 tons of steel in the hull, while a concrete dock requires 3,800 tons of concrete in the hull to achieve the same lift. Still, concrete floating docks offered a host of advantages over steel, namely a reduced first cost of up to 70 percent, virtually non-existent maintenance costs associated with corrosion, cheaper repairs, and an improved resistance to water leaks and fires (Fougner 1922:59). Concrete docks find their niche in the Navy though, as the onset of the Second World War brought about significant increases in the demand for repair vessels and alternative construction materials.

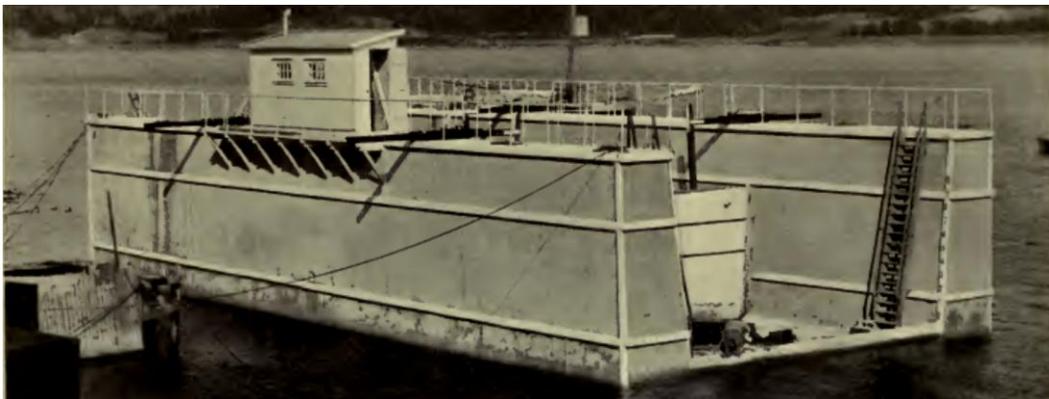


Figure 38. First concrete hulled floating dry dock, Christiania, Norway (Fougner 1922:59).

United States Naval Floating Docks and the Second World War

Developments in commercial floating docks during the first quarter of the 20th century consisted primarily of increasing the overall dock capacity, in both dimension and tonnage, while repositioning certain features and joints to a more favorable location while still maintaining the sectional form. In 1924, the Southern Railway Company of Southampton, England received a 960 foot long bolted sectional dock capable of lifting 60,000 tons, adding to the numerous steel commercial docks already popular there during the beginning of the 1900s (Hawkes 1928:141). During this same period, naval floating dry docks expanded exactly zero percent, with the *Dewey* and the Algiers docks representing the only floating docks owned by the United States until 1934 (Beggs 1953:5). But this changed in 1924 with the consummation of studies conducted by the Bureau of Yards and Docks, elapsing nearly a decade, regarding the mobility of both sectional and one-piece box floating dry docks (Cook 1957:290; Hartney 1995:1.9).

One of the greatest arguments claimed in favor of floating dry docks of any type is their inherent mobility. Indeed, commercial and naval architects preached this benefit throughout their development, undoubtedly securing more than a few contracts based on this premise alone. In practice, however, towing these structures was a challenging maritime undertaking, as their boxy, trough-shape design proved unwieldy and difficult to control. Previous docks, such as the first iron floating dock of Bermuda in 1868, employed false bows and rudders, designed to shape the broad angles of the dock like the bow of ship. In the case of the *Dewey*, and for reasons unknown (an obvious possibility is pecuniary), no such apparatuses existed to assist in towing the vessel some 13,000 miles from Maryland to Cavite in the Philippines. During this voyage, the crew experienced virtually every conceivable problem and delay, from broken hawsers to failed towing engines and heavy seas, resulting in a voyage lasting 150 days, with an average of

under 90 miles per day, Figure 39 depicting the perilousness of the journey (Beggs 1953:3). See Bennett “Voyage of the Dewey” (1907) for a thorough and colorful account of the entire trip.



Figure 39. Artist rendering of the *Dewey* floating dry dock under tow, bound for the Philippines (U. S. Navy Historical Center 1907:NH 54498).

In the interest of improving upon the hazardous trip experienced towing the *Dewey*, the Bureau of Yards and Docks spent the period from 1924 to 1933 investigating all manner of conceivable enhancements without building a single dock. The culmination of these studies resulted in a 1933 naval appropriation, authorizing the construction of an experimental 2,200 ton capacity floating dock, designated *ARD-1* (auxiliary repair dock), illustrated passing through locks in the Panama Canal in Figure 40 (Cook 1957:290). This new dock functioned as a classic floating graving dock, with a basin-type interior space impounded by a hinged gate, coupled with a single compartmentalized pontoon for additional buoyancy. Once completed in 1934, the United States subjected the new dock to extreme tests simulating potential operational experiences, such as docking a vessel while under tow, a thought inconceivable in a dock shaped like the *Dewey* (Cook 1957:292). The *ARD-1* represented a clear divergence from previous floating docks, whose design resembles the 1816 floating dock patented by J. Adamson (Figure

13) with the use of a ship-shaped bow at one end and removable stern gate at the other. Unlike the *Dewey* and *Algiers* floating docks, the *ARD-1* was of single-unit construction and incapable of self-docking, requiring an additional basin larger than the dock or a limpet for servicing. One of the key components required of naval docks not found in commercial docks was an improved degree of self-sufficiency. Having the dock operate in an advance base location required the ability to generate and supply its own power, water, and air, so designers equipped the *ARD-1* with diesel-electric engines, a first for any floating dock (Hartney 1995:1.10).



Figure 40. *ARD-1* passing through Panama Canal locks en route to Pearl Harbor (U. S. Naval Historical Center 1934:80-G 455970).

The success of the *ARD-1* in just over a year of testing prompted the Bureau of Yards and Docks to seek a \$10,000,000 appropriation for second, considerably larger version of the *ARD-1*, capable of servicing any vessel within the fleet (Hartney 1995:1.10). Congress appropriated the requested funds in 1935 for a single-piece ship-shaped floating dry dock 1,027 feet long, 165 feet in beam and with a molded depth of 75 feet, capable of lifting 50,000 tons, designated *ARD-3*, as depicted by a sketch in the February 1937 issue of *Popular Science* shown in Figure 41. In the

two years following the appropriation, the cost of labor and materials appreciated by some 20 percent, prompting an increase in the lowest bids for the contract to \$16,000,000, forcing representatives from the Bureau to return to congress and seek additional funding through the legislature. It is clear from the tone of state officials in transcripts of the 1937 and 1938 naval appropriations bill hearings that they felt the costs of the dock were becoming exorbitant and unjustified, despite the potential a tool of this magnitude offered the navy (United States House of Representatives 1937:684-689).

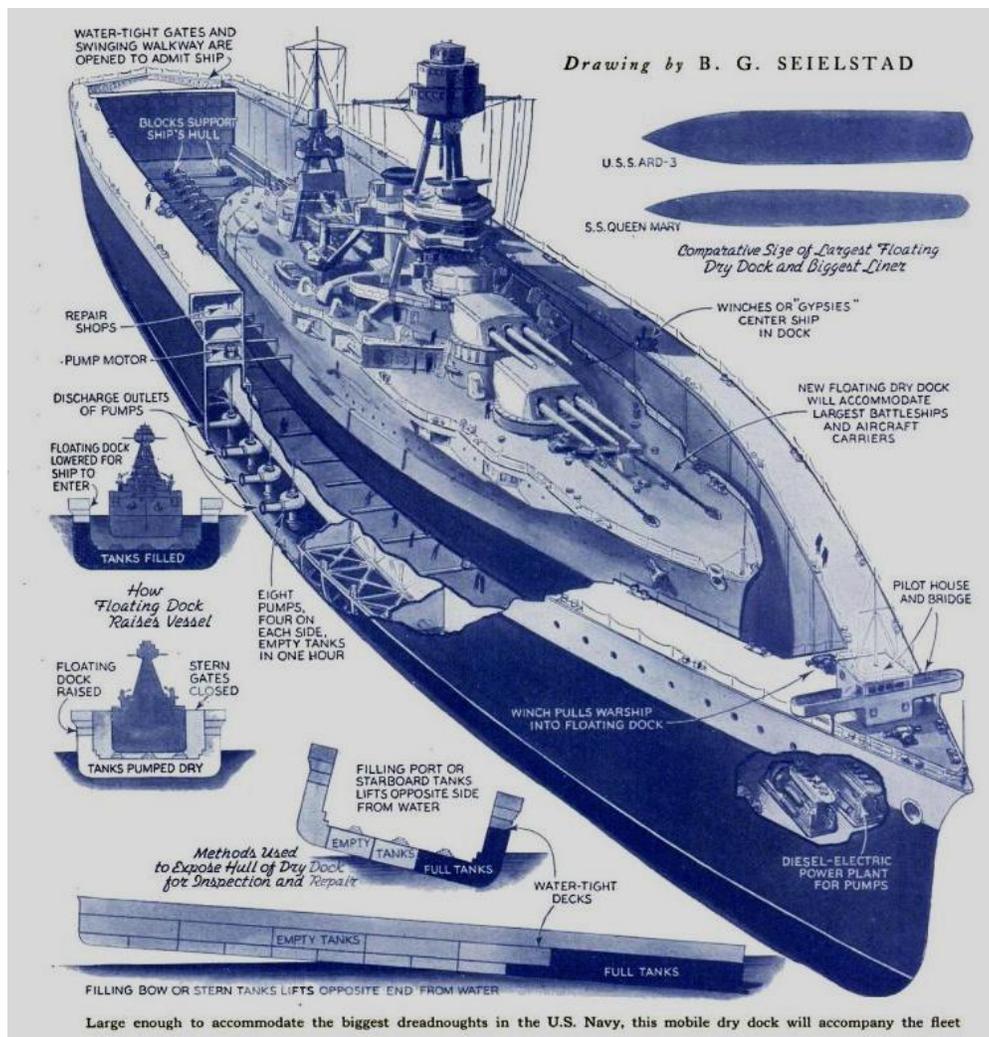


Figure 41. Sketch of proposed ARD-3, the project scrapped due to budgetary concerns (Seielstad 1937:42).

During these communications, the question arose as to the potential of instead constructing a graving dock in place of the proposed new floating dock. To the chagrin of the committee, Assistant Secretary to the Navy Henry Roosevelt proclaimed that a graving dock of similar dimensions would cost roughly \$8,000,000, a full \$2,000,000 less than the cost of the *ARD-3*. This is the first identified example of the initial cost of a floating dry dock exceeding the initial cost of a comparably sized basin graving dock, and one of the reasons the committee remained skeptical about the value of *ARD-3* operating in the same capacity as a graving dock at Pearl Harbor, Hawaii, unless needed elsewhere. Admiral Joseph Taussig, the Chief of Naval Operations at the time, responded to the criticism by arguing, “from a viewpoint of the operation of the fleet...that it would be a decided step backward to change this dock from a floating to a graving dock” (United States House of Representatives 1936:9). Generally unhappy with the direction of developments, Congress elected not to provide the additional funds in the 1938 appropriation, effectively dissolving the *ARD-3* project. In 1940, the Bureau received funding to commence construction of the *ARD-2* and *ARD-5*, sister docks comparable in size to the *ARD-1*. Twenty-seven additional ARD-type docks received commission following a massive naval appropriation in 1941, averaging more than one dock per month between 1943 and 1944 (Hartney 1995:1.10). Beginning in 1943, steel became a scarce resource at the construction yards, with priority of use given to other programs over floating docks, compelling construction of 12 docks of the ARDC class, or Auxiliary Repair Dock, Concrete (Beggs 1953:3). Though requiring greater mass than a steel dock to achieve comparable lift, the ARDC proved more stable than the ARDs due to the lowered center of gravity while also requiring less water to become negatively buoyant, making them immensely popular during the war (Hartney 1995:1.17).

In addition to the ARD series, the navy desired a class of floating docks capable of servicing their many smaller patrol boats and minesweepers, resulting in construction of the AFD, or Auxiliary Floating Dock, class of dry docks 200 feet long and capable of lifting 1,000 tons (Hartney 1995:1.17). Unlike the ARDs, the AFDs possessed an open-ended trough design with a welded, single-unit hull (Beggs 1953:5). A related class of dock, the Auxiliary Floating Dock, Lengthened, or AFDL, refers to 5 of the 29 AFDs lengthened by 88 feet to 288 feet long with a lifting capacity of 1,900, primarily to aid with overhaul destroyer escorts (Hartney 1995:1.19).

The most diverse of all Second World War floating dry dock classifications, the Yard Floating Dock, or YFD, described the floating dry docks designed to service the United States merchant marine during the war. Able to lift between 400 and 20,000 tons, this wide swath of floating docks existed to aid the crippled commercial ships damaged during enemy attacks while relieving pressure on the naval repair docks. Between 1941-1944, the United States constructed or purchased 64 docks of various size and type for operation in yards along the Pacific and Atlantic coasts, while also reclassifying the 1905 *Dewey* and 1902 Algiers floating docks as *YFD-1* and *YFD-2* respectively, though they continued their commission of primarily servicing naval vessels. Designs for these docks included single piece timber docks, Rennie and Donnelly sectional docks, as well as the Harris type three-piece trough dock, developed after the general design of the *Dewey*. Interestingly, the navy relocated the Algiers dock to Pearl Harbor prior to the attacks on 7 December 1941, and one of the more famous images captured of that day shows the magazine of the USS *Shaw* exploding while in the Algiers dock, seen in Figure 43. Figures 42 and 44 show additional images of the dock taken before and after the explosion. Though

significantly damaged, the navy quickly raised and repaired the *YFD-2* to continue rendering aid in Pearl Harbor following the raid (Hartney 1995:1.19; Beggs 1953:3).



Figure 42. USS *Shaw* set ablaze by Japanese bombers while in *YFD-2*, prior to magazine explosion 7 December 1941 (United States Naval Historical Center 1941:80-G32719).



Figure 43. Magazine of USS *Shaw* exploding in *YFD-2*, 7 December 1941 (United States Naval Historical Center 1941:NH 86118).



Figure 44. USS *Shaw* in *YFD-2* after magazine explosion (United States Naval historical Center 1941:NH 64481).

Though proven effective for repairing destroyer escorts, submarines, and relatively smaller sized craft, the one-piece ARDs were too small to service vessels exceeding 500 feet in length and 3,500 tons displacement (Hartney 1995:14.2). Having conducted experiments with both sectional and single-unit floating docks, the Bureau of Yards and Docks elected to pursue construction of a large sectional floating dock as a replacement for the single-unit *ARD-3*, the principle benefits of a sectional dock being the reduced burden while under tow and the ability to self-dock individual sections. The primary objection preventing the earlier implementation of sectional designs was the desire for naval vessels to use the strongest and stiffest floating docks possible, resulting in the single-piece ARD-type. After failing to secure appropriations for *ARD-3*, the Bureau recognized their need to make certain concessions regarding longitudinal strength to salvage any hope of adding large mobile floating dry docks to advance fleets (Hartney 1995:1.10).

The largest and most technologically innovative of all floating docks built during the Second World War were the Advance Base Sectional Docks, or ABSDs. These docks consisted of 10 sections (in one case only seven), each 256 feet long and 80 feet wide, capable of

independently producing 10,000 tons lift. When combined side to side, as depicted in Figures 45 and 46, 10 of these sections formed a dock 927 feet long and 256 feet wide overall (effectively 827 feet long and 133 between the wing walls), with a combined lifting power of 90,000 tons (Bureau of Yards and Docks 1947:212). *ABSD 1-6* were all identical in design and proportion, while the smaller *ABSD 7* consisted of only seven pontoons, with each section 240 feet long and 101 feet wide, able to independently lift 8,000 tons. When combined side to side, they produced a dock 825 feet long by 240 feet wide (effectively 725 feet by 120 feet) with a lifting capacity of 55,000 tons (Bureau of Yards and Dock 1947:212). In order to facilitate towing, designers faired the bow and stern of each section to follow the lines of a ship, with the intention of making each section self-propelled, though none of the *ABSD* class ever received propulsion machinery. Another significant feature designed to aid in towing of the *ABSDs* was the ability to fold the wing walls down inwards, reducing the profile wind resistance while under way, using 500-ton hydraulic jacks, depicted in Figure 47 (Hartney 1995:2.17). For a detailed history of United States naval floating dry docks in the Second World War, see Hartney 1995, and Bureau of Yards and Docks 1947.



Figure 45. *ABSD-1* stationed at the New Hebrides Islands with *Antelope* and *LST-120* in dock (Bureau of Yards and Docks 1947:226).

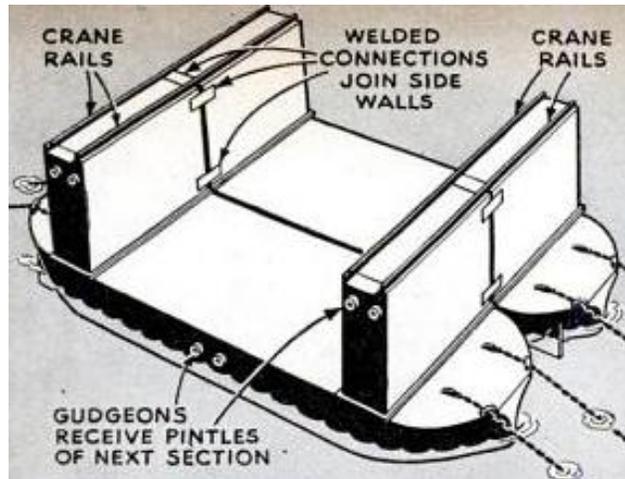


Figure 46. Side to side connection of two ABSD sections (Angas 1945:122).

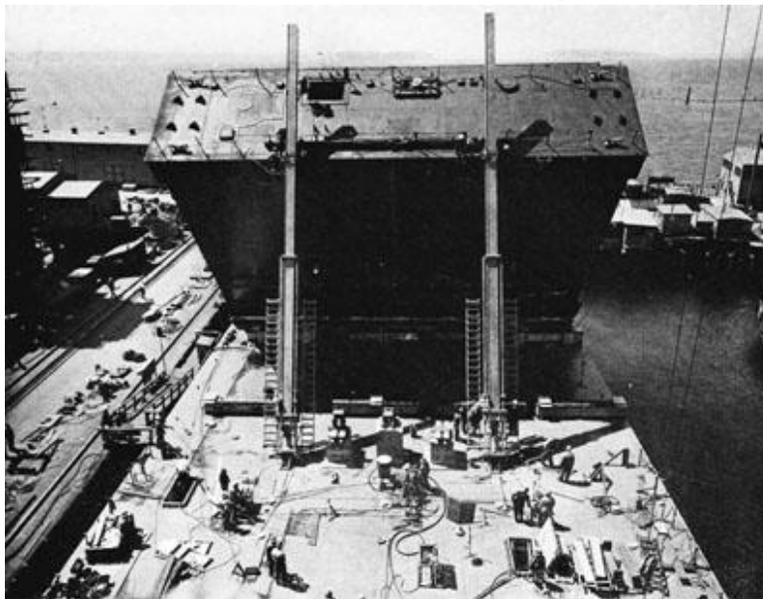


Figure 47. Using hydraulic jacks to raise the wall on a section of ABSD (Bureau of Yards and Docks 1947:214).

Following the Second World War, the navy reclassified the floating dry docks into four categories designed to be more descriptive. AFDB, or Auxiliary Floating Dock Big, encompassed any dock 30,000 tons lift or larger, including all ABSDs. AFDM, or Auxiliary Floating Dock Medium included any docks 10,000 to 30,000 tons lift, incorporating many of the former YFDs. AFDL, or Auxiliary Floating Dock Little represented all docks under 10,000 tons lift, which includes some of the YFDs, ARDs, and all the AFDs. The final designation was

AFDL(C), or Auxiliary Floating Dock Little (Concrete), replacing the concrete YFDs and the ARD(C) designation. Figure 48 represents a slightly disambiguated table describing these terms as well as a total number of floating docks in each class owned by the navy during the war.

Capacity in tons	Material	Number of sections	WWII designation	Present designation	Number Constructed
NON-MILITARY					
400 to 20,000	Timber and steel	1 to 6	YFD	YFD	61
MILITARY					
1,000	Steel	1 piece	AFD	AFDL	28
1,900	Steel	1 piece	AFDL	AFDL	5
2,800	Concrete	1 piece	ARDC	AFDL	12
3,500	Steel	1 piece	ARD	ARD	29
6,500	Steel	1 piece	ARD	ARDL	1
15,000 to 18,000	Steel	3	YFD	AFDM	10
56,000 to 100,000	Steel	7 to 10	ABSD	AFDB	7

Figure 48. Table of United States naval floating docks in the Second World War (Beggs 1953:4).

Floating Docks Through Today

During the war, the United States floating dry dock fleet increased from 3 to 153, adding 50 docks of timber, 88 of steel, and 12 of concrete, a truly astounding accumulation (Beggs 1953:4). As the threat of instability remained following the close of the war, the United States continued building AFDL class docks through 1955, while simultaneously placing many others in mothballs at naval reserve facilities around the country. The navy split many of the ABSDs into smaller docks or sold them to commercial ventures, where many continued successful operation through 1995 (Hartney 1995:1.25). One of the more notable naval performances of a floating dry dock following the Second World War came during the Vietnam conflict, where a 9-section floating dock, comprised of 4 sections of AFDB-1 and 5 sections of AFDB-2, lifted naval vessels virtually non-stop in Subic Bay, Philippines (Hartney 1995:15.1; Hepburn 2003:139). As happens following any major conflict, the navy experienced a significant downsizing of the fleet, implicating a reduced need for docking facilities that required substantial expenditure for upkeep. In 1955, the United States navy owned and operated 106 floating dry docks, 62 graving

docks and 12 marine railways. By 1995, following the end of the cold war, those numbers dwindled to 23 graving docks (a reduction of 63%), 8 marine railways (a reduction of 33%), and 4 floating docks (a reduction of 96%). While these numbers are staggering on their own, they correspond to a roughly 60% reduction of commissioned warships over the same period, justifying to some degree the drawdown of docks (Hepburn 2003:161-162).

While the United States government sought to cut naval expenses by shedding floating docks and facilities, commercial shipping and private yards embraced floating dry docks. “Private yards found floating dry docks attractive as they were easily purchased and sold as the economic climate dictated. The shipyards did not have to give up prime waterfront property or commit to a permanent structure, as in the case with a marine railway or graving dock” (Hepburn 2003:140). People also began to accept floating dry docks as temporary structures, like ships, that eventually reach a point of obsolescence, leading them to prefer more temporary structures like floating dry docks. Technological developments in underwater photography, videography, and ultrasonic plate gauging permitted examination of underwater areas without the need for self-docking, while improved protective coatings and cathodic protection systems extended the useful life of floating docks before repairs (Gaythwaite 2004:443). For these reasons, single-piece welded steel floating dry docks, referred to by Lloyd’s as caisson docks, replaced the sectional pontoon dock as the preferred design for commercial docking between the end of the Second World War and 1978 (Thatcher 1978:2). After a considerable run as the longest enduring general floating dock design, social valuations changed the direction of future development, eliminating the need for sections designs. Figure 49 depicts a modern 1,115 foot long 300,000 ton lift single-unit floating caisson dock.



Figure 49. Modern 300,000 ton lift floating caisson dock (People's Daily Online 2006).

In addition to their 3 floating dry docks and 20 graving docks, the modern United States Navy employs a handful of alternative methods for similar requirements. The first is a modernized version of the Clark hydraulic lift designed 100 years prior, known as the Syncrolift. This modern ship lift incorporates features of the first United States naval floating dry docks and early marine railways, namely the connection of a cradle with guideways capable of transporting a vessel off the platform, freeing up the lift and facilitating the turnover of ships using the dock. Like all floating docks and lifts, the Syncrolift requires keel and bilge blocks for supporting the vessel once lifted, and like a marine railway the blocks rest atop a steel cradle, the entire structure extracted from the platform and transported to an appropriate staging area (Hepburn 2003:150).

The next alternative, the heavy lift ship, resembles the ARD class ship-shaped floating docks prevalent during the Second World War, employing a large open cargo deck, rather than an enclosed docking basin (Wasalaski 1991:71-72). First constructed in the 1960s, off-shore drilling companies designed the heavy lift ships for transportation of large oil rigs, cranes,

floating platforms, floating hotels, and floating power plants to sustain the crew while operation away from shore (Wasalaski 1991:72). Though not owned by the navy, they have contracted these vessels for use transporting mine countermeasure ships and damaged vessels across vast expanses of ocean, most notably for bringing home the USS *Cole* from Yemen after terrorists attacked it in October 2000 (Hepburn 2003:155). These heavy lifts operate exactly as a floating dock, using floodable air and ballast chambers within the hull to raise and lift the vessel, differentiated only by virtue of its self-propulsion and open-walled design. Figure 50 shows a modern heavy lift vessel, the MV *Blue Marlin* transporting a floating x-band radar platform for the United States navy in 2005.



Figure 50. Commercial heavy lift ship MV *Blue Marlin* transporting x-band radar platform for United States navy (Department of Defense 2005:1).

One final alternative to floating docks employed today is that of a floodable barge, incredibly similar to the pontoons of the 1800s. Two options exist for docking a vessel using a barge. In the first method, the barge is sunk with ballast between guideposts, a vessel positioned

over the blocks, and the water pumped out raising the barge, exactly as in a pontoon. In the second method, a barge is drawn into a graving dock and sunk by opening a valve, resting on the floor of the dock. Then, the vessel to be lifted warps into the dock above the blocks on the barge, the water is pumped out of the dock, and the vessel secured atop the barge. After the water completely drains from the dock and barge, the valve is closed on the barge and water admitted back into the dock, floating the barge and vessel together, the barge now ready for towing. Unlike the heavy lift ship, floodable barges employ the same technological structure as some of the earliest forms of buoyantly raising vessels within or above the water column, first discovered around the turn of the 19th century.

Floating dry docks historically experience periods of rapid growth and development followed by periods of relative inactivity, exemplified by booms in the 1830s, 1860s, 1900s and 1940s. These booms tended to reflect change in a societal input, such as improved raw materials preparation, the introduction of steam engines, competition with railway lines, or war. Following the close of the Second World War, the general American public and the United States navy gained a full and appropriate appreciation for the flexibility offered by floating dry docks, while also recognizing modern designs possess a safety record on par with that of graving docks. In the history of floating dry docks, a traceable pattern exists that when drawn back to its origin, highlights the growth and adaptation of floating dry docks in an evolutionary manner. From the tumultuous early years to their heyday in the in the twentieth century, the development of the floating dry dock changed the face of naval and commercial operations around the globe. With the great reduction of naval repair capabilities that took place over the previous 20 years, the United States inadvertently (and maybe unknowingly) is committing to a future proliferation of floating dry docks for naval use. In the event an increase in demand suddenly arises, a

proposition not unlikely given the current instability of our globalized civilization, available graving docks in the United States would be unable to handle the volume. Given the speed of construction and reduced costs, the most likely solution would be a massive build-up of naval floating dry docks of various sizes, similar in scope and intensity to the American undertaking in the Second World War.

CHAPTER 6: ANALYSIS OF EVOLUTION WITH FLOATING DRY DOCKS

Introduction

From the description of adaptations experienced by floating dry docks during their relatively brief existence, one can characterize their chronological development as analogous to that of an evolution. Interestingly, the term evolution already exists in maritime terminology, defining the completion of an entire docking sequence as a single evolution (warping a vessel into the dock, draining the surrounding water, performing repairs or cleaning, readmitting water, and warping the vessel out). However, for the purposes of analysis within this thesis, evolution defines “the process by which all objects of some class are related by ties of common descent from the collection of earlier objects” (Arthur 2009:14). This definition of evolution fits neatly within the cumulative synthesis theory described previously in this thesis, emphasizing the importance of individual minor improvements while simultaneously recognizing the significance of the inventor (Basalla 1988:23). Of foremost relevance is the first premise of the cumulative synthesis theory, stating that society must perceive of a delinquency in the current method of action before creation of a new design can take place. This premise forms the basis of subsequent arguments favoring the acceptance of a consolidated floating dry dock evolution. An analysis of floating dock developmental stages provides requisite evidentiary support, in addition to the primary factors contributing to the manifestation of an invention, as described by Ogburn, also outlined in the theory chapter of this text.

Historically, various individuals intimately associated with floating dry docks have described their development as evolutionary, including Lyonel Clark, of Clark and Standfield, and Leonard Cox, United States Navy Civil Engineer who presided during construction of the *Dewey* dock (Cox 1907:98; United States Senate 1898:18). The opinions of these individuals

further bolsters the argument made herein, specifically responding to allegations leveled against describing progressive advances in the design and construction of floating dry docks as an evolution. Case in point, Drs. Richard Gould and Donna Souza claim the 1869 Bermuda floating dock belongs in a separate category independent of comparison with previous docks, as special environmental constraints dictated its design and construction, resulting in a one-off technological development not deriving from a linear developmental progression (Gould and Souza 1996:19).

As previously mentioned, the evolution of the floating dry dock depends wholly on a corresponding evolution taking place in the construction of ships; again, directly relating to the first premise of cumulative synthesis theory, for without ships there would be no accumulation of biofoul to scrape or split keel to replace, and hence no perception of inadequacy. S. Colum Gilfillan identified and described the evolutionary pattern of vessel construction, from dugout canoe to steamship, in his seminal 1935 work *Inventing the Ship* (Gilfillan 1935). Transitively applied, the establishment of this evolutionary state allows for a similar and simultaneous evolution to occur in technologies directly connected with ships and shipping, namely floating dry docks.

Impetus for Change: Floating versus Graving Docks

Because they occupy the same ship repair niche, many articles in engineering journals and government publications of the 19th and 20th centuries discussed the relative merits of floating versus graving docks. In some of the earliest periodicals advocating the adoption of floating docks, authors readily articulated the advantages these new docks held over their graving counterparts (Humphries et al. 1827:5-6). In response, graving dock proponents issued stout rebuttals against the perception of their system as inferior, establishing an early dichotomy

between supporters of each technology (Smith 1848:6). The International Navigation Congress took up the issue during their 1902 meeting in Dusseldorf, Germany, concluding that floating dry dock possessed some very desirable characteristics, but in general remained inferior to the graving dock for providing the greatest vessel security and stability, recommending floating docks only where external constraints precluded graving dock construction (Clark 1905:49). A variety of considerations contributed to the decision handed down by the Congress, many of which civil engineer Bryson Cunningham outlines in his 1904 *Treatise on the Principles and Practice of Dock Engineering*, including accessibility, ventilation, light, capacity, initial cost, maintenance and repairs, working expenses, durability, and general adaptability (Cunningham 1904:464-470). Additional concerns, such as location, construction time, and future expansion also played key roles in evaluating each docking system, as well as the personal preference and experience of the intended operators.

The first consideration given to the construction of any dock is location. Traditional excavated graving docks originated in England, where the rise and fall of tide greatly exceeds that of the east coast of the United States, the Baltic Sea, The Mediterranean Sea and the Caribbean Sea (Clark 1905:2). During the development of the graving dock, engineers utilized this tidal flux to aid in the flooding and draining of their docks, greatly reducing the amount of pumping required, since most of the impounded water sluiced out with the ebb tide. Statistics compiled by Lyonel Clark, cousin of then-late intrepid engineer Edwin Clark and managing partner of Clark and Standfield, bear out the correlation between small tidal fluctuation and increased proportion of floating versus graving dry docks in 1905:

In the United Kingdom, there are only 18 floating docks out of 240 dry docks of all kinds, equivalent to 7.5 per cent; whereas in the Baltic Ports there are 22 out of 60, equivalent to 36.7 percent, and on the east coast of North America, there are 53 out of 75, equivalent to 70.7 per cent (Clark 1905:2).

Many desired locations for dry docks cannot support construction of the excavated basin type, due to inadequate soil composition or lack of available shoreline, restricting available options to a floating dock, marine railway, patent slipway or ship lift. All forms of docks operate most efficiently when protected within a sheltered harbor, separated from the waves by means of a breakwater. Floating docks require a greater depth of water to operate than graving docks, often prompting the construction of a site-specific basin, dredged to the required depth, for permanent mooring and operation of the dock (Stuart 1852:46). In some locations, such as Callao, Peru and Valparaiso, Chile, floating docks operated in an open roadstead, the large underwater portion of the dock maintaining stability even in choppy seas. In Valparaiso, workers employed an improvised bulwark on the open end of the dock facing the sea, maintaining smoother water within the dock for better control during lifts (Horner 1907:26).

Additionally, the specific location of a dock within a harbor is another key factor influencing selection of a docking system, as large vessels usually must turn perpendicularly in a channel or narrow waterway in order to enter a graving dock at the appropriate angle. In ports situated along riverbanks, floating and off-shore docks allow vessels to enter without performing this 90 degree turn, which may prove impossible for a severely stricken vessel. In locations with a steep riverbank or narrow channel requiring admission of the dock parallel to shore, side-haul marine railways operated with some success, though the distribution of hauling machinery along the relatively long cradle causes load sharing problems, resulting in an overdesigned and inefficient docking system (Salzer 1986:114). The situation of the dock relative to navigation, prevailing winds, and currents all require proper evaluation of the environment prior to construction (Gaythwaite 2001:415).

The issue of accessibility to the submerged portions of the hull greatly contributed to the sense of deficiency experienced with early docking methods such as beaching and careening, where the lower portions of the keel remained partially or completely obstructed, limiting access to for inspection and repair. All docking systems obviate this problem by supporting the hull above the dock floor by means of removable keel and bilge blocks, allowing for inspection of all lower sections of the hull and keel (Cunningham 1904:464).

The availability of light and ventilation on the floor of the dock when drained often represents the first argument made in the case for floating docks. In many graving docks, especially those in England, dockworkers complained about dark and damp conditions experienced while servicing vessels within the dock, exasperated by noxious odors emitting from the exposed biofoul. Given the positioning of a graving dock floor well below both the waterline and the surrounding earth, very little breeze passes over the hull of a ship when in dock, rendering the drying time of paint and hull coatings numbingly slow. Similarly, the graving dock reduces the amount of sunlight able to penetrate to the floor, a serious problem in docks prior to the advent of electricity and artificial lighting. While floating docks offer a noted improvement in both these categories over graving docks by raising the ship above the waterline, alternative structures such as pontoons, gridirons, and lifts provided the freest access of sun and wind (Cunningham 1904:465).

The issue of capacity looms as an important factors in selecting a docking system. For small vessels, patent slips and marine railways offer effective and relatively efficient alternatives, able to handle lengths up to 350 feet and displacements of 8,000 tons, though some recent designs proposed a capacity of 12,000 tons (Cunningham 1904:466; Salzer 1986:110). Slips and railways become exponentially more expensive as they increase in size and capacity, due to the

large amount underwater structure required for the floor of the inclined plane and guideways, making them economically impractical for larger classes of vessels. Alternatively, graving and floating docks both offer virtually limitless capacities, with the largest graving docks in existence exceeding 1,000 feet and 1,000,000 tons lift, while the largest floating docks measure over 1,000 feet and 300,000 tons lift (Salzer 1986:111-114). The economic interplay between these two structures is fascinating, as historically small graving docks tended to cost more than a comparably sized floating dock, but once they reach a certain size the initial cost flips, with large graving docks costing less than similar large floating docks (United States House of Representatives 1937:684-689). This situation results from the increased steel construction material required to produce a large floating dock, compared with the less expensive reinforced concrete used for the primary structure of a large graving dock. However, capacity alone creates problems for comparison of floating and graving docks, as

The capacity of a graving dock is based upon its linear dimensions, the weight of any incoming vessel not entering into account, while a floating dock, open at each end, is gauged by the weight which it can lift, and is practically independent of size (Cunningham 1904:465).

In many cases, the true determining factor is the amount of water available over the sill of the dock. As graving docks progressively grew larger, their depth lagged slightly behind, as the addition of even a single foot in depth disproportionately increased the overall cost, prompting many designs to accept the largest draft vessels only during spring tides. Although many vessels unload their cargo and machinery to lighten draft before entering a dry dock, an incapacitated ship may require immediate service while fully laden, or have an exaggerated list caused by damage, exceeding the acceptable capacity of a graving dock. Floating docks prove much more versatile, as they can conform to the list of a stricken vessel, and their open ends permit their

partially raising ships longer and heavier than the designed capacity (Cunningham 1904:465-466).

When considering the cost of floating and graving docks, three important distinctions exist: the initial cost of construction and delivery, the long-term cost of repair and maintenance, and the long-term cost of operation. The initial cost depends heavily on a variety of factors, most significantly the price of labor, materials, and site considerations. In many cases, contracted yards built floating docks at their own facilities before towing the fully-assembled structure to the desired location, saving on material and labor but adding to the delivery cost. Conversely, graving docks necessitated the acquisition of expensive waterfront land for their site, required a variable degree of excavation depending on substrate composition, and required more hours of labor to construct, leading to the common practice of increasing the contingency margins built into estimates for graving docks (Swan, Hunter, and Wigham Richardson, Limited 1903:32).

The cost of maintenance and repair also differs immensely between these two principal docking systems, depending primarily upon their material of construction. In masonry graving docks (and to a lesser degree marine railways and patent slips), the chief construction material is typically concrete, a medium virtually unaffected by salt water or marine borers and therefore requiring little upkeep. The iron or wooden dock gates of the graving dock and cradle of the marine railway suffered the most degradation, along with any other ferrous or timber fittings in contact with the water during flooding or draining. Thus, the reduced maintenance cost somewhat offsets the higher initial cost of a graving dock. During the 19th century, many ports in the United States began employing timber for the walls of their docks, whose perishability had the opposite effect of reducing initial cost while increasing repair cost (Navy Department 1892:46). For floating docks, their ubiquitous construction of timber, and later steel, made them

inherently more susceptible to the deleterious effects of marine borers and salt water than docks built of concrete. The composite docks of Donnelly (discussed in the previous chapter) utilized wood for the pontoons and steel for wing walls, minimizing repair costs by the selective use of construction materials in locations where they were best preserved (Cunningham 1904:468).

The greatest disparity exists in regards to the operational cost of floating and graving docks, specifically the energy required for pumping. In a graving dock unassisted by the tide, the pumps must remove the total volume of impounded water minus the displacement of the vessel. In a floating dock, the pumps only need extract from the pontoons a volume of water roughly equal to the displacement of the vessel, a comparatively significant reduction in energy expenditure versus the graving dock. In graving docks, small vessels require more pumping as they naturally displace less water from the interior of the dock when impounded, while large ships displace a greater volume and therefore require relatively less pumping for complete evacuation. For floating docks, the inverse holds true: small vessels require less lifting power while large vessels require more. Additionally, graving docks must employ auxiliary pumps to expel leaking water from within the basin, and in the case of drainage docks to remove water from a channel beneath the dock floor. Drainage docks overcome the hydrostatic uplift problem by rerouting the groundwater around the dock with pumps to reduce pressure, reducing the initial cost by allowing for lighter, less expensive walls, but increasing the operational cost by requiring constant pumping of groundwater around the structure (Gaythwaite 2004:420).

A few other significant factors exist for consideration regarding the relative merits of floating and graving docks. Floating docks required a much shorter construction time, typically between seven and nine months, whereas large graving docks required multiple years. This factor alone boosted floating dock popularity amongst commercial enterprises, as shorter

construction time meant a faster return on their investment than a graving dock. During their developmental heyday around the turn of the 20th century, docks frequently outlasted their period of usefulness due to constantly increasing vessel dimensions; a much greater concern for the expensive, permanent graving docks than the cheaper, temporary floating docks. This temporary nature of floating docks also appealed to private and commercial yards that could buy or sell them as the market or their business dictated, unlike being essentially stuck with a graving dock (Hepburn 2003:140). At the time of the Dusseldorf Congress in 1902, floating docks possessed a spotty record of safety inherent to any burgeoning technology undergoing growing pains, likely contributing to the consensus opinion that graving docks offered superior stability and safety. However, Cunningham admits that recently the safety record was much improved and the newest floating docks operated on par with safety afforded by graving docks (Cunningham 1904:470).

The Cumulative Synthesis of Floating Dry Docks

Four main premises guide the theory of cumulative synthesis. The previous section briefly discussed the first premise (perception by society of an unsatisfactory pattern in the current method), as it is of greatest significance to this analysis. The remaining three tenants also directly apply to floating dry dock evolution: the arrival of an individual with a penchant for greatness, the essential solution of the problem, and the critical revisions (Usher 1954:10). For floating docks, the unsatisfactory pattern stems from the slew of shortcomings experienced in constructing and operating graving docks, prompting exploration of alternative forms of laying up ships for maintenance and repair. In the somewhat mystified account of the first camel dock, the ship of the British merchant captain required attention, but the scarcity and inefficiency of dry docks nearby necessitated his locating a suitable substitute. The question thus remains, from

what did this individual with a penchant for greatness divine his influence? Cumulative synthesis argues it is from their experience as a sailor and captain, frequently interacting with graving docks and possessing a keen understanding of their physical operation. The distinction of captain implies an individual skillfully learned in all things nautical, and it is entirely possible (though at the moment improvable) that they witnessed or heard of similar structures in his their prior to constructing his camel dock. Even had they not, the cumulative synthesis of their vast nautical experience provided the mental raw materials necessary for his prescient reconfiguration of a hulk into a dry dock.

The final premise, the critical revision, still occurs to this day, in the form of advanced floating dry docks, ship lifts, heavy lift ships, and virtually any other existing alternative to the graving dock. Rather than causing a specific design or type to reach a state of perfection, the critical revisions end up creating new patterns of deficiency, such as the introduction of iron as a construction material, which demanded entirely different facilities and equipment for handling, as well as an amended design, created specifically for work with iron scantlings. This new unsatisfactory condition prompted a subsequent group of individuals (with a penchant for greatness) to create new essential solutions to the problem, which then underwent their own critical revisions, perpetuating the cycle indefinitely. Perfection is thus never achievable, as external stimuli will continuously alter and expand the function and physical limits of engineering, countering one of the primary arguments made by Gould (2003:14).

Once individuals begin analytically exploring the intricacies of a certain technology, critical revision suggests the probable creation of similar, related component technologies, capable of operating within the same niche as the original technology. Many designs solve the problem of accessing submerged hull sections for inspection and repair, exemplified by the

various floating dock offshoots discussed in the previous chapter, specifically the depositing and off-shore docks, and later the Syncrolift. Despite the significant inroads made into the market by these alternative docking structures, the floating dry dock proved unmatched in mobility, ease of operation, and comparatively small initial cost, contributing mightily to its retention and continued development at the expense of many alternative designs.

With the ever expanding size of shipping and naval vessels, the longevity afforded by stone and masonry excavated docks began to reach a point of diminishing returns for those inclined to construct them. Such an enormous investment of time and capital required for constructing graving dry docks often resulted in only a few years of operation where the capacity of the dock exceeded the size of the largest ship. Even outdated dry docks still maintained the capacity to service smaller vessels, but their value necessarily diminished as larger classes of ships sought repairs elsewhere. Though some instances reveal the expansion of graving dock facilities to accommodate the increase in vessel size, the financial impracticality of such an investment prompted many shipyards to consider building cheaper, less permanent floating docks more frequently, rather than construct a single massive graving dock one time (Cunningham 1904:470).

A clear disparity exists when comparing the functional aspirations of commercial and naval floating docks, foremost among them the drive for profits. The vast majority of floating dry docks constructed prior to the Second World War operated in the commercial sector, for many of the reasons alluded to previously in this chapter (smaller initial investment, faster construction time, resale potential, etc.). Their design incorporated economically attractive characteristics, such as the reduction of material, creating a dock with the greatest dimensions and displacement at the least cost, often sacrificing longitudinal strength in the process.

Commercial vessels naturally possess stiffer hulls with evenly distributed loads, requiring less reinforcement from the dock, and allowing vessels to dock in a position most similar to their situation when afloat. Conversely, the hulls of naval vessels often draw comparison to the fragility of an egg shell, considerably less stiff than commercial vessels and containing unevenly distributed loads, requiring a uniform strength and deflection over the entire dock floor (Cunningham 1903:483).

Evolution and the First Bermuda Dock

Given the availability of renowned studies in technology and ship construction evolutions, coupled with the evidence of development and progression within the design of floating dry docks, it seems odd that an archaeologist or historian would single out a specific dock as not belonging in the same category with contemporary structures. This situation occurred following an archaeological investigation into the remains of the HM Floating Dock *Bermuda*, the 1869 wrought-iron U-shaped floating dry dock built in England and towed to the Royal Naval Dockyard in Bermuda, depicted and discussed in the previous chapter. Drs. Richard Gould and Donna Souza argue in their “History and Archaeology of the HM Floating Dock *Bermuda*” that this dock:

[...] was as a unique, one-off technological development intended to operate under special conditions imposed by Bermudian geography. The unique engineering characteristics of the Bermuda Floating Dock, as known through historical and archaeological sources, serve as caution to maritime scholars who might be tempted to assume that the development of dry-docking and floating dock technology followed a linear developmental progression (Gould and Souza 1996:19).

This statement contains three vital parts that require addressing. First, the special conditions imposed by Bermudian geography. Second, that those conditions produced a one-off

technological development intended to overcome those special conditions. Third, that floating dock technology followed a non-linear progression.

The special condition referenced regarding Bermudian geography is merely the porosity of the coralline limestone substrate comprising the foundation of the islands. In order to construct a graving dock, the walls must be sufficiently strong to withstand the hydrostatic pressure exerted upon them, and anchored to withstand the immense positive buoyance created by an excavated dock (Department of Defense 2002:2.4). Gould and Souza aptly argue that such a condition precluded construction of an excavated dock at Bermuda, which absolutely is correct. However, their claim that the dock “was adapted to local conditions” supposes that the U-shaped design was the *only* type of floating dock capable of operating at the dockyard, which is plainly false, evidenced by the institution of a second Bermuda floating dock of 1902 (Gould and Souza 1996:19). In reality, any floating dock contemporary with the first Bermuda dock could operate successfully in the Bermuda Dockyard, including wrought-iron structures already operating in Surabaya, Java, Callao, Peru, Saigon, Cochin-China, Cartagena, Spain, and St. Thomas, Dutch West Indies, all covered in the previous chapter. The entire idea behind a floating dock is that they operate, for the most part, independent of shoreline geographical concerns, other than depth of water. Therefore, no geographic conditions exist unique to Bermuda requiring a specific type of floating dry dock; they simply required construction of *a* floating dry dock.

The characterization of the U-shaped hull design as “unique” is quite accurate, as no other dock appears to have employed the same design, including the second Bermuda floating dock, which was of the Havana sectional type designed by Clark and Standfield (Fife 1902:700). This is principally because the center of gravity in a U-shaped hull is higher than in a rectangular or box shaped hull, making the U-shape design less stable, requiring the addition of caissons to

impound and drain water from within the structure, as in a floating graving dock (Cunningham 1904:481). Also contributing to the lack of adoption of this design, rectangular docks used up to one-third the raw materials of the Bermuda U-shaped dock, giving the box dock a highly improved weight to lift ratio. Most contemporary iron docks employed a less-faired U-shape for the interior floor and walls to assist with placement of shores for the vessel, while the hull exterior remained rectangular, as seen in Figure 13 in the previous chapter of the 1860 Callao, Peru floating dock. While the U-shaped exterior hull was unique, operational components such as compartmentalized pontoon air chambers and use of caissons for additional lift existed well before construction of the first Bermuda dock, making its classification as a “one-off technological development” only partially correct.

These perspectives reflect the opposition of Gould to unilinear cultural evolution, or “the ex post facto history presenting the past as a series of stages leading to a final result,” the main proponents of which were 19th century scholars Lewis Henry Morgan and E. B. Tylor (Gould 2000:14). Although this thesis agrees with the premise of unilinear cultural evolution in respect to floating docks, it in no way attempts to argue that any development is truly “linear,” as illustrated by the diverse operations of floating dry docks and alternative structures. As a quick example, the 1816 ship-shaped floating dock design of J. Adamson remained largely ignored, after limited early success, until the United States sought to develop an easier to tow dock in 1938, constructing the experimental *ARD-1*. By omitting the unilinear “false sense of inevitability” Gould claims to be inherent with all evolutionary approaches, this theory meshes perfectly with the cumulative synthesis model, allowing for the stage-wise progression of floating dry docks where all previous designs contribute something to the future construction, whether positive or negative. Much of the data generated by construction of the first Bermuda

dock regarding the cumulative synthesis model was negative, bearing out the inadequacies of flawed design concepts for the edification of future engineers. Therefore, this thesis stands in direct opposition to the concept that the first Bermuda floating dock “should not be viewed as a stage within a linear progression of floating dock technology, but was more a response to local conditions” (Gould 2000:315).

This author agrees with the presumption that no true linear progression of floating dock technology exists (only to the extent that “true” linear progressions are academic constructions and are in reality nonexistent), but argues that the accumulation and dissemination of engineering knowledge related to floating dry docks makes it impossible for any floating dry dock to be a “one-off” creation. The problem is deeper than mere semantics, as the basic conceptual arrangement of a floating dry must have existed preceding inception of the design professed as “revolutionary.” As noted previously by Kingery, the beginning of every design process starts with a “normal configuration” existing within the mind of a designer, derived from observation, experience, and instruction in their everyday world (Kingery 2001:127). The inspiration for a new design must come from a previously conceived external stimulus, and the case is no different for the HM Floating Dock *Bermuda*. Designers Campbell and Johnstone worked on the Tyne River, a major hub for 19th century English shipbuilding, observing along those crowded banks some of the most innovative docks of their day. Their location and vocation imply they must have been aware of floating dry docks and sought to produce an improved version, using the material of choice in England at the time (wrought iron), and incorporating a potentially more stable design, capable of self-careening for frequent service and repair. To state repeatedly that this structure ought not to receive a place in the evolutionary path of floating docks ignores and discounts the valuable data garnered from its construction. The purported ease with which

operators could self-careen was in reality a challenging and dangerous undertaking, and the interior pontoons proved especially vulnerable to the corrosive processes of salt water and incredibly difficult to access for cleaning and painting, facts born out only following its construction and operation (American Society of Naval Engineers 1898:678).

Adoption and Diffusion of Floating Dock Technology

Conceptually, all forms of biological evolution require the acceptance of three essential mechanisms: one for generating variability in the biological organism, one for selecting desirable variants, and one for the transmission of the selected variation to subsequent generations (Conlin 1998:4). The mechanism for generating variability exists as the cultural and environmental constraints dictating the design and operation of component sub systems within a dock, such as the pumping machinery, construction material, and unit morphology. As witnessed, developments within a single sub system prompt necessary reconfigurations or alterations to other sub systems, where the most functionally successful repeatedly appear in future design, extensively expanded upon earlier in this work. The mechanisms for selecting desirable variants and transmitting them to subsequent generations of floating docks, better known in technological terms as adoption and diffusion, complete the cumulative synthesis model of floating dock evolution.

Adoption refers to the selection of a technology by an individual (or group) at a specific time in lieu of alternative technologies. Various stages of adopters exist, each selecting the technology at different times for different reasons, such as relative advantage over previous designs, compatibility with existing values and needs of adopters, complexity and ease of understanding, trialability of new designs with gradual exposure, and the observability of many individuals within a community (Rogers 1995:221). Individuals evaluated the relative merits of

various docking systems consciously and subconsciously against these factors and decided which technology to adopt and when to adopt it. For the early adopters, necessity often dictated their decision more than any other factor, as in the case of the first Bermuda dock where substrate conditions prevented construction of graving docks. These adopters demonstrate the successful operation of a new technology to their peers and the community, triggering the wider adoption by the early majority. The early majority subscribe to the saying “be not the first by which the new is tried, nor the last to lay the old aside,” and typically take longer to deliberate before adopting than innovators and early adopters. Late majority adopters take on the new technology well after the average member of a system, usually only do so out of economic necessity or increasing peer pressure. They approach technology with skepticism and caution, waiting for critically revised improvements and developments before electing to adopt, and are followed only by the laggards, whose reference point for technology is the past. Laggards conscientiously reject new technologies on the basis that previous designs adequately solved the problem, therefore must obtain a guarantee that a new technology will offer substantial benefit, as failure would cause a catastrophic economic loss (Rogers 1995:263-267). Compared with other vocations, those associated with maritime endeavors traditionally fit the category of late majority and laggards regarding any technological developments, due to the unchanging set of problems presented by the sea and the mechanisms required for its navigation (Conlin 1998:7).

The diffusion of floating docks depends directly on the rate of adoption, defined as the process by which “an innovation is communicated through certain channels over time among members of a social system,” and is likely a gradual process depending on the pace at which secondary improvements refine the original technology (Rogers 1995:11; Rosenberg 1972:7). Floating dry docks possessed a keen ability to traverse communication channels due to their

immense size and visibility within a shipyard. With waterborne transportation the primary means of moving people and goods for the better part of civilized existence, many individuals otherwise disconnected from maritime life witnessed these majestic structures towering above their ports and harbors while docking vessels. Their frequent inclusion in popular engineering journals and magazines further exposed their design and operation to the public at large, effectively crossing multiple social channels and speeding acceptance among late-adopting groups. The evolution of floating dry docks directly correlates to this diffusion-adoption theory in the form of an increasing number of docks over time. The earliest forms of floating docks offered little functional improvement over graving docks, operated in select locations as little more than a novelty, were derisively looked down upon by the public, and required over 100 years to pass from invention to early adoption. The 1848 decision of the United States navy to supplement their repair capacity with four floating docks in the ports of Portsmouth, Philadelphia, Pensacola, and San Francisco revealed a confidence in the new technology unprecedented in the history of the navy. Rather than adopting with the late majority or laggards, the navy joined the early adopters in the acceptance of the floating dock, acting as the force responsible for bridging the gap between early adopters and the early majority. Commercial shipping and repair yards, whose “public minds seem disposed to try a floating dock at a navy-yard,” gained confidence following the naval adoption to implement floating dry docks of their own, using the navy dock experiments as a barometer for the efficacy of the sectional and balance dock (Gilbert 1843:14).

Around the world, other nations looked to the United States as leaders in the field of floating docks; for example, the first floating dock in Amsterdam built by J.D. Diets in 1843 relied solely upon “very poor and incomplete drawings” taken from American docks (Lemmers 1998:66). Even though the earliest floating dock for which a patent record exists dates to 1785 in

England, the United States most fully embraced their potential between during the 19th century, earning them a reputation as an “American invention” (Donnelly 1906:449). Despite commercial yards in the United States owning a far greater number of sectional, balance, and pontoon docks than all other countries combined over this period, they lagged considerably in the use of iron for both fittings and structural components. The wide availability of inexpensive timber as a construction material, the relatively small size of most commercial vessels needing service from floating docks, and the substantial influence held by the timber industry limited the desire of Americans to experiment with iron and steel during the early stages of its development. In this regard, the English clearly possessed the upper hand, producing a litany of iron and steel docks for colonial ports around the globe starting in 1859, over 40 years before the United States built their first steel dock in 1902 (Navy Department 1909:152-289). By 1909, floating dry dock technology readily diffused to all industrialized seafaring nations, with the ports of Hamburg and Greater New York City operating them in the highest concentrations of iron and wood construction, respectively (Navy Department 1909:98-100,190-192).

With the onset of Second World War the United States navy began constructing timber, steel, and concrete floating dry docks at a blinding rate, increasing the total number from 3 to 153 (50 timber, 88 steel and 12 concrete) between 1941 and 1945, establishing the largest naval fleet of such docks ever assembled (Beggs 1953:4). The Cold War kept many naval docks operation in the decades after the Second World War, gradually reducing their number as the number of ships diminished, leaving the navy in control of only four docks in 1995. During this interim, commercial yards continued operating floating dry docks around the world, completely phasing out timber as a construction material and building only with steel and to a lesser extent concrete today. The need for frequent inspection and repair in modern steel docks is far less than

their early 20th century progenitors, due to the advancement of protective hull sealants and paints, causing new construction of sectional docks (or “pontoon docks” as defined by Lloyds’ in 1973) to cease altogether by 1978 (Thatcher 1978:3). The desire for lighter, stronger, less expensive commercial docks initiated a resurgence in construction of box or “caisson” docks, similar to the balance dock pioneered by Gilbert in the 1840s. One of the premier ship classification firms in Japan (similar to Lloyd’s Register of Shipping), the Nippon Kaiji Kyokai (NKK) (the Japan Marine Association), lists the number of active commercial floating docks over 130 feet (40 meters) operating around the world today at roughly 184; the longest dock measuring 1,328 feet (405 meters), and the strongest capable of lifting 300,000 tons. The NKK also lists 219 active commercial graving docks longer than 210 feet (64 meters), the longest measuring an astounding 1,476 feet long (450 meters), and the greatest lift capacity 700,000 tons, though some graving docks not listed exceed 1,000,000 dwt (Pelletier 1998:253). Additionally, the NKK lists 21 slipways with capacities up to 705 feet (215 meters) long and 12,000 tons, and 13 lift-based systems (including Syncrolift) measuring up to 754 feet (230 meters) long and able to lift up to 50,000 tons (Nippon Kaiji Kyokai 2011). The complete NKK list for 2011 appears in Appendix A.

While floating dry docks evolved from simple hollowed hulks into 1,000 foot long complicated repair structures over a period of less than 350 years, most essential applications of buoyant structures to lift ships developed over a period from 1816-1850. The ship-shaped dock, the balance dock, the sectional dock, the floating graving dock, floating pontoons, ship lifts and marine railways all essentially developed during this windfall period of new construction during the first half of the 19th century. Almost every docking system experienced a period of relative nonuse and a period of reinvention, where antiquated designs return to the mainstream through

improved construction materials or component technologies. The 1816 ship-shaped dock of Adamson did find immediate employment, but almost entirely faded from the maritime landscape until the Second World War and the implementation of the ARD class floating docks. The single-unit balance dock operated in a handful of navy and commercial yards from 1848 through the end of the Second World War, though it reached true prominence in the latter half of the 20th century, monopolizing the modern floating dry dock type. The sectional or pontoon type proved the longest reigning in floating dock history, comprising virtually every large design from 1848 through the ABSD class navy docks of the 1940s. Once hull coating and underwater monitoring technologies improved, commercial enterprises sought to improve longitudinal strength and reduce overall displacement without reducing lift capacity, solved entirely by the single-unit box or caisson dock. The marine railway and ship lift consistently maintained a relatively small share of the market, accounted for by physical and financial constrictions on docks above 8,000 tons, but proved sufficiently effective for vessels under this size that their use endures in many ports around the world (Nippon Kaiji Kyokai 2010).

The graving dock, developed long before all of these, continues leading the way as most prevalent dry docking system in the world. For all their deficiencies, drawbacks, and inefficiencies, they create the one docking scenario least dependent upon mechanical contrivances for operation. Floating docks risked capsizing if improperly pumped or exposed to heavy weather while performing a lift, while the unintended flexibility of early docks could warp keels and throw docks out of alignment. Aside from an untimely flooding caused by faulty dock gates with graving a vessel, excavated docks were far less susceptible to any comparable dangers and disturbances. In the evolution of floating docks, this notion held true during the earliest stages, motivating engineers to obtain the same level of security as their graving counterparts,

though challenging them to retain the materially beneficial capabilities unique to floating docks (mobility, flexibility, self-docking). Selective processes among those employing docks changed, most directly in the form of pecuniary interests, promoting the development a new, less expensive means of servicing and repairing vessels, especially as they incessantly grew larger. Graving dock design evolved to a near-modern state during the late 19th century, with the implementation of three basic graving dock types: the gravity dock, the anchored dock, and the pressure-relieved dock. The oldest type of graving dock, the gravity dock overcomes the hydrostatic uplift of percolating water within the soil by utilizing an extremely heavy structural mass for the walls and floor (masonry, stone, carved bedrock), relying upon to force of gravity to hold the dock in place. Anchored docks utilize long piles driven into the surrounding substrate to anchor down the walls and floor of the dock, and pressure-relieved docks physically rerouted the groundwater into culverts below the dock, using auxiliary pumps to drain the water.

Regardless of design, many settings exist where environmental conditions altogether preclude construction of graving docks, giving floating docks a guaranteed share of the dry docking market by virtue of their ability to function where the more popular system cannot. However, their occupation of 42% of the global market reveals the enduring value of their other beneficial characteristics, and that preference for floating docks extends well beyond their mere necessity in certain locations. The existence and successes of floating docks today is the unequivocal product of their ability to evolve and adapt to vessel designs, user requirements, and varying environmental factors in a fashion comparable to (and in some cases superseding) the efficacy of graving docks. Slow and steady improvements in the understanding and application of physical laws, raw materials refinement, and component technologies transformed the crude floating dock hulks and camel docks into modern feats of engineering. Though for all their

improvements, the general shape and function of modern floating docks would be instantly recognizable to the individuals responsible for their initial development nearly 200 years earlier.

CHAPTER 7: CONCLUSION

Floating Docks as Evolutionary Technologies

Using various theories of technological evolution, this thesis demonstrated that the development of floating dry docks qualifies as evolutionary, concluding that not only did floating dry docks evolve within themselves, but they directly descended from graving docks. Analogous to the development of component technologies contributing to ship evolution, the component technology of floating dry docks manifested a handful of various solutions to the deficiencies in their early designs, in some cases resulting in entirely new floating structures. Though unlike ship evolution, the developments of floating dock component technologies was a reaction to perceived stability inefficiencies when compared with graving docks, and not a response to operational environment restrictions. The evolution of component technologies in ships, dictated by wind and wave action, intended function, and environmental conditions within their sphere of operation, brought about the greatest changes in material expression of the ship (Conlin 1998:011). The floating dry dock as a whole represents the comparable response to environmental limitations, with the development of component technologies serving primarily to create a structure equivalent in strength and safety to their rival graving docks. The utility of any new design rests with the degree to which it promotes a reevaluation of previous solutions, and from the many examples in this text, floating docks clearly fit that description. Accordingly, a 42% share of worldwide modern commercial ship repair facilities attests to the utility afforded by floating dry docks in virtually any location, not only those inhospitable to graving docks.

While this thesis developed as a riposte to the belief that specific floating dry docks warrant omission from the greater thread of evolutionary developments, it opposes the presumed concept that unilinealism acts as the overarching guiding principle. The evolution of floating dry

docks proposed herein ascribes to the theory that technological progression is continuous and cumulative over time, with each incarnation necessarily drawing inspiration from previous designs and invariably bestowing influence on future ones (Loch and Huberman 1999:163) . No single preeminent pattern of development exists that this evolution must follow, no perfect design to which each manifestation of dock aspires; rather, docks only changed when dictated by the effects of external stimuli, specifically increases in ship dimensions and capacity. Part of the reason floating dry dock perfection has not and will never occur is the changing social valuations society places upon their design. Early during development, floating docks acquired a derisive stigma among proponents of graving docks, and thus did a majority of the population, as most never heard of this new technology and had only the opinions of a relative few upon which to base judgment. This created a situation where a somewhat limited number of individuals devoted their professional careers to designing floating dry docks, restricted primarily to those familiar with the concept and believing in its potential, as cultural conditions placed a higher premium of developing known technologies (Ogburn 1926:226). Through the indispensable sequence of trial and error, designers selected pertinent features for new docks based on the relative success or failure of previous specimens, metaphorically enabling their “reproduction” in future generations of ship repair, a key component when drawing analogies with evolutionary biology (Conlin 1998:12). Over time, societies deemed certain characteristics to possess greater value than others (the prolonged use of wood as a construction material in the United States, for example), prompting the proliferations and contractions of virtually every floating dock type at various points in history.

Still, the most contentious issue then is the connection of floating dry dock evolution to its graving brethren, and the potentiality of the earliest floating docks forming an irrefutable link

between the two. As defined previously, historical evidence categorizes the progression from repurposed hulk to camel dock to floating graving dock to floating pontoon dock and beyond in a reasonably complete manner, with each succeeding design incorporating features slightly more complicated than earlier models. Undoubtedly, this analysis neglects examples of early floating docks for which no historical or archaeological data existed within the grasp of the author. Nevertheless, the available (and quite extensive) information proves sufficient to establish a basic phylogeny of floating dry docks covering practically the entirety of their existence, including their descent from graving docks. This informational database references an evolutionary history incorporating two vital facets: macro-elemental modifications, where reassembly of the component technologies results in a functionally similar but principally altered form, and micro-elemental changes occurring within the component technologies themselves, gradually improving each generation of floating dry dock to varying degrees. For example, offshore and depositing docks represent macro-elemental modifications, as they retained use of buoyant pontoons for the necessary lift, but spaced them uniquely, added an outrigger, and removed a wing wall, creating an arrangement bearing few structural parallels with floating dry docks, though both preformed the same function. The use of compartmentalization within pontoon chambers characterizes a micro-elemental modification, for while the immediate function of their design was to reduce interior sloshing during lifting and lowering, their implementation inadvertently enabled the creation of new pumping configurations, permitting additional innovations not envisioned during the initial modification stages. These modification distinctions establish an amorphous evolutionary path of floating docks, where each design experiences peaks and valleys in popularity, similar to the cladogenesis found in punctuated equilibrium models of evolutionary biology (Gould and Eldredge 1977:116).

Accepting the first camel dock ascribed to the British merchant captain as the forerunner to the floating dry dock also accepts the graving dock of the middle 17th century as the influencing precursor to the camel dock. The supported argument that all related technological changes are cumulative applies even here, as the captain necessarily derived his knowledge of docks and docking from tacit life experiences in the maritime industry. These experiences formed a general understanding of excavated dry dock operations and principles from which the captain created his camel dock. However, the idea of repurposing ships also existed during this time, as many former sailing vessels became hulks upon conclusion of their seagoing capabilities, as evident by those readily available for purchase by the captain (Staples 1922:647). Thus, the required act of insight bridging the floating and graving dock gulf consisted of further repurposing the already repurposed hulk, gutting it, and adding a gate to form a dry dock-like basin, all concepts for which the captain demonstrated a succinct knowledge through experience. The fact remains that an astute individual must mentally assemble their accrued knowledge into a new design, an act not guaranteed to occur without the presence of specific individuals. Had John Standfield pursued an interest designing railroad engines instead of floating docks, cumulative synthesis does not guarantee the eventual construction of the depositing dock by another individual. The component technologies existed for mental reassembly by another individual, and therefore the possibility certainly exists that someone else could generate a similar new design, demonstrating the value each individual possesses in spite of the presumption of cumulative knowledge.

The Significance of the Floating Dock Evolution to Maritime History

Establishing an evolutionary pattern of floating dry docks overcomes the discontinuities associated with patents and individual desires for glory that often credit single individuals for an

invention while ignoring the multitude of people and ideas directly contributing to its development. For example, history generally credits Robert Fulton for invention of the steamboat with his *Clermont*, when in reality John Fitch constructed and operated a handful of steam powered vessels beginning in 1785, over fifteen years before Fulton. However, Fulton validated the economic viability of the new technology, something Fitch struggled with until his death in 1798 (Navy League of the United States 1912:29). Still, a vast majority of people when asked who invented the steamboat will answer Fulton, and while partially correct, it blatantly alienates Fitch and others responsible for developing the technology to a degree where it became economically viable for Fulton to exploit. Rather than absolving Fulton of any praise, cumulative synthesis recognizes his contributions but places them in an appropriate historical context, positioning the *Clermont* within an evolutionary pattern that followed the path of with James Watt and his work with steam engines. One of the most awesome features of modern society is the capacity to enshrine and pay due respect to the individuals directly responsible for the technological advancements that led to the improved existence of humans on this planet. However, the constantly changing nature of technology lends itself to overlook easily those who came before by overly distinguishing creators of modern improvements.

Another apt comparison is the modern “smart phone,” incorporating components of telephones, computers, cameras, books, tools, etcetera. Society often credits the late Steve Jobs for amassing these technologies into a single element (never mind the work of his team), but should they also credit Bell, Eastman, and Gutenberg for their early work on the component technologies comprising the smart phone? With modern technology drawing influence from an ever growing pool of knowledge (as in the iPhone), its history becomes increasingly convoluted, placing a higher premium on the generation of accurate and complete codices of specific

technological niches. Undoubtedly, a slew of individuals responsible for influencing major technological developments remain ambiguous in their respective recorded histories, their inventions unfortunately living beyond their name. Cumulative synthesis theory aims to protect these individuals from such blatant historical pilfering, and performs an admirable job in its application to the evolution of floating dry docks without the necessity to remove single examples as “one-off” technologies. All floating docks operate on the same general principles and therefore preclude such arbitrary categorizations, and one cannot with certainty claim the existence of any singular design as deriving no influence from elsewhere nor bestowing a similar influence on latter constructions.

The application of cumulative synthesis to any docking system proves incredibly challenging due to the utilitarian, blue-collar nature of their operation. While much of the population possessed a cursory knowledge of boats and ships (owing to their status as the most efficient means of transportation), a far smaller percentage knew of or gleaned an interest in the mechanisms responsible for their maintenance and cleaning. Despite representing some of the most colossal structures populaces witnessed in various localities (as docks were by necessity larger than most ships), graving docks received scarcely a passing interest by the community at large. Not until the proliferation of floating docks did people begin to recognize the feats of engineering prowess embodied in physically extracting massive vessels from their operational medium, as it was then and remains today quite a spectacle to witness a large vessel raised above the waterline in its entirety, from bottom of keel to top of mast or funnel. This general lack of interest, spurred by a dearth of large ships necessitating alternatives to docking techniques such as careening or beaching, resulted in few surviving publications containing reference to the design, construction, or function of the earliest floating and graving docks.

Though the documented historical record tends to blur the farther one looks back in time, the archaeological record offers hope for some clarification. Many ancient graving docks, though constructed of stone or excavated directly into the shore, are unlikely to survive long after falling into disuse due to their occupation of traditionally valuable waterfront or harborfront property. Frequently, individuals or communities purchase the occupying land and “reclaim” it by filling the dock, as was the case with one of the earliest dry docks in Australia, Mort’s Dock on the Balmain peninsula near Sydney, now converted into a public park as seen in Figure 58. Similarly, Swedish furniture giant Ikea purchased land including the historic Graving Dock No. 1 of the Erie Basin Repair Yard in the Red Hook district of Brooklyn, New York, paving over the filled dock for their parking lot (White et al. 2010:631). By exploring coastal regions with heavy documented vessel traffic or identified vessel construction and repair facilities, archaeological investigation could reveal the existence of previously unknown dry docks, which would directly contribute our understanding of the evolution occurring within graving and floating dry docks. Unlike graving docks, the preponderance of floating dry dock structures remaining in the archaeological record is very low, as their structural components often contained an intrinsic value that encouraged their frequent sale to salvagers and shipbreakers upon termination of their use. In some cases, people filled in floating dry docks as part of land reclamation projects just as they did graving docks; for example the P&O floating dry dock of 1866 that sunk during World War I, was partially salvaged, and eventually buried in a landfill on the Albany, Western Australia foreshore in 1915 (Western Australia Museum 2011). However, these scenarios are rare, with little information available regarding the wrecking or abandoning of even the most well-known floating dry docks; once again, owing to their general perception as nothing more than functional components of the ships they serviced.



Figure 51. Satellite image of the filled in Mort Dock near Sydney, Australia. Note the use of the original caisson as part of the sea wall (Google Maps 2011).

Potential for Future Studies

While this thesis explores in depth the basic evolutionary stages of floating dry dock development, there exist multiple avenues for further research related the subject. A comprehensive study of graving docks, with an intensified focus on ancient and colloquial docks dating before construction of the Portsmouth excavated dock of 1495, would be an excellent complement to the evolutionary studies of vessels and floating dry docks, though undoubtedly a difficult undertaking. Similarly, examinations of the principal components of ports and harbors, such as quays, jetties, piers, and wharves, would assist in completing the metaphorical reconstruction of such a maritime cultural landscape for virtually any time throughout history. More closely related to the subject matter of this thesis, further explorations in the evolution of various pumping systems and configurations, blocking and shoring arrangements, crane and

derrick systems, machine shops, and similar related technologies could form the basis of a valuable comparative analysis between their operation in graving and floating dry docks. Specific investigations into the development of slipways, with emphasis on the earliest examples of ship sheds from the ancient Mediterranean, could attempt to discern a possible connection with the marine railways that became popular in the United States contemporaneously with floating dry docks.

From an anthropological perspective, information about individuals who worked the docks comprises very little of the current historical record, and while difficult to ascertain would prove highly beneficial to the understanding of the daily lives of these nameless individuals. *The Secret Blue Collar War* by Hartney delves substantially covers the lives of men stationed on the over 150 United States floating docks of the Second World War, and provides a solid basis for similar ethnographies. Additionally, a thorough biographical study of key individuals in floating dry dock evolution (Clark, Standfield, Rennie, Donnelly, and so forth) would be potentially the most beneficial to this thesis, as much of the arguments within hinge upon the knowledge and experience of these individuals. A historical evaluation of the floating dry dock design firms many of these individuals established, and the history of construction following the death of the founders, may help to analyze the actual role of the principal inventor and their influence within the development of new floating dry dock types.

Another viable topic for consideration, and one receiving an unfortunately small devotion of time and space in this thesis, is the role of the construction firm or yard responsible for the physical assembly of floating docks. The transition from wood to iron and steel hulls probably affected the shipyards more directly than any other development, as they required specialized

knowledge and facilities to manipulate the new raw material, shifting the construction market dramatically.

Final Thoughts

By thoroughly examining the litany of floating dry docks constructed throughout history, the author identified a developmental trend indicative of the technological definition of evolution. With the assistance of theoretical modeling, namely that of cumulative synthesis, various manifestations of dry docking systems revealed their interconnectedness through the incorporation of specific component technologies, allowing for the unification of all docks expressing similar physical properties, despite the presence of certain unique features. Although this evolution is not unilineal, it traces a gradual development partially mirroring the established evolutionary nature of vessel construction, though the identification of social valuation and other pertinent factors absolutely affected the direction and pace of progress. The evolution of floating docks, like most evolutions, is multivariate in nature, where the incorporation of a wide variety of factors across multiple platforms contributes to development. While many factors altered the path of this evolution, advances in hull construction material generated the most significant changes to floating dock morphology.

In the process of answering the question “is the development of the floating dock indicative of an evolution,” the author compiled the most complete account of floating dry docks from their inception to modernity, focusing on seminal examples of greatest consequence to the overall pattern of development. No single monograph has ever attempted such a comprehensive overview of their types and distinctions, much less endeavored to draw parallels between their development and that of graving docks. Despite floating docks occupying of a hefty share of the modern large vessel repair market, very little technical information exists regarding their design

and construction, especially covering the previous 50 years. This made their research slow and time consuming, where the frequent scanning of 1,000+ page texts often netted scarcely more than a paragraph referencing floating docks, resulting in the extensive and diverse bibliographical entries. However, the gradual amalgamation of this minutia eventually created a complete analytical study of the history, development and significance of floating dry docks.

BIBLIOGRAPHY

Alden and Beardsley

1857 *The Book of the Ocean, and Life on the Sea*. Publisher Unknown, Auburn, NY.

American Society of Naval Engineers

1899 “Four Immense Dry Docks—League Island, Mare Island, Boston and Portsmouth.” *Journal of the American Society of Naval Engineers*, 11(4):984-991.

1898 “The Stettin Floating Graving Dock.” *Journal of the American Society of Naval Engineers*, 10(3):677-684.

Amirikian, Arsham

1957 “Analysis and Design of Floating Dry Docks.” *Transactions: Society of Naval Architects and Marine Engineers* 65(1):307-361.

Anderson, Sven (Ed.)

1907 *Floating Drydocks*. The Maryland Steel Company, Sparrows Point, MD.

Angas, W. Mack

1937 “Docking the Big Fellows.” *Popular Mechanics* 67(1):82-84.

1945 “Seagoing Navy Yard Follows the Fleet.” *Popular Science* 147(5):121-124.

Arthur, W. Brian

2009 *The Nature of Technology: What it Is and How it Evolves*. Free Press, New York, NY.

Athenaeus of Naucratis

1854 *The Deipnosophists, or, the Banquet of the Learned of Athenaeus*, C. D. Yonge, translator. Henry G. Bohn, London, England, UK.

Barnes, David W.

1922 “Building Floating Drydocks.” *Pacific Marine Review* 19(4):238-240.

Barron, James

1837 *Dry Dock*. Patent #272. United States Patent Office, Alexandria, VA.

Basalla, George

1988 *The Evolution of Technology*. Cambridge University Press, Cambridge, England, UK.

Beggs, A. H.

1953 “Big Brothers to the Fleet: Floating Dry Docks Increase Fighting Efficiency of Ships.” *Bureau of Ships Journal* 1(12):2-7.

Bennett, F. M.

1907 “The Voyage of the Dewey” *Proceedings of the United States Naval Institute* 32(4):77-131.

Blackman, David

1987 "Triremes and Shipsheds." *Tropis Symposia Proceedings* (II):35-52.

2000 "Progress in the Study of Ancient Shipsheds: a Review." In C. Beltrame (Ed.) *Boats, Ships and Shipyards: Proceedings of the Ninth International Symposium on Boat and Ship Archaeology, Venice 2000*. Oxbow Books, Oxford, England, UK.

Bramwell, Frederick J.

1867 "On Floating Docks, and other Arrangements for Affording Access to Ships for External Repairs." *Institution of Mechanical Engineers Proceedings*, Published by the Institution, Birmingham, England, UK.

Braynard, Frank O.

1963 *S.S. Savannah, the Elegant Steam Ship*. University of Georgia Press, Athens, GA.

Brown, Charles and Thomas Biddlecombe

1889 *Floating Dock*. Patent #398,223. United States Patent Office, Alexandria, VA.

Bureau of Yards and Docks

1947 *Building the Navy's Bases in World War II*. Government Printing Office, Washington, DC.

Burke, Edmund

1847 *List of Patents for Inventions and Designs: Issued by the United States from 1790-1847*. J. and G. S. Gideon, Washington, DC.

Carayon, Nicolas

2005 "Le Cothon ou Port Artificiel Creuse. Essai de Definition." *Revue Mediterranee* 104(1):5-13.

Chambers, W. R.

1870 *Chambers's Encyclopaedia: A Dictionary of Universal Knowledge for the People*. J. B. Lippincott and Company, Edinburgh, Scotland, UK.

Cherry, Bridgette, Charles O'Brien, Nikolaus Pevsner

2005 *The Building of England: London 5: East*. Yale University Press, London, England, UK.

Clark, Edward

1828 "Floating Dry Dock." *The Register of Arts, and Journal of Patent Inventions* 1(1):120-122.

Clarke, Hyde

1845 "A Description of the Plans Adopted at New York for Docking Ships." *Quarterly Papers on Engineering*, 4(1):1-73.

Clark, Lyonel Edwin

1897 “Recent Developments in Docks and Docking Appliances.” *Transactions of the Institution of Naval Architects* 38(1):23-43.

1905 “Floating Docks.” *Minutes of Proceedings of The Institution of Civil Engineers*, 161(1):1-113.

1907 “Modern Floating Docks.” *Transactions of the Royal Institution of Naval Architects* 49(1) 238-255.

Clowes, William Laird

1897a “The Wrong Way With the Navy.” *The Fortnightly Review* 1(LXI):728-745.

1897b *The Royal Navy: A History from the Earliest Times to the Present, Vol. 1*. Sampson Low Marston and Co., London, England, UK.

Colson, Charles

1894 *Notes on Docks and Dock Construction*. Longman’s Green and Co., London, England, UK.

Conlin, David L.

1998 “Ship evolution, ship ‘ecology,’ and the ‘Masked Value Hypothesis.’ *International Journal of Nautical Archaeology* 27(1):3-15.

Cornick, Henry F.

1958 *Dock and Harbour Engineering*. Charles Griffin & Co. Limited, London, England, UK.

Covenhoven, Edward

1821 Patent Sketch of Floating Dry Dock. United States Patent Office, Arlington, VA.

Cox, Leonard M.

1907 “The Naval Floating Dock: Its Advantages, Design and Construction.” *Transactions of the American Society of Civil Engineers*. 58(1042):97-195.

Crandall Dry Dock Engineers

1967 *A Short History of Railway Dry Docks Since Their Inception in 1854: With Methods of Tonnage and Blocking Determination and Load Distribution*. Crandall and Sons, Cambridge, MA.

Cunningham, A. C.

1903 “The Cavite Steel Floating Drydock: It’s Strategic Value in Defending the Philippines.” *Journal of the American Society for Naval Engineers*, 15(2):472-511).

1907 “Modern Floating Drydocks.” *Floating Dry Docks*, Sparrows Point, MD. 266-310.

Cunningham, Brysson

1904 *A Treatise on the Principles and Practice of Dock Engineering*. Charles Griffin & Company, London, England, UK.

Dakin, Samuel

1844 *A Brief Sketch of the Plan and Advantages of A Sectional Floating Dry Dock Combined with a Permanent Stone Basin and Platform, and Connected with Level Bedways, Sliding ways, and Housed Slips for Repairing, Launching, and Laying Up in the Ordinary of Ships of the United States Navy.* Jared W. Bell, New York, NY.

Dampier, William

1699 *A New Voyage Round the World, Volume I.* The Crown at St. Paul's Churchyard, London, England, UK.

Dawson, Charles

2009 "A Short History of the Camel." *Nautical Research Journal* 54(4):219-232.

Dear, I.C.B. and Peter Kemp

2006 *The Oxford Companion to Ships and the Sea.* Oxford University Press, Oxford, England, UK.

Department of Defense

2002 "Design: Graving Drydocks." *Unified Facilities Criteria*, Annapolis, MD.

Donnelly, William T.

1906 "Floating Dry Dock Construction." *Brooklyn Engineers' Club, Proceedings for 1905*, Brooklyn Engineers' Club, Brooklyn, NY.

1909 "A 6,000-ton Floating Dry Dock." *International Marine Engineering*, 14(8):294-298.

1910 Floating Dry Docks in the United States; Relative Value of Wood and Steel for Their Construction. In *Transactions of the Society of Naval Architects and Marine Engineers, Vol. XVIII.* Principle Office of the Society, New York, NY.

Dorwart, Jeffery

2001 *The Philadelphia Naval Yard: From the Birth of the U.S. Navy to the Nuclear Age.* University of Pennsylvania Press, Philadelphia, PA.

Elwin, Charles

1878 "On a Floating Dock Upon an Improved System at the Victoria Graving Docks." *Proceedings of the Institution of Mechanical Engineers*, 139-183. Published by the Institution, Westminster, England, UK.

Engineering

1871 "Janicki's Floating Dock." *Engineering: A Weekly Illustrated Journal*. 7(9):185-186.

Falconer, William

1780 *A Universal Dictionary of the Marine; Or, A Copious Explanation of the Technical Terms and Phrases Employed In the Construction, Equipment, Furniture, Machinery, Movements, and Military Operations of a Ship.* Printed for T. Cadell, in the Strand, London, England, UK.

- Fife, Richard
 1902 “The Great Floating Docks of Bermuda and Algiers.” *Proceedings of the United States Naval Institute*, 28(3):699-702.
- Fincham, John
 1851 *A History of Naval Architecture*. Whittaker and Co., London, England, UK.
- Fremdling, Rainer
 2005 “Foreign Trade—Transfer—Adaptation: British Iron Making Technology on the Continent (Belgium and France).” *The Industrial Revolution in Iron: The Impact of British Coal Technology in Nineteenth-Century Europe*. Ashgate Publishing, Burlington, VT.
- Fletcher, R.A.
 1910 *Steam-Ships: The Story of Their Development to the Present Day*. J.B. Lippincott Co., Philadelphia, PA.
- Forbes, Robert James and D. R. O’Beirne
 1957 *The Technical Development of the Royal Dutch/Shell: 1890-1940*. Royal Dutch Petroleum Company, The Hague, Netherlands.
- Ford, John D.
 1903 “Floating Drydocks—Their Military Possibilities and Value.” *Journal of the American Society of Naval Engineers* 15(1):1-18.
- Fougner, N. K.
 1922 *Seagoing and Other Concrete Ships*. Henry Frowde and Hodder & Stoughton, London, England, UK.
- Gaythwaite, John W.
 2004 *Design of Marine Facilities for the Berthing, Mooring and Repair of Vessels*. American Society of Civil Engineers Press, Reston, VA.
- Ghose, Saroj
 2007 “Technology: What is it?” *Science, Technology, Imperialism and War* [Gupta ed.]. Center for Studies in Civilizations, New Delhi, India.
- Gilbert, John S.
 1841 “Specification of a Patent for an Improved Mode of Construction Dry Docks.” *Journal of the Franklin Institute* 2(1):69.
 1843 *Review of the Sectional Dock Company’s Pamphlet, Together with a Statement of the Comparative Merits of the Sectional Floating Dry-Dock and Gilbert’s Balance Dock*. Washington, DC.

Gilfillan, S. Colum

1935 *Inventing the Ship: A Study of the Inventions Made in her History Between Floating Log and Rotorship*. Follett Publishing Company, Chicago, IL.

Goldingham, C. S.

1918 "The Navy Under Henry VII." *The English Historical Review* 33(132):472-488

Goodwin, Peter

2000 *101 Questions & Answers about HMS Victory, Nelson's Flagship at Trafalgar 1805*. Conway Maritime Press, London.

Gould, Jay and Niles Eldredge

1977 "Punctuated Equilibria: The Tempo and Mode of Evolution Reconsidered." *Paleobiology* 3(2):115-151.

Gould, Richard A.

2000 *Archaeology and the Social History of Ships*. University Press, Cambridge, England, UK.

Gould, Richard A. and Donna Souza

1996 "History and Archaeology of HM Floating Dock *Bermuda*." *International Journal of Underwater Archaeology*, 25(1):4-20.

Grantham, John

1868 *Iron Ship-Building with Practical Illustrations*. Virtue and Company, New York, NY.

Gray, Horace Jr.

1867 *Reports of Cases Argued and Determined in the Supreme Judicial Court of Massachusetts*. Little, Brown and Company, Boston, MA.

Greene, Richard Gleason (ed.)

1890 *International Cyclopaedia: A Compendium of Human Knowledge, Volume VI*. Dodd, Mead and Company, New York, NY.

Gregory, Desmond

1990 *Minorca, the Illusory Prize: A History of the British Occupations of Minorca between 1708 and 1802*. Associated University Presse, Cranbury, NJ.

Gwyn, Julian

2004 *Ashore and Afloat: The British Navy and the Halifax Naval Yard Before 1820*. University of Ottawa Press, Ottawa, Ontario, Canada.

Hartney, John Donald

1995 *The Secret Blue Collar War: A History of the Floating Dry Docks in World War II*. Insty-Prints, Madison, Wisconsin.

Hawkes, Ellison

1928 "Some Wonderful Docks." *The Wonder Book of Engineering Wonders*. Ward, Locke and Company, Ltd., London, England, UK.

Hepburn, Richard D.

2003 *History of American Naval Dry Docks: A Key Ingredient to Naval Power*. Noesis, Arlington, VA.

Hinds, Asher C.

1907 *Hinds' Precedents of the House of Representatives of the United States, Including References to Provisions of the Constitution, the Laws, and Decisions of the United States Senate, Volume IV*. Government Printing Office, Washington, DC.

Hocker, Frederick J.

2004 *The Philosophy of Shipbuilding: Conceptual Approaches to the Study of Wooden Ships*. Texas A&M University Press, College Station, Texas.

Horner, Joseph Gregory

1907 *Henly's Encyclopedia of Practical Engineering and Allied Trades, Volume V*. Norman W. Henly Publishing Company, New York, NY.

Howell, Martha C. and Walter Prevenier

2001 *From Reliable Sources: An Introduction to Historical Methods*. Cornell University Press, Ithaca, NY.

Humphreys, J., Chase Stewart, A.J. Dallas, Hartman Banche, John Randel, George W. Smith, John Wilson.

1827 "Report of a select committee of the Franklin Institute on a Dry Dock, projected by Commodore James Barron, and also, by Captain Thomas Caldwell." *The Franklin Journal and American Mechanics' Magazine* 3(1):3-10.

International Marine Engineering

1913 "A German-Built 25,000-Ton Floating Dock." *International Marine Engineering* 18(7):278.

Jackson, George Briant Wheeler

1849 *Description of the Great North Holland Canal, and the Works and Niewediep; with an Account of the Mode of Gaining Land from the Sea by Polders, and the Art of Building with Fascine Work*. W. Clowes and Sons, London, England, UK.

Jackson, Gordon

1983 *The History and Archaeology of Ports*. Windmill Press, Surrey, England, UK.

Jeanes, Peter D.

2004 *Seafaring Lore and Legend: A Miscellany of Maritime Myth, Superstition, Fable, and Fact*. International Marine, New York, NY.

Johnson, Charles F.

1840 *Dry-Dock*. Patent #1506. United States Patent Office, Alexandria, VA.

Jones, Thomas J.

1834 "For an Improved Floating Dry Dock, invented by John Thomas." *Journal of the Franklin Institute of the State of Pennsylvania*. 14(1):252-253.

Kenealy, A. J.

1905 *Boat Sailing in Fair and Foul Weather*. Outing Publishing Company, New York, NY.

Kingery, W. David

2001 The Design Process as a Critical Component of the Anthropology of Technology in *Anthropological Perspectives on Technology*, Michael B. Shiffer, editor, University of New Mexico Press, Albuquerque, NM.

Kingston, William Henry G.

1876 *The Child of the Wreck; Or, the Loss of the Royal George*. Griffith and Faran, London, England, UK.

Knight, Edward Henry

1874 *Knight's American Mechanical Dictionary: Being a Description of Tools, Instruments, Machines, Processes and Engineering; History of Inventions; General Technological Vocabulary; and Digest of Mechanical Appliances in Science and the Arts*. J.B. Ford and Company, New York, NY.

Lavery, Brian and Patrick O'Brian

1989 *Nelson's Navy: The Ships, Men, and Organisation 1793-1815*. Conway Maritime Press, London, England, UK.

Lemmers, Alan

1998 "The Historical Experience of Scaled-Down Nineteenth Century Drydock Technology." *The Northern Mariner/Le Marin du Nord* 8(3):63-87.

Leslie, Frank

1856 "The Russian Camel, or Floating Dock." *Frank Leslie's New York Journal* 3(1):145.

Levin, Lewis B.

1846 *Amendment to the Naval Appropriation Bill, Directing the Construction of a Sectional Floating Dry-Dock, Basin, and Railways, at the Philadelphia Navy Yard*. Printed at the Union Office, Washington, D.C.

Lightfoot, Thomas Bell and John Thompson

1883 "The Design and Construction of Repairing Slipways for Ships." *Minutes of Proceedings of The Institution of Civil Engineers; With Other Selected and Abstracted Papers*. Published by the Institution, Westminster, England, UK.

Lloyd's Register Committee

1890 *Particulars of the War Ships of the World*. Lloyd's Register of British and Foreign Shipping, London, England, UK.

Loch, Christoph H. and Bernardo A. Huberman

1999 "A Punctuated-Equilibrium Model of Technology Diffusion." *Management Science* 45(2):160-177.

Loven, Bjorn

2006 "Ancient History—The Ship-sheds." Zea Harbour Project
<http://www.zeaharbourproject.dk/3/3_09.htm>

Marine Engineering

1903 "Havana Floating Dry-Dock Now at Navy Yard, Pensacola, Florida." *Marine Engineering* 8(12):597-600.

Markoe, Glenn

2000 *Phoenicians: Peoples of the Past*. University of California Press, Berkeley, CA.

Martin, Joseph T.

1840 *Dry Dock*. Patent #1518. United States Patent Office, Alexandria, VA.

Marx, Karl and Frederick Engels

1906 *Manifesto of the Communist Party*. Charles H. Kerr and Company, Chicago, IL.

Maxton, James

1899 "The Evolution of Floating and Other Dry Docks." *Reports and Proceedings of the Belfast Natural History and Philosophical Society, for the Session 1897-1899*. Mayne & Boyd (Printers to Queen's College), Belfast, Ireland, UK.

Mazurkiewicz, B. K.

1980 *Design and Construction of Dry Docks*. Trans Tech Publications, Rockport, MA.

McBride, William M.

2000 *Technological Change and the United States Navy: 1865-1945*. Johns Hopkins University Press, Baltimore, MD.

McCarthy, Michael

2005 *Ship's Fastenings: From Sewn Boat to Steamship*. Texas A&M University Press, College Station, TX.

Meijer, Cornelius

1685 *L'arte di Restituire a Roma la Tralasciata Navigazione del suo Teuere: Divisa in Tre Parti*. Nella Stamperia del Lazzari Varese, Rome, Italy.

Mokyr, Joel

1990 *The Lever of Riches: Technical Creativity and Economic Progress*. Oxford University Press, New York, NY.

Moore, Frank

1862 *The Rebellion Record: A Diary of American Events, Volume III*. G.P. Putnam, New York, NY.

Moriarty, E.O.

1873 "Report on the Subject of Docks Generally, Bearing Upon the Proposal of the Government to Construct a New First Class Dock at Cockatoo Island." *Journal of the Legislative Council of New South Wales, Session 1873-4*. 23(1):715-734.

Morris, Michael H., Donald F. Kuratko, Jeffrey G. Covin

2008 *Corporate Entrepreneurship and Innovation*. Thomas Higher Education, Mason OH.

Muckelroy, Keith

1978 *Maritime Archaeology*. Cambridge University Press, London, England, UK.

Museum Catalogue

1889 *Catalogue of Ship Models and Marine Engineering in the South Kensington Museum*. Eyre and Spottiswoode, London, England, UK.

National Parks Service

2011 Salem Marine Society Certificate. < www.nps.gov/sama/historyculture/certificate.htm>

Navy Department

1892 *Coaling, Docking, and Repairing Facilities of the Ports of the World, With an Analysis of Different Kinds of Coal*. Government Printing Office, Washington, DC.

Navy League of the United States

1912 *John Fitch: The First in the World's History to Invent and Apply Steam Propulsion of Vessels through Water*. Navy League of the United States, Admiral Bunce Section No. 42. R. S. Peck and Company, Hartford, CT.

New South Wales Legislative Council

1874 "Docks. Report from the Engineer-in-Chief for Harbours and Rivers." *Journal of the Legislative Council of New South Wales, Session 1873-4* 23(1):715-738.

New York Times

1902 "Havana Dock Useless." *The New York Times* 19 September.

Nippon Kaiji Kyokai

2011 Repair Dockyard List. Nippon Kaiji Kyokai Classification Society, Tokyo, Japan. <http://www.classnk.or.jp/hp/directory/DockData/index_en.aspx>.

Office of Naval Intelligence

1909 *Coaling, Docking and Repairing Facilities of the Ports of the World*. Government Printing Office, Washington, DC.

Ogburn, William F.

1926 "The Great Man versus Social Forces." *Social Forces*, 5(2):225-231.

Oppenheim, Michael

1896a *A History of the Administration of the Royal Navy*. John Lane the Bodley Head, London, England, UK.

1896b *Naval Accounts and Inventories of the Reign of Henry VII*. Navy Records Society, London, England, UK.

Pelletier, James L.

1998 *Worldwide Ship and Boat Repair Facilities*. Marine Techniques, Inc., Augusta, ME.

People's Daily Online

2006 World's Largest Floating Dock Starts Operation in NE China.

<http://english.peopledaily.com.cn/200605/11/eng20060511_264707.html>

Pepys, Samuel

1666 *The Diary of Samuel Pepys*. Cassell & Company, Limited, New York, NY.

Pollock, David H.

1905 *The Shipbuilding Industry*. Methuen and Company, London, England, UK.

Preston Digital Archive

2011 T. W. Wards Gridiron, Diversion Quay, Preston Dock c. 1920. <www.flickr.com/photos/rpsmithbarney/5116608732/>.

Rennie, George B.

1869 "On the Iron Floating Dock of Carthage, Its Proportions and Relative Stability." *Transaction of the Institution of Naval Architects, Volume X*. Printed by the Office, London, England, UK.

1884 *Papers and Discussions on Engines, Boilers, and Torpedo Boats*. Naval Professional Papers No. 16:213-219, Washington, DC.

Rennie, George B., J. R. Baterden, Cecil H. Peabody, C. Colson, and A. C. Cunningham

1906 "The Naval Floating Dock—Its Advantages, Design and Construction." *Proceedings of the American Society of Civil Engineers* 32(6):1025-1038.

Robertson, Henry

1897 "New Dry Dock at Hamburg." *Consular Reports*, 54(200):386-389.

- Rodger, N. A. M.
1998 *The Safeguard of the Sea: A Naval History of Britain 660-1649*. HarperCollins, New York, NY.
- Rogers, Everett M.
1995 *Diffusion of Innovations*. The Free Press, New York, NY.
- Rosenberg, Nathan
1972 "Factors Affecting the Diffusion of Technology." *Explorations in Economic History*, 10(1):3-33
1974 "Invention and Economic Growth." *The Economic Journal*, 84(333):90-108.
1976 "On Technological Expectations." *The Economic Journal*, 86(343):523-535.
1982 *Inside the Black Box: Technology and Economics*. Cambridge University Press, Cambridge, UK.
- Russell, Bertrand
1921 *The Practice and Theory of Bolshevism*. George Allen & Unwin LTD, London, England, UK.
- Ruttan, Vernon W.
1959 "Usher and Shumpeter on Invention, Innovation, and Technological Change." *The Quarterly Journal of Economics*, 73(4):596-606.
- Rutter, Jeremy
2008 *Lesson 18: The Nature and Extent of Neopalatial Minoan Influence in the Aegean and Eastern Mediterranean Worlds*.
<<http://projectsx.dartmouth.edu/classics/history/bronzeage/lessons/les/18.html>>.
- Sacramento Daily Union*
1860 Additional By Pony Express. *Sacramento Daily Union* 7 December, 20(3000):1. Sacramento, CA.
- Salzer, J. Richard
1986 "Factors in the Selection of Drydocking Systems for Shipyards." *Journal Of Ship Production* 2(2):110-119.
- Sarder, M. D. B., Ahad Ali, Susan Ferreira, Mohammad A. Rahman
2010 "Managing Material Flow at the US Shipbuilding Industry." *Proceedings of the 2010 International Conference on Industrial Engineering and Operations Management, Dhaka, Bangladesh, January 9-10, 2010*.
- Sarton, George
1946 "Floating Docks in the Sixteenth Century." *Isis* 36(3):153-154.
- Schumpeter, Joseph A.
2004 *The Theory of Economic Development*. Harvard University Press, Cambridge, MA.

Schuyler, Eugene

1890 *Peter the Great, Emperor of Russia: A Study of Historical Biography, Volume I*. Charles Scribner's Sons, New York, NY.

Science News Letter

1946 "Floating Drydocks Used in Combat Zones." *The Science News-Letter*, 49(16):245.

Scott, Nora E

1942 "Egyptian Cubit Rods." *The Metropolitan Museum of Art Bulletin* 1(1):70-75.

Sears, Joshua M. Jr.

1904 "Oeniadae: VI. The Ship-Sheds." *American Journal of Archaeology* 8(2):227-237.

Secretary of War

1893 *Annual Report of the Secretary of War for the Year 1893*. Government Printing Office, Washington, DC.

Seielstad, B. G.

1937 "Monster Seagoing Dry Docks Keep our Navy in Shape." *Popular Science* 130(2):42-43.

Select Committee on Dockyards

1864 "First Report from the Select Committee on Dockyards; Together with the Proceedings of the Committee, Minutes of Evidence, and Appendix." *Chain Cables and Anchors Bill; Dockyards; Public Accounts; Thames Conservancy Bill; Weighing of Grain (Port of London) Bill*. Printed for the House of Commons, London, England, UK.

Smith, Joseph

1848 "Miscellaneous Document No. 71." *Miscellaneous Documents Printed By Order of The House Of Representatives During the First Session of the Thirtieth Congress 2 December 1847*. Tippin & Streeper, Washington, DC.

Smith, William (Ed.)

1863 "Iron Floating Dock, Sourabaya, Java." *The Artizan*, 1(8):185.

1868 "Floating Docks and other Arrangements for Affording Access to Ships for External Repairs." *The Artizan*, 2(4):98-101.

Standfield, John

1882 "On Floating Docks—The Depositing Dock and the Double-Power Dock." *Society of Engineers: Transactions for 1881*. E. & F. N. Spon, New York, NY.

1889 *Floating Dock*. Patent #412,992, United States Patent Office, Alexandria, VA.

Staples, A. F.

1922 "World's First Floating Dock Was Built Under Peter the Great." *The Nautical Gazette*, 102(21):647.

Staples, Sydney F.

1898 "Floating Docks." *Cassiers Magazine*, 13(4):337-353.

Stenholm, Leifh

2008 "The Naval Town of Karlskrona, Sweden—Changes in Continuity in a Living World Heritage." ICOMOS 16th General Assembly and International Scientific Symposium, Quebec, Canada.

Stuart, Charles Beebe

1852 *The Naval Dry Docks of the United States, Part Two*. C. B. Norton, London, England, UK.

Supplement

1886 *Supplement to Encyclopedia Britannica, Volume III*. J. M. Stoddart, New York, NY. pp. 293-294.

Swan, Hunter, & Wigham Richardson, Limited

1903 *Ship, Engine, and Floating Dock Builders and Repairers*. Swan, Hunter, & Wigham Richardson s.d., Wallsend and Walker on Tyne, England, UK.

Talbot, Frederick A.

1906 "The Importance of Floating Docks." *The World's Work and Plan: An Illustrated Magazine of National Efficiency and Social Progress*, 8(47):474-484.

Thatcher, K. C.

1978 "Floating Docks—Developments and Modern Trends." *Lloyd's Register Technical Association*, Paper No. 4.

The Illustrated London News

1869 *The Illustrated London News*. 3 July 1869, pp. 21.

Thiesen, William H.

2006 *Industrializing American Shipbuilding*. University of Florida Press, Gainesville, FL.

Thirtle, Colin G. and Vernon W. Ruttan

1987 *The Role of Demand and Supply in the Generation and Diffusion of Technical Change*. Hardwood Academic Publishers, Chur, Switzerland.

Thomas, John

1837 *Floating Dry Dock*. Patent #522, United States Patent Office, Alexandria, VA.

Thomas, William

1840 *Floating Dock*. Patent #1609. United States Patent Office, Alexandria, VA.

Toppan, Andrew C.

2002 *Bath Iron Works*. Arcadia Publishing, Portsmouth, NH.

Trevithick, Richard

1810 "Inventions by Mr. R. Trevithick, Relative to Nautical Affairs." *The Belfast Monthly Magazine*, 4(18):52-55.

Unger, Richard W.

1980 *The Ship in the Medieval Economy 600-1600*. Croom Helm, London, England, UK.

United States House of Representatives

1936 *Navy Department Appropriation Bill for 1937: Hearing Before Subcommittee of House Committee on Appropriations, Seventy-Fourth Congress, Second Session*. Government Printing Office, Washington, DC.

1937 *Navy Department Appropriation Bill for 1938: Hearings Before the Subcommittee of the Committee on Appropriations, Seventy-Fifth Congress, First Session*. Government Printing Office, Washington, DC.

United States Government

1827 *Acts Passed at the Second Session of the Nineteenth Congress of the United States*. Printed by Peter Force, Washington, DC.

United States National Archives

1784 *Records of the Bureau of Yards and Docks*. Record Group 71.1-71.6, Washington D.C.

United States Naval Historical Center

1907 U. S. Naval Historical Center Photograph #: NH 50360. Washington Navy Yard, Washington, D.C.

United States Navy Department

1849 *Sketch of the Plans, Present Condition, and Proposed Results of the United States Dry Docks, At the Navy Yards of Philadelphia, Kittery, and Pensacola; Upon the New System of Floating Docks, Basin & Railways*. P. Miller & Son, New York, NY.

United States Senate

1843 *Public Documents Printed By Order of the Senate of the United States, First Session of the Twenty-Eighth Congress, Begun and Held at the City of Washington, December 4, 1843, in the Sixty-Eighth Year of the Independence of the United States*. Printed by Gales and Seaton, Washington, DC.

1847 "Executive Document Number 11." *Executive Documents Printed By Order of the Senate of the United States During the First Session of the Thirteenth Congress, Begun and Held at the City of Washington, December 6, 1847*. 3(1):1-152.

1898 "Statements Before the Committee on Naval Affairs, United States Senate, Tuesday and Saturday, 22 March and 26 March, 1898, on the Amendment Relative to the Docking of Vessels of the Navy, Intended to be Proposed by Senator Platt, of New York, to the Naval Appropriation Bill." *United States Congressional Serial Set, 1898*:3-81.

- Urquhart, G. D.
1869 *Dues and Charges on Shipping in Foreign Ports; a Manual of Reference for the use of Shipowners, Shipbrokers, and Shipmasters*. Blunt and Co, New York, NY.
- Usher, Abbott Payson
1954 *A History of Mechanical Invention*. Harvard University Press, Cambridge, MA.
- van Loon, Hendrik Willem
1989 *Ships and How they Sailed the Seven Seas*. Tynron Press, London, England UK.
- Walsh, E. S.
1896 *Construction of Dry Docks*. Patent #561,458, United States Patent Office, Alexandria, VA.
- Warburton, J.W.
1894 "Report on the Trade and Commerce of the Consular District of Valparaiso for the Year 1894." *Diplomatic and Consular Reports, Annual Series Issues 1486-1540*. 1516(1):1-37.
- Wasalaski, Robert G.
1991 "U. S. Navy Uses Heavy Lift Ships." *Naval Engineers Journal* 103(6):71-72.
- Webb, Thomas
2001 *A Brief History of the Floating Dry Dock Dewey*. Thomas Webb, NP.
- Western Australian Museum
2011 Shipwreck Databases, Western Australia Museum. <www.museum.wa.gov.au/maritime-archaeology-db/>.
- White, Arnold and E. Hallam Moorhouse
1905 *Nelson and the Twentieth Century*. Cassell and Co. LTD, London, England, UK.
- White, Norval, Elliot Willensky, Fran Leadon
2010 *AIA Guide to New York City*. Oxford University Press, New York, NY.
- White, Trumbull (editor.)
1902 *Our Wonderful World*. NP.
- Wijnolst, N
1995 *Design Innovation in Shipping*. Delft University Press, Delft, Netherlands.
- Wilkinson, Henry C.
1973 *Bermuda from Sail to Steam, Vol. II*. Oxford University Press, London, England, UK.
- Williams, Archibald
1904 *The Romance of Modern Engineering*. J.B. Lippincott Company, London, England, UK.

Woolsey, Theodore

1876 *The First Century of the Republic: A Review of American Progress*. Harper & Brothers
Publishing, New York, NY.