Preface

Rationale for This Work

The genesis of this work was a conversation I had with my then-girlfriend (now my wife), Mirna, in the summer of 1987 while on a drive in the countryside. Having recently finished my master’s degree in naval architecture at University College London (where British naval constructors are educated), and back to work designing ships for the U.S. navy, I remarked to her that we naval architects use many theorems and formulas named for people we know nothing about. We learn that the Froude number, used in scaling models for towing-tank tests, was devised by the British civil engineer William Froude, who in the 1870s developed the basic theories used today to predict ship powering. But he is almost the only person known to us. In particular, I pointed out that naval architects frequently use “Bonjean curves” to quickly determine displacement and center of buoyancy at any draft. But who was Bonjean? The only reference to him is a short statement in the standard textbook Principles of Naval Architecture: “The diagram of Bonjean curves was first proposed at the beginning of the nineteenth century by Bonjean, a French naval engineer.”

As I discovered 15 years later, Antoine Nicolas François Bonjean was a midlevel French naval constructor who served his country during the Napoleonic Wars, built a few ships, had one publication to his name, and retired at a very early age due to illness. He was born in Paris in 1778 and became a student engineer in 1794, during the height of the French Revolution, first as a civil engineer and then in the navy. He became a constructor in the French Corps of Maritime Engineering in 1798, serving his first years on a frigate fighting against the British in Egypt, later helping investigate Egyptian antiquities. He returned to France in 1801 after Napoleon’s defeat at Alexandria, and worked in various dockyards around the country on the construction of several frigates and bomb vessels. In 1808, while he was at Lorient, he wrote and subsequently had published Nouvelles Échelles de déplacement (New Scales of
Displacement), which described the “Bonjean curves,” perhaps his only legacy. In 1813 he was sent to help Frankfurt, still an ally of Napoleon, build a flotilla for the Rhine River, but suffered terribly from “famine” and an unnamed disease, and returned to France. In 1815 he was given special dispensation to retire at age 37 due to illness. There is no record of any family, and his dossier ends in 1822.

I began with the idea of writing about unknown people such as Bonjean. The idea evolved into writing about the major developments in ships, but I soon discovered that the field was vast, including several well-researched areas in marine archaeology and naval history. Later, while working on exchange at the French Directorate of Naval Construction, (DCN), I discovered that the application of theory to ship design was still largely unexplored, even in France, where most of the early developments began. I decided to pursue my Ph.D. dissertation on that subject at the University of London’s Imperial College. I completed it in 2004, and it forms the basis for this work. In fact, this book has been 20 years in the making.

Although naval and maritime history has always included a study of ships as well as personnel, strategy, and tactics, it is only since the 1970s that a handful of naval and maritime historians around the globe have taken a critical look at the fundamental matters of ship design and construction, as well as the infrastructure of shipyards, laboratories, and personnel that supports them. However, the role of scientific theory in the development of ships is very rarely examined. During my discussions with historians around the world, I came to realize there are very few critical works on historical aspects of naval architecture in any language; the few that there are, tend to be very specific to a particular subject; and almost no major work of naval architecture has been critically evaluated.

This is not true of many other engineering disciplines. For example, the field of aeronautics is the grist for the mill for Walter Vincenti, who uses it to demonstrate how engineers work day-to-day in his book What Engineers Know and How They Know It: Analytical Studies from Aeronautical History. Hunter Rouse and Simon Ince’s History of Hydraulics provides a comprehensive, critical history of the subject and gives some context for its scientific and technological development. By contrast, there has never been, to my knowledge, a synthesis of the history of naval architecture in any language that critically evaluates the reasons for its development and application, and takes into account the exchange of ideas between individuals of different nations.

Very well: I will write the first.

I have aimed this first comprehensive work at three separate but related audiences: science and technology historians, as an analysis of a previously overlooked facet in the development of rational mechanics; naval and maritime historians, as a crucial
part of the evolution of ships; and naval architects, to help them better understand how their profession came to be. My hope is that this book will inspire further research in the history of naval architecture by a mixture of these three groups. I am aware that my book will, to some extent, shape the ideas and research for some time to come. I accept—and expect—that this further research may call into question my own assumptions and overturn many of my analyses. This work will have succeeded if it becomes the standard reference in five years’ time. It will have failed if it continues to be the standard reference thirty-five years hence.

Structure of This Work

This is the first part of a two-part project describing the history of naval architecture from its beginnings until today. This first work, which is quite self-contained, covers the birth of naval architecture within the Scientific Revolution, which the science historian Alfred Rupert Hall nominally dated as lasting from 1500 to 1800. However, I set the beginning of my subject at about 1600, when the works of the Dutch engineer Simon Stevin and the French philosopher Blaise Pascal first expanded on Archimedes’ fundamental theorems, which then became integrated into rational mechanics and began to play a role in the study of naval architecture. Similarly, I have chosen 1800 as a natural end point for this work, marked both by the French Revolution and the Napoleonic Wars that stifled much government-sponsored scientific research, and by the short-lived British Society for the Improvement of Naval Architecture, which heralded the development and use of ship theory by independent engineers. The second work in this project, tentatively titled *Bridging the Seas: The Development of Naval Architecture in the Industrial Age, 1800–2000*, will pick up the story at that point, and will include certain themes that had begun in the period of the first book (e.g., research into structures and strength, as well as mechanical propulsion) that were not fully developed until the advent of iron and steam.

My objective in this work is to tell the story of how and why naval architecture—, i.e., the implementation of ship theory in design—was originally developed and subsequently used by constructors. This story has many threads. For a start, much of the development of ship theory was carried out under the auspices of the navies, which were the first to make use of it in ship design and construction. However, the men who developed ship theory were the same ones who expanded integral and differential calculus and solved the problems of planetary orbits, tides, vibrating strings, and ballistics; ship theory was for them part of the overall study of rational mechanics. Several navies—the French navy in particular—worked closely with their scientific
establishments to encourage such research, which they believed would lead to improvements in the construction and navigation of its ships. That knowledge had to be disseminated to both a Europe-wide scientific audience, as well as to an increasingly literate officers corps, through an evolving web of science journals, academy memoirs, and books. Finally, a new system of professionalization—education, training, and career structure for naval constructors—had to be created almost from scratch, in order that this new knowledge of ship theory could be methodically applied to ship design and construction.

The central thread in this complex fabric is the writing and publication of *Traité du navire* (Treatise of the Ship) in 1746 by Pierre Bouguer, who is also the central figure here. Bouguer and his book are emblematic of the sometimes surprising nature of this story. Bouguer was a French mathematician and astronomer, not a constructor, with no experience in building ships. He wrote *Traité du navire*, the first true synthesis of naval architecture, while on the ten-year Geodesic Mission in the Peruvian Andes to measure the figure of the Earth. The book contained no practical instructions for how to build a ship, but explained for the first time how to predict the characteristics and performance of the ship before it was built. It pulled together the previous lines of investigation into a coherent whole, thus becoming the single most important source of fundamental ship theory for over a century. One concept in particular—the metacentre as a measure of ship stability—is used to this day.

Given the complexity of the story of naval architecture, I have structured this work so that the contextual elements are woven into the chapters rather than being set apart. This preface provides a rationale and explanation for the work as a whole. The prologue and epilogue tell the story of Bouguer and the writing of *Traité du navire*, to set the stage for the rest of the work. Chapter 1 serves as an overall introduction, establishing the underlying thesis that naval architecture was developed and implemented in response to a bureaucratic need by naval administrations for greater control over their constructors, rather than as a means of optimizing the engineering of ships. The chapter then describes the changing naval and maritime situation in Europe and explains how it provided the catalyst for the development and acceptance of naval architecture as part of ship design.

The three major elements of ship theory that were formulated during this time occupy the central chapters in this book. In roughly chronological order, they were maneuvering and sail theory (chapter 2, which also describes the dissemination of scientific knowledge); ship resistance and hydrodynamics (chapter 3, also explaining rational mechanics); and stability theory (chapter 4, which also looks at hazards of the sea and the development of tunnage rules). Chapter 5 explores the books that had
the greatest impact on the development of naval architecture during this era. Finally, chapter 6 describes the process of professionalization of naval constructors that was the true legacy of this period. The end of chapter 6 provides the general conclusion to this work, describing the leap of naval architecture from French scientists in the burned-out Scientific Revolution, across the English Channel to the British engineers working at the dawn of the Industrial Age.

This account is told from the points of view of both the constructor and the naval administrator, in order to describe not only the developments of ship theory but also how that theory was perceived and used by ship constructors and, perhaps most important, why naval administrators encouraged and financed its development. It looks at the development not only across 2 centuries but also across the navies and nations of Europe, since the flow of ideas and people across borders was continuous even in times of conflict. Indeed, the separation of ship theory development and construction practices by nation is often artificial, as there were strong and continuous links between scientists and constructors of all nations.8

**Previous Histories of Naval Architecture**

Although I state that this is the first critical synthesis of the history of naval architecture, I do not mean that no such history has ever been written. However, none of them has attempted to cover the entire range of topics, and to place them into social, political, and strategic contexts. Some histories have been spectacularly wrong. An 1860 paper on the state of naval architecture confounded the name of a particularly important individual, the Spanish constructor Jorge Juan y Santacilia, with his naturalist colleague Antonio de Ulloa, to arrive at the very un-Spanish name Juan d’Ulloa, a mistake perpetuated through a number of books that touch on naval architecture history.9

Historical accounts of the development of naval architecture began soon after the field was born. Jorge Juan y Santacilia, in the preface to his 1771 work *Examen marítimo* (Maritime Examination), thoughtfully provided a long discourse on its history until that time.10 In 1791, the German translation of Duhamel du Monceau’s *Elémens de l’architecture navale* (Elements of Naval Architecture) included a long bibliography of works on the subject.11 The magisterial *Histoire des mathématiques* (History of Mathematics) by Jean Etienne Montucla, which covered such topics as the development of geometry and the calculus, included a surprisingly large section on the history of maneuvering and construction of ships as part of the range of applied mathematics.12 All these works were simply summaries of events or publications
which, though immeasurably aiding historical researchers, provided little or no critical analysis.

In 1800, the first book alluding to the history of naval architecture, *A History of Marine Architecture*, was printed in Britain by John Charnock. However, it was primarily a standard naval and maritime history, mostly of Britain. Its use of the term “marine architecture” was limited to the earliest ideas of a ship being simply a work of architecture, so it described many ships and their characteristics but did not mention any developments in ship theory. A small improvement was made in 1851 by the naval constructor John Fincham in *A History of Naval Architecture*, which though another straight naval history (mostly of Britain), was at least prefaced by a 75-page “Introductory Dissertation on the Application of Mathematical Science to the Art of Naval Construction,” and did in fact give some critical analysis of various works.

Finally, the truly magnificent (for a naval architect) four-volume textbook *Architecture navale: Théorie du navire* (Naval Architecture: Ship Theory), written in 1890 by the French naval constructors Jules Pollard and Auguste Dudebout, started with a long bibliography of works on naval architecture going back to the 1600s, with helpful commentaries on each.

Most historical works of the early-to-mid-twentieth century in this field were concerned with technology, such as the development of steam propulsion or the introduction of iron, and treated developments in naval architecture only as an aside, with limited and often inaccurate information. This began to change in the middle of the century. In 1958, the British ship surveyor William (“Fred”) Stoot delivered a paper titled “Some Aspects of Naval Architecture in the Eighteenth Century” before a combined session of the British Institution of Naval Architects and its French counterpart, the Association Technique Maritime et Aéronautique (Maritime and Aeronautical Technical Association). Combined with its follow-on paper, “Ideas and Personalities in the Development of Naval Architecture,” Stoot provided some of the first analyses of the history of naval architecture that gave it political and scientific context, and went a long way to dispelling some of the misinformation surrounding it. Stoot’s papers remain an essential source of historical insight into the subject.

Interest in the subject has been growing since that time, slowly but steadily. In 1979 the German constructor Gerhard Timmermann published a synthesis of the historical developments in geometrical modeling, stability, resistance, and maneuvering from the 1600s until the twentieth century, *Die Suche nach der günstigsten Schiffsform* (The Search for the Most Favorable Ship Form). A short book (only 176 pages), it is more of a flying survey than a critical analysis, and remains difficult to find outside Germany. In 1980, Alfred Rupert Hall delivered a lecture to the Newcomen Society,
titled “Architectura Navalis,” that was perhaps the first critical (albeit very brief) overview of the subject by a noted science historian. Since 1990, studies by individuals such as Horst Nowacki and Julián Símón Calero, extensively referenced in this work, have greatly added to the state of knowledge of the subject. In short, the historical interest in the development of naval architecture is starting to grow.

What Is Naval Architecture?

In order to write this history, my first task was to define exactly what is meant by the term “naval architecture.” Quite by coincidence, in 1999 the Royal Institution of Naval Architects (RINA) invited members and nonmembers to suggest suitable definitions of “naval architecture” or “naval architect.” Their responses were published in the pamphlet RINA Affairs and excerpts were posted to the RINA Web site. Many of the responses concentrated on who naval architects were (“shipwrights with attitude!” said one), or what naval architecture consisted of (“combines imagination, artistic instincts, and proven scientific principles, tempered by basic engineering considerations, in designing the means of ocean transportation”), but few explained exactly what naval architecture is.

Standard definitions are unhelpful. For example, the Random House Dictionary defines it as “the science of designing ships and other waterborne craft”; Webster’s Unabridged Dictionary simply says “the art of building ships.” My French and Spanish dictionaries give similar definitions. For my purposes, these definitions are far too expansive—they would include all aspects of conceptualization, design, and fabrication, and would cover the range from log rafts to ocean liners. So I began reading primary sources in order to trace the evolution of the term.

The first known use and definition of the term “naval architecture” was made around 1610 by the Portuguese mathematician and engineer João Baptista Lavanha in his unpublished treatise “Livro primeiro de arquitectura naval” (First Book of Naval Architecture): “Naval Architecture is that which with certain rules teaches the building of ships, in which one can navigate well and conveniently.” Lavanha consciously used the well-known architectural text De architectura libri decem (Ten Books on Architecture), by the Roman architect Marcus Vitruvius Pollio, to outline his theories, thus placing naval architecture as one of the disciplines of architecture. Since the manuscript was made public only in the twentieth century, it is not clear how widely it was circulated at the time, nor whether Lavanha’s definition was well known. However, the same idea was behind the first published use of the term, in Architectura Navalis (Naval Architecture), written in 1629 by the German architect Joseph Furttenbach as
part of a six-volume series on architecture that included military, civilian, and recreational architecture. Furtenbach never defined the term, which may indicate that it was already in some widespread use. His writings show that he saw ship design as simply a subset of the range of architecture types. Thus, the first definitions for “naval architecture” really meant “an architecture of the sea.”

But architecture has always had a mathematical basis, especially in terms of proportions, so it became commonplace to link mathematics to naval architecture. In 1579 the British mathematician Thomas Digges promised to write (but never did) a “briefe Treatise of Architecture Nauticall,” which would contain rules and patterns to follow. In 1646 the British expatriate constructor Robert Dudley, living in Florence, wrote that “Architecture Nautical” was concerned with seven types of geometrical symmetry. And in 1677, *L’Architecture navale* (Naval Architecture), by the French constructor Charles Dassié, argued that mathematics had previously been applied to civil and military architecture, but not to naval architecture. He attempted to do so by defining the proportions (e.g., length to beam) to be given to ships with different numbers of guns.

The term “naval architecture” came into widespread use in most European languages during the 1700s, by then denoting the application of geometry to ship design; for example, one of the early (1776) French textbooks for students was titled *Essai géométrique et pratique sur l’architecture navale* (Geometrical and Practical Essay on Naval Architecture).

It was during this time that theories of mechanics (e.g., hydrostatics, fluid dynamics, etc.) were being developed and applied to ships. Ship theory thus became linked to naval architecture, a point made clear in *A History of Naval Architecture* (1851), which spoke of naval architecture as a “science of Ship-building,” including laws of resistance of fluids and motions of ships at sea. The 1890 French textbook *Architecture navale: Théorie du navire* (Naval Architecture: Ship Theory) noted that naval architecture included the mechanics of floating bodies, which was developed in “successive steps by Science.” So by the turn of the twentieth century, the term “naval architecture” contained the notion of science as an integral part of the definition.

At this point I found it necessary to turn to a related but more complex set of questions: What is science? What is technology? What is engineering? How are they connected? Science is usually associated with experimentation, technology generally involves making and using tools to achieve a purpose, and engineering somehow links the two. Once again, standard definitions are unhelpful—especially the ones stating that technology is “applied science.” Historians of science and technology often expand these definitions to include extensive cultural explorations of the professions,
which are too detailed for my use and don’t help me set the boundaries of the subject. I note that technology has frequently (perhaps most often) been developed without any recourse to scientific theory—witness, for example, the development of the steam engine by the British inventors Thomas Newcomen and James Watt in the 1700s, well before a useful theory of thermodynamics was published in 1822 by the French engineer Sadi Carnot.

But the application of scientific theory to technology is the critical element in my search for a definition of naval architecture, and is most frequently associated with the definition of engineering. Whether through the use of fundamental mathematical theory (e.g., Carnot’s laws) or empirically derived data (e.g., steam tables which give experimental values for heat), engineering is aimed at prediction—the ability to determine the characteristics and performance of a system before it is built—and is part of the process of creating a technology. It is through such prediction that a technology can be optimized or improved without a complete reliance on trial and error (construct, test, and change). In other words, engineering is sandwiched within the process of creating a technology, somewhere between formulating the concept and building the thing itself. So for my purposes, a useful set of definitions is the following:

**Technology**  The creation of tools or artifacts to achieve a specific purpose.

**Science**  Theoretical explanation of physical phenomena, through the use of fundamental mathematics or empirically derived data.

**Engineering**  The application of scientific theory to the process of creating technology, with the purpose of predicting the characteristics and performance of a technology before it is built.

This brings me to a final set of personal observations before venturing into a definition of naval architecture. Ship design, like any engineering effort, does not begin with scientific principles, but rather with “rules of thumb.” As a naval architect for the U.S. navy, I would begin my design of, say, a destroyer or frigate, using basic rule-of-thumb proportions for length, displacement, and so on. For example, I would set the hull length-to-depth ratio (L/D) at about 10–15; more than 15 generally produces high stresses and makes the hull too flexible (e.g., for accurate weapons alignment), while under 10 means that the structure is not working efficiently, i.e., the minimum thickness for local loadings governs, so the hull steel is thicker (therefore heavier) than is needed for longitudinal strength. The ideal balance is a hull steel thickness that adequately meets both local loads and hull girder loads. This process was not different from the rules of thumb that ship constructors used in the eighteenth century, before
any notion of ship theory was developed. They all understood, even if they could not articulate it in mathematical terms, that if the L/D ratio was too large—if the ship was too long for its depth—there would be cracking and splitting in the frames and planking. The difference between the constructors of three centuries ago and today is that the constructor today takes the additional step of using ship theory to calculate (in this case) the hull stresses, to determine if the structure is feasible and efficient. In other words, naval architecture allows the constructor to predict a ship’s characteristics—in this case providing a rational basis for confirming or modifying the constructor’s design decisions. Modern ship design begins by using the kinds of rules of thumb known to the most ancient boatbuilders—but science and engineering “inform” the constructor throughout the design and construction process, allowing him or her to predict the characteristics and performance of the ship before fabrication even begins. This concept places naval architecture as an engineering discipline, sandwiched between concept and fabrication in the process of ship design and construction. Which brings me to my definitions:

*Ship design and construction* The technology of creating the ship, from conception to fabrication.

*Ship theory* The science explaining the physical behavior of a ship, through the use of fundamental mathematics or empirically derived data.

*Naval architecture* The branch of engineering concerned with the application of ship theory within the design and construction process, with the purpose of predicting the characteristics and performance of the ship before it is built.

These definitions broadly correspond to the division of knowledge in two standard reference works published by the U.S. Society of Naval Architects and Marine Engineers: *Ship Design and Construction*, which contains practical information on laying out and building a ship but makes almost no reference to theory, and *Principles of Naval Architecture*, which is completely theoretical. I emphasize that these definitions are solely for my purposes in putting some boundaries on this work.

**Some Notes on Usage**

*Royal navies* Many navies were royal, not just the British navy, so I refer to them by nation.

*Shipyard and dockyard* Shipyard is the generic term; it could be as simple as a slipway for construction. I use dockyard to denote the more complex industrial facilities, generally with drydocks for repair.
Constructors I use the word “constructor” to denote the men who designed and built ships, regardless of the era. In each nation, the terms evolved over time and carried different meanings; in English, for example, the term “shipwright” encompassed a wide range of professions—not only hull design and construction but also mastmaking and building oars, blocks, and small boats. In French, the early title charpentier meant “carpenter,” the same as furniture maker, but later the terms “constructor” and “engineer” were used. In Danish, the terms skeppskonstruktör and fabrikmester meant “shipbuilder” and “master fabricator.” The Venetian word proti normally meant “shipwright,” but later the term architetto (architect) came into use. For my purposes, the single term “constructor” avoids confusion among all these titles and, more important, dispenses with the connotations that each one brings.

Formation I use the term “formation” to describe the combination of education, both elementary and more advanced, and on-the-job training. It is a French word that has no current equivalent in English, but should.

Names and titles As a rule I use the birth names of individuals (e.g., Johann instead of Jean Bernoulli, or Giulio Mazzarini instead of Jules Mazarin), though in some cases I will provide the other name in parentheses, especially if it was more common. Many of the important people in this work were landed gentry, and it was common practice to refer to them by the title of the estate they owned; for example, Jean-Frédéric Philippe Phélypeaux, count of Maurepas, was usually called Maurepas even though his family name was Phélypeaux. I note here that although most Spanish authorities refer to the constructor Jorge Juan y Santacilia as simply Jorge Juan, I use his entire surname to be consistent within this book.

Translations I include the English-language translation of most works at least once per chapter for easier reference; all are translated in the bibliography. I use the English-language names for institutions and places wherever possible.

Ships I refer to warships by the number of guns and not “rates,” as the designation of rates according to firepower (first rate = 100 – 120 guns, etc.) varied between nations. I refer to ships as “it” instead of “she,” conforming to the practice of the influential maritime newspaper Lloyd’s List as of 20 March 2002.