SHAPING THE VICTORIAN NAVY

Experiment, experience and the culture of expertise in naval architecture

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Submitted for the degree of doctor of philosophy
2009

I have determined to make an end of all flesh, for the earth is filled with violence through them. Behold, I will destroy them with the earth. Make yourself an ark of gopher wood. Make rooms in the ark, and cover it inside and out with pitch. This is how you are to make it: the length of the ark 300 cubits, its breadth 50 cubits, and its height 30 cubits. Make a roof for the ark, and finish it to a cubit above, and set the door of the ark in its side. Make it with lower, second, and third decks.

Genesis, 6:13-17.

[W]hereas the material with which ships were built, the manner in which their parts were combined, and the means by which they were propelled had remained unchanged from the beginning of human experience down almost to our own day, the ship has of late years been transformed in every one of these great particulars.

Edward Reed, 'On the value of technical education to the shipwright and shipowner, 25 November 1886', in [The Worshipful Company of Shipwrights] (ed.), The Worshipful Company of Shipwrights lectures (London, 1886-87), pp. 3-28, esp. 3-4.

Experience, divine instructress of the soul,
Whose grasp doth close around the unwilling wrist,
The while thy finger points, thine Hours unroll
The changing scenes that break through Sorrow's mist.

The mind, enforced to judgment, bares the past
Of golden hues, divests the verse of sound
That o'er its vacant phrase such sweetness cast,
And where an Eden shone, but sand is found.

'Experience', Chambers's Journal, 99 (1865), p. 736.

Acknowledgements

This thesis owes an immense personal and scholarly debt to my supervisor Crosbie Smith, who introduced me to the cultural history of science and technology on an undergraduate course on the 'Tools of Empire' and a subsequent stint as a researcher on the AHRC 'Ocean Steam Ship' project. These experiences fuelled my interest in the subject and enriched my views on history. A year of early modern history at Cambridge gave me time to reflect on how I thought about history and what I wanted to research. Since the start of my doctoral work in 2006 I have further profited from Crosbie Smith's generous support, intellectual curiosity and constructive engagement with my ideas. I also owe a debt to Stefan Goebel, my supporting supervisor, for keeping me 'Victorian' and challenging my history of science tendencies. I also thank Ben Marsden, Graeme Gooday, Richard Dunn, Laurie Ferreiro, Charlotte Sleigh, Jon Wills, Karen Jones, Mike Brown, Joe Street, Tim Bowman, Tim Keward, Jackie Waller, Emma Long, James Baker, Joel Halcomb and various other colleagues at the University of Kent and friends for their interest and input. Lastly I thank my family and Elaine Wood for keeping me imaginative.

This thesis has profited from the help and advice of archivists and librarians at the Templeman Library, Canterbury; Canterbury Cathedral Archives; National Maritime Museum, Greenwich; the National Archives, Kew; the British Library Manuscripts and Rare Book reading rooms; the Institution of Mechanical Engineers; the Science Museum, London and Swindon; the Manuscript, Rare Rooks and Official Publications reading rooms of the University of Cambridge; Churchill College, Cambridge; St. Johns College

Cambridge; the Rare Book and Manuscript Reading Room at Bristol University; the Borthwick Institute, University of York; the manuscript reading room at the National Archives of Scotland; Glasgow University Archive Services; Glasgow University manuscripts reading room; Scottish National Maritime Museum at Dumbarton; and the Library of Congress, Washington DC. I wish to thank Mary Lou Reker, Carolyn Brown and the many library specialists and scholars at the John W. Kluge Center at the Library of Congress for making my stay as a Kluge Fellow both welcoming and stimulating. I thank the Kluge fellows for their comments on an early draft of the introduction which I presented during my stay. I also thank the audiences of two papers presented to the University of Kent's History Research Seminar for their valuable feedback. I also value the comments and criticisms offered by conference audiences at the British Society of the History of Science, History of Science Society, Society for the History of Technology and British Association for Victorian Studies annual conferences over the past three years.

Finally I acknowledge the valuable support of a number of organisations. I am grateful for the initial support of a Maurice Crosland Scholarship at the Centre for the History of Science, Technology and Medicine, University of Kent and a Colyer-Fergusson Research Grant, University of Kent. The Arts and Humanities Research Council also funded this work through a Doctoral scheme scholarship and a Kluge Fellowship (in collaboration with the Economic and Social Research Council) at the Library of Congress.[1]

[1] Doctoral scheme award 2007/135185 and Kluge Fellowship award LOC57.

Abstract

The Victorian navy was not the closed community of aristocrats and sailors that historians tend to suggest. Nor was the Victorian ship a readymade object of naval power. Instead, the Victorian navy was shaped by artisans as well as aristocrats, scientists as well as sailors, and a cast of actors from parliament and the press to law and literature. The interactions between these groups of actors demonstrate that the ship did not belong to a small section of naval history but rather touches on important themes in the history of science and technology and Victorian cultural history at large.

This thesis argues that Victorian ships were shaped by the concerns, curiosities and controversies of the various actors who surrounded the ship. As such the ship becomes a lens to examine issues regarding 'expertise', 'mechanics', 'power' and 'science'. This thesis traces a series of controversies through which men of science, engineers and naval architects wrestled with sailors and politicians as the ship was taken from the realm of seamanship to science. This process altered the ship in ways that were not possible without the simultaneous reordering of control and expertise within the naval community. This thesis offers a co-production framework to examine the decline of wood sail ships and the rise of iron steam ships; the weakened authority of professional sailors and the strengthened authority of engineers; and the fall of aristocratic control and the ascendency of scientific expertise in the British navy.

Part I of the thesis (Experience and expertise in a Victorian institution) places naval architecture and the issue of expertise in a series of political, institutional and social contexts. Chapter 1 explores the structure and culture of decision making in the Admiralty, using pamphlets, periodicals and press reports to examine how

contemporaries understood craftwork, science and material change in the Royal Navy. I specifically trace the contribution of naval architects in these debates, paying attention to the cultural authority that underpinned their arguments. These various discourses demonstrate the connections in Victorian society between administration, expertise and science – three constituent elements of the politics of naval supremacy. I conclude the chapter by examining the establishment of the Institution of Naval Architects (INA) as an expert community and the mechanisms they used to simultaneously promote their authority and mark the boundaries of their expertise.

Chapter 2 further develops the identity and function of craftwork and 'rules of thumb' within the matrix of working knowledge that prevailed in Admiralty dockyards and the wider shipbuilding community. My analysis draws on scholarship in the history of science that emphasises 'production', 'practice' and 'mind/hand' dynamics in order to examine the tensions between craft, art, theory and science. Instead of focusing exclusively on the perspectives of scientists and engineers I describe the discourse that existed between them and the administrators, politicians and naval officers who were largely unsympathetic to 'theory', and administered the educational system that naval architects and engineers sought to reform. Using parliamentary debates, papers delivered to the INA and documents describing pedagogical approaches to naval architecture I explore how INA members made a space for, and educated, scientific experts within a craft culture.

Part II of the thesis (Experiment and the science of naval architecture) focuses on the cultures of experiment and science in Victorian naval architecture. I examine the ideas and working practices of a group of naval architects, engineers, men of science, mathematicians and naval officers that I identity as a coherent social network. Chapter 3 uses the private papers and published works of James Robert Napier, W.J. Macquorn

Rankine, John Scott Russell and William Froude to describe the nature of 'experiment' and demonstrate how knowledge of (and trust in) hydrodynamics was housed within a network of individual's reputations, social dynamics, institutions, local concerns and object meanings.

Experiments in naval architecture were conceived in an array of cultural and intellectual contexts. Chapter 4 specifically focuses on Froude's contributions as both a member of a social network of naval architects and as a Victorian influenced by the culture of intellectual and religious doubt. I explore Froude's lengthy correspondence with John Newman, leader of the Oxford Movement and convert to Roman Catholicism, to emphasise the connections between scientific method and Victorian culture. I then turn to a series of debates between Froude and members of the INA to demonstrate how themes of 'doubt' and 'certainty' informed Froude's approach to hydrodynamics.

Chapter 5 concludes my analysis of the culture of experiment and suggests that British naval architects sought to reconfigure the ship as an object of science, specifically in relation to the trends within Victorian science toward model experiments, mechanical science and precision measurement. I trace the culture in which Froude's test tank took shape, broadening my analysis from chapter 4 by examining discussions in the INA, the scientific community and the British Admiralty. The chapter begins with an examination of the socio-cultural politics of the Admiralty's decision to fund Froude's test tank and model experiments, shedding further light on the culture of Admiralty decision making. The chapter concludes with a discussion of craft and science, drawing in issues discussed in chapter 2 to examine the mind/hand dynamics at work in Froude's experimental practices.

Part III of the thesis (Experiment, experience and expertise in the navy) returns to the broader perspectives discussed in Part I to explore how the skills possessed by naval architects were understood and promoted in the Victorian naval community and governmental machinery. Chapter 6 follows members of the British social network of naval architects through their disputes with naval officers and administrators over the use of science in making ships. I specifically pay attention to the discourses of naval officers in pamphlets, Victorian periodicals and the press to examine the authority of the sailor as ship designer and expert of ship behaviour. Through a discussion of how sailors understood 'science' I locate the controversies surrounding H.M.S. *Captain* and H.M.S. *Devastation* within a dispute over expertise.

Chapter 7 draws my discussion of the culture of expertise to a close. I explore how naval architects and officers understood and expressed these changes, paying particular attention to the functions of experiment and experience, the nature of mechanical power and the establishment of a class of scientific managers within the Admiralty shipyards. I emphasise how these processes took place in relations to the decline in the authority of naval officers and their skills to judge ship behaviour, the transition in the shipbuilding industry from a craft orientated practice to a mechanical one, and the changing nature of Victorian expertise.

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Abbreviations

BAAS	British Association for the Advancement of Science.
BJHS	British Journal for the History of Science.
Correspondence	*Cardinal Newman and William Froude, F.R.S.: A Correspondence*, ed. G.H. Harper (Baltimore, 1933).
INA	Institution of Naval Architects.
Letters	*The Letters and Diaries of John Henry Newman*, ed. I. Ker & T. Gornall (32 vols., Oxford, 1979).
Reports	*Reports of British Association for the Advancement of Science.*
RSNA	Royal School of Naval Architecture.
RUSI	Royal United Service Institution.
RUSI Journal	*Journal of the Royal United Service Institution.*
Transactions	*Transactions of the Institution of Naval Architects.*

Prologue

What did H.M.S. *Captain* take with it to the bottom?

7 Wednesday [September]: This sad catastrophe is a most dreadful affair. 509 officers and crew launched into eternity.

Admiral Alexander Milne records the loss of the H.M.S. Captain in his diary.[2]

As soon as I got inside the turret I felt the ship heel over deeper and deeper, and a heavy sea strike her on the weather side, the water flowing into the turret as I got through the pointing hole. On emerging from the turret I found myself overboard; the last I saw of the ship was her prow; the time from capsizing until she sank was from five to ten minutes.

One of the eighteen survivors of the Captain describes his experience of the capsizing.[3]

When the committee presided over by Lord Dufferin was appointed by the Lords Commissioners of the Admiralty to examine the designs upon which ships of war have recently been constructed, the point on which the public were most anxious to be satisfied was whether our ironclad ships were safe against such disasters as had just before overwhelmed the Captain. This was a scientific problem of the highest order, with which few men could deal, but fortunately the scientific was by far the strongest side of the committee, which comprised the names of Sir William Thomson, Dr. Woolley, Professor Rankine, and Mr. Froude.

Engineering observes that the loss of the Captain represented a serious scientific question.[4]

On 17 August 1870, a squadron of ships, including H.M.S. *Captain*, a newly launched experimental turret ship, H.M.S. *Monarch*, the Royal Navy's first turret ship, and H.M.S. *Warrior*, the navy's first ironclad, arrived off the west coast of Spain to join the Channel and Mediterranean squadrons under the command of Admiral Alexander Milne, Admiral Sir Hasting Yelverton and Rear-Admiral Henry Chads. Sometime after midnight 7 September, the *Captain*, cruising off Cape Finisterre, disappeared from view. The ship had experienced heavy gales and capsized, taking over five-hundred officers and men to the bottom, including Cowper Phipps Coles, ship's designer, Hugh Burgoyne, the captain, Admiral Sir Baldwin Walker's (Controller of the Navy) son-in-law and Hugh Childers

[2] Alexander Milne's Diary, 7 September 1870, London, National Maritime Museum (NMM), Milne papers 175/13.
[3] 'Loss of Her Majesty's Ship Captain', *The Times*, 14 September 1870, p. 9.
[4] 'Naval Architect – No. XI: The development of the science of naval architecture from the 1860 to the present time', *Engineering*, 17 May 1872, p. 323.

(First Lord of the Admiralty) and the Earl of Northbrook's (secretary of war) sons. In the wake of the tragedy memorials to the ship and crew were unveiled in St. Paul's cathedral and Westminster Abbey.

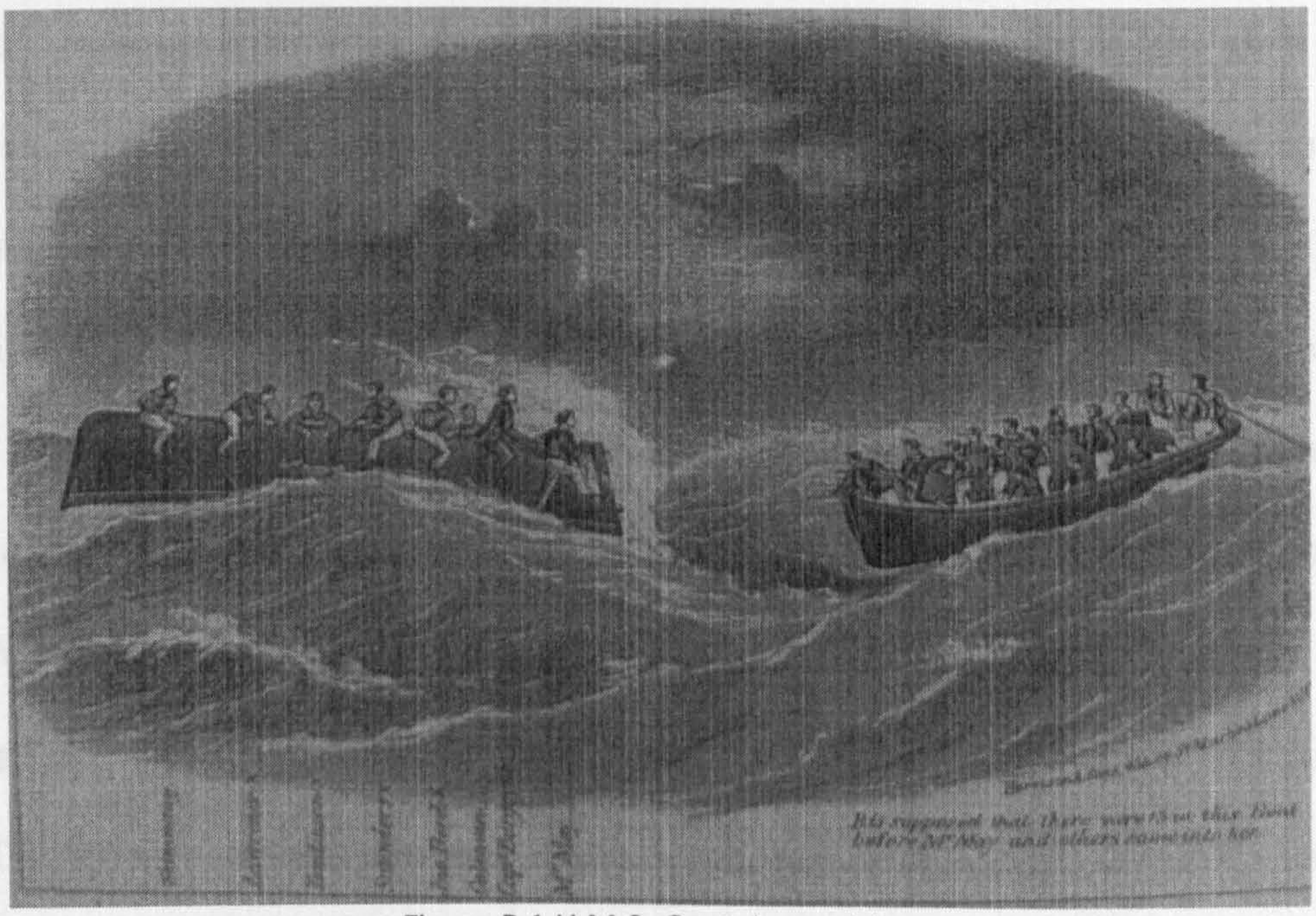

Figure P.1 H.M.S. *Captain* capsizing

On 13 September, in a frenzy of press coverage, *The Times* printed a letter written by a midshipman who had witnessed the Captain's final cruise from H.M.S. *Lord Warden*.

> [I]t began to blow very strongly from the south-west... As it was the first heavy gale of wind she had been in, and being such a peculiarly constructed ship, great fears were entertained for her safety ... We continued to look for her until about 4 in the evening, when we picked up one of her yards ... So I am afraid the Captain went down on the morning of the 7th, with all hands on board – nearly 600 men and officers ... Captain Burgoyne, the captain of her, was liked much by every one who had sailed with him. It will be a great shock to the confidence of the public in turret vessels.[5]

A court-martial concluded that the ship's design was seriously flawed. The combination of a large canvass of sail and low freeboard (height of the lowest deck above the water-line) meant that the ship would likely capsize in heavy wind. News of the loss and investigations into its cause spread like wildfire in Victorian Britain, engulfing the bureaucratic Admiralty that commissioned the vessel, the naval officers who supported

[5] 'Her Majesty's Ship Captain', *The Times*, 13 September 1870, p. 3.

her construction and the professional naval architects who cautioned against the ship's design.

The loss of the *Captain* did not simply shake public confidence in Admiralty experiments with turret ships but became a focal point and source of fuel for a range of controversies concerning the value of experiment, experience and the culture of expertise in the Royal Navy. These controversies criss-crossed the traditionally closed aristocratic world of the Victorian Admiralty, the craftwork culture that pervaded Britain's dockyards and the credibility of a network of naval architects, engineers, men of science and mathematicians who sought to make science a tool that could guaranteed naval power.

The *Captain* was designed by Coles, a naval officer and the inventor of a gun turret system. Coles had used his influence in the Royal Navy and a series of public disputes in *The Times* and *Standard* regarding the turret system designed for the *Monarch* by Edward Reed (Chief Constructor of the Navy), to pressure the Board of Admiralty into authorising him to design his own ship. Coles' design was intended to combine both the destructive powers that U.S.S. *Monitor* and C.S.S. *Virginia* had demonstrated during the United States Civil War and the ocean-going performance expected of a fully-rigged Royal Navy ship deployed to guard the British Empire. In 1869, the *Captain* was launched from Laird's shipbuilding yard at Birkenhead and impressed the captains and admirals who oversaw its subsequent trial. Naval historians have dismissed the *Captain*'s loss as a result of its controversial conception, design and trials.[6] I argue that the *Captain* was actually a product of the socio-cultural nexus of naval authority and craft-production that prevailed in the Victorian Royal Navy. The Victorian Admiralty depended on public trust, and as such many of its ships were conceived, like the

[6] John Beeler, *Birth of the battleship: British capital ship design 1870-1881* (Chatham, 2001); Andrew Lambert, *Battleships in transition: the creation of a steam battle fleet* (Chatham, 1984).

Captain, in parliament and the press. Moreover, the Admiralty's decision to give a naval officer full control over the design was not unusual, nor was it rare for officers to dictate ship design to the craftsmen who served in Britain's H.M. and commercial shipyards.

What makes the loss of the *Captain* a significant event in naval history, and, I argue, more importantly Victorian history and the history of science and technology, is the nexus of social networks, cultural authority, institutional power and expertise that surrounded the ship, shaping both its identity and the identity of those who made ships. The peculiar shape of the *Captain* (a fully rigged iron turret ship with a low freeboard) was emblematic of the dramatic material changes that had begun with the launch of the *Warrior*, Britain's first ironclad ship of the line, and the complex web of object representations of power, popular understandings of iron and mechanics and the social reconfiguration of the British sailor that material changes induced. The decision to empower Coles to design the *Captain* sheds light on the culture of authority and expertise in Victorian Britain, demonstrating popular perceptions of mechanical art and the belief that practical knowledge and experience made successful ships. The *Captain*'s successful trial further reveals the culture in which ship behaviour was understood through visual observation and tacit experience (rather than the emerging trends for precision measurement and mechanical objectivity).

The loss of the *Captain* was surrounded by a complicated web of social relations, cultural associations, political dimensions and technical questions regarding who was trusted to design, build and test a safe, efficient and powerful ship. Within this question of *who*, was the matter of *what* skills and knowledge were equated with safety, efficiency and power. This thesis uses these questions to follow a group of naval architects – scientifically orientated ship designers – who sought to take the ship into the domain of science, experiment and mechanical expertise. The growth of this group's authority took place through a series of public controversies, institutional and social re-orderings of knowledge and power, and depended on the ability of social networks (be they naval officers, craftsmen or naval architects) to demonstrate their expertise to shape the Victorian Royal Navy in the image of the values they thought appropriate. Events like the loss of the *Captain* were thus focal points with the power to wreak more destruction than the immediate loss of material and life.

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Introduction
What shapes a ship?

a Ship of the Line is the most honourable thing that man, as a gregarious animal, has ever produced. By himself, unhelped, he can do better things than ships of the line; he can make poems and pictures, and other such concentrations of what is best in him. But as a being living in flocks, and hammering out, with alternate strokes and mutual agreement, what is necessary for him in those flocks, to get or produce, the ship of the line is his first work. Into that he has put as much of his human patience, common sense, forethought, experimental philosophy, self-control, habits of order and obedience, thoroughly wrought handwork, defiance of brute elements, careless courage, careful patriotism, and calm expectation of the judgment of God, as can well be put into a space of 300 feet long by 80 broad.

John Ruskin suggests some 'cultures' that shape the ship.[1]

In reviewing the history of the British navy through the greater part of the last century, we see much sound, practical knowledge, generally marking the conduct of the surveyors of the navy, in forming their designs. And the character which their ships bore, in long and arduous duties, makes the names of their several constructors to be respected in the English naval service. Apart from mathematical reasoning and investigation, to which they did not pretend, they carefully compared the various facts of experience, and cautiously and judiciously drew their conclusions. On the other hand, mathematicians have laboured in the investigation of causes but they have generally reasoned on hypotheses insisted on facts; and hence, there is scarcely a formula on any part of this science that can be applied and depended on for accurate results.

John Fincham, master shipwright of Her Majesty's dockyard Portsmouth draws the lines between craftsmen and mathematicians.[2]

Of all the nineteenth century 'technologies', the ship is most suited to being deployed in an historical narrative as a camera-obscura of Victorian attitudes, practices and ideas toward the cultures of science, engineering, craft and technical expertise. John Ruskin's elegant précis of the qualities embodied in the British warship provides the ideal point from which to consider how the ship was historically understood within social, cultural and epistemological systems, be they scientific, craft-based, political or naval. Following a broadly cultural constructivist approach, this thesis traces how actors developed some of the cultures Ruskin identified around the Victorian ship of the Royal Navy.[3] The ship

[1] John Ruskin, *The harbours of England* (1856) in E.T. Cook & Alexander Wedderburn (eds.), *The works of John Ruskin* (39 volumes, London, 1904), 13:1-76, esp. 28.

[2] John Fincham, *A history of naval architecture: to which is prefixed, as introductory dissertation on the application of mathematical science to the art of naval construction* (London, 1851), p. 252.

[3] For constructivism in the history of science and technology see Jan Golinski, *Making natural knowledge: constructivism and the history of science* (Chicago, 2005); Donald Mackenzie & Judy Wajcman, 'Introductory essay: the social shaping of technology', in MacKenzie & Wajcman (eds.), *The social shaping of technology* (Buckingham, 1985, 2nd edt. 1999), pp. 3-28.

is employed as a window to both 'look in' at how actors performed and negotiated discourses and practices of experiment and experience, and 'look out' at how these discourses shaped the ship and established the identity of technical 'expertise' outside the scientific and engineering community.

My approach to these issues has been shaped by two historiographic concerns regarding the history of science and Victorian Britain. James Secord has argued that the greatest problem facing the history of science and technology is that its methodological identity drawn from studying the local and the construction of knowledge alienates the wider historical profession. As Secord astutely observed, '[t]he process of situating knowledge ends up as a conclusion rather than a method', and historians of science become dependent on other historians to 'take account of our work in general studies.'[4] Historians of science need to know what lies beyond the boundaries of their chosen science and community of investigators. In a similar way, Victorian historiography regarding the increasingly entangled relationships between scientific research, technological change and military enterprise has adopted a restricted perspective on the role of scientific and engineering 'experts'. Specifically, historians have made assumptions about the significance of those 'experts' within the early period of British modernity without scrutinising their skills or the reasons for their authority.[5] This thesis aims to respond to these two issues by following the ship through a series of contexts to provide a fresh perspective on the culture of naval supremacy and new

For a critical discussion of constructivism and its relativist philosophical underpinning see Thomas Gieryn, 'Relativist/constructivist programmes in the sociology of science: redundance and retreat', *Social Studies of Science*, 12 (May, 1982), pp. 279-297; Peter Burke, *History and social theory* (Cambridge, 2005), pp. 116-122

[4] James Secord, 'Knowledge in transit', *Isis*, 95 (2004), pp. 654-672, esp. 659.

[5] David Edgerton, *Science, technology and the British industrial 'decline'* (Cambridge, 1996); S.J.D. Green & R.C. Whiting, 'Introduction: the shifting boundaries of the state in modern Britain', in Green & Whiting, *The boundaries of the state in modern Britain* (Cambridge, 1996), pp. 1-14, esp. 3-5; R. Angus Buchanan, *The engineers: a history of the engineering profession in Britain* (London, 1989); W.H.G. Armytage, *Rise of the technocrats: a social history* (London, 1965). Contrast with Merritt Roe Smith's valuable contribution to these questions in the United States, see Merritt Roe Smith (ed.), *Military enterprise and technological change: perspectives on the American experience* (Cambridge, MA., 1985).

insights into the matrix of knowledge, skills and expertise in which the Victorian public sphere trusted to secure their peace and prosperity.[6]

TRACING SCIENCE, TECHNOLOGY AND CRAFT-PRACTICE IN VICTORIAN BRITAIN

Ruskin's Royal Navy ship of the 1850s was made of wood, propelled by sails and designed by artisans who privileged experience and craftwork as ways of making knowledge and objects. Ships in 1880, in contrast, were clad or made of iron (later steel), propelled by reciprocating engines (although built with masts) and designed by a group of institutionalised experts with recourse to a range of scientific experiments and measurements. These material changes in the ship are known to naval historians as the 'ship revolution', a monolithic shift in the shape and identity of the ship.[7] But like all 'revolutions' something more interesting and complex had taken place.[8] This 'revolution' provides the leading edge for this study to examine the relationship between science, craft, technology and Victorian values. The ship, arguably one of the most symbolic objects in Victorian culture, literally navigated between these fields of production and representation.[9]

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[6] For growing literature on the Royal Navy's significance place in Victorian culture, society and politics see Mary Conley, *From Jack Tar to Union Jack: representing naval manhood in the British Empire* (Manchester, 2009); Jan Rüger, *The great naval game: Britain and Germany in the age of empire* (Cambridge, 2007); Margarette Lincoln, *Representing the Royal Navy: British sea power, 1750-1815* (Aldershot, 2002); Muriel Chamberlain, *'Pax Britannica'? British foreign policy, 1789-1914* (London, 1988).

[7] John Beeler, *British naval policy in the Gladstone-Disraeli era* (Stanford, 1997); Andrew Lambert, *Battleships in transition: the creation of a steam battle fleet* (Chatham, 1984); David K. Brown, *Warrior to Dreadnought: warship development, 1860-1905* (Chatham, 1997); Nicholas Rodger, *The command of the ocean* (London, 2004), pp. 408-425.

[8] I am thinking here specifically of Steven Shapin's examination of the 'scientific revolution' that denies a monolithic revolution in favour of situating ideas and asking questions regarding epistemological issues and human practices. Steven Shapin, *The scientific revolution* (Chicago, 1996), pp. 4-5. Contrast this cultural and social constructivist perspective of knowledge, authority and practice with the uneasy appropriation of Kuhnian paradigm shifts in William M. McBride, *Technological change and the United States navy, 1865-1945* (Baltimore, 2000), esp. pp. 5-6, 38-63. Also see Thomas Kuhn, *The structure of scientific revolutions* (Chicago, 1962, 2nd edt. 1996).

[9] For a cultural treatment of objects see Ken Alder, 'Focus: thick things. Introduction', *Isis*, 98 (2007), pp. 80-83; Lorraine Daston (ed.), *Things that talk: object lessons from art and science* (New York, 2004).

Victorian naval architecture was not a cohesive discipline in early-Victorian Britain. It spanned craft traditions and associations with the scientific revolution. The Oxford-educated mathematician William Froude, together with a number of scientifically inclined ship designers, believed that craftsmen watched their newly launched ships 'with as anxious and uncertain an eye as if she were an animal he had bred ... not a work which he had himself completed, and whose performance he could predict'.[10] A social network of British naval architects, including Froude, W.J. Macquorn Rankine, James Robert Napier, John Scott Russell, Edward Reed, Nathaniel Barnaby and William White, worked to change the practices with which ship designers guaranteed the behaviour, efficiency, safety and power of their designs. This was specifically the case with Froude's test tank, an experimental project that enabled the naval architect to take the ship into the domain of science by testing the affects of various alterations to ship form on models without the cost and risk of full scale shipbuilding experiments.

Shipwrights and craftsmen trained through apprenticeship schemes in the mechanical arts advocated an alternative approach to ship design.[11] Charles Lamport, a north England shipbuilder, believed 'the practical designer who takes data determined by such experiments [*i.e.* test tank experiments] as his guide builds upon hollow ground'.[12] Lamport, influenced by utilitarian philosophy and a Unitarian moral economy, believed that the ship designer's job was to produce efficient ships based not on scientific enquiry and experiment but on economics and experience.[13] The contributions of 'practical designers' to naval architecture have been marginalised in

[10] [Anon.], 'William Froude', *Nature*, 12 June, 1879, pp. 148-150, esp. 148.
[11] For a sympathetic but technologically deterministic account of craft and practical shipbuilding see William Thiesen, *Industrializing American shipbuilding: the transformation of ship design and construction, 1820-1920* (Gainesville, 2006). For a more engaging study see David McGee, 'From craftsmanship to draftsmanship: naval architecture and the three traditions of early modern design', *Technology and Culture*, 40 (1999), pp. 209-236.
[12] Charles Lamport, 'The problem of a ship's form, as presented to the practical builder', *Transactions*, 6 (1865), pp. 101-115, esp. 103.
[13] Crosbie Smith, Ian Higginson & Phillip Wolstenholme, '"Avoiding equally extravagance and parismony": the moral economy of the ocean steamship', *Technology & Culture*, 44 (2003), pp. 443-69, esp. 444-50.

past scholarship - reflecting the general trends in the historiography of Victorian science and technology that have obscured the role of craftsmen.[14] Craft-practice was an system of knowledge and material production in Victorian Britain, both as an oppositional category to science and as a vital part of scientific practice.[15] Emphasising craft thus sheds a new light on historiographical debates concerning theory and practice, and pure and applied science.[16] Naval historians have similarly marginalised the authority of craft, largely because their treatment of technology has been to emphasise what might be deemed 'modern', 'progressive' or even 'revolutionary' in Victorian ship design.[17] Thus they have tended not to examine the numerous controversies in which naval officers, administrators and constructors disagreed over the types of expertise that could guarantee naval supremacy.

This thesis responds to the above observations and demonstrates that experience in working practices, relationships between art, mechanics and science, and ways of knowing that were far from being what we might consider 'scientific' continued to have a significant influence in debates concerning scientific expertise and technological change.[18] This theme is even clearer when the naval dimension of technological change

[14] See for example David K. Brown, *The way of a ship in the midst of the sea: the life and work of William Froude* (Penzance, 2006); Tom Wright, 'Ship hydrodynamics, 1710-1880' (Ph.D. thesis, Science Museum, London/University of Manchester Institute of Science and Technology, 1983); Stanley Sandler, *The emergence of the modern capital ship* (Newark, 1979); George Emmerson, *John Scott Russell: a great Victorian engineer and naval architect* (London, 1977).

[15] For studies that touch on Victorian craft see Lissa Roberts, Simon Schaffer & Peter Dear (eds.), *The mindful hand: inquiry and invention from the late Renaissance to early industrialization* (Amsterdam, 2007); John V. Pickstone, *Ways of knowing: a new history of science, technology and medicine* (Manchester, 2000). Also see Pamela H. Smith, *The body of the artisan: art and experience in the scientific revolution* (Chicago, 2004).

[16] For theory and practice see David F. Channell, 'The harmony of theory and practice: the engineering science of W.J.M. Rankine', *Technology and Culture*, 23 (1982), pp. 39-52. For pure and applied science see Ronald Kline, 'Construing "technology" as "applied science": public rhetoric of scientists and engineers in the United States, 1880-1945', *Isis*, 86 (1995), pp. 194-221. For the traditional disciplinary divisions between the histories of science and technology see John M. Staudenmaier, *Technology's storytellers: reweaving the human fabric* (Cambridge, MA, 1985).

[17] John Beeler, *Birth of the battleship: British capital ship design 1870-1881* (Chatham, 2001); Matthew Allen, 'The deployment of untried technology: British naval tactics in the ironclad era', *War in History*, 15 (2008), 269-293; Andrew Lambert, *Warrior: the world's first ironclad then and now* (Annapolis, 1987), pp. 9-26; Jon Tetsumo Sumida, *In defence of naval supremacy: finance, technology and British naval policy, 1889-1914* (Boston, 1989).

[18] This contrasts the trend within previous scholarship that emphasises a monolithic notion of 'professionalization' as scientism, see James Pritchard, 'From shipwright to naval constructor: the professionalization of 18th century French naval shipbuilders', *Technology and Culture*, 28 (1987), pp. 1-25; Sidney Pollard & Paul Robertson, *The British shipbuilding industry, 1870-1914* (Cambridge, MA, 1979), pp. 130-50; Randolph Cook, 'Scientific servicemen in the Royal Navy and the

is considered. The reaction of naval officers following the loss of H.M.S. *Captain*, described in the prologue, reveals the culture of control within the navy and the perceived threat of treating ships as objects of science. In public lectures, open letters in newspapers and privately published essays, senior naval officers defended the honour and character of their fellow sailor Cowper Coles from the attacks of men of science and 'theorists' who had no experience of seamanship, and fought bitterly to maintain their perceived control over the work of naval architects.

The continuation of craft-practice and the authority of naval officers in British science and technology reflect a broader dimension of 'modernity' in Victorian Britain, namely the active negotiation of past, present and future.[19] Ships of the line, together with the Bluecoats and Jack Tars who operated them, were culturally entrenched icons of British power, manliness and empire.[20] Thus the ship provides an opportunity to explore the culture of technological change during the shift from craft orientated systems of making, knowing and social order to mechanical systems.[21] The emergence of 'mechanical expertise' specifically provides a vehicle to explore the rise of scientific naval architecture, the reconfiguration of craft orientated systems of production and the decline of traditional gentlemanly authority in Victorian Britain.[22]

Ruskin saw no end of human qualities, values and skills in the ships that defended the British Empire and carried out commercial activity around the globe. The Victorian ship was inherently 'Victorian' in how it was built, understood and deployed within the

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professionalization of science, 1816-1855', in David M. Knight & Matthew Eddy (eds.), *Science and belief: From natural philosophy to natural science, 1700-1900* (Aldershot, 2005), pp. 95-111.

[19] Martin Daunton & Bernhard Rieger, 'Introduction', in Daunton & Rieger (eds.), *Meanings of modernity: Britain from the late-Victorian era to World War II* (Oxford, 2001), pp. 1-21, esp. 3-5.

[20] Christopher Harvie, *Floating commonwealth: politics, culture and technology on Britain's Atlantic coast, 1860-1930* (Oxford, 2008); Rüger, *Great Naval Game*. For the authority of tradition see Eric Hobsbawm & Terence Ranger (eds.), *The invention of tradition* (Cambridge, 1992).

[21] Peter Mathias, *The transformation of England in the eighteenth-century* (London, 1979), pp. 21-72.

[22] David Cannadine, *The decline & fall of the British aristocracy* (London 1990); Harold Perkin, *The rise of professional society: England since 1800* (London, 1989). For seamanship and masculinity see Quentin Colville, 'Jack Tar and the gentleman officer: the role of uniform in shaping the class and gender-related identities of British naval personnel, 1930-1939', *Transactions of the Royal Historical Society*, 13 (2002), pp. 105-129.

naval community. I develop this point throughout this study by utilising a co-production framework to show how '[s]olutions to the problem of knowledge', and arguably technology too, 'are solutions to the problem of social order.'[23] A co-production approach develops the connections between ideas and order through which knowledge is made and understood, and helps us to understand how identities, institutions and representations were made.[24] Take, for example, the word 'technology', the popular usage of which is very much a concept belonging to the age of 'modernity'.[25] Victorian sailors, scientists, aristocrats and administrators had no understanding of the values we take from the word or the regimes of truth and trust through which modern technocratic societies operate.[26] To throw 'technology' into the nineteenth century is to disfigure the dynamics between craft-practices, machines and social politics in Victorian culture that can be traced through a co-production approach.[27]

A co-production approach can also be used to conceptualise a culture of 'technological change'. Co-production highlights 'the often invisible role of knowledge, expertise, technical practices and material objects in shaping, sustaining, subverting or transforming relations of authority.'[28] For example, the introduction of measurement, mechanics and scientific standards in the ship (see part III of the thesis) were not

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[23] Steven Shapin & Simon Schaffer, *Leviathan and the air-pump: Hobbes, Boyle, and the experimental life* (Princeton, 1985), p. 332.

[24] Sheila Jasanoff, 'Ordering knowledge, ordering society', in Sheila Jasanoff (ed.), *States of knowledge: the co-production of science and social order* (London, 2005), pp. 13-45.

[25] Bernhard Rieger, *Technology and the culture of modernity in Britain and Germany, 1890-1945* (Cambridge, 2005).

[26] See the following informative discussions of pure/applied science and technology Ronald Kline, 'Forman's lament', *History and Technology*, 23 (2007), pp. 160-166; Chunglin Kwa, 'Shifts in dominance of scientific styles: from modernity to postmodernity', *History and Technology*, 23 (2007), pp. 166-176. Also see Thomas P. Hughes, *Human-built world: how to think about technology and culture* (Chicago, 2004); Eric Schatzberg, '*Technik* comes to America: changing meanings of *technology* before 1930', *Technology and Culture*, 47 (2006), pp. 486-512.

[27] To address the conceptual difficulties in negotiating the often retrospective use of words like 'science', 'technology' and 'engineering' I have found it useful to promote actors categories such as 'mechanics', 'matériel' and 'science' within local settings. For conceptual discussions of actors categories with regards to interpretation and rhetorical conflicts in the history of technology, see Ben Marsden & Crosbie Smith, *Engineering empires: a cultural history of technology in nineteenth-century Britain* (Basingstoke, 2005), pp. ix, 4-5.

[28] Sheila Jasanoff, 'The Idiom of Co-Production', in Sheila Jasanoff, *States of knowledge*, pp. 1-12, esp. 4. For examples of such scholarship see Thomas P. Hughes, *Networks of power: electrification in western society, 1880-1930* (Baltimore, 1983); Bruno Latour, *Science in action: how to follow scientists and engineers through society* (Cambridge, MA, 1987).

understood as a shift towards science but as a reconfiguration of the scope of human agency and the authority of traditional naval control. 'The ship-builder and engineer may, in the course of time', the naval architect Nathaniel Barnaby wrote, 'make life on shipboard so much a matter of routine and mechanism that we shall find only seafarers where we have looked for seamen.'[29] Over the course of the nineteenth century, sailors were engaged less in physical labour and more in machine operations. Naval constructors and officers made the identity of the mechanical ship, while the mechanical ship made the identities of naval constructors and officers. Such an approach develops sophisticated social and cultural insights that contrast with the often simplistic narratives of mechanised warfare.[30]

MECHANICAL EXPERTISE

The era of British modernity, roughly 1880-1920, has been 'identified with the triumphs of science-based expertise'.[31] The supposed triumphs included the foundations of specialised expert dialogues (sometimes at the expense of public dialogues), professionalization and the vital shift from craft to science in key industries, such as the electrification of Britain, organic chemistry and shipbuilding. The terms of these triumphs need closer analysis. Theodore Porter has astutely noted that the 'age of science' in British modernity saw politicians and administrators both pursue a

[29] Nathaniel Barnaby, *Naval development in the century* (London, 1902), pp. 25-6.
[30] For example see Barton C. Hacker, 'Military institutions, weapons, and social change: towards a new history of military technology', *Technology and Culture*, 35 (1994), pp. 768-834; Alex Roland, 'Review essay. Technology and war: the historiographical revolution of the 1980s', *Technology and Culture*, 34 (1993), pp. 117-134; Maurice Pearton, *Diplomacy, war and technology since 1830* (Lawrence, 1984). Contrast with Ken Alder's valuable contribution toward a history of science, technology and war that joins knowledge, skill and social order in a common cultural framework, Ken Alder, *Engineering the revolution: arms and enlightenment in France, 1763-1815* (Princeton, 1997).
[31] Theodore Porter, 'Statistical utopianism in an era of aristocratic efficiency', *Osiris*, 2nd series, 17 (2002), pp. 210-227, esp. 212.

'scientific method' in government and reject the limited wisdom of scientific experts.[32] Meanwhile, the historiography surrounding professionalization portrays expertise 'as a response to the needs of an increasingly complex society', but assigns little significance to educational cultures, professional practices or personal ambitions.[33] In order to unpack these issues for further examination I ask the following questions: what was an expert? Who was an expert? From where did experts gain authority? And how can the process of 'gaining expertise' be examined?

Many histories of modernity, science and technological change that deal with 'expertise' fail to look beyond a select group of university trained scientists and government specialists.[34] That is a limiting way of conceptualising the subject. In the broadest sense, an expert was someone who gained knowledge and skill from experience and was treated by non-experts as authoritative in their specialist subject. The terms 'expert' and 'expertise' both entered common usage in Victorian Britain, and they were linked intrinsically and etymologically with 'experience'. An expert was someone who knew what they were about, but not necessarily schooled in the technical principles of an object or an idea. Indeed, because expertise was rooted in 'experience', it arguably conveyed a sense of wisdom rather than knowledge.[35] In Victorian Britain wisdom was prized above mere facts. Matthew Arnold's culture and teaching pedagogy thought the former while Mr. Gradgrind's oppressive school drilled the latter.[36] Thus it

[32] Ibid., p. 218. Also see Theodore Porter, *Trust in numbers: the pursuit of objectivity in science and public life* (Princeton, 1995).
[33] Perkin, *Professional society*. See the useful critique in Porter, 'Statistical Utopianism', pp. 211-12
[34] Roy MacLeod & E. Kay Andrews, 'Scientific advice in the war at sea, 1915-1917', *Journal of Contemporary History*, 6 (1971), pp. 3-40. David Edgerton's economic and industrial study in *Warfare state* (2006) follows these trends, albeit also with an eye on industrial experts, citing numerous examples from the late-nineteenth-century as part of a pre-history of the post-world war one science-industry-government nexus. See David Edgerton, *Warfare state: Britain, 1920-1970* (Cambridge, 2006), esp. pp. 319-322.
[35] For knowledge, wisdom and science in modernity see Steven Shapin, *The scientific life: a moral history of a late modern vocation* (Chicago, 2008); Lorraine Daston & Peter Galison, *Objectivity* (New York, 2007); Nicholas Maxwell, *From knowledge to wisdom: a revolution for science and the humanities* (Oxford, 1984, 2nd edt., 2007).
[36] Stefan Collini, *Matthew Arnold: a critical portrait* (Oxford, 1994). For science as culture see Paul White, *Thomas Huxley: making the 'man of science'* (Cambridge, 2003), pp. 67-99.

is possible to draw the distinction between the acquisition of wisdom through experience and the acquisition of knowledge through mechanical learning.

In 1833, Frederick Marryat, editor of the *Metropolitan Magazine* and author of numerous naval novels, offered a social reading of expertise with machines.[37] Marryat cast the issue in terms of imagination, making knowledge and the social and moral repute of those who handled machines. In Marryat's account the steam engine, logarithms and spinning jenny were invented by people who had wisdom and experienced situations in which the respective machine might be useful. Marryat explicitly distinguished those individuals from the 'mere mechanics' who built and repaired. 'Every department of science has gained more from those who have not been trammelled by technicalities,' Marryat argued, 'and why? Because they had nothing to unlearn ... they reflected for themselves, respecting but not worshipping authority, and, aided by practice, their theory was crowned with success.'[38] Applying this notion of expertise to the ship, Marryat made the case that captains were experts of naval architecture. '[H]e has time for reflection, opportunity for observation to the utmost extent, and, by long practice and experimental workings, he brings her under that control, which almost verifies Byron's sublime idea, "She walks the waters like a thing of life."'[39] Thus experience with machines was deemed more important to the identity of an 'expert' than technical knowledge of how the machine worked.

Victorian notions of expertise were intrinsically rooted in the process of *critically* applying knowledge to a problem. Such skill was identified with individuals like Watt, Stephenson and Arkwright, who, Marryat believed, were 'practical minds' versed in

[37] F. M[arryat]., 'School of naval architecture', *Metropolitan Magazine*, 8, November 1833, pp. 225-232, esp. 228.
[38] Ibid., p. 228.
[39] Ibid., p. 228.

'mechanical art'.[40] This conception of mechanical expertise reveals much about the social politics of Victorian Britain. Like Thomas Carlyle, Marryat viewed mechanics with a scepticism drawn from evaluating what, in a mechanical society, would remain noble, personal, even human.[41] Marryat also drew a class division between the wisdom and expertise of those who worked with their hands and those who worked with their heads. 'His [the shipbuilder's] tools are in his hands, and he reasons with them more than with his understanding; to a suggestion he answers with his pencil and a calculation ... to conceive originality, would be in him a species of heresy at which he would shudder.'[42]

Marryat's conception of expertise serves as a starting point from which to examine the emergence of an alternative type of expertise that rose out of the scientific and engineering community's growing interest in 'mechanical objectivity'.[43] Men of science like T.H. Huxley increasingly dismissed Marryat's notion of expertise as part of a 'rule of thumb' tradition. In its place they promoted the unique expertise held by trained, skilled experimenters who operated between science and engineering, between discovery and invention.[44] However, few Victorians saw the knowledge acquired through experiments in the same light as knowledge acquired from experience. The distinction rested on how a wider public understood the 'uses of experiment' and the purpose of science in society.[45] In effect, Victorian men of science and engineers had to demonstrate that

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[40] Walter E. Houghton, *The Victorian frame of mind* (New Haven, 1957), p. 113.
[41] For cultural discussions of mechanics and Victorian frameworks of 'knowing' – religious being the most prevalent – see Boyd Hilton, *A mad, bad, & dangerous people? England 1783-1846* (Oxford, 2006), pp. 439-492.
[42] M[arryat., 'School of Naval architecture', p. 228.
[43] Daston & Galison, *Objectivity*, pp. 43, 115-125.
[44] T.H. Huxley, *Science and culture* (London, 1880).
[45] Steven Shapin, 'Social uses of science', in George Rousseau & Roy Porter (ed.), *The ferment of knowledge: studies in the historiography of eighteenth-century science* (Cambridge, 1980), pp. 93-139.

experiments could guarantee meta-issues such as efficiency, national security and progress – or even the ability to help administrators make decisions.[46]

In 1874, Froude, an engineering colleague of I.K. Brunel and gentleman experimenter, advised a royal commission on scientific instruction and the advancement of science that 'there ought to be, certainly, some method in which the highest scientific knowledge of the country can make itself available'.[47] Froude, who rose to prominence in the scientific and engineering communities as a leading authority on hydrodynamics, was intensely concerned that 'the highest scientific knowledge in the country has no direct method of making itself felt; it can only make itself felt at rare intervals, when the Government has incidentally been led to call on it for assistance'.[48] It may be helpful here to draw a comparison between the study of scientific advice and science popularisation, namely that audiences had to be receptive to the messages knowledge holders offered.[49] Regarding this issue, Froude observed that 'scientific advice' was not requested from the scientific community as a 'constituted assemblage' of practitioners but sporadically from 'one or two individuals' with reputation who were familiar to politicians, such as William Thomson, the prominent Glasgow mathematician and physicist.[50]

Such channels for 'scientific advice' suggest that quests for mechanical 'efficiency' were not ultimately determined by the will of scientific and engineering communities but by small, diversely constituted social networks of men of science, engineers,

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[46] Frank M. Turner, *Contesting cultural authority: essays in Victorian intellectual life* (Cambridge, 1993), p. 177.
[47] *Royal commission on scientific instruction and the advancement of science: minutes of evidence, appendices, and analyses of evidence* (London, 1874), ii:147-149, esp. 149.
[48] Ibid., p. 149.
[49] Roger Cooter & Stephen Pumfrey, 'Separate spheres and public places: reflections on the history of science popularization and science in popular culture', *History of Science*, 32 (1994), pp. 237-67.
[50] *Commission on Scientific Instruction*, p. 149. For Thomson see Crosbie Smith & M. Norton Wise, *Energy and empire: a biographical study of Lord Kelvin* (Cambridge, 1989).

politicians, aristocrats and, in this study, naval officers.[51] Thus the processes through which a social group of naval architects and their supporters sought to establish institutional and public channels for the transmission of scientific advice depended on their ability to appeal to wider Victorian concerns regarding naval supremacy, industrial efficiency and trust in engineers. Through these processes, an emerging social network of naval architects developed both the content and the context in which their skills and knowledge could be comprehended by selected audiences.

It is evident, from these introductory observations, that expertise is not monolithic in nature, but contested between groups with specific social, institutional and cultural politics. Historians interested in expertise have increasingly dismissed Frank Turner's classic discussion of professionalization in Victorian Britain, rooted in a binary framework of expertise in which the authority of scientific naturalists grew as the authority of theologians declined.[52] Roger Cooter and Stephen Pumfrey's influential argument in 'Separate spheres and public places' (1994) that reassessed what counted as 'scientific activity' in Victorian Britain has served to expand the range of available actors and interpretative possibility in the history of 'scientific expertise'.[53] Harry Collins & Robert Evans have recently contributed to this debate by further expanding these interpretative possibilities by rejecting the notion of a single class of expertise. The authors astutely observed that matters of expertise were often choices between social groups of specialists, who themselves entered the status of 'expert' through 'socialization into the practices of an expert group'.[54] Collins and Evans get to the crux of historicising expertise – namely that matters of expertise were conflicts between types

[51] This reflects G.R. Searle's analysis of quests for efficiency in late-Victorian Britain, see G.R. Searle, *The quest for national efficiency: a study of British politics and political thought, 1899-1914* (Oxford, 1971).
[52] Turner, *Cultural authority*, p. 175.
[53] Cooter & Pumfrey, 'Separate spheres', p. 252. See for example the discussion of expertise on the periphery of scientific networks in Sarah Dry, 'Safety networks: fishery barometers and the outsourcing of judgement at the early meterological department', *BJHS*, 42 (2008), pp. 35-56, esp. 38-39.
[54] Harry Collins & Robert Evans, *Rethinking expertise* (Chicago, 2007), p. 3.

of authority – but use that position as a basis to explore non-relativistic boundaries between those who know and those who do not.[55]

I suggest an alternative model to both Turner's binary presumption and Collins & Evans' realism idiom. The authority of experts must be found in social relations and publicly built upon a cultural map. Sociologist Thomas Gieryn has argued precisely that the formation of trust and meaning in science is rooted in mediating cultural resources between private and public spaces.[56] Thus the authority of 'experts' also depended on how the metaphors and values that were used to describe their ideas and skills resonated with specific localised audiences.[57] Thus Gieryn's notion of 'cultural cartography' is particularly useful in order to conceptualise how actors established meaning by mapping new expertise on to the landmarks of prior knowledge and the boundaries of cultural authority.[58] A boundary-work analytical model ultimately offers a way of placing engineers, men of science, naval officers and practically-minded politicians in a public space of discourse, institutional entanglement and cultural engagement where 'expertise' was neither logical nor stable, but social and fragile.

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[55] Collins & Evans' claim that only those inside a culture can know the 'science', rejecting the ultimately worth of thick description. The authors instead suggest a 'periodic table of expertises' to examine how non-expert publics might decide between different types of specialist expertise when two social groups of experts pass judgement on the same material or epistemological object. Ibid., p. 127, 1-12.

[56] Thomas Gieryn, *Cultural boundaries of science: credibility on the line* (Chicago, 1999).

[57] For examples which draw from religious, moral and economic culture see Crosbie Smith and Anne Scott, '"Trust in providence": building confidence into the Cunard line of steamers', *Technology and Culture*, 48 (2007), 471-96; Smith *et al*, 'Moral economy of the ocean steamship'; Alison Winter, '"Compasses all awry": the iron ship and the ambiguities of cultural authority in Victorian Britain', *Victorian Studies*, 38 (1994), pp. 69-98.

[58] Gieryn conceptualises 'cultural cartography' as an analytical tool for 'mapping out of epistemic authority, credible methods, reliable facts – with borders and landmarks used to locate in the "culturescape", a space for science, surrounded by less believable or useful terrain.' Gieryn, *Cultural boundaries*, p. 4. Gieryn envisions this tool as a continuation in the sociologist of science's use of anthropological and cultural theory, see Shapin & Schaffer, *Leviathan and the air-pump*; Clifford Geertz, *The interpretation of cultures* (New York, 1973).

PART I

EXPERIENCE AND EXPERTISE IN A VICTORIAN INSTITUTION

[T]he age of chivalry is gone. That of sophisters, economists, and calculators, has succeeded; and the glory of Europe is extinguished for ever. Never, never more shall we behold that generous loyalty to rank and sex, that proud submission, that dignified obedience, that subordination of the heart, which kept alive, even in servitude itself, the spirit of an exalted freedom. The unbought grace of life, the cheap defence of nations, the nurse of manly sentiment and heroic enterprise, is gone! It is gone, that sensibility of principle, that charity of honour, which felt a stain like a wound, which inspired courage whilst it mitigated ferocity, which ennobled whatever it touched, and under which vice itself lost half its evil, by losing all its grossness.

Edmund Burke, Reflections on the revolution in France (London, 1790), p. 113.

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The politics of naval supremacy

It was a fatal mistake of the Conservative Government of Wellington, when it introduced a miserable spirit of economy into our dockyards, grinding the working-people down to a state of degradation and poverty, for the saving of a few pounds to the nation; it was beginning at the wrong end, and in the wrong way. We had at that time the best workmen and the worst "officers" in the world; we have now lost that class of artisans, and the least said about the present superiors the better. Lower and lower have the mechanics been humbled by wretched and culpable policy - morally, physically, numerically, and artistically, have been reduced.

A Victorian periodical laments the state of 'economy' in the dockyard that degraded Britain's 'artisans'.[1]

The Wooden Walls of England of which we used to boast are worse than useless now that iron has supplanted them, for it costs us thousands yearly to let them lie and rot ... [yet] these wooden walls are not so costly to the country as the wooden heads that constitute our Admiralty Board.

Punch places the blame on Admiralty administrators for their handling of matériel change.[2]

On the morning of 1 March 1860, London's newspapers sang the praises of Lord John Russell. The metropolis filled with hope that the parliamentary patriarch of liberalism, and then foreign secretary in Palmerston's 1859 cabinet, would later that day reveal a legislative programme to continue the work begun by the 1832 Reform Bill.[3] *The Morning Chronicle* believed that Russell would ask parliament 'to affirm the proposition, that the time has again arrived for admitting within the doors of the Constitution a large and industrious class at present labouring under the grievance of exclusion.'[4] It was a good time, the article continued, to reignite the reform movement.

> Agitation is silent. The country is rich and prosperous. The people are contented and happy. We are at peace with the world. The two great parties who successively guide the destinies of the Empire are united in principle upon this question, and are even so committed to details as to render any factious opposition impossible.[5]

Later on 1 March, Vice-Admiral Charles Yorke, the Fourth Earl of Hardwicke, made a journey from Westminster to the Royal Society of the Arts, where he spoke to another

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[1] Anon., 'Naval Architecture', *The English Gentleman*, 18 July 1846, p. 10.
[2] 'Naval Reform Bill Wanted', *Punch*, 27 June 1868, p. 277.
[3] K. Theodore Hoppen, *The mid-Victorian generation, 1846-1886* (Oxford, 1998), p. 212.
[4] *Morning Chronicle*, 1 March 1860, p. 4.
[5] *Morning Chronicle*, 1 March 1860, p. 4.

industrious class of individuals who felt excluded from the machinery of government administration and policy: the newly formed Institution of Naval Architects (INA). This assemblage of craftsmen, engineers, shipbuilders, men of science, mathematicians, entrepreneurs, professional sailors and politicians joined a discourse on administration and authority in Victorian government. Professional members of the INA bore a resemblance to parliamentary reformers of the mid-Victorian era who wanted to make government more accountable to commoners (the gentlemen and professionals who sat in the Commons).[6] Significantly, the INA also attracted the interest of aristocrats and Sea Lords, like Hardwicke, who hoped the engineers and shipbuilders of the INA would strengthen the traditionally aristocratic navy. When Hardwicke spoke to the INA he recalled the trip he had made that evening, drawing a comparison between the political reforms under discussion at Westminster and the shipbuilding reforms that members of the INA were preparing to address.

> Before I came here this evening I visited that celebrated arsenal at St. Stephen's [Chamber, Houses of Parliament], where I found them cobbling the old ship "Constitution," and I thought the material they were putting into her was of a very inferior description; and I must say I left that dockyard with a belief that I should be happier here, and with the hope that the good old ship would be too strong even for their cobbling, as she requires a great deal of hammering to break her to pieces.[7]

Hardwick concluded that in the 'race for improvement' of the British empire 'I doubt not you will have very much the advantage in the result.'[8]

Hardwicke, a conservative member of the aristocracy, was representative of the officer class in the Royal Navy. He wanted to preserve the empire his father (Rear-Admiral Sir Joseph Sydney Yorke, first sea lord, 1813-1818) helped forge, and prosper

[6] Hugh Cunningham, *The challenge of democracy: Britain 1832-1918* (Edinburgh, 2001), pp. 60-69.
[7] 'Cobbling' described the act of craftsman who join and repair in a rough or clumsy fashion. The use of a phrase with strong links to work and manufacture implies that Hardwick believed naval architecture was a craft practice. [Charles York] Earl of Hardwicke, 'Introductory address', *Transactions*, 1 (1860), pp. 7-9, esp. 7-8. For Hardwicke see J. K. Laughton, 'Yorke, Charles Philip, fourth earl of Hardwicke (1799–1873)', rev. Andrew Lambert, *Oxford Dictionary of National Biography*, (Oxford, 2004).
[8] Hardwicke, 'Address', p. 7-8. Jan Rüger notes that the British navy was 'one of the most important metaphors of Britishness in the nineteenth century', see Jan Rüger, *The great naval game: Britain and Germany in the age of empire* (Cambridge, 2007), p. 3.

as a member of the ruling aristocracy.[9] He told members of the INA that 'It is with great satisfaction that I come where I shall certainly see the practical art of maritime construction advanced', contrasting the naval architect's work to strengthen a cultural icon of British power with Westminster politicians who, in his opinion, weakened the British franchise by filling it with commoners.[10] Hardwicke's juxtaposition of naval architecture and the English constitution induced questions about the persons and skills that secured English power and influence on the seas around the globe.[11]

Victorian politicians, administrators, naval officers and naval architects held various views on the ship and the 'engineering' skills that they believed guaranteed naval supremacy. Hardwicke's speech to the INA, for example, contained many references to the art, practical knowledge and craft practice of ship building.[12] In contrast Henry Chatfield, a shipwright (and one of the first to join the INA), believed that ships should be designed on a scientific system of shipbuilding.[13] Naval officers, constructors and administrators also held a range of views on how Britain's shipbuilding programme should be managed. Captain (later Vice-Admiral) Edward Pellew Halsted believed that politicos and professionals, like the civilian First Lord of the admiralty who did not have tacit knowledge of the ship yet shaped naval policy in parliament, were the greatest obstacles to building a strong navy.[14] John Scott Russell believed otherwise. A leading Victorian civil engineer who believed engineers should be

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[9] The fourth earl had inherited the title from his uncle, Philip Yorke.

[10] Hardwicke, 'Address', p. 7-8.

[11] For the ocean/sea in the imagination of political writers see Charles Dilke, *Greater Britain: a record of travel in English-speaking countries during 1866 and 1867* (2 volumes, London, 1868); James Anthony Froude, *Oceana: or, England and her colonies* (London, 1887). Also see Christopher Harvie, *Floating commonwealth: politics, culture and technology on Britain's Atlantic coast, 1860-1930* (Oxford, 2008); Duncan Bell, *The idea of greater Britain* (Princeton, 2007).

[12] Hardwicke, 'Address', p. 7.

[13] In 1832, Henry Chatfield observed that ' "Science" has been defined to be "Knowledge reduced to a system": if, therefore , we aim at Science in the Construction of ships, it is not a question whether theoretical and experimental knowledge should be collected and arranged with the utmost regard to method; but the inquiry is – how is it to be effected?' Quoted in William H. Thiesen, *Industrializing American shipbuilding: the transformation of ship design and construction, 1820-1920* (Gainesville, 2006), p. 16.

[14] Edward Pellew Halsted, *The experiments on "the Trusty": a lecture delivered (in continuation) at the Royal United Service Institution on April 8th, 1861* (London, 1861), pp. 56-7.

given independence from naval officers in their work, Russell argued that only politicians could affect change. Russell thought that any change in the social order of expertise in the Admiralty would be at the urging of the government.[15]

This chapter places these above discourses alongside one another to highlight the different agendas and conflicting perspectives on how the *matériel* of the navy could be managed and improved. I use these perspectives to examine the connections between Victorian criticisms of naval mismanagement, perspectives on the 'uses of science', the transformation of naval *matériel* and social control over the ship that naval historians have hitherto overlooked. This chapter places the ship and shipbuilding back into the political culture and social context of Victorian Britain, and challenges the prevailing views that 'the power-political framework in which the Pax Britannica operated was not undergoing any revolutionary change' and that the 'British public ... retained an unjustified confidence in its navy's invincibility'.[16]

1.1 THE STRUCTURE OF THE ADMIRALTY

Victorians readily acknowledged that the *matériel* of the navy was in transition. From the use of iron to the growing credibility of steam power at sea, the material, shape and deployment of ships was radically altering. Hardwicke was just one observer to note the need for detailed, technical knowledge about these new ships and their behaviour in order that some uniformity could be employed in the navy. 'Look at the exhibitions in the public dockyards,' Hardwicke told the INA, '[w]e do not know how it is, but we see

[15] In an 1862 essay he remarked that construction of the first Royal Navy ironclad H.M.S. *Warrior*, which took five years to be turned from an idea to a reality, was ultimately carried through by politicians against the wishes of the navy. John Scott Russell, *The fleet of the future in 1862; or England without a fleet* (London, 1862), p. 68.
[16] Paul Kennedy, *The rise and fall of British naval mastery* (London, 1976), pp. 177-78.

two vessels launched of the same nominal tonnage, but of entirely different forms, and yet designed for the same purposes.'[17] Russell, who was equally concerned by British ship design and the navy's shipbuilding policy, believed the lack of uniformity was a symptom of the Admiralty's social and hierarchical order.

> The first lord is generally a man who knows nothing about the navy. The first constructor of ships is frequently a man who knows nothing about the construction of ships. The first officer at the head of a dockyard knows nothing about ship-building; and the chief builder of a ship is permitted to know nothing of the designs and calculations on which the construction is founded, and he is not even permitted to entertain an opinion on the subject. This is the systematic principle of organisation of the Admiralty, its departments, and its establishments. Of course there is talent in the Admiralty ... they have the knowledge, but not the power.[18]

The Victorian Admiralty was run by a board of admirals under the direction of a civilian First Lord of the Admiralty. The civilian was traditionally an aristocrat with strong naval ties, but the emergence of a gentrified professional class of businessmen and industrialist politicians meant that the office was increasingly trusted to a respected administrator.[19] When Charles Wood, a former chancellor of the exchequer and president of the Board of Trade, was appointed First Lord in 1855 by Palmerston, the ship owner and MP William Lindsay wrote in his journal that, 'he has no other qualification than that he is brother-in-law of Earl Grey, and was for some years Secretary at the Admiralty.'[20] Similarly, Hugh Childers, who presided over the Admiralty between 1868 and 1870, was a bureaucrat and economiser in the Treasury before being appointed First Lord in William Gladstone's administration after the 1868 Liberal victory.[21]

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[17] Hardwicke, 'Address', p. 8.
[18] Russell, *Fleet of the Future*, p. 81.
[19] David Cannadine, *The decline & fall of the British aristocracy* (London, 1990); Harold Perkin, *The rise of professional society: England since 1880* (London, 1989); Roy MacLeod, 'Introduction', in MacLeod (ed.), *Government and expertise: specialists, administrators and professionals, 1860-1919* (Cambridge, 1988), pp. 1-26.
[20] William Schaw Lindsay's Private Journal, vol. 2, London, NMM, Lindsay papers 35/3, p. 140.
[21] Childers had some experience as a civil lord of the Admiralty towards the end of Palmerston's 1859-1865 administration, but the criticism of inexperience was still made by the press. William Carr, 'Childers, Hugh Culling Eardley (1827–1896)', rev. H. C. G. Matthew, *Oxford Dictionary of National Biography* (Oxford, 2004).

Administrative experience and, in particular, financial expertise, were common among the mid-Victorian First Lords. Thomas Corry, George Goschen, George Ward Hunt and even the aristocrat Edward Adolphus Seymour, Duke of Somerset, had backgrounds in administration.[22] W.H. Smith, the most infamous of the era's First Lords, was popularly portrayed through the character of Joseph Porter in William Gilbert and Arthur Sullivan's *H.M.S. Pinafore* (1878).[23] This culture of rewarding economic and practical competence was not unusual, but in the Admiralty, where the First Lord had a great influence over the shape of the Victorian Navy, contemporaries were concerned when administrators brought their practical minds to bear on ship design. Members of Benjamin Disraeli's own party criticised his decision to appoint Smith, a London merchant and newsagent, to the highest naval office in the land.[24] Clarence Paget, an admiral who was appointed to Somerset's board to serve as parliamentary secretary and the public face of the Royal Navy, recorded in his journal that the country needed a First Lord who will 'abstain from that which appears hereditary with first lords, namely, the vanity of supposing, after they have been a few years, or even months at the Admiralty, that they can build and arm a ship.'[25]

The First Lord was assisted by a small group of secretaries who helped in administration matters and three admirals, who were appointed the first, second and fourth Sea Lords in charge of the naval service, personnel and shore establishments, and supplies respectively.[26] These admirals tended to be experienced, older officers, born to

[22] W. F. Rae, 'St Maur , Edward Adolphus, twelfth duke of Somerset (1804–1885)', rev. H. C. G. Matthew, *Oxford Dictionary of National Biography* (Oxford, 2004).
[23] Porter, off course, 'grew so rich that I was sent, by a pocket borough into Parliament. I always voted at my party's call, and I never thought of thinking for myself at all. I thought so little, they rewarded me by making me the Ruler of the Queen's Navee!' William Gilbert & Arthur Sullivan, *H.M.S. Pinafore, or the lass that loved a sailor* (London, 1878).
[24] Richard Davenport-Hines, 'Smith, William Henry (1825–1891)', *Oxford Dictionary of National Biography* (Oxford, 2004).
[25] *Autobiography and journals of Admiral Lord Clarence E. Paget, G.C.B.*, ed. Arthur Otway (London, 1896), p. 366.
[26] An early-Victorian reform of the board removed the office of third lord, who was in charge of the *matériel* of the navy, but from 1869-1871 Childers reinstated the position *de facto* by letting Robert Spencer Robinson, controller of the navy, to sit on the Board. For the inner-workings of the Admiralty see Nicolas A.M. Rodger, *The Admiralty* (Lavenham, 1979).

conservative families and trained for naval service. These officers had unparalleled authority to decide strategy, dictate shipbuilding policy and counsel the government on naval matters. They also, from time to time, served as authorities on ship design, dictating designs and providing technical specifications - sometimes in peculiar, but telling fashion.

In the late 1850s, Paget was sent to France to spy on a ship under construction by the French government, *La Gloire* (1859), a wooden ship clad in iron armour (ironclad). Iron and ironclad ships had been employed in the Victorian merchant navy, and even in a limited way in the Royal Navy, but they had yet to be employed as the ships of the line that controlled the seas and symbolised naval power. The French government had refused any British visitors to the stocks at Toulon where *La Gloire* was under construction, so the Admiralty encouraged Paget, a spokesman and naval officer with little technical knowledge of ship design, to take an impromptu holiday on the continent with his wife. Early one morning, when small vessels usually came alongside the stocks with supplies, Paget hired a row boat to take him up to the boat to make observations (much to the boat owner's fears of treason).[27] Paget described how he examined the ship.

> I had carefully measured my umbrella, and having succeeded in getting alongside among a crowd of bumboats, I climbed the side steps, avoiding the accommodation ladder, and so got a careful measurement of the height of her ports [using the umbrella as a rule]. Arrived on deck, the officer of the watch accosted me civilly but firmly, requesting me to turn round and go back to my boat, which I did, after apologizing and taking careful note of the turret which stared me in the face.[28]

Paget's report to the Board provided the Admiralty constructors with a rough idea of the height of the armoured deck, the height of the main battery above the waterline and the general dimensions of the ironclad in comparison to France's existing line-of-battle ships.

[27] *Autobiography*, ed. Otway, pp. 194-196.
[28] Ibid., p. 195.

Paget privately looked on the *La Gloire* episode as an example of the how the two countries managed their respective military enterprises. He believed that the disorder in the British shipbuilding programme was a symptom of the system of government aristocratic patronage. In contrast, the culture of order and 'interchangeability' in France's state shipbuilding enterprise was a result of her government's meritocratic bureaucracy.[29] Paget observed that '[e]ach [French] ship is similarly fitted, as also their engines, so that an accident to one by breakage in any part can be replaced by another. In fact, they are *homogeneous.*'[30]

The authority of naval officers and administrators to shape the *matériel* of the Royal Navy frustrated a number of the engineers who built for the Admiralty. Russell, who had a vested interest in the authority of engineers, believed that the Admiralty's institutional hierarchy and social politics marginalised technical expertise. There was no direct representation given to technical experts in the Admiralty. The Controller and Chief Constructor of the navy were the only two officials directly involved in ship design and construction, but they were kept at a distance from the Board. The Controller managed the navy's shipbuilding programmes, ordinances, dockyards and stores. The Chief Constructor, who worked through the Controller, traditionally deferred to the broad designs dictated to him and worked within shipbuilding's prominent craftwork culture.

In 1863, following Isaac Watt's resignation from the post of Chief Constructor of the Admiralty, Somerset appointed Edward James Reed, a private shipbuilder, graduate of the Portsmouth Central School of Naval Architecture and Mathematics and editor of

[29] For interchangeable parts in French engineering see Ken Alder, *Engineering the revolution: arms and enlightenment in France, 1763-1815* (Princeton, 1997).
[30] *Autobiography*, ed. Otway, p. 284.

the *Mechanic's Magazine*, to the vacancy.[31] At the time Somerset was under fire for not breaking the hold that old, experienced artisans had on ship construction, but with Reed's appointment Somerset also came under criticism for appointing a journalist and a theorist, deemed to have no shipbuilding experience, to the highest position a naval architect could hold.[32] Frederic Smith, who led the charge against Reed in the Commons, used his voice to tell the nation that Reed 'had never built a ship in his life, and was now building a ship which was only an experiment, and might be a failure.' He concluded by urging Somerset to appoint a practical shipbuilder.[33] Somerset believed that it was impossible to please the public opinion when it came to British shipbuilding policy.[34] This public conflict over who should replace Watts as Chief Constructor reveals the knowledge and skills that many politicians believed were important to design successful ships.

The initial design of a Royal Navy ship took place in the Board of Admiralty's meetings. Board members took into consideration the speculations of politicians (who cared for budgets and the politics of Anglo-French naval rivalry), the experiences of officers at sea and the tactical requirements of the fleet. The Controller and Chief Constructor of the navy were then instructed on what 'type' (note the implicit use of *past experience* to describe future designs) of ship the Board desired, its approximate size and the attributes it should possess (displacement, number of guns, thickness of armour). Russell satirised this process in *The Fleet of the Future* (1862), describing Paget's attempt to get the Chief Constructor to design two ships identical to H.M.S. *Warrior*, but half the size.

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[31] David K. Brown, 'Reed, Sir Edward James (1830–1906)', *Oxford Dictionary of National Biography* (Oxford, 2004).
[32] 'The Navy – Appointment of Mr. Reed. – question', *Hansard*, 20 Feb 1863, pp. 572-3.
[33] 'The Navy – Estimates', *Hansard*, 23 Feb 1863, pp. 705-6. Reed defended himself in a private letter to Smith which the MP quickly placed on public record in an attempt to show that Reed had acted with misconduct in responding to his accusation, and his appointment to Chief Constructor should be terminated. 'Breach of Privilege', *Hansard*, 26 Feb 1863 pp. 800, 877-78.
[34] Anon. [Edward Adolphus St. Maur], *The naval expenditure from 1860 to 1866, and its results* (London, 1867), pp. 30-1.

Lord C.	What, the guns carried two feet nearer the water? I said she should be the same as the "Warrior."
Con.	But your Lordship will do me the justice to remember I said it could not be done.
Lord C.	But I told you it was an order of the Board, and must be done. But about the coals: I can't see that half the coals should not carry a ship of half the size over the same distance as double the coals carries twice the size of ship.
Con.	It is on account of the slower speed, my Lord.
Lord C.	What! Slower speed? Why should the speed be slower?
Con.	It is, my Lord, slower in the proportion of 11 to 14.
Lord C.	But the Board did not order that. How do you get that?
Con.	By calculation.
Lord C.	Oh, but that is matter of opinion. No, I think she will go on as fast as the "Warrior." I am a sailor, and if I had the command, I should make her do it. But won't the ports take in the water? ... why don't you put them higher?
Con.	Because it would make her a worse sea boat then she is.
Lord C.	You don't mean to say that she is not a good sea boat?
Con.	I fear not my Lord.
Lord C.	But why should she not have good qualities? I like the look of her.
Con.	We have done the best we could.
Lord C.	Well, I like her look, and I think I can set my opinion an experienced seaman against yours.[35]

Thus, financially skilled administrators and professional sailors managed British shipbuilding policy, revealing the type of skills that the various mid-Victorian governments perceived were necessary to secure naval supremacy: economic wisdom, bureaucratic control and 'practical' knowledge. These skills were widely trusted to guarantee naval supremacy at a reasonable price but, as I demonstrate in the next section, the design problems and possibilities presented by iron, fear of French naval power and steady increases in the size of the navy estimate (the annually voted budget for shipbuilding) brought into question 'in whom did the Victorians trust to secure naval supremacy?'[36]

[35] Russell, *Fleet of the Future*, pp. 74-5.

[36] Economic concerns were particularly acute for conservative governments at this time that were eager to show they could manage national finances with the same skill and control exhibited by William Gladstone. For naval spending see John Beeler, *British naval policy in the Gladstone-Disraeli era* (Stanford, 1997). For Gladstone's expertise in financial management see, A.B. Hawkins, 'A forgotten crisis: Gladstone and the politics of finance during the 1850s', *Victorian Studies*, 26 (1983), pp. 287-320; H.C.G. Matthew, 'Disraeli, Gladstone, and the politics of mid-Victorian budgets', *Historical Journal*, 22 (1979), pp. 615-43.

1.2 MANAGING *MATÉRIEL*

The trial of the Somerset Board

Press speculation over the state of Britain's naval power was continuous in Victorian Britain, yet criticism of the Board of Admiralty reached a peak in the 1860s with constant calls for its immediate reform and a change to dockyard management, coastal defence and ironclad construction policy. Although such complaints manifested chiefly as economic concerns, they were underpinned by issues regarding the value of experimentation, experience and expertise. An article in *The Times* argued that 'our HYDE PARKERS, BERKELEYS, DUNDASES, MARTINS, GREYS, and MILNES have alike wasted the public moneys in the construction of obsolete ships.'[37]'[I]t is a fatal error,' the report continued, 'to intrust [sic] to aged Admirals the direction of our great national workshops and the final decision upon the problems of practical science which the design, the plating, and the equipment of the fleet of the future necessarily in these latter days involve.'[38] Naval historians have been preoccupied by the financial nature of naval supremacy and have largely ignored vital episodes in the social history of administration and expertise that simultaneously shaped and were shaped by the culture of naval supremacy.

Press criticism of the Admiralty reached a frenzy in 1866-7, focusing on the Duke of Somerset, who, from 1859-1865, served as First Lord of the Admiralty in Palmerston's Liberal administration. Somerset, whose service during the Crimean War

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[37] *The Times*, 11 June 1868, p. 8. Naval historians have remained largely focused on the financial aspect of this debate see, Beeler, *British naval policy*. As such, surveys of Victorian history fail to go beyond the criteria of finance in assessing criticisms of administrative efficiency in the navy, for example see Norman McCord & Bill Purdue, *British history, 1815-1914* (Oxford, 2007), p. 321.

[38] *The Times*, 11 June 1868, p. 8. See for example Samuel Bentham's dockyard reforms. Bentham recommended that the Admiralty install admirals and captains as dockyard superintendents because "[a] naval officer's experience afloat would have rendered him competent to form a general estimation of the fitness of works doing to a ship in hand; whilst the habit of command on board ship must qualify him to judge generally of the due management of both officers and men of shore." Quoted from William J. Ashworth, ' "System of terror": Samuel Bentham, accountability and dockyard reform during the Napoleonic Wars', *Social History*, 23 (1998), pp. 63-79, esp. 67.

was one of bureaucratic observation, was not a popular figure.[39] The Somerset Board oversaw the early 'experiments' (the usage of the word, I will show, really meant 'trials' to administrators and naval officers) in iron shipbuilding. Somerset's Board was perceived to have wasted money on a series of 'failed' experiments in ship design, carried on construction of old fashioned wood ships and let England's navy fall behind its greatest rival, France. These criticisms, although in appearance financial, were underpinned by a series of presuppositions regarding experiment, experience and expertise that require further analysis.

Russell, who was one of many fierce critics of the Somerset board's shipbuilding policy, believed that Somerset had inherited a strong Admiralty from Sir John Pakington, Lord Hampton. Russell publicly argued that Somerset 'doubted - hesitated - pondered - and did nothing' to continue the *matériel* changes Pakington began - which included commissioning the *Warrior*, Britain's first ironclad.[40] Russell, who championed iron and had been involved in plans for the construction of the *Warrior*, considered any wooden ship a waste of money. He claimed that the £30,000,000 in naval estimates voted to the Admiralty between 1855 and 1862 had resulted in the 'value [of] ... about £1,000,000 in the two "Warriors" produced', the rest having been 'wasted' on wood. Russell actively linked the Somerset Board's spending on *matériel* to the low standing of technical experts who advocated iron shipbuilding within the 'constitution and administration of the Admiralty and the great naval establishments.'[41]

Somerset, in response to his critics, took the unprecedented step of defending himself and his Board in a pamphlet for public circulation. 'The human memory cannot

[39] W. F. Rae, 'St Maur , Edward Adolphus, twelfth duke of Somerset (1804–1885)', rev. H. C. G. Matthew, *Oxford Dictionary of National Biography* (Oxford, 2004).
[40] The ships built during his reign, including the *Defence* and *Resistance* were, in Russell's eyes, 'two [of the] worst designed ships that have ever floated'. Russell, *Fleet of the future*, pp. 72-3.
[41] Russell also used the threat of French naval supremacy to establish the importance of shifting authority and expertise to technical experts. Ibid., pp. 80-1.

recall', Somerset claimed, 'the period when the department of the Admiralty was not the subject of accusation and complaint.'[42] Somerset defended the *matériel* developments his Board had paid for, and criticised the logic of observers whose 'complaint has been that the Admiralty did not make allowance for the novelty of the work'.[43] Somerset concluded that 1860-66 was a 'transitional period of ships and of armaments' during which '[t]he progress of improvement was rapid, and ships were hardly completed before they were superseded by better designs.'[44] In effect, he sought to excuse himself and his fellow administrators from blame.

Somerset surmised that the great 'economic' pressure on the Admiralty was not financial, but a manifestation of the tension in achieving the following three objectives without waste: to build an ironclad fleet which could rival France; to experiment with the design features of iron; and to alter the ships already in production so that they could simultaneously meet the first two objectives. Somerset argued that it was difficult to 'experiment' with designs and, at the same time, to expect the new ships to be better than those previously constructed. Experiment, as Somerset understood it, did not guarantee 'progress'. Thus the former First Lord concluded that the 'economic' management of the Admiralty did not necessarily guarantee 'progress' and naval supremacy – or even that large naval estimates guaranteed naval power.[45]

Somerset's defence made compelling points about the risks iron ships involved and the problems inherent to 'experimenting' with ship design on a large scale, yet it failed to stem the tide of public criticism. *The Times*' response to Somerset's pamphlet

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[42] Edward Adolphus Seymour [Duke of Somerset], *The Naval Expenditure from 1860 to 1866, and its results* (London, 1867), p. 3.
[43] Ibid., p. 26.
[44] Ibid., pp. 37, 43.
[45] Thus Somerset implicitly rejected the 'law of progress' that grew in cultural authority in Victorian Britain, but in doing so offered a perceptive view of the skills and values which underpinned 'progress'. For the cultural authority of the 'law of progress' see Cunningham, *Challenge of democracy*, pp. 84-87; Walter Houghton, *The Victorian frame of mind* (New Haven, 1957), pp. 33-45.

was, first, to criticise Somerset for inviting further attacks by publicly defending himself, and second, to label the entire Admiralty an old-fashioned, perennially 'unready' institution, lost in a sea of 'change' and 'progress'. 'They squander our moneys, they neglect our coast defences, they maintain at a huge expense a wooden navy rotting in our harbours', the correspondent complained, 'and the Ironclads they build are built on so false a principle that an enemy can sink them as they roll, without being hit himself, "except by accident or miracle."'[46] The article continued,

> In no department of human affairs at the present day is change the condition and progress the necessity so much as in the preparation of the implements of naval warfare. In no body of men is the objection to change so ingrained, the indisposition to take counsel of other and younger minds so decided the incapacity for progress so confirmed, as in the elder Admirals and Vice-Admirals who, time out of mind, have directed the naval policy of Whitehall.[47]

The Times associated *matériel* reform with the social politics of the Admiralty. In this and other criticisms of the Board, 'progress', often a watchword for cultural historians of science and technology, became an important actors' category to be negotiated as a barometer for measuring the work of actors who managed the *matériel* of the navy.

Russell believed that 'progress' was a transition to iron shipbuilding and administration by technical experts; a transition that Somerset did not possess the technical knowledge or administrative finesse to negotiate. 'It is this inability to decide among conflicting opinions [from the various departments of the Admiralty and government]', Russell wrote, 'which renders the present position of the First Lord, so difficult.'[48] He continued, explicitly linking *matériel* and naval management, and noting that '[i]n the two apologies which he has had officially to make, for the abject failure of his department either to reconstruct itself or the fleet, he has frankly told the Lords that it is to the Commons of England, and to them only, that he has been looking for the

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[46] *The Times*, 11 June 1868, p. 8.
[47] *The Times*, 11 June 1868, p. 8.
[48] Russell, *Fleet of the future*, p. 81.

reform of the navy'.[49] Somerset's defence reflected the great mid-Victorian deference to the Commons, even in technical matters concerning the *matériel* of the navy.[50]

Discussions surrounding public disapproval of the Somerset board invite further reflection on two issues. The first is how iron was understood in the early 1860s as a functional material, but also as a material with a cultural value within a social network.[51] There was an implication in the criticisms of Somerset's board that the Admiralty lacked experts who understood the material that was on trial. Thus the second issue emerges: that the public sphere was increasingly anxious whether or not political administrators and professional sailors held the appropriate skills and knowledge to guarantee naval power. To emphasise the significance of these questions is to highlight the weaknesses of a technologically deterministic approach to the politics of naval supremacy. It also contributes to political debates concerning the boundaries of the state and the important question that S.J.D. Green & R.C. Whiting have asked elsewhere: 'what (if any) have been the connections between the emergence of so many associated fields of scientific ... "knowledge" and the ... moral authority pertaining to their practitioners to employ that understanding on behalf of the state, and for the common good?'[52]

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[49] Russell claimed that 'when further asked why a particular kind of shield ship was not sooner undertaken, he [Somerset] naïvely replies, that he thought it better to wait and see what the opinion of the House of Commons in the next session of Parliament might be.' Ibid., p. 15; [Somerset], *Naval expenditure*, p. 39.

[50] Cunningham, *Challenge of democracy*, p. 61.

[51] I allude here to actor network theory and the treatment of objects as vessels of inscribed meaning, even agency, see for example Bruno Latour, *Reassembling the social: an introduction to actor-network-theory* (Oxford, 2005), pp. 63-86. Also see Ken Alder, 'Thick things: introduction', *Isis*, 98 (2007), pp. 80-83.

[52] S.J.D. Green & R.C. Whiting, 'Introduction: the shifting boundaries of the state in modern Britain', in Green & Whiting, *The boundaries of the state in modern Britain* (Cambridge, 1996), pp. 1-14, esp. 5.

1.3 'THE IRON AGE AFLOAT'
A social perspective on *matériel* change

In 1860 the Royal Navy launched the *Warrior*, the first ironclad built for British national security.[53] Iron had already been used in the commercial sector for shipbuilding, and in the Royal Navy for small vessels, but the Admiralty did not explore iron line-of-battle-ships until the successful launch of *La Gloire*. Articles in Victorian newspapers and periodicals pressed for the government to meet the challenge and argued with conviction that the use of iron ensured stronger, faster, more powerful ships.

Such an article in *Blackwood's Edinburgh Magazine* claimed that 'A cellular skin, upon the Great Eastern principle, together with a number of perfect internal compartments, and steam pumps capable of delivering a large volume of water, will make the sinking of such ships as the *Warrior* a very difficult feat indeed.'[54] In this spirit the same article denounced those who would continue to build with wood, '[w]e have had enough of these now useless, overgrown, but highly ornamental ships, mere dreams in wood; and duty compels us to take a common-sense view'.[55] Thus it was that the material of the Victorian ship was understood by associating and inscribing them with values, two of the most important being Victorian notions of aesthetics and mechanics.

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[53] I will examine the rhetoric of experiment and speculation that surrounded *Warrior*'s sister ship, H.M.S. *Black Prince*, in chapter 3.
[54] [Sherad Osborn], 'Iron-clad ships', *Blackwood's Edinburgh Magazine*, 88 (1860), 616-32, 633-49, esp. p. 629.
[55] Ibid., p. 633.

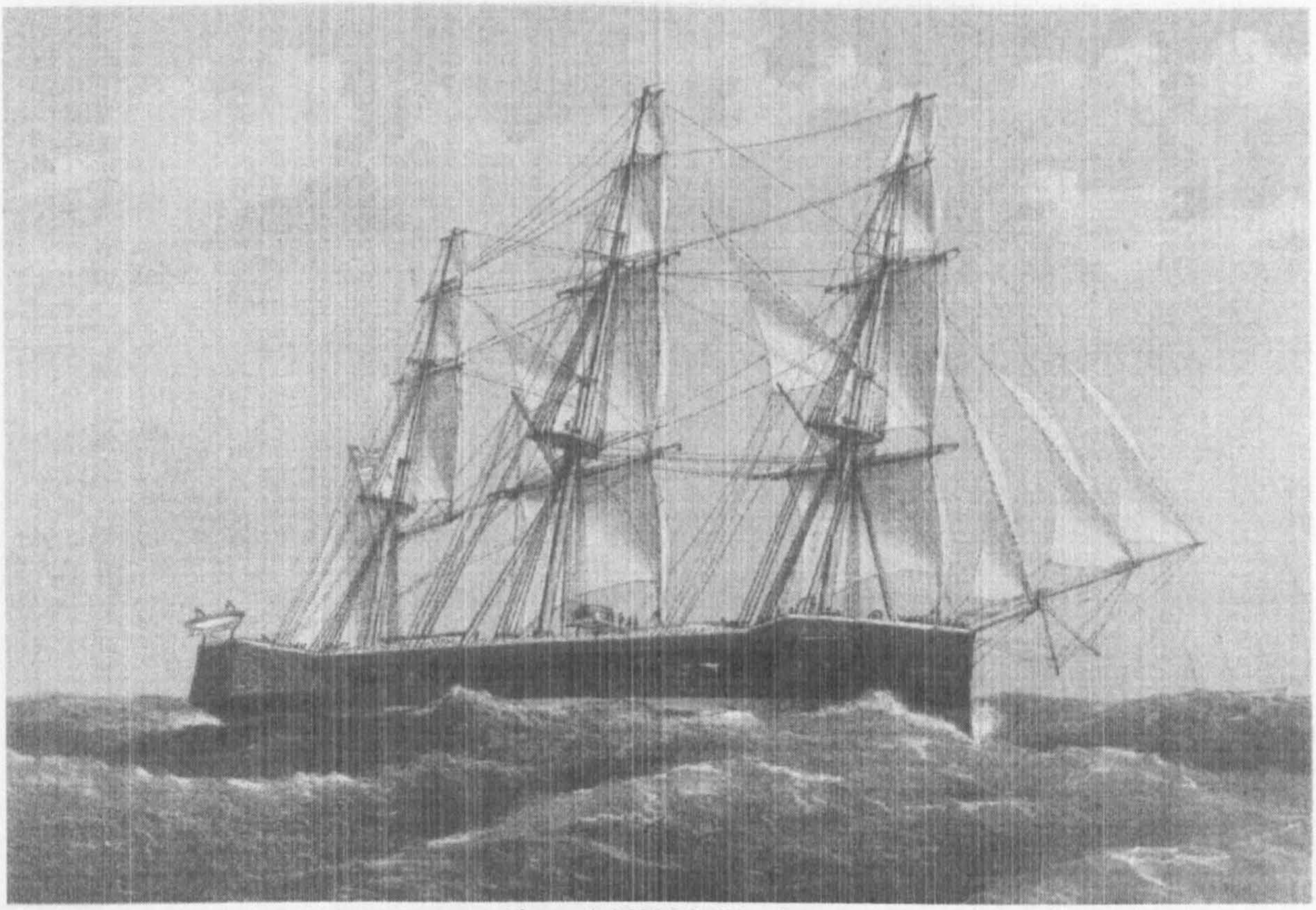

Figure 1.1 H.M.S. *Warrior.*

It has been customary in Victorian historiography to account for iron's economic significance rather than consider the extent of its identity and agency.[56] Asa Briggs' examination of 'carboniferous capitalism' in *Victorian Things* (1988) treated iron solely as a thing with an impact, rather than representing the many possible values and associations that objects hold.[57] The spread of iron in shipbuilding was understood not by unknown 'impacts' but themes like 'aesthetics' and 'mechanics'. Ship designers, professional sailors, politicians and the press positioned themselves and their discourses according to these themes. Iron, crucially, was understood as a 'progressive' but ugly material, and caught the public imagination because it contrasted the cultural

[56] John Beeler, *Birth of the battleship: British capital ship design 1870-1881* (Chatham, 2001); Michael Carroll Dooling, 'The thin line: the Crimean War transforms naval power', *Naval History*, 18 (2004), pp. 36-41; Peter Goodwin, 'The Influence of iron in ship construction: 1660-1830', *Mariner's Mirror*, 84 (1998), pp. 26-40. For wider histories of iron in economics and industry see Martin Daunton, 'Society and economic life', in Colin Matthew (ed.), *The nineteenth century: the British Isles, 1815-1901* (Oxford, 2000), pp. 41-84, esp. 52; William Ashworth, *An economic history of England, 1879*-1939 (London, 1960).

[57] Asa Briggs, *Victorian things* (Bath, 1988), pp. 289-326; Manfred E.A. Schmutzer, 'Iron rules rule iron rails: cultures and their technologies', *Mitteilungen des Osterreichischen Staatsarchivs, Special Issue*, 7 (2004), pp. 305-319. Contrast with Lorraine Daston (ed.), *Things that talk: object lessons from art and science* (New York, 2004).

iconography of Britain's naval past: '"What!" exclaim others to-day, as good and as true as Oliver Lang – "what! put our Benbows, our Hawkes, Nelson, and Victorias into armour? cover our heart-of-oak with iron, Sir? Have a care!" Yes! alas! we say, good sirs, it must be so.'[58] Such a cultural approach to the wood/iron question moves scholarly discussion away from the inherent physical features of a material to what it represented to actors.[59]

Charles Beresford, naval officer, MP and second son of the Reverend John de la Poer Beresford, fourth marquees of Waterford, wrote on his transfer to H.M.S. *Defence*, an ironclad, that "[a]fter the immaculate decks, the glittering perfection, the spirit of fire and pride of the *Marlborough*, I was condemned to a slovenly, unhandy tin kettle."[60] This sentiment was shared by many professional sailors across Europe. Rear-Admiral Edmond Paris of the French navy believed that seamanship on the wooden wall 'was a beautiful and grand profession – one that directly daunted the elements; and it is no wonder that every old sailor regrets the change'.[61] The attitude of professional sailors to the new material and aesthetics of naval construction reflected the social makeup of the officer class and the aristocratic preference for craftsmanship, elegance and disdain for mechanics.[62]

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[58] [Sherad Osborn], 'Iron-clad ships of war', p. 616. For Oliver Lang and master shipwrights see Andrew Lambert, *The last sailing battlefleet: maintaining naval mastery, 1815-1850* (London, 1991), pp. 74-85.
[59] For a similar approach, albeit emphasising the cultural authority used to close the compass deviation controversy associated with the wood-iron question, see Alison Winter, '"Compasses all Awry": the iron ship and the ambiguities of cultural authority in Victorian Britain', *Victorian Studies*, 38 (1994), pp. 69-98.
[60] Quoted in R.K. Massey, *Dreadnought: Britain, Germany and the coming of the great war* (London, 1991), p. 390. Also see Nicholas A. Lambert, *Sir John Fisher's naval revolution* (Columbia, South Carolina, 1999), pp. 75-6. For Beresford see V. W. Baddeley, 'Beresford, Charles William de la Poer, Baron Beresford (1846–1919)', rev. Paul G. Halpern, *Oxford Dictionary of National Biography* (Oxford, 2004).
[61] Edmond Paris, 'On the naval architecture of the exhibition of 1862', *Transactions*, 4 (1863), pp. 193-204, esp. 195.
[62] This bears comparison with the attitude of William Morris, who 'idealised craftsmanship, beauty, naturalness and simplicity in design and manufacture, and eschewed the dubious benefits of cheap, mass-produced goods.' Charles Harvey & Jon Press, 'William Morris: art and idealism', in Gordon Marsden (ed.), *Victorian values: personalities and perspectives in nineteenth-century society* (London, 1990), pp. 201-213, esp. 212. Also see my discussion of Marryat in the introduction.

Paris, who embodied both naval and scientific concerns (he was a member of the French Academy of Sciences and a frequent visitor to meetings of the INA), mourned that 'Exact science seems nearly always to have driven away elegance'.[63]

> the age of iron, so much did it banish poetry, and so much did it give its ships the aspects of reptiles, especially when compared with those noble ships that were so justly called Men-of-war, but which, however, will be compelled to yield before those creeping things, as much to be dreaded as if they were venomous.[64]

Paris concluded that 'if the new ship is less elegant, she is better suited to her true warlike purpose.'[65] This sentiment was echoed in *Punch*, that observed that '[o]ur Ironclads are ugly, Rous, 'tis not to be denied, Unlike our wooden walls of old, with towering brave broadside. Britannia ruler of the waves may reign as heretofore; But her Kingdom's grandeur and its glory show no more.'[66]

THE "UGLY DUCKLING."

NEPTUNE. "WELL, OF ALL THE HIDEOUS——!"
BRITANNIA. "AH, SHE ISN'T PRETTY, CERTAINLY; BUT REMEMBER, FATHER NEP, HANDSOME IS THAT HANDSOME DOES!"

Figure 1.2 H.M.S. *Devastation* as an 'Ugly Duckling'.

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[63] Paris, 'Naval architecture', p. 195.
[64] Ibid., p. 202-3. Paris was elected to the French Academy of Science in 1863, where he joined a number of other officers of high status, see Maurice Crosland, *Science under control: the French Academy of Sciences, 1795-1914* (Cambridge, 1992), pp. 170, 211.
[65] Paris, 'Naval architecture', p. 195.
[66] 'Our ugly ironclads', *Punch*, 9 September 1871, p. 108.

It is curious to consider the cultural authority that surrounded the celebration of tradition and memory of Britain's naval past. W.H. Davenport Adams, an author of popular naval histories who wrote that 'the gallant vessel which walked the waters like a "thing of life" is fast being converted into an iron tortoise', was one of many writers who found a market for books about the 'achievements of our old men-of-war'.[67] The aforementioned article in *Blackwood's* certainly appreciated the cultural influence of traditional naval aesthetics and specifically the authority that the 'poetry' of wood continued to exert in the naval community, but its author assigned that influence to the realm of irrationality. 'They [sailors and naval architects] are just as intractable upon the question of covering their wooden ships with armour', the article observed, 'as he (the landsman) would be if the matter were one of Puseyite innovation, church-rates, town-drainage, or municipal taxes.'[68]

The anonymous author of the *Blackwood*'s article, Sherad Osborn, like many commentators in the press, believed that by 1860 the advantages of iron shipbuilding were clear. Moreover, claims of superior strength, speed and safety had become intrinsically entwined with the pressing concern that the French and American navies had already built ironclads. The reservations of officers and administrators were therefore represented in the press as a backwardness and dangerous ignorance in a geopolitical context where dominance on the seas meant 'defence, safety, and the commerce of the world.'[69] The *Blackwood's* article concluded with a rally call: '[p]itch secrecy to the French, call in the mechanical and engineering skill of England and America openly in the face of all nations, and let other match us if they can.'[70]

[67] W.H. Davenport Adams, *Famous Ships of the British Navy: Stories of Enterprise and Daring* (London, 1878), p. 7.
[68] [Sherad Osborn], 'Iron-clad ships', p. 616.
[69] Ibid., p. 649. For Anglo-French relations and their resonance see Kennedy, *Naval Mastery*, pp. 97-122.
[70] [Sherad Osborn], 'Iron-clad ships', p. 649.

Figure 1.3 'Vulcan arming Neptune', *Punch*, 19 April 1862

Victorian representations of the wood/iron debate carried an explicit commentary of the social politics of *matériel* change and expertise. A *Punch* cartoon in April 1862 depicted Vulcan, the god of mechanics, dressing Neptune (with the tattoo J.B., meaning John Bull, on his arm) in an iron suit. This illustration demonstrates the literal and metaphoric significance of forcing Britain's maritime legacy into iron vessels, depicted through the trope in contemporary caricature of dressing John Bull in uncomfortable clothes.[71] The cartoon also shows the new role of mechanics in making the Royal Navy. Thus iron was not just a building material but a social material with an identity and a particular actor's network of engineers and mechanics.[72] The engineer was identified as somehow 'owning' or 'controlling' the new material. The shift to iron thus represented

[71] I thank James Baker for this point concerning caricatures.

[72] For the 'material' and 'social' see Latour, *Reassembling the social*, pp. 74-76. Also see Langdon Winner, 'Do artifacts have politics', in Donald MacKenzie & Judy Wajcman (eds.), *The social shaping of technology* (Buckingham, 1985, 2[nd] edt. 1999), pp. 28-40.

both a superficial and substantial change in the shape of the Victorian navy, *both* of which altered the social and cultural control of the fleet.

The growth of Britain's ironclad fleet was chronicled in Victorian periodicals as a largely social phenomenon. Contributors chiefly examined *matériel* change through the lens of how life on shipboard would alter. An article in *Punch* titled 'The Iron Age Afloat' argued that '[t]here seems very little doubt that steam and iron will between them turn the sailors of our Navy into stokers and sea-soldiers, and effect a revolution in the commonest naval matters.'[73] One of the many ways this occurred was through a reconfiguration of the vocabulary of the ship and sailor. Wooden walls were common phraseology for naval ships, but it was also common to refer to the officers who commanded them as 'hearts of oak'.[74] A new phraseology was needed for iron, and in 1860 *Punch* observed that,

> No longer can we boast of the Wood Walls of Old England, for those walls must now be made of a different material; not hearts of oak, but –
> Ribs of steel are our ships,
> Engineers are our men[75]

This passage from *Punch* emphasises the overtly social dimension of *matériel change* that opens the culture of technology in the Victorian navy to detailed scrutiny of 'expertise', identity and the technical skills that guaranteed naval supremacy.[76]

Iron was culturally linked to James Watt and Robert Fulton's inventive legacies, which stressed the importance of mechanical skill and engineering power. Early advocates of iron and steam complained of the treatment they were given by the naval community.

> We remember, that the first men who crossed from Dover in a steam-boat were insulted, pelted with mud, - and the sailors, packet-owners, and boatsmen, cocked their hats on one side, put their hands in their jacket pockets, and asked – "If they was the gentlemen who was

[73] 'The Iron Age Afloat', *Punch*, 3 May 1862, p. 175.
[74] See for example Davenport Adams, *Famous Ships*.
[75] 'England's Iron Walls', *Punch*, 3 November 1860, p. 171.
[76] Sheila Jasanoff, 'The idiom of co-production', in Jasanoff (ed.), *States of knowledge: the co-production of science and social order* (London, 2005), pp. 1-12, esp. 2-3. Also see Bruno Latour, *We have never been modern* (Cambridge, MA, 1993).

> going to sea in a tea-kettle?" and added, "if it comes on to blow they'll simmer on the Goodwin." It was not until their trade was destroyed that they would believe the efficiency of the power.[77]

The anonymous author of this article in *The United Service Journal* believed that the attitude to oppose 'scientific mechanicians' and 'mechanical power', particularly within the government, was based on social and cultural concerns: class politics and noble traditions.

The author argued that admirals and captains celebrated the naval tradition and not the inventive tradition. He pointed to the Royal Yacht Squadron, an aristocratic club that threatened to expel any member who used steam propulsion, as evidence that there was no encouragement given to science and engineering.[78] The author asked 'Is such conduct worthy of our Government? Is such indifference creditable to our aristocracy? Is such neglectful ignorance, tolerable among our wealthy manufacturers?'[79] The author believed that the only reasonable excuse for the government's attitude to mechanics was that they feared a change in social politics and power. 'It is supposed by the generality of mankind, that whatever promotes the interests of any particular class of men, will be supported and adopted by that class', the author claimed, '[t]he illustrious Watt, whom we justly praised when dead ... was left by the Government, and the nobles, and the wealthy, unnoticed and unaided.'[80]

Iron appeared synonymous with mechanics, and after the American Civil War, naval power. Steam had existed in unison with wood and sail; onboard such ships steam was used as an auxiliary mode of propulsion, but the 'floating forts' that debuted in America, the *Monitor* and the *Merrimac*, embodied a new aesthetic in naval design and

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[77] [Anon.], 'On mechanical power, and the neglect of the scientific mechanicians', *The United Service Journal and Naval and Military Magazine*, 3 (1833), pp. 220-226, esp. p. 226.
[78] Thomas Assheton Smith, a member of the squadron who commissioned a steam yacht from Robert Napier, was one such member to be expelled. Crosbie Smith & Anne Scott, ' "Trust in providence": building confidence into the Cunard line of steamers', *Technology & Culture*, 48 (2007), pp. 471-496, esp. 482-83.
[79] [Anon.], 'Mechanical power', p. 221.
[80] Ibid., p. 220.

way of naval life.[81] Sailors in these ships were encased in iron, propelled exclusively by steam and fought using cupola turrets. In 1862, *Punch* speculated that,

> if the cupolas succeed, the Navy will consist of shot-towers, not ships ... We can fancy the disgust with which a man-o'-war's man, one of the old school, would hear that he was to serve on board a cupola! We should think he would as life be clapped in irons out and out, as be stewed up in an iron barge without a sail to reef, or a rope to handle.[82]

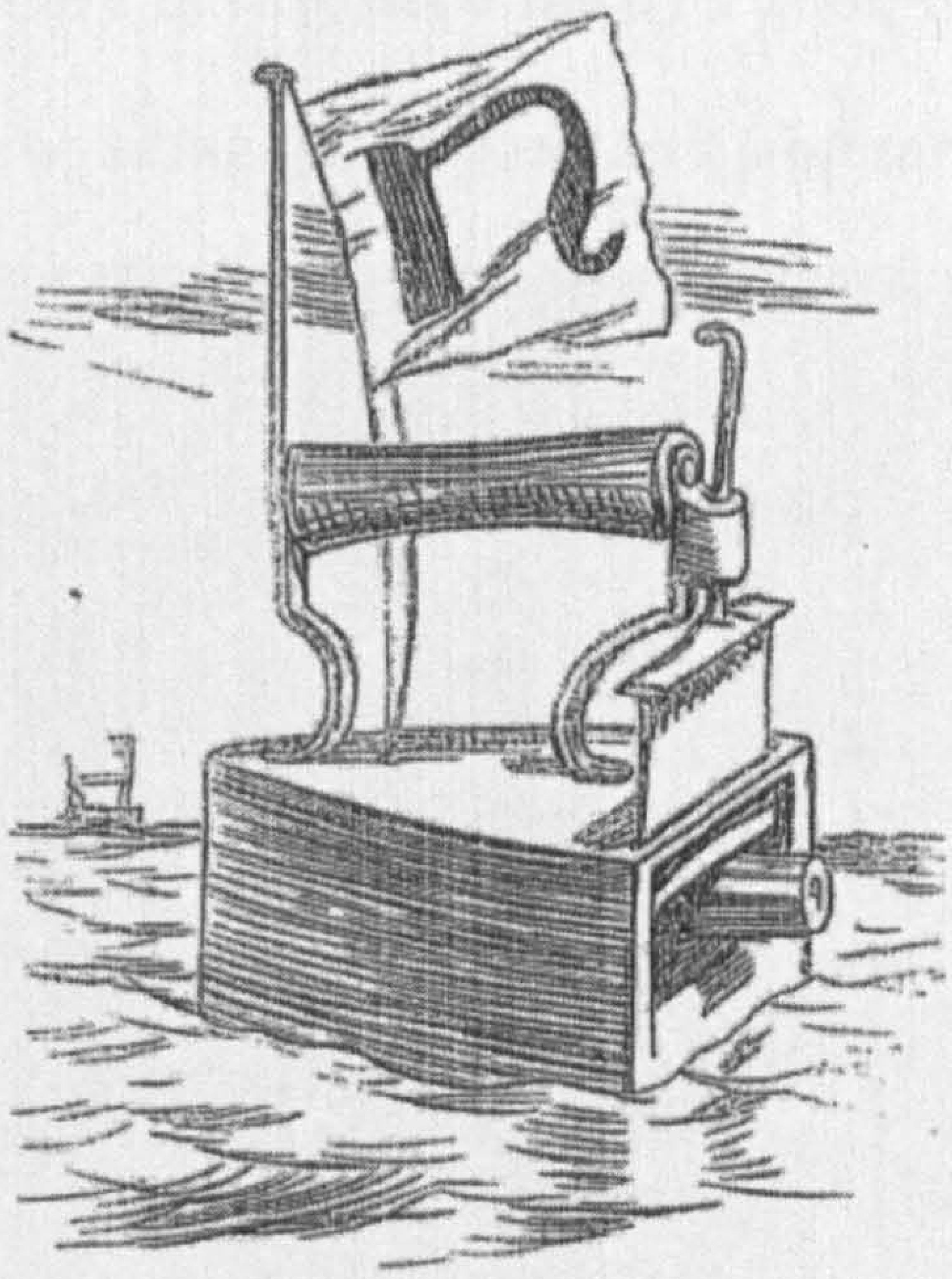

Figure 1.4 'Frozen out sailors', *Punch*, 10 May 1862

The experience of war and iron in the Civil War was a source of great authority in Britain. Russell was convinced that iron ships would form the fleet of the future and utilised testimonies from American sailors and reports of the Battle of Hampton Roads to support his claims.[83] During this battle the ironclad C.S.S. *Virginia* (formerly U.S.S. *Merrimac*) swiftly destroyed the wooden U.S.S. *Cumberland* and *Congress*. Russell quoted from an eyewitness the scene on the wooden *Congress*,

> The wounded were in crowds, horribly cut up. The ship, too, was on fire. The shells had kindled her woodwork in several places; nearly all the guns were dismounted; the bulkheads blown to pieces; rammers and handspikes shivered; the powder-boys all killed. The inside of the ship looked like the inside of a burnt and sacked house. Everything was in fragments, black or red, burnt or bloody.[84]

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[81] For the social shaping of these ships during the American Civil War, see David A. Mindell, *War, technology, and experience aboard the USS* Monitor (Baltimore, 2000).
[82] 'Sailors frozen out', *Punch*, 10 May 1862, p. 191.
[83] Russell, *Fleet of the future*, p. 8.
[84] Ibid., p. 9.

Neither the *Virginia* nor *Monitor* were built as seagoing vessels, but reports of how they destroyed multiple men-of-war during the Civil War influenced public opinion toward the use of iron for the *matériel* of the navy and the policies of the Admiralty. Both Sir Frederick Grey and Robert Spencer Robinson justified iron shipbuilding projects to Alexander Milne, First Sea Lord during Lord Derby's 1866-8 government, by citing the authority of experience surrounding the *Virginia* and *Monitor*.[85]

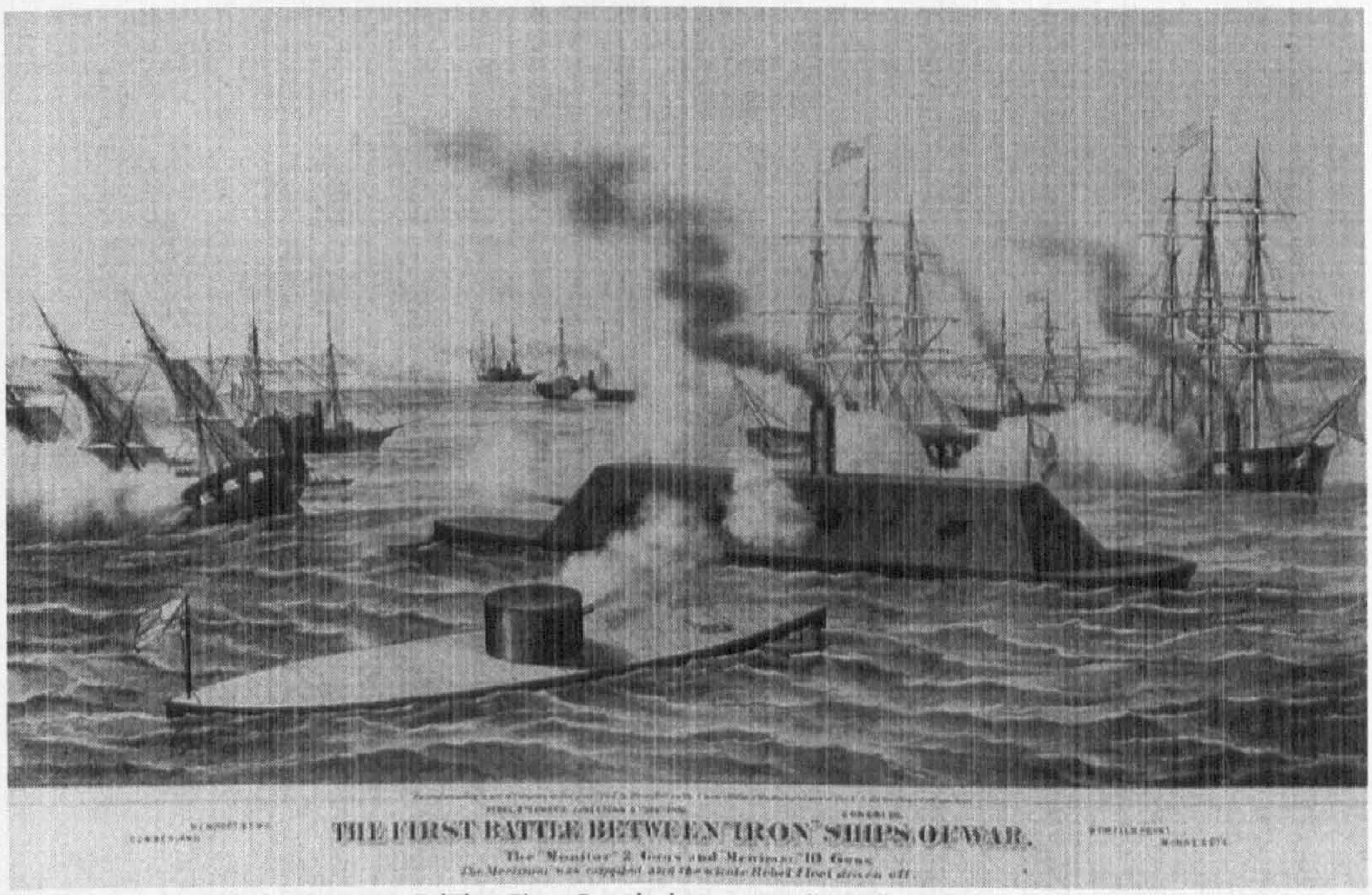

Figure 1.5 'The First Battle between "Iron" Ships of War'

The question of iron shipbuilding quickly became a politically charged topic as Pakington, the conservative First Lord of the Admiralty in Derby's 1858 and 1866 governments, used the *matériel* change of the navy as a weapon to attack the Liberal party's approach to securing British naval supremacy. In his inaugural address as president of the INA, Pakington observed that the 'rapid improvements' in physical science and engineering had levelled the navies of the world, in effect beginning a new

[85] Sir Frederick Grey, 'Memorandum for my successor', [1866], London, NMM, Milne papers 143/1; [Robert Spencer Robinson], 'A General Outline of the wants of the navy at the present moment with reference to ships', 23 August 1866, Milne papers 143/2.

naval race between France, Russia, the United States and England.[86] Success in this naval race, Pakington argued, would only be achieved by,

> taking care that, by the exercise of the skill of our scientific men, our vessels shall be so constructed ... as to enable them to carry, either, on the one hand, heavy guns and large crews, or, on the other, large cargoes, and still derive all the benefit which they ought to derive from also carrying steam-engines to propel them.[87]

The politics of naval supremacy were thus technical and dependent on how governments interacted with the groups who claimed expertise to manage the *matériel* of the navy.

1.4 GUARANTORS OF NAVAL POWER

Science or empiricism

The interwoven *matériel* and social changes of the 1860s brought engineers into greater contact with the naval community and further complicated the mix of disdain and ambiguity with which officers viewed the skills of men of science. Those skills were generally neither understood nor appreciated within the navy, yet they were constantly referenced in public discussions. Naval historians have done a limited amount to shed light on the relationship between management, science and naval power. For example, Sir Baldwin Walker, controller of the navy, has been highlighted as the 'modern' 'responsible for proposing the *Warrior*', yet William White noted that it was Walker's policy that England ought not "to take a lead in naval improvement, but only to follow on a larger scale the improvements of others".[88] Furthermore, *Punch* dedicated a whole page to Walker's resignation of office in 1861, containing satirical verses and a dictionary definition of Walker as *overseer*: 'it had been his business not so much quite

[86] John Somerset Pakington, 'Inaugural address', *Transactions*, 1 (1860), pp. 1-6, esp. 3.
[87] Pakington, 'Inaugural address', p. 4.
[88] Frederic Manning, *The life of Sir William White* (London, 1923), pp. 38-39. For Walker see C. I. Hamilton, 'Walker, Sir Baldwin Wake, first baronet (1802–1876)', *Oxford Dictionary of National Biography* (Oxford, 2004).

to look over as over look.'[89] On reflection, the biographical – even hagiographical – and teleological trends in naval history must give way so that scholars can turn their attention to understanding 'naval power' as a Victorian construct, and not as acts of valour, strategic 'genius' or counting ships.[90]

Walker was said 'to boast, with some manliness and undoubted truth, that he knew nothing whatever of the science of naval architecture'.[91] White criticised Walker and the Admiralty's traditional policy toward 'improvement', locating both in the culture of stubbornly holding to what was known to work. '[I]nstead of initiating a policy, or relying, as did the French upon the skill of their naval architects,' White wrote in an article in the *British Quarterly Review*, 'they waited for the pressure of public opinion before venturing on anything like extensive changes.'[92] The awareness of naval architects towards how their political and administrative superiors decided policy further cements the importance of the public debates between naval architects, naval officers and politicians.

The Victorian industrialisation of civil engineering gave engineers a greater sphere of authority. Engineers trained in mechanics, metallurgy and mathematics brought skills and values with them to ship design that had not previously figured in the design of wood ships (I will examine this in detail in chapter 2). Engineers who perceived that the iron steam ship was a complicated mechanical structure grew increasingly frustrated with members of the naval community who were used to dictating design types to craftsmen. Russell publicly requested ship owners to try and appreciate the function of naval architects and the problems they faced in the design process. The engineer

[89] 'Walker is the one who walks', *Punch*, 23 March 1861, p. 119.
[90] Rüger, *Naval game*, p. 4. Contrast with Andrew Lambert, *Admirals: the naval commanders who made Britain great* (London, 2008).
[91] Russell, *Fleet of the future*, p. 69. For Walker see C. I. Hamilton, 'Walker, Sir Baldwin Wake, first baronet (1802–1876)', *Oxford Dictionary of National Biography* (Oxford, 2004).
[92] William White, 'The ironclad reconstruction of the navy', *British Quarterly Review*, 57 (1873, January), pp. 87-124, esp. 94.

believed the naval community was unaware of the complexities of iron shipbuilding and asked ship owners and officers to appreciate and '*adjust ... their wishes and demands to that which is really possible.*' Russell emphasised that a strong working relationship between the naval community and constructors required officers and ship owners to recognise the knowledge and skills possessed by naval architects and trust in their expertise.[93]

Russell was less conciliatory about the trust between the naval community and constructors in private, venting his frustrations at ship owners who did not understand ship design. Russell's views were representative of many engineers and shipbuilders who believed their skills and knowledge of iron and steam distinguished them from craftsmen. Those engineers believed they could be invaluable to the administrators and admirals who managed national shipbuilding projects, if only they were trusted. The following is from an 1860 letter to James Robert Napier, a Scottish shipbuilder and engine maker,

> Ever since the time of Socrates, there has been no surer way of becoming unpopular than to insist on having right things done for right reasons. Besides the carrying out of true principles, requires a great deal of self-denial, and it is very difficult to convince a man who has nothing better than opinion to go upon, that you who go upon principle have any better title to be heard than he has.[94]

Over the following twenty years engineers and naval architects fought to demonstrate that scientific skills, knowledge and ways of working could guarantee naval power (and by extension national peace and prosperity).

Tensions between engineers and administrators were largely ingrained in the cultural perception of shipbuilding within British society. The relationship between government and the various short lived schools of naval architecture provide a lens to examine this tension. In 1811 the Admiralty established such a school at Portsmouth as

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[93] John Scott Russell, 'On the professional problem presented to naval architects in the construction of iron cased Vessels of war', *Transactions*, 2 (1861), 17-37, esp. 23.
[94] John Scott Russell to James Robert Napier, 31 Jan 1860, Glasgow, University archive service, Napier papers, 90/2/4/36.

part of a programme to differentiate dockyard workers from 'dockyard officers' who would have superior technical knowledge and lead the workforce.[95] In 1833, First Lord of the Admiralty Sir James Graham in Earl Grey's Whig administration, closed the school. A second smaller school was opened in 1841, the Central School of Mathematics and Naval Construction, which was also closed on the order of Graham, then serving as First Lord in Sir Robert Peel's Conservative administration. On both occasions the school was closed because the respective governments believed the state was not receiving any advantage from giving a small group of the workforce a specialised education.[96]

Naval architects believed the willingness of government to close schools that taught the science of shipbuilding demonstrated the authority that 'empiricism' had with administrators, that is, the belief that shipbuilders only needed experience. In 1834 Chatfield, who had attended the first school and believed that experience alone was not enough to build ships, argued that the country needed experts 'educated at a very liberal national institution' to 'protect ... naval science against the dangers of empiricism'.[97] Russell, who had not attended these schools (he had been a student at Glasgow University, and then lecturer of natural philosophy at Edinburgh), made the same argument in 1863 when he led a petition to the government to establish a third school. The naval architect remarked that the building erected for the original Royal College of Naval Architecture was presently home to a clerk and an accountant paying a 'paltry' £60 rent to the Admiralty for its use. Such a use of resources was a reminder of a

[95] Simon Schaffer, ' "The charter'd Thames": naval architecture and experimental spaces in Georgian Britain', in Lissa Roberts, Simon Schaffer & Peter Dear (eds.), *The mindful hand: inquiry and invention from the late Renaissance to early industrialization* (Amsterdam, 2007), pp. 279-305, esp. 280.
[96] This pattern reflected the traditional values through which state involvement in such matters were understood. William C. Lubenow, *The politics of government growth: early Victorian attitudes toward state intervention, 1833-1848* (Newton Abbot, 1971), esp. pp. 12, 183-185.
[97] [Henry Chatfield], 'The school of naval architecture: in reply to the "Metropolitan Magazine;" by the author of "An apology for English shipbuilders"', *The United Service Journal, and Naval and Military Magazine*, 1 (1834), pp. 227-30, esp. 228.

time when experience and 'empiricism' – 'an empiricism which pretended to despise the laws, methods, and the principles of science' – prevailed over 'the cause of science and professional skill' for credibility and authority in the Navy.[98]

Russell claimed that the government's attitude to educational provisions for naval architects was emblematic of its attitude to scientifically inclined naval architects. The current use of the school's building, Russell fumed, 'typifies and represents the condition of the science of naval architecture, as it exists and is promoted by the Government of great naval England ... It is the monument of a mutilated profession, holding up in sight of the British public the stump of its right arm.'[99] The engineer believed that naval architects had no authority except when,

> the Admiralty are driven to a new reconstruction of the English fleet, and when they can no longer proceed in the routine of copying old plans and replacing old ships, they cast about to find in the rising generation of architects, men of fresh energies, and warm zeal, and modern science.[100]

The lack of provisions for the scientific education of naval architects was also a concern to men of science who worked with the Admiralty.

William Snow Harris, a natural philosopher and fellow of the Royal Society whose work on lightning conductors lent credibility to his standing with the Admiralty, was among the fiercest advocates of opening a new school. Harris wrote a pamphlet that asked: '*How comes it that the most powerful naval and commercial country ... is absolutely without any public establishment for the cultivation of that science upon which its glory and its influence in the scale of nations so mainly depends?*[101]' Harris shared the perspective of Chatfield and Russell that the obstacle to scientific skills lay in the

[98] John Scott Russell, 'On the education of naval architecture in England and France', *Transactions*, 4 (1863), pp. 163-185, esp. 165. Thomas F. Gieryn briefly examines the cultural maps of various notions of empiricism and the identity of the mechanic in John Tyndall's work, see Gieryn, *Cultural boundaries of science: credibility on the line* (Chicago, 1999), pp. 48-62.
[99] Russell, 'Education', p. 163.
[100] Ibid., p. 168.
[101] William Snow Harris, *Our dockyards: past & present state of naval construction in the government service. Its future prospects* (Plymouth, 1863), p. 4. For Harris see Frank A. J. L. James, 'Harris, Sir William Snow (1791–1867)', *Oxford Dictionary of National Biography* (Oxford, 2004).

widespread perception that experience and tradition would guarantee naval power. Chapter two examines this perception in greater detail and explores how a third school was established and maintained in lieu of such attitudes.

Naval architects believed that obstacles to their skills were ingrained in the social hierarchy of the navy. Russell claimed that, with few exceptions, the structure and decision making culture of the Admiralty gave no authority to technical experts – a claim that implied that naval officers were not good judges of *matériel*. 'It has been well said, that no man can measure men much superior to himself, either in talent or information', Russell argued, 'how then can a first lord, possessing neither extraordinary talent nor knowledge, settle whom he shall trust, and whose advice he shall adopt'.[102] That being the case, the Board usually placed faith in noble born admirals and government bureaucrats who had a clearly defined social and institutional superiority over engineers. Russell's diagnosis was clear, 'WHERE THE KNOWLEDGE IS, THE POWER IS NOT; and WHERE THE POWER IS, THE KNOWLEDGE IS NOT ... [and] no mere mechanism of office can remedy this fatal wrong.'[103]

Russell believed that reform could only come from parliament, fuelled by a shift in public opinion regarding 'what ships it [the Admiralty] shall build; to whom it will entrust the design of these ships; to whom the execution.'[104] Thus Russell pressed the public to reconsider what skills guaranteed a good ship. The engineer drew a comparison between how British prime ministers and Napoleon III managed the *matériel* of the navy in an attempt to galvanise public anxiety and fear of French naval supremacy to emphasise his point.

> The first thing he did was to look out for the ablest man he could find; he did not search for a first lord of the Admiralty [Somerset] who had sound Tory principles, or an accomplished

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[102] Russell, *Fleet of the future*, p. 81.
[103] Ibid., p. 81.
[104] Ibid., pp. 16-7.

> nobleman of pure Whig descent. He did not look out for a Surveyor of the Navy [Sir Baldwin Walker] who never in his life had either mastered the science of naval architecture, or even possessed the practical experience of building a ship or even a jolly-boat. He did not appoint by seniority the most aged shipbuilder in the dockyard [Isaac Watts] to stand at the head of his profession, and be designer of ships for the navy. He did as any practical man would do in his own business; having got a difficult thing to do, which had not been done before, which had no precedent to guide it and no authority for an example, he looked out simply for the man of most talent - best scientific acquaintance with the principles of his profession - ... in short, the man who seemed most fitted for his work.[105]

Thus establishing that there was no one on the Somerset Board that had the skills that could guarantee naval supremacy, Russell urged the public to petition the Admiralty to cease building ships and instead buy from private yards, such as Messrs J. Russell & Co. of Millwall - therefore abolishing government dockyards and their social control of technical experts.[106]

Educational reforms and institutional redefinitions of expertise were just two facets of constructing a perception of shipbuilding that moved beyond empiricism, experience and craftsmanship. Naval architects wanted to broadly establish their ability to perform precision measurements, experiments and mathematical analysis as the key skills involved in designing and building ships - together with the authority of those who held those skills as experts, in contrast to the thousands of craftsman employed in Victorian shipbuilding. Roy MacLeod has observed that Victorian usage of the word expertise 'begins to suggest a special connotation of knowledge, set apart from general information, which is possessed by a few, who are certified as possessing that knowledge.'[107] But, as I noted in the introduction, such expertise was viewed with scepticism by the traditional ruling class. In chapter 2 I will examine this further, before returning to the issue of expertise in Part III of this thesis.

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[105] Ibid., pp. 59-60.
[106] Ibid., pp. 81-2.
[107] MacLeod, 'Introduction', p. p. 21.

1.5 The Institution of Naval Architects
Marking scientific expertise

Russell, who was known to many Victorians as one of the organisers of the Great Exhibition and an associate of Isambard Kingdom Brunel, organised a meeting in 1859 at his home in Sydenham to address the issue of technical expertise in the Admiralty. His guests were Reed (then editor of the *Mechanic's Magazine*), Nathaniel Barnaby (naval architect in the Admiralty office of Naval Construction) and Woolley (a third wrangler of the Cambridge Mathematics Tripos, formerly professor at the Central School of Mathematics and Naval Construction and presently an H.M. inspector of schools). During the evening the four men decided to form an institution of naval architects; a learned society which would encourage discussion between ship owners, Admirals, politicians, men of science and naval architects.[108] The founders of the INA simultaneously pursued an agenda of differentiating expert naval architects from shipbuilders.[109]

The first aim of the INA was to open a discourse that considered the ship as an object of scientific enquiry. Papers presented to the INA ranged from reports of Admiralty ship construction and trials to mathematical analyses of the physical phenomenon of ship behaviour. Meetings of the institution were held at the Royal Society of Arts in London and attracted hundreds of individuals from across the naval community. Reed, who served as the INA's first secretary, believed it was 'desirable to solicit the services of a number of noblemen and gentlemen of great ability and

[108] Particulars from the night are not extant. The official historian of the INA claims that Russell offered to pay any initial expenses incurred in holding meetings. Kenneth Barnaby, *The institution of naval architects, 1860-1960: an historical survey of the institution's transactions and activities over 100 years* (London, 1960), p. 8.
[109] For institutions and control see Steven Shapin & Barry Barnes, 'Science, nature and control: interpreting mechanics' institutes', *Social Studies of Science*, 7 (1977), pp. 31-74.

eminence ... who might be willing to act as Vice-Presidents.'[110] Pakington was approached to be the first president of the INA, while a number of vice-presidents were appointed from the shipbuilding and scientific communities (for the ruling council of the INA see Appendix A).[111] The founders of the INA also sought to bridge the divide between themselves and the Admiralty's administrators by appointing civilians with influence over Admiralty policy like Paget, Graham, Corry and Francis Baring to vice-president positions in order to gain legitimacy and influence (as was common practice for learned societies).[112] The INA's discussions reveal that numerous naval officers and politicians commented on papers.

Russell, Reed, Barnaby and Woolley thus used the INA to reach out to the naval community to enter a discourse with naval architects. They also used the INA to shape that discourse by highlighting a specific type of ship designer, the naval architect, and empowering him to break from the craft traditions embodied by the artisan or the shipwright. Russell informed Napier of his hope that 'The society of naval architects ... will ... be a most powerful body for the protection of the true interest of naval architects ... [from practical] shipbuilders who "know what they are about."'[113] Reed similarly used his position as secretary to isolate '[m]any of our shipbuilders [who] are not naval architects'.[114] Like Russell, Reed differentiated the naval architect from the dockyard labourers and shipwrights who had mastered the practice of ship construction through craftwork and experience. Woolley shared Reed's outlook and believed that the naval

[110] [Edward J. Reed], 'Introduction', in *Transactions*, I (1860), pp. xv-xix, esp. xvii.
[111] Pakington was not the first choice to preside over the new institution. The vice-presidents and members of council requested Algernon Percy, the fourth Duke of Northumberland, but without success. Pakington was elevated from the vice-presidency to the presidency, which he held until his death in 1880. For Pakington see Paul Chilcott, 'Pakington , John Somerset, first Baron Hampton (1799–1880)', *Oxford Dictionary of National Biography* (Oxford, 2004).
[112] For a classic study of the role of gentlemen and gentility within science see Steven Shapin, *A social history of truth: civility and science in seventeenth-century England* (Chicago, 1994). In Victorian Britain the consciousness of class was less rigid but there was still a widespread perception that the gentlemen was still the individual who would be deferred to in political and social problems, while gentleman still saw that there burden was to govern and mediate disputes, see Cunningham, *Challenge of democracy*, pp. 71-2.
[113] Russell to Napier, 31 Jan 1860, Napier Papers 90/2/4/36.
[114] [Reed], 'Introduction', pp. xv-xix, esp. xvii.

architect's distinguishing mark was their skill to perform precision measurements, experiments and mathematical analysis.[115] The intention to single out naval architects was reflected in who Russell, Reed, Barnaby and Woolley invited to a meeting to establish the INA.

The four founding members sent out forty invitations and received fourteen returns to attend a preliminary meeting. Eight of the fourteen were in the service of the Admiralty: George Turner (Master Shipwright of H.M. dockyard, Woolwich), Oliver Lang (master shipwright of H.M. dockyard, Chatham), Alexander Moore, W. Braham Robinson, Philip Thornton (all Assistant Master Shipwrights), Henry Chatfield (former master shipwright of the Royal Victoria Dockyard, Deptford), and Frederick Kynaston Barnes and J.B. Chessell Crossland (of the department of the Controller of the navy, Admiralty, Whitehall). This cluster of shipwrights from H.M. dockyards signifies the strong link between the INA, led by members of the constructor's department within the Admiralty who saw themselves as naval architects, and not the craft tradition that was prominent in the dockyards. Within this group there was a smaller social network linked by education. Chatfield, Barnaby, Barnes, Crossland and Reed (appointed Chief Constructor of the Navy in 1863) had all been Woolley's students at the Central School of Naval Architecture and Mathematics, Portsmouth.[116]

The individuals who formed the INA agreed that the institution would pursue three broad objectives. First, to bring together the various 'results of experience' from shipbuilders, engineers and naval officers. The founders believed that it was vital to establish a sense of common experience and community through which the interests

[115] Woolley vehemently disagreed with the perception within the Admiralty and the dockyard that trainee shipbuilders 'should be made far less profound in exact science ... and should take many things on trust.' Joseph Woolley, 'On the education of naval architects', *Transactions*, 5 (1864), pp. 262-71, esp. 265.

[116] Reed and Barnaby were also brothers-in-law. David K. Brown, 'Reed, Sir Edward James (1830–1906)', *Oxford Dictionary of National Biography* (Oxford, 2004). The remaining six members were John Grantham and John White (shipbuilders), John Penn (president of the Institution of Mechanical Engineers), John MacGregor (barrister), James Martin and J. Horation Ritchie (Lloyd's surveyors). [Reed], 'Introduction', pp. xv-xix, esp. xv.

and skills of naval architects might be recognised and made accessible beyond a small group of experts.[117] Secondly, pursuant of the first objective, the founders determined 'by the collective agency of the Institution' to promote 'experimental and other inquiries as may be deemed essential to the promotion of the science and art of shipbuilding, but are of too great magnitude for private persons to undertake individually.'[118] It was widely recognised that experimental enquiry required Admiralty support and the use of their ships. A single body of naval architects and technical specialists might be more persuasive than a lone experimenter in securing support. Thus the founding members placed great emphasis on utilising the INA to lend uniformity and solidarity to a disparate community of naval architects, craftsmen, engine makers, sailors and theoreticians. This was further demonstrated in the INA's third objective, 'the examination of new inventions, and the investigation of this Institution, because no public body to which professional reference could be made, then existed.'[119] The notion that the INA alone could examine new inventions reflects the institutional and social character of the expertise that founding members of the INA wanted to mark.[120]

The INA was an imagined community, for it was dispersed over dockyards, draughtsmen's offices, sites of experiment and universities, yet had at its core a particular identity. The founding members all shared an approach to ship construction that was scientifically orientated, encouraged precision measurements and trusted in mathematics and experiment. These skills and activities were actively promoted as symbols of identity that could be used to tell naval architects from non-naval

[117] 'Objects of the institution', *Transactions*, 1 (1860), pp. xxv.
[118] Ibid., pp. xxv.
[119] Ibid., pp. xxv.
[120] The creation of expertise through exclusion demonstrates an important way in which expert status rests on socialization into a defined community of experts, see Harry Collins & Robert Evans, *Rethinking expertise* (Chicago, 2007), pp. 79, 91.

architects.[121] Reed believed that the greatest obstacle facing the INA was to mark out the 'few real naval architects in the country', and promote their expertise within the naval community.[122] To establish the different categories of expertise Reed designated the individuals who subscribed to the INA as 'member' or 'associate member'. In 1859 Reed asked Napier to suggest some names for nomination to the society,

> it being understood that Members should be such persons who are in your judgement worthy to be deemed "naval architects" - persons who may write after their names "M.I.N.A.", without in any way discrediting the Institution. Associate members are to be such shipbuilders, marine engineers, officers of the Royal and Mercantile Navies, men of science, and other gentlemen as may be able to co-operate with naval architects in the advancement of their profession.[123]

Members of the INA promoted their expertise through a number of mediums and discourses. The first paper presented to the Institution, Woolley's 'On the present state of the mathematical theory of naval architecture', outlined the national danger of neglecting the science of shipbuilding. The former professor of naval architecture described the weakness of a 'rule of thumb' approach to design, by which he meant 'the adoption of some approved lines, with little or no modification'.

> Those designers who resort to this mode are pretty safe, and may generally calculate on producing a good vessel; but they make no step in advance of existing practice, they add nothing to the professional science; and whenever the majority of designers are of this class, and persist in all their ships in perpetuating some received model, refusing to accept improvements, because unable to judge of their real merits...[124]

Woolley firmly laid down his belief that shipbuilding was both a 'professional science' and an art. He added to this an alarmist concern that without scientific enquiry 'the practice of ship-building must on the whole be stationary, and the country where this state of things exists must be content to see her ships surpassed by those of a country where science is in more request.'[125] Thus members of the INA promoted naval

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[121] See Benedict Anderson's exploration of how cultural symbols and codes of interaction shape and fortify common identity, Benedict Anderson, *Imagined communities: reflections of the origin and spread of nationalism* (London, 1983).
[122] [Reed], 'Introduction', p. xvi.
[123] Reed to Napier, 31 Dec. 1859, Napier Papers 90/2/4/39.
[124] Joseph Woolley, 'On the present state of the mathematical theory of naval architecture', *Transactions*, 1 (1860), pp. 10-38.
[125] Ibid., p. 10-38.

architecture by speculating over the comparative weakness of support for the science of shipbuilding in Britain.

The founding members of the INA were not always in agreement over how to advance their profession, and on a number of occasions disagreed over to what extent the skills and practices of trained men of science and engineers could benefit their own working practices. The earliest of these disagreements concerned William Froude, an Oxford trained mathematician, and his use of model experiments to understand the subject of ship roll (see chapters 3 and 5). Reed, who supported Froude's work, told the institution that,

> it is some discredit to us as naval architects to know that we are behind hand with many question of importance - that we are obliged, for example, to commit the question of the rolling of ships to my friend Mr. Froude - an engineer - and that he, an engineer, and not professionally a naval architect, has taken a high position in respect of one of the profoundest problems in naval architecture.[126]

I will discuss the members of the INA and their debates throughout the thesis. Chapter 7 specifically explores how members marked the boundaries of expertise, developed the institution's identity as an imagined community and cemented its place in the material naval community.

1.6 Conclusion

The *matériel* changes of the early 1860s complicated what had previously been a well defined culture of naval power, ship construction and autocratic Admiralty authority. Thus 'the power-political framework in which the Pax Britannica operated', which Paul Kennedy has argued remained unchanged during this time, was about to undergo a

[126] Russell, 'Education', p. 183.

significant reconfiguration.[127] The transition from wood to iron was more than a material shift, it was cultural and social, and infused debate over naval power with a consciousness of the construction (and increasingly) the science of the ship. I have shown that the politics of naval supremacy cannot be reduced to economic and strategic debates between aristocrats, administrators and admirals. Trials with ironclads, the continuation of wood shipbuilding and widely publicised criticisms of shipbuilding policies embroiled numerous Boards of Admiralty in Victorian Britain in discussions concerning the 'management of *matériel*', 'social control and shipbuilding', 'science as a guarantor of naval power' and 'marking expertise'.[128]

An analysis of 'who' and 'what' shaped the Victorian navy must examine the interactions between the traditional guarantors of naval supremacy (admirals and administrators), the class of engineers who were actively engaged in marking the boundaries of their expertise and the *matériel* – the ships – that linked them. These social groups simultaneously negotiated and shaped influential Victorian discourses of 'financial mismanagement, 'progress', 'mechanics', 'aesthetics', 'economics', 'experience', 'experiment', 'naval threats' and 'scientific expertise' to gain authority and credibility. The remainder of this thesis examines how naval architects negotiated these discourses through the 1860s, 70s and 80s as they reconfigured the identity of the ship as an object of science and 'engineering science'.[129] Lastly, by placing the focus on the culture of naval supremacy instead of personalities and policies, insights are opened on the broad issue of 'who manages best' that contribute to the patchy history of the culture of expertise in government-science relations in Victorian Britain.

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[127] Kennedy, *Naval mastery*, pp. 177-78.

[128] For Victorian discussion of trust in ironclads, see Winter, '"Compasses all Awry"', pp. 69-98. For ironclads and political intrigue see the case of the H.M.S. *Captain* in chapter 6.

[129] For issues of actor control and black-boxing technology see Donald Mackenze & Judy Wajcman, 'Introductory essay: the social shaping of technology', in Donald MacKenzie & Judy Wajcman (eds.), *The Social Shaping of Technology* (Buckingham, 1985, 2nd edt. 1999), pp. 3-28, esp. 22.

2

Theory, practice and education in a craft culture

There is probably no section of engineering science of greater national importance to this country than what may be called marine engineering, embracing the science of naval architecture, and the designing of engines and machinery for the propulsion of vessels. There is at the same time no section of engineering work in which so many experiments are made; and yet out of all these experiments very few are of real use, even to those who conduct them, and not one in a hundred is of the slightest value to the rest of the world, including the hungry little army of investigators already mentioned.

Engineering report on wasted opportunities to use ship trials as accurate experiments.[1]

Practical men believed that the idol whom they worship - rule of thumb - has been the source of past prosperity, and will suffice for the future welfare of the arts and manufactures. They were of the opinion that science is speculative rubbish; that theory and practice have nothing to do with one another; and that scientific habit is an impediment, rather than an aid, in the conduct of ordinary affairs.

T.H. Huxley responds to the 'anti-intellectualism' approach to Victorian engineering.[2]

Victorian engineers frequently criticised the Admiralty for its uncritical enquiry, imprecision and lack of standardised measuring procedures in designing the ships on which Britain's Imperial strength rested. Professed practitioners of 'engineering science' wanted more accurate methods than those commonly deployed in the dockyard and during the ship trial for understanding the 'performance' of vessels. The 'army of investigators' on the seas - an idea which resonated with ideas of empire and scientific inquiry in Roderick Murchison's geological survey - constituted a powerful social group, but they were perceived by a core of self-styled 'scientific experts' to be more concerned with naval traditions than disciplined standards of measurement.[3] A similar critique was made of the British dockyards that were home to well-trained technicians who learnt craft-practices through experience and slowly perfected the art of shipbuilding. W. Gowling, a critic of craft-practice, wrote that in the dockyards 'the teachings of

[1] [Anon.], 'Trial trips', *Engineering*, 23 October 1874, p. 323.
[2] T.H. Huxley, 'Science and culture' (1880), in *Science and education: essays* (New York, 1893), p. 137.
[3] For 'imperial science' see Robert A. Stafford, *Scientist of empire: Sir Roderick Murchison, scientific exploration and Victorian imperialism* (Cambridge, 1989), pp. 189-223, esp. 194; Paul White, *Thomas Huxley: making the "man of science"* (Cambridge, 2003), p. 36.

experience are equally as slow as they are sure, and the dim gropings after excellence may be greatly expedited by the light of theoretical considerations.'[4]

Gowling was a student of the Royal School of Naval Architecture and Marine Engineering (RSNA), an establishment founded in 1865 to create a physical and pedagogical space for mathematics and experiment in ship design. This school, located in London's emerging centre of technical training in Kensington, had been the idea of the INA, which had itself only been established in 1860. The institution wanted to open naval architecture to greater scrutiny and publicity, bringing admirals, ship owners, engineers, artisans and men of science into discussion with each other. The previous chapter argued that although INA welcomed a variety of papers from a wide selection of professions, its early meetings were dominated by 'scientific engineers', such as John Scott Russell, Joseph Woolley, Nathaniel Barnaby and Edward Reed, who wielded a specific agenda. These individuals sought to make the design of ships a science, based on mathematical principles and critical observations of 'the way of a ship in the midst of the sea'.

This chapter explores how INA members made a space in which they could educate scientific experts in a craft culture. The analysis begins by surveying the matrix of 'working knowledge' that shipwrights used in Britain prior to the spread of 'scientific shipbuilding'. My focus on 'working knowledge' draws on scholarship in the history of science that emphasises 'production', 'practice' and 'mind/hand' dynamics.[5] John Pickstone's notion of 'working knowledge' is particularly insightful as a frame for breaking down traditional historiographical divisions between practice and knowledge, and instead examining the 'various modes of work ... [that] have different histories and

[4] W. Gowling, 'Technical education of naval architects', *The Annual of the Royal School of Naval Architecture and Marine Engineering*, 2 (1872), pp. 21-8, esp. 23-4. As a student at the Royal School of Naval Architecture and Marine Engineering Gowling had experienced dockyard practices, but also advanced mathematics and material sciences.

[5] Simon Schaffer, '[Art and industry:] Introduction' in Lissa Roberts, Simon Schaffer & Peter Dear (eds.), *The mindful hand: inquiry and invention from the late Renaissance to early industrialization* (Amsterdam, 2007), pp. 309-323; Sheila Jasanoff (ed.), *States of knowledge: the co-production of science and social order* (London, 2006); Jan Golinski, *Making natural knowledge: constructivism and the history of science* (Chicago, 2005), pp. 79-102.

form different patterns across time.'[6] The connections this chapter examines between craft, art, theory and science within the shipbuilding community that had been shaped by its long tradition of craftwork provides a fresh perspective on scientific and engineering theory and practice.[7] Instead of focusing exclusively on the perspectives of scientists and engineers I describe the discourse that existed between them and the administrators, politicians and sailors who were largely unsympathetic to 'theory', and administered the educational system that scientists and engineers sought to reform.

This chapter examines the following questions: what traditions governed the building of the ship? What values were important in the dockyard and the drafting room? And how did 'science', as it was understood by a variety of actors, complement, complicate, elevate and alienate craftwork? I examine how advocates of a 'scientific' approach to ship design used spatiality, public opinion and cultural symbols to gain independence from administrators, politicians and aristocratic admirals, and took control of the education and training of naval architects.

The 'scientific' was a powerful theme in Victorian Britain. It represented a new way of thinking and working which was analogous with the economic and material interests of Victorians. Chapter 1 began to examine how mathematics and science were rhetorically used in the public sphere as guarantors of power, peace and prosperity. This chapter explores how mathematics and science were institutionalised in the RSNA and taught to students. I examine how advocates of a scientific approach to ship design negotiated space and place to make their agenda and approach credible. I conclude by arguing that the making of scientific experts in a craft culture was a social, cultural and

[6] John V. Pickstone, 'Working knowledge before and after circa 1800: practices and disciplines in the history of science, technology and medicine', *Isis*, 98 (September, 2007), pp. 489-516, esp. 495.

[7] For studies which examine the tensions and harmonies between theory and practice see Ben Marsden, 'Engineering science in Glasgow: economy, efficiency and measurement as prime movers in the differentiation of an academic discipline', *BJHS*, 25 (1992), pp. 319-346; David F. Channell, 'The harmony of theory and practice: the engineering science of W.J.M. Rankine', *Technology and Culture*, 23 (1982), pp. 39-52. Contrast these contextual studies with the 'universal', philosophical definitions attempted in the early years of the Society for the History of Technology, for example, Mario Bunge, 'Technology as applied science', *Technology and Culture*, 7 (1966), pp. 329-347; James K. Feibleman, 'Pure science, applied science, technology, engineering: an attempt at definitions', *Technology and Culture*, 2 (1961), pp. 305-317.

political struggle that reflected traditions and tensions in Victorian society, especially with regard to the naval community and the culture of expertise that prevailed in the government's relationships with one of its largest industries, shipbuilding, and formidable social and cultural institutions, the Royal Navy.

2.1 WORKING KNOWLEDGE
Art, craft and mechanics

The Georgian navy had been built within a craft environment (pejoratively referred to by 'scientific' engineers as rule-of-thumb) controlled by shipwrights and aristocratic Admiralty administrators. The work undertaken in this environment was guided by the generational lessons and expertise of artisans in dockyards, the experiences of sailors at sea, and intellectual piracy. If the lines and proportions of a ship were found to make for a fast, responsive and stable vessel, they were often made the blueprint for future designs.[8] Yet within this tightly controlled system of dockyard working knowledge where invention and manufacture were bound-up in the utilitarian needs of Admiralty administrators there was some space for science. Simon Schaffer has argued that the Royal Navy's place at the heart of the 'fiscal-military state' makes the dockyard 'a remarkable site for historical reflection on the relation between knowledge and skill in the epoch of industrialization.'[9]

Schaffer argues that terms such as 'reason', 'theory' and 'experiment' had particular politically and socially contingent meanings in Georgian Britain through

[8] Gowling explained that the ship designer, 'when called upon to design a vessel ... must rely on some good type of the ship required and make his own as like it as circumstances will allow.' Gowling, 'Technical education', p. 25. Also see the traditions described in James Pritchard, 'From shipwright to naval constructor: the professionalization of 18th-Century French naval architecture', *Technology and Culture*, 28 (1887), pp. 1-25.

[9] Simon Schaffer, ' "The charter'd Thames": naval architecture and experimental spaces in Georgian Britain', in Lissa Roberts, Simon Schaffer & Peter Dear (eds.), *The mindful hand: inquiry and invention from the late Renaissance to early industrialization* (Amsterdam, 2007), pp. 279-305, esp. 281. Also see the important contributions in Steven A. Walton (ed.), *Instrumental in war: Science, research, and instruments between knowledge and the war* (History of Warfare Series, vol. 28, Brill, 2005); Merritt Roe Smith (ed.), *Military enterprise and technological change: perspectives on the American experience* (Cambridge, MA, 1985).

which naval architects sought to distinguish themselves from shipwrights.[10] William Shubsole, a dockyard labour campaigner, believed that shipwrights alone made discoveries and 'savings' in shipbuilding, apart from mathematicians, and so they sought to be 'recompensed'. In his view the navy's sites of 'calculation' and 'mathematical ingenuity' were to be found in the workshops of naval dockyards, quite at odds with a nineteenth century meta-narrative of scientism.

On the other hand, John Sewell's 'genteel' Society for the Improvement of Naval Architecture and its anti-France, anti-labour members wanted to elevate an elite class of mathematically trained scientific experts.[11] Schaffer notes that the society 'would simultaneously accumulate texts and models for public display in the City, pay for large-scale model trials in the yards of the Rotherhithe builders and agitate publicly for the foundation of a new naval architecture academy under government administration where proper attention would be given to mathematics.'[12] The society was also responsible for heightening the perception that French warships were faster and more powerful, 'diagnosing this as a result of state support for academic hydrography.'[13]

Schaffer's study of the military and monetary organisation of the Georgian dockyard draws out the social and spatial politics that shaped sites of experiment and the distribution of knowledge and control over the shipbuilding process. The institutional and spatial control of mathematics and experiment, for example, can tell us how science was ordered, where its boundaries (cultural and geographical) lay and whether experts or administrators controlled it. Such an analysis helps define the cultural processes through which 'working knowledge' was made and organised. Thus it is possible to put 'reason', 'theory' and 'experiment' back 'in the places where politicized

[10] Schaffer, ' "The charter'd Thames"', p. 279.
[11] Simon Schaffer, 'Fish and ships: models in the age of reason', in Soraya de Chadarevian & Nick Hopwood (eds.), *Models: the third dimension of science* (Stanford, 2004), pp. 71-105, esp. 87-91.
[12] Schaffer, ' "The charter'd Thames"', p. 299.
[13] Ibid., p. 299. For further details on the French organisation of science and shipbuilding see Pritchard, 'Shipwright to naval constructor'.

languages of art and practice provided their peculiar forceful sense' – as opposed to their modern meanings.[14]

Historians who have written on the ship during the middle of the nineteenth century begin by celebrating the era of artisan shipbuilding and then mark a definite point-in-time at which craft-practice became a folly because iron ships, for one teleological reason or another, required a treatment inherently modern and obvious. Stanley Sandler, in one of the most authoritative accounts of the ship revolution, argued that 'The new technology of iron shipbuilding demanded far more sophisticated methods of design and construction than the traditional rule-of-thumb system that had served the Royal Navy so badly in the past.'[15] Iron ships certainly required a new set of methods and a fresh body of knowledge concerning hydrodynamics, but Sandler's judgement on the toothlessness of the rule-of-thumb system is unhelpful. The dynamic between science and craft requires a nuanced analysis of how ship designers worked knowledge and produced *matériel* in an environment split between those who celebrated and those who were suspicious of mechanics.

Agitators for scientific training and the experimental study of hydrodynamics successfully established a school of naval architecture in 1810, but it was closed in 1833. Model experiments gained little credibility, shipwrights secured their authority in the dockyard and the Society for the Improvement of Naval Architecture folded. Thus the Victorian advocates for a scientific approach to ship design began their petitioning without a specialised society until the INA was formed in 1860. Instead dockyard workers contributed to discussion at meetings of the Royal United Service Institution and the Company of Worshipful Shipwrights, while mechanically and scientifically

[14] Schaffer draws a comparison between his essay and Ken Alder's *Engineering the revolution: arms and enlightenment in France, 1763-1815* (Princeton, 1997), as both studies examine how 'controversial changes in the form of life of engineers and artisans accompanied programmes to transform and manage the role of analysis and experiment.' Schaffer, ' "The charter'd Thames"', p. 279, 283.

[15] Stanley Sandler, *The emergence of the modern capital ship* (Newark, 1979), p. 33. Also see John Beeler, *Birth of the battleship: British capital ship design 1870-1881* (Chatham, 2001).

minded naval architects who worked outside of the traditional spaces of shipbuilding contributed to the British Association for the Advancement of Science, Institute of Mechanical Engineers and Institution of Civil Engineers. The mid-Victorian generation reignited the institutional concerns of Georgian reformers and brought to bear their Victorian values and views on mechanics, mathematics and experiment. Individuals from the respective craft and scientific cultures of ship design thus continued to negotiate their relationships within and between their social networks - and also with the governments that funded their activities.

Shipwrights - a term used largely by craft-orientated ship designers for collective identity - continued to shape the ship through experience and approximation. John Fincham, Master Shipwright at Her Majesty's dockyard, Portsmouth, noted in his *A history of naval architecture* (1851),

> It was not only during the earliest ages of the employment of ships, that the art of building them had to carried on separately from the aid of science in their construction; but this state of things has marked almost the entire course of history. If we turn back to centuries that have passed away, we perceive that ships have been built much in accordance with the ages respectively, determined ultimately, as mechanical skill was able to give a good or only an indifferent effect to the designs of constructors.[16]

Fincham was one of the leading shipwrights in Britain in the first half of the nineteenth century, contributing to the Royal Navy with ships like H.M.S. *Raleigh* (1845). His expertise drawn from experience was sought for government committees such as the Committee of Reference that met in 1848 to examine the design of the ships that had been introduced into the navy during William Symonds' reign as surveyor (1832-1847).[17]

Fincham was struck by how the art of shipbuilding did not wait for a 'scientific' basis upon which the ideas and practices of shipwrights might be grounded. The activities of shipwrights, as with craftsmen in any age, were governed by the mechanical

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[16] John Fincham, *A history of naval architecture: to which is prefixed, as introductory dissertation on the application of mathematical science to the art of naval construction* (London, 1851), p. ix.

[17] Andrew Lambert, *The last sailing battlefleet: maintaining naval mastery, 1815-1850* (London, 1991), pp. 79, 82, 84-85, 90.

contrivances and methods of control (be it regarding labour, industry or inventiveness) relevant to the historical era.[18] Fincham argued that 'mathematical science' had not necessarily affected the art of shipbuilding.

> [T]here were tastes proper to countries as well as to periods marking a state of rudeness or of comparative refinement, long before any thing like a scientific basis was laid for so important an art. The development of art *never waited for this basis*; necessity impelled it onwards; and, gathering on the side of truth, and rejecting on that of error, a long course of experience produced ships of a high order of excellence, and capable of fulfilling the objects of their respective periods, before any theory of naval construction existed.[19]

The art and science of shipbuilding were frequently referenced together by ship designers, but not always in the manner that Fincham had in 1851. 'Science', as a label, was new to the nineteenth century and did not exclusively mean natural philosophy to the Victorians. 'Science' was understood to mean a range of ideas, ideals and activities sometimes old and sometimes new – sometimes in disagreement with each other.[20] The likes of Edward Reed, Nathaniel Barnaby and Joseph Woolley, who wanted to build credibility and acquire government support for mathematics, theory and experiments through the INA, referred to 'art' to elicit the cultural authority of tradition and experience.[21] At the outset of *Shipbuilding: theoretical and practical* (1866), a voluminous and dense work of structural engineering, hydrodynamics and marine engineering, the co-authors, Isaac Watt, Frederick Barnes, James Robert Napier and W.J. Macquorn Rankine, expressed their hope that '[t]his treatise provides a complete system of influence on the Art of shipbuilding and on the scientific principles upon which it is founded, at a price within the means of the general body of practical men who are

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[18] See for example the series of dockyard reforms described, largely in 'intellectual' detail which ignores how administrators and labours responded, in William J. Ashworth, ' "System of terror": Samuel Bentham, accountability and dockyard reform during the Napoleonic Wars', *Social History*, 23 (1998), pp. 63-79.

[19] Fincham, *Naval architecture*, p. ix.

[20] See for example the types of science and range of meanings in George Levine, 'Defining knowledge: an introduction', in Bernard Lightman (ed.), *Victorian science in context* (Chicago, 1997), pp. 15-23; Roger Cooter & Stephen Pumphrey, 'Separate spheres and public places: reflections on the history of science popularisation and science in popular culture', *History of Science*, 32, (1994), 237-67.

[21] The circumstances of these tensions and the vital significance of the craft traditions of the navy distinguish the politics of this case-study from studies of theory and practice in academic and scientific contexts. Contrast Fincham's rhetoric with Rankine's 'diplomatic and propagandistic skill' in the construction of 'engineering science' in Glasgow, see Marsden, 'Engineering Science', p. 320-21, 321, 326-330.

engaged in that Art.'[22] These naval architects – a contrasting label to 'shipwright', increasingly used to forge a collective identity for scientifically-minded ship designers – were happy to rhetorically refer to 'art' as they built credibility for scientific ways of thinking and working.

Shipwrights like Fincham, in contrast, were less keen to stress the scientific nature of their work. They saw less practical purpose in the use of theory and experiment, and yet from time-to-time talked of a science of ship design, albeit that it meant something else when it came to working in the dockyard. Fincham was a professional shipwright working in a government dockyard. He expressed some favourable views towards the science of ship design in moderation. For example, he supported efforts to ensure mathematical training for shipwrights because he was worried that science and hydrodynamic theories could be harmful if taught too eagerly to young ship designers.

Fincham demonstrated this understanding of science in an explanation for why he recommended Pierre Bouguer as a model example to scientifically minded ship designers who sought to understand the activities of shipwrights and shed light on their workings.

> [H]e [Bouguer] distinctly acknowledges the insufficiency of abstract reasoning to reach the end he had in view, whilst he had proof enough of the inadequacy of knowledge derived simply from practical sources. "Experience would be the best means of perfecting naval architecture, if the thing were possible; but it is plain enough that practice is insufficient in many cases. It is certain, that if this alone is capable of rendering some parts perfect, it has need, in an infinity of others, to be aided by the light of theory."[23]

Thus Fincham understood the value of 'science' through the *theories* it generated that could suggest ways of improving the dockyard work he was expected to do in a craft environment. Science, in Fincham's view, could never offer ship designers the practical lessons that could be learnt from experience. Science was an important feature of Fincham's toolbox, but it was not the most valued.

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[22] Isaac Watt, Frederick Barnes, James Robert Napier and W.J. Macquorn Rankine, *Shipbuilding: theoretical and practical* (London, 1866), p. 1.
[23] Fincham, *Naval architecture*, p. xxii.

Fincham appeared to have expected clear, concise and applicable lessons from science to aid the practice of ship design. He admired a 'well-constructed theory' which could be universally applied and help decision making: 'anticipate all coming time, and are applicable in all conceivable diversities of practice'.[24] But Fincham also recognised, perhaps lamented, the 'extreme difficulty of applying abstract principles to so complicated a machine, with the conditions of its proper element so little understood'.[25] Thus he struggled to harmonise the new materials, mechanical contrivances and scientific texts of hydrodynamics within his parameters of working knowledge. Compare Fincham's position to Samuel Bentham's, who earlier in the century urged that "[p]ractice alone may show how work has been done, but practice is insufficient to teach how it *ought* to be done."[26] The contrast lay in an individual's valuation of 'science', 'reason', even 'theory', as ways of working, but also understanding and management of naval *matériel.*

Fincham drew a fresh line dividing the craft (the traditional art and the application of science which could be assimilated into his working knowledge) and the abstract theories and knowledge which could not be readily applied or were coded in the language and style common to natural philosophy – take for example the work of William Whewell and Rankine on waves and fluids which were written more for an academic audience than a working audience.[27] As such, Fincham concluded that the 'common aversion in practical ship-builders to have recourse to theory' – an aversion which marred the 'difficulties and discouragements of science' in ship design – was

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[24] Ibid., p. xiii.
[25] Ibid., p. xiii.
[26] Ashworth, ' "System of terror"', p. 68.
[27] For example see Ben Marsden, ' "The progeny of these two "Fellows"": Robert Willis, William Whewell and the sciences of mechanisms, mechanics and machinery in early Victorian Britain', *BJHS*, 37 (2004), pp. 401-434.

unlikely to change until mathematics and theory were either made self evidently 'useful' or scientifically trained ship designers could express their authority as 'experts'.[28]

Neither of these conditions had been successfully accomplished when the INA began to meet in London. Craftwork remained trustworthy well into the second half of the century and this was reflected in the meetings of the INA. Craftwork was not inherently old fashioned. It emphasised artisan expertise and tried and tested working practices at a time when shipbuilders and owners grappled with the problems and possibilities of iron. Moreover, craftwork was believed to produce 'practical' and trustworthy vessels precisely because they built on experience and tradition, rather than abstract theory, experiment and speculative behaviour.[29] William Denny, for instance, an advocate of scientific shipbuilding, complained that a large number of individuals in the naval community categorized his ideas and working practices as mere 'dilettante amusement'.[30]

Cumbria-based Charles Lamport, a self professed 'practical shipbuilder', presented a paper to the INA in 1865 which instructed members to place faith in experience and safe-compromises.

> The best model for a merchant ship realizes the most perfect adjustment of a series of compromises. No one good quality can be obtained in full, without the sacrifice of some other. The attainment of speed, *à priori*, means the relinquishment of capacity. Stability trenches upon ease of motion, while deep rolling is the price paid for the advantages of great length. A sharp ship will pitch deeply, and one that can stand well up to her canvas may be so laboursome as to endanger her masts.[31]

Lamport's insights, shaped by his strong social links with ship owners, captains, entrepreneurs and engineers, provide a valuable critique of the state of naval architecture in the 1860s and how it was understood by the social networks of

[28] Fincham, *Naval architecture*, p. xiii.
[29] Ben Marsden & Crosbie Smith, *Engineering empires: a cultural history of technology in nineteenth-century Britain* (Basingstoke, 2005), pp. 149-50, 151, 157, 165.
[30] A.B. Bruce, *The life of William Denny: shipbuilder, Dumbarton* (London, 1889), pp. 163-64.
[31] Charles Lamport, 'The problem of a ship's form, as presented to the practical builder', *Transactions*, 6 (1865), pp. 101-115, esp. 101.

shipowners and merchants who profited from the operation of ships after they had been built.

Lamport was guided by a utilitarian philosophy that emphasised 'usefulness' and 'economy'. As such he based his manual work designing ships and his papers to the INA on commercial judgements that valued the use of capital, the practicality of a ship design and the reliability of the vessel produced. Lamport's chief concern as a ship designer was to produce efficient ships, an agenda he shared with his Liverpool colleague and brother William J. Lamport and his partner George Holt.[32] Lamport shared their hostility to the empty promise of progress without utility. His approach to building efficient ships was not based on a desire to utilise theory and experiment, but economics and experience: 'let the owner test the designer's skill by the results in his ledger, rather than in the ship's log'.[33] Thus Lamport's explicit concern was whether science was a guarantor of efficiency. The response to this question – which was also frequently the guide by which scientific ways of working were judged in Victorian Britain at large – was important for the credibility of scientific experts in the craft culture of ship design.[34]

Lamport's 1865 INA paper made specific reference to Mark Beaufoy's stability experiments, undertaken at the Greenland Dock with aid of the Society for the Improvement of Naval Architecture. 'The practical designer who takes data determined by such experiments as his guide,' Lamport told INA members, 'builds upon hollow ground; for being defective and illusory, they require much tentative and practical skill for even the most partial application.' The implication was that experiment shed light on the science of hydrodynamics but confused shipbuilders whose job was to build an effective ship based on commercial use or military efficiency. Scientific research did not

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[32] Crosbie Smith, Ian Higginson & Phillip Wolstenholme, ' "Imitations of God's own works": making trustworthy the ocean steamship', *History of* Science, 41 (2003), pp. 1-48, esp. 20-23; Crosbie Smith, Ian Higginson & Phillip Wolstenholme, '"Avoiding equally extravagance and parismony": the moral economy of the ocean steamship', *Technology & Culture*, 44 (2003), 443-69, esp. 444-50.

[33] Lamport, 'Ship's form', p. 102.

[34] For a survey of various meanings of efficiency see Jennifer Karns Alexander, *The mantra of efficiency: from waterwheel to social control* (Baltimore, 2008).

evidently produce efficiency.[35] Lamport instead felt that science muddied the waters: 'without in the slightest degree undervaluing the labours of mathematicians, as regards scientific construction, I venture to affirm that it would be unsafe for a builder to model his ship altogether according to their deductions.'[36]

Lamport shared Fincham's belief that the interaction of theory and practice - and the exchanges between ship designers interested in mathematics and theory and shipwrights drawing on craft tradition - was too tense and awkward for a harmonious relationship. Lamport thus rejected both approaches.

> I have endeavoured to take it [naval architecture] out of the hands of mathematicians, not because I undervalue the results of their labours, but because I believe that the mistake in shipbuilding in this country is that nine out of ten ships are built by what is called rule of thumb. I do not know whether Mr. Scott Russell and Professor Rankine will agree with me in this opinion, but I have a practical acquaintance with many shipbuilders in this country who assure me that to a great extent this is the condition of our naval architecture.[37]

Lamport envisaged stark divisions between the 'benefit' of experimentation and experience in the ship design process. His opinion, however, was not shared universally in the INA. For example, Rankine, a professor of engineering at Glasgow University, supported Lamport's argument albeit with reservations.

Rankine had profited from a working relationship with Napier, a Clyde-based naval architect and marine engineer who designed many ships for commercial buyers. Rankine put much greater emphasis on the usefulness of mechanics and mathematics than Lamport, but he shared his scepticism towards model experiments (I will further examine the role and identity of models in chapter 3). Rankine, who advocated an ideal and practice called 'engineering science' which was distinguished from 'pure science' and 'pure practice', told members of the INA that there was a 'great superiority of experimental data obtained by the performance of actual vessels in various sorts of

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[35] Frank M. Turner, *Contesting cultural authority: essays in Victorian intellectual life* (Cambridge, 1993), pp. 177, 180-82.
[36] Lamport, 'Ship's form', p. 103.
[37] Lamport, 'Ship's form', p. 114.

weather over experiments made by models and in smooth water.'[38] Rankine and Lamport both wanted to produce knowledge based on the experiences of steam ships but their respective emphasises on commercial utility or scientific knowledge and hydrodynamic theories differed.

Russell pursued a more optimistic relationship between science and shipbuilding, through which scientists, engineers, sailors and ship owners (be they commercial owners or the Admiralty) might develop a common perspective on the requirements of use and the requisite of progress. Russell believed that the ends of the engineer and the entrepreneur were essentially the same: 'we can, by laying our heads and hands together, successfully work out the great object we both so earnestly desire, of seeing the Navy of England continue to maintain its distinguished position in the new era of naval tactics and of naval construction which we now see opening before us.'[39] Thus scientific knowledge, developed with the aid of mathematics, theory and experience, was knowledge which could help shipbuilders understand what made an efficient ship. As this idea became popular the controversial issue of control and expertise grew in importance.

The trials of newly built ships became a source of controversy to scientifically inclined, exacting, enquirers. The engineering press complained of the untrustworthiness of ill-defined trials, the frequency of incorrectly read measuring apparatus, the absence of second witnesses and the simple forgetfulness to make measurements. Contributors to *Engineering* pressed for changes to the treatment of sea trials and their significance as sites of experiment.

> A trial trip might be rendered a complete scientific experiment upon the largest scale, and under all, or nearly all, the conditions of actual practice – just the kind of experiment, in fact, which is most urgently needed. The short-sightedness of the system which, partly to save a

[38] Lamport, 'Ship's form', p. 110. For Rankine's 'engineering science' and views on model experiments see Marsden, 'Engineering science', p. 320-21, 335-36.

[39] John Scott Russell, 'On the professional problem presented to naval architects in the construction of iron cased vessels of war', *Transactions*, 2 (1861), 17-37, esp. 18.

> few pounds and a little trouble, and partly to make a "vain show," converts a *trial* into a *trip*, must be strongly condemned.[40]

The working knowledge that naval architects believed could be produced by extending the system of mechanical observations and the authority of scientifically minded experts over the ship design and trial process became a key debate in mid-Victorian engineering and naval communities. This issue resonated in a society that was suspicious that measurement and mechanics removed the veil of tradition and challenged the social control of aristocrats and administrators. Naval architects leading the increasingly influential INA wanted greater control over naval architecture and placed the issue of education at the heart of its petitions to the government.

2.2 A GOVERNMENT SCHOOL?

The most striking feature of the education provisions for naval architecture was how scarce it was. In 1860 there was no government school. Nor were there private courses in universities. There was no formal mechanism to learn naval architecture as a field of knowledge, theories and working practices combined. This was not surprising given that there was no formal engineering degree offered in the UK until the end of the nineteenth century. The education of naval architects either came from shipyard apprenticeships or university mathematics and natural philosophy courses. John Scott Russell, for example, had been a student of natural philosophy at Glasgow (and briefly a professor of natural philosophy in Edinburgh). William Froude, not strictly a naval architect but a civil engineer, had studied mathematics and classics at Oriel College, Oxford before undertaking an apprenticeship with the railway designer Henry Palmer. The first university provisions for naval architecture began in 1883 at Glasgow with the creation

[40] 'Trial Trips', *Engineering*, 23 October 1874, p. 324.

of the Elder Chair of Naval Architecture, endowed by John Elder's wife and held by Francis Elgar (formerly a student of the RSNA).

The issue of making new experts of ship design and ship behaviour was thus immensely contingent on the culture of craftwork through which much ship design and shipbuilding was managed. The INA's petition to the government to sponsor a new school of naval architecture (this being the third) was dependent on the tensions examined above: the place of calculation, experiment and control over knowledge; whether theory could be assimilated into a 'working knowledge' matrix; and the tensions between utility, experience, speculation and experiment. The credibility of the scientific 'expert' depended on wider trust in the notion that science was a guarantor of efficiency.

Russell used a paper at the INA to make the case for a new school. Russell, who had been the driving force behind the formation of the INA, observed that promising naval architects, including among them present Admiralty constructors and the sons of commercial ship designers, were sent to Toulon, L'Orient and Paris to learn the mathematics and science necessary to understand the theories and practices of ship design from naval architects like Dupuis de Lôme and M. Reesch.[41] The influence of citing an Anglo-French rivalry built momentum for Russell's justifications. He alluded to the belief that while Britain produced the world's finest sailors, they were forced to fight in some of the world's most poorly planed vessels. Russell joined to this point his belief that the union of science and craftsmanship would produce better ships.

INA members who claimed superiority for French ships rested their claim on a belief that the application of science and mathematics guaranteed a successful ship. Woolley spoke with envy at how,

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[41] John Scott Russell, 'On the education of naval architecture in England and France', *Transactions*, 4 (1863), pp. 163-185, esp. 164.

> men [such] as Bouquer [sic], the Bernouillis, and Euler, were invited [by the French navy] to give their attention to this subject, and their investigations were treated not as mere theories having but a remote, if any bearing on the actual design of ships, but on the contrary, as affording a true basis for the principles on which their ships were built.[42]

This view has been shown to have been based largely on a perception of how France's shipwright profession was educated and organised.[43] More difficult, however, was the process of building credibility and support for the claim that connecting science, practical arts and mathematical training made for efficient and powerful ships. This perception required naval architects to convince politicians and the public that the British navy was not the strongest in Europe.

It was not unusual for Victorians to appeal to the looming fear of European competition, threat and superiority to build support for ideas and policies.[44] Men of science were no different in speculating about continental strengths and the links between state and science to extract funds from the British government and amenable domestic institutions. Charles Babbage built support for his calculating machine by taking the idea to continental sponsors. Similarly, when the founders of the BAAS wanted greater government support they would tell influential Britons about the achievements being developed by other European scientific societies.[45] Thus when the INA began to push for a new school of naval architecture it appealed to the longstanding concerns held by the Victorian public and successive parliaments that the British navy was in disarray (examined in chapter 1).

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[42] Joseph Woolley, 'On the education of naval architects', *Transactions*, 5 (1864), pp. 262-271, esp. 262, 264.
[43] James Pritchard has argued that 'French excellence and perceived superiority in naval shipbuilding' was a myth and that historians should look beyond it. Nevertheless, because the perception was alive and well within the British naval community it should not be ignored. Augustin Francis B. Creuze noted in his widely read article on naval architecture in the *Encyclopædia Britannica* (1840), that "The ships of England, throughout the wars of the reigns of George III. and George IV., were notoriously inferior to those of France." Woolley used these articles in 1864 to build a critique of the 'ignorance of science on the part of those entrusted with the duty of constructing the British Navy': Woolley, 'Education of naval architects', p. 264. Pritchard, 'Shipwright to naval constructor', p. 4-5.
[44] See for example English responses to the threat of revolution, Jonathan Parry, *The politics of patriotism: English liberalism, national identity and Europe, 1830-1886* (Cambridge, 2006), pp. 60-1.
[45] Anthony Hyman, *Charles Babbage: pioneer of the computer* (Princeton, 1985), pp. 62-74; Jack Morrell & Arnold Thackray, *Gentlemen of science: early years of the British Association for the Advancement of Science* (Oxford, 1981), pp. 329-34.

Russell's paper at the INA on the education of naval architects in Britain galvanised those individuals who looked to science and mathematics to guarantee the progress, peace and prosperity of Britain on the seas. His paper was discussed in parliament and by the press, and continued to resonate with the INA until, in 1864, the Admiralty announced that a portion of the funds available under the 'scientific branch' in the navy estimate would be allotted for the founding of a new college, in the controversial location of Kensington, London. In 1864, as parliament was beginning to listen to debate over the constitution for this new school, Woolley lent his support to Russell's 'admirable and well-timed Paper ... profound at the time, and leading to immediate action on our part', by providing a testimony to the importance of mathematical knowledge and experimental skill to the ship designer.[46]

Woolley, who had served as a professor at the Central School of Naval Architecture and Mathematics in Portsmouth, spoke with authority on the possible educational provisions of a new school. He remarked that English naval architects were no doubt 'men of great natural ability ... but deficient in the knowledge of scientific principles'. Natural ability, Woolley believed, was not enough to solve the problems of modern naval architecture that affected the naval security of Britain.[47] This was not a new concern. In fact this very criticism had been made in *The English Gentleman* in 1846, regarding the tense relationship between the dockyard system of apprenticeships, 'working knowledge' transfer and the natural philosophical tradition of theory and experiment. 'We have had men of experience, and men of experiment, but no men of genius. There has been no encouragement to their growth.'[48]

Pakington, President of the INA and formerly First Lord of the Admiralty, told the Commons that,

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[46] Woolley, 'Education of naval architects', p. 263. Also see 'School of Naval Architecture. Resolution', *Hansard*, 30 June 1864, p. 503.
[47] Woolley, 'Education of naval architects', p. 265.
[48] 'Naval architecture', *The English Gentleman*, 18 July 1846, p. 10.

> Acting on the request of the Council, he had several interviews with the Duke of Somerset [First Lord of the Admiralty], and with the noble Lord the Secretary to the Admiralty, and he would not be doing justice to them if he did not acknowledge the frank and cordial manner in which they entered into the scheme, and evinced their readiness to meet the views of the merchant service as represented by the Institution of Naval Architects.[49]

In parliament Pakington pushed the issue by frequently asking questions about the progress of schemes for a new school of naval architecture. Pakington's questions were answered by Rear-Admiral Lord Clarence Paget, who between 1859 and 1866 served as political secretary to the Admiralty.

Paget's role in the Admiralty administration had been the idea of Lord Palmerston, who wished to use Paget's credibility as a naval commander, 'radical links, parliamentary talent, and aristocratic origins' to offset the unpopularity of the then First Lord of the Admiralty, the Duke of Somerset.[50] Somerset was initially successful in maintaining Palmerston's naval spending plans, but in 1863 he came under fierce attack by the economy movement in the Liberal Party, during which Paget's close alliance with the economic radicals Richard Cobden and William Schaw Lindsay was able to lessen some of the public damage.[51] In April 1863 Paget, who frequently used his parliamentary skills to exaggerate the positive image of the administration, told Pakington that 'the Admiralty were quite impressed with the absolute necessity of some steps being taken for the promotion of that most important branch of science – naval architecture', and that any proposals from INA would be 'favourably considered by the Admiralty'.[52]

No action was taken, and in June 1863 Pakington repeated his question, to which Paget responded by telling the House that 'the Admiralty were making inquiries with a

[49] 'School of naval architecture. Resolution', *Hansard*, 30 June 1864, p. 503.
[50] Paget was made a commander in the Royal Navy at the age of 23, in part due to the influence of his father who served as Lord Lieutenant of Ireland in various administrations of the first half of the nineteenth-century. Paget later served in the Baltic, and along with other aristocratic officers publically criticised Sir Charles Napier's command. In 1857 he was promoted to rear-admiral. Andrew Lambert, 'Paget, Lord Clarence Edward (1811–1895)', *Oxford Dictionary of National Biography* (Oxford, 2004).
[51] W. F. Rae, 'St Maur , Edward Adolphus, twelfth duke of Somerset (1804–1885)', rev. H. C. G. Matthew, *Oxford Dictionary of National Biography* (Oxford, 2004).
[52] 'School of naval architecture, question', *Hansard*, 30 April 1863, p. 990.

view to a future supply of Architects, not only for the Royal Navy, but also for the private trade of this country; and all their inquiries tended to the establishment of a mixed system of education rather than of one confined exclusively to the Royal Navy.'[53] Victorians interested in joining professions tended to attend technical schools with links to their chosen profession (and such schools depended on those links for survival), or they took advantage of the 'new career pattern ... with promotion within an organization and examination to validate skills.'[54] The individuals who administered government departments were loath to pay for advanced education unless it was an 'economic' and 'efficient' use of state capital. Michael Argles notes that '[f]or the State to have taken some action to improve the quality of labour would not only have meant an increase in educational and similar expenditure, but would have been contrary to the Victorian doctrine of self-reliance'.[55] Yet during the annual vote on navy estimates in February 1864, Paget announced that £2,300 would be used to prepare rooms and pay two lecturers, thereby establishing a new school of naval architecture.[56]

Parliamentary debate on the financial vote initially rested on the liberal coalition's economic concerns. Augustus Smith, liberal MP for Truro, remarked that the 'Vote was one of those of which the House has seen too many. It was a small sum at the commencement, but it pledged the House to go on, and to incur probably, a heavy expense in the end.'[57] Smith, a philanthropist who established numerous social improvement projects and schools of industry, took issue with the government's decision to 'waste money' on establishing a new educational facility while there were already facilities at sites in industrial shipbuilding towns (including laboratories at

[53] 'School of naval architecture, question', *Hansard*, 8 June 1863, pp. 518-9.
[54] Martin Daunton, *Wealth and welfare: an economic and social history of Britain, 1851-1951* (Oxford, 2007), pp. 500-507, esp. 501.
[55] Michael Argles, *South Kensington to Robbins: an account of English technical and scientific education since 1851* (London, 1964), p. 15.
[56] 'Discussion of science and the School of Naval Architecture during a session on Navy Supply', *Hansard*, 29 February 1864, pp. 1308-9.
[57] Ibid., p. 1308.

Portsmouth and Devonport).[58] To focus national money on a central school when there were already provisions in port schools seemed absurd.

Smith's views on government financial support for the RSNA were underpinned by the widespread opinion that naval architecture was a 'practical' art, dependent on craft, industry and skilled labour, not mathematics, metallurgy and methodologies used by men of science. Thus Smith argued that '[t]he school ought to be established where there could be daily instruction in all the different practical operations of shipbuilding.'[59] Thus the politics of place and utility were closely linked together in politicians' discussions and press speculation about the new school. The discussions reflected concerns regarding government control and private/public sector education ventures which were typical of the government spending habits of the mid-Victorian minimalist state. But the politics of place also uncover, as Schaffer explored in the Georgian dockyard, the connections between sites of theory, sites of manufacture and spheres of control within government and military institutions.

The Board of Admiralty, together with the INA, wanted the RSNA to be based at the Department of Art & Science in Kensington. The choice reflected the concern that the new school would attract promising naval architects (and marine engineers) from naval and commercial shipyards. Paget argued that '[i]f we put it [the school] at any of the dockyards or in any Admiralty building it would be looked upon as a Government school, and it would be said "This is a Government concern. It is not open to the public. We shall be too much in the power of Admiralty."'[60] The focus was not to train youths from traditional shipping towns but to provide an education that was accessible to everyone in Britain. The next section of this chapter explores the cultural significance of,

[58] 'School of Naval Architecture. Resolution', *Hansard*, 30 June 1864, p. 501. For Smith see Peter Mandler, 'Smith, Augustus John (1804–1872)', *Oxford Dictionary of National Biography* (Oxford, 2004).
[59] Ibid., p. 501.
[60] 'Paget's presentation of the navy estimate scientific branch', *Hansard*, 25 February 1864, p. 1112.

and social network that advocated the choice of Kensington for the location of the school – a location that shaped perceptions of the expertise of the naval architect.

2.3 NAVAL ARCHITECTURE AT KENSINGTON
Control and the curriculum

At the end of February 1864, Paget presented parliament with the Board of Admiralty's justification for wanting to establish the RSNA at Kensington. He explained that 'the School at Portsmouth was felt to be a purely Government school', and '[i]f the School were put at Portsmouth, or any one of the dockyards, it would have the air of an Admiralty establishment; but they did not want that, nor did they desire that the Admiralty should interfere with the details.'[61] The choice of a location which was not a site of shipbuilding was cause for concern.

> What do you think we are going to have at South Kensington now? Fortifications? No. A Shakespeare memorial? No; though the site would be as appropriate as one in the Green Park. Rifle ranges? No. O, you would not guess. A school of Naval Architecture. You don't believe *that*. ... the House was so stunned that the Government triumphed over foes in a state of coma. A School for Shipbuilding at South Kensington! Arrangements are to be made for launching the vessels into the basin in the Horticultural Gardens, in front of Mr. Durham's memorial, and if they don't sink, they are to be carried on the tops of omnibuses to the Serpentine, and there put into commission.[62]

Punch's satire was not unfounded. Members of Parliament complained that 'the Government wanted to send everything to South Kensington, where they believed perfection reigned; but by the country at large the proposal to send the School of Naval Architecture there was looked on as simply ridiculous.'[63] The proposal to create a new centre of science, art and learning in London, connected to Kensington's status as a centre of British industriousness and invention, had its critics and represented a controversy over the role, function and identity of naval architects in Britain – and more

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[61] 'Discussion of science and the School of Naval Architecture during a session on Navy Supply', *Hansard*, 29 February 1864, p. 1312.
[62] 'Punch's Essence of Parliament', *Punch*, 12 March 1864, p. 103.
[63] 'School of Naval Architecture. Sir William Snow Harris. Motion for papers', *Hansard*, 9 May 1864, p. 196.

broadly science in a craft culture that treated mechanics and calculations with suspicion.[64] Kensington's place as the home of the Great Exhibition of 1851 contributed to how politicians viewed the proposed RSNA. Jeffrey Auerbach notes that the exhibition was not just the symbol of peace, progress and prosperity that it has come to represent in much historiography, but a battlefield of Victorian values towards machinery, industry and modernization.[65] The exhibition became a place to educate the Victorians to the power and industriousness of machinery, iron and steam and instil a sense of progressive spirit to those who believed England's economy and society should instead surround the garden and the field.[66]

Politicians (including in particular those with a background in the army and navy) queried what a naval architect could learn in Kensington. For example Seymour Fitzgerald, Conservative MP for Horsham, remarked that 'the proposition to place a School of Naval Architecture at Kensington permanently would be just as reasonable as to fix a School of Agriculture in the heart of London.'[67] Comments like these reflected the wide perception that naval architects primarily needed 'practical skills'. Thus the education of naval architects and the activity of naval architects depended on proximity to the sea.

The parliamentary debate over the choice of Kensington to be the home of naval architecture very quickly concerned itself with more fundamental issues concerning the role and skills required by naval architects. Captain Henry Jervis-White-Jervis, Conservative MP for Harwich told the House that 'The great object of a school of naval architecture must be to teach people to build ships capable of holding such guns as were

[64] For the identity and space of South Kensington see Sophie Forgan, ' "But indifferently lodged ...": perception and place in building for science in Victorian London', in Crosbie Smith & Jon Agar (ed.), *Making space for science: territorial themes in the shaping of knowledge* (Basingstoke, 1998), pp. 195-215; Graeme Gooday, 'The premisses of premise: spatial issues in the historical construction of laboratory credibility', in Smith & Agar (ed.), *Making Space*, pp. 216-245.
[65] Jeffrey Auerbach, *The Great Exhibition of 1851: a nation on display* (New Haven, 1999).
[66] Ibid., pp. 104-108. The reference to garden and field corresponds to the views of John Ruskin and William Morris.
[67] 'Discussion of science and the School of Naval Architecture during a session on Navy Supply', *Hansard*, 29 February 1864, p. 1314.

required at the present day, but what opportunity was there at Kensington to test the displacement of water?'[68] Moreover, Jervis argued, 'It was absurd to teach a number of boys to draw lines upon paper. What was wanted, was to enable them to lay down lines for ships - to become practical shipbuilders - and that could not be done at Kensington.'[69]

Critics of the location were drawn to the practice of naval architecture, and thus questioned the importance of theory, mathematics and experiment that members of the INA advocated. The press, however, welcomed the RSNA's focus on mathematical training. One newspaper in particular recalled that 'the pupils of the first school have been recognised as among the best servants whom the navy could obtain', while students of the second school, with its yet greater focus on mathematics, 'were said to combine sufficient skill in modern science with knowledge of past tradition, to be trusted with the reconstruction of the navy.'[70] *The Daily News* believed that the new, third school would extend the influence of 'scientific' control over the ship and compensate for the Board of Admiralty's endemic mismanagement of the navy.

The Board of Admiralty, for now, were willing to follow the advice of those who criticised their former policies and develop a new school of naval architecture which had a view towards scientific training. Paget told MPs that it was the intention of the Admiralty that the RSNA 'might become a great national institution', in which the union of theory, practice, mathematics and material science which many believed lay at the heart of mechanical progress and naval power might be realised. But the extent to which the Board of Admiralty would allow the curriculum to challenge the status quo in the dockyard was unclear.[71] The group of actors who were responsible for locating the RSNA at Kensington certainly did not represent the interests of naval officers and

[68] Ibid., p. 1312.
[69] Ibid., p. 1312.
[70] *Daily News*, 2 November 1864, p. 5.
[71] 'Paget's presentation of the navy estimate scientific branch', *Hansard*, 25 February 1864, p. 1112.

administrators but engineers, industry and naval architecture. However the Admiralty's decision to follow this group's advice reflects the growing authority of mechanical science and the independence of scientific experts within government bureaucracy.[72]

Granville Gower (second Earl Granville), Sir Henry Cole and Russell had met at the Society for the Encouragement of Arts, Manufacturers and Commerce.[73] Granville, a Whig politician with connections across the political sphere, had served as Vice-President of the Board of Trade and Chancellor of the University of London (1856-1871), took an important but undefined role in providing provisions for the RSNA.[74] Paget told parliament how Granville's connections brought Woolley and Sir Henry Cole into communication and advocated the Department of Science and Art at Kensington as the location for the new school.[75] Cole, a civil servant, spent twenty years working to make South Kensington a national centre for the arts and sciences.[76] Between the 1850s and 1870s the South Kensington Museum, the Department of Science and Art, the Albert Hall and the gardens of the Royal Horticultural Society were all built from the profits and successes of the Great Exhibition - all projects which, together with the RSNA, united Granville, Cole and Russell.

The RSNA was placed under the control of the Department of Science and Art. Earl Granville took overall responsibility for the education of students, providing Department of Science and Art apparatus and apartments for the students.[77] Woolley was appointed

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[72] Roy MacLeod writes that 'the "expert" – a protean image of authority and rational knowledge – became a key factor in the "technique of government" that accompanied the nineteenth-century revolution in government.' Roy MacLeod, 'Introduction', in MacLeod (ed.), *Government and expertise: specialists, administrators and professionals, 1860-1919* (Cambridge, 1988), pp. 1-26.

[73] D.S.L. Cardwell, *The organisation of science in England* (London, 1972), pp. 75-85. For Cole and South Kensington chemistry see Robert Bud & Gerrylynn K. Roberts, *Science versus practice: chemistry in Victorian Britain* (Manchester, 1984).

[74] Muriel E. Chamberlain, 'Gower, Granville George Leveson, second Earl Granville (1815–1891)', *Oxford Dictionary of National Biography* (Oxford, 2004).

[75] 'Discussion of science and the School of Naval Architecture during a session on Navy Supply', *Hansard*, 29 February 1864, p. 1312. For Cole see Elizabeth Bonython & Anthony Burton, *The great exhibitor: the life and work of Henry Cole* (London, 2003).

[76] Auerbach, *Great Exhibition*, pp. 199-200.

[77] For physics laboratory teaching and teaching at the Department of Science and Art, see Graeme J.N. Gooday, 'Precision measurement and the genesis of physics teaching laboratories in Victorian Britain' (Ph.D. thesis, Canterbury, 1989). Also see Argles, *South Kensington*, pp. 21-29.

Superintendent, the office he had held at the Central School of Naval Architecture and Mathematics.[78] Charles Merrifield, a lawyer who had taught himself mathematics and become an influential member of the INA, was appointed Principal.[79] And Henry John Purkiss, a senior wrangler from the Cambridge mathematics tripos, was appointed Vice-principal.[80] Purkiss was one of many 'brilliant younger graduates of Cambridge University' who joined the teaching staff at Kensington.[81] This connection was no doubt facilitated by Woolley, who was a fellow of St. John's College. In 1864 the RSNA was opened with a short address by Woolley on the objects of the school, and a paper by Merrifield aptly titled 'The Science of Naval Architecture'.[82]

The first class of students at the RSNA included sixteen apprentices from Royal Navy dockyards and four private students. The RSNA subsequently advertised scholarships in the London newspapers, accepted students from abroad (who were, after some debate, permitted to compete for Admiralty scholarships with domestic students) and, at Woolley's request, began to accept students who had already completed a training programme (of more than six years) as dockyard apprentices.[83] The teaching texts used at the school included Rankine's *Manual of applied mechanics* (1868), Reed's *Shipbuilding in iron and steel: a practical treatise* (1869), Golding Bird and Charles Brook's *The elements of natural philosophy* (1867), Steven Parkinson's *An elementary treatise on mechanics* (1863), Rankine *et al*, *Shipbuilding* (1866) and Woolley's *The elements of descriptive geometry* (1850).[84] Students were also encouraged

[78] 'Discussion of science and the School of Naval Architecture during a session on Navy Supply', *Hansard*, 29 February 1864, p. 1308. 'Introductory proceedings', *Transactions*, 6 (1865), pp. xvii-xxiv, esp. xvii-xviii.
[79] Throughout the 1860s and 70s Merrifield was a central figure in INA and section G of the BAAS. He joined Russell and Rankine in refuting Froude's early theories on ship behaviour. For Merrifield see Adrian Rice, 'Merrifield, Charles Watkins (1827–1884)', *Oxford Dictionary of National Biography* (Oxford, 2004).
[80] Purkis died shortly after being appointed vice-principal of the South Kensington School while bathing in the Cam. He had returned to Cambridge to compete for a fellowship at Trinity College. 'Introductory Proceedings', p. xxiv.
[81] William White, 'The history of the Institution of Naval Architects and of scientific education in naval architecture', *Transactions*, 53 (1911), pp. 1-33, esp. 20.
[82] Frederic Manning, *The life of Sir William White* (London, 1923), p. 10.
[83] 'Admiralty Letter Digests Section 1.a, 1866', London, TNA, Admiralty papers 12/788.
[84] [Anon.], 'Information concerning the school', *The Annual of the Royal School of Naval Architecture and Marine Engineering*, 1 (1871), pp. 84-91, esp. 90-1.

to read theological texts, including William Paley's *A view of the evidences of Christianity* (1794) and Joseph Butler's *The analogy of religion* (1734).

Reed referred to the education provided at Kensington as a 'French course' in naval architecture, designed to first improve knowledge of mathematics, then the theory and practice of naval architecture.[85] The school's association with the Department of Science and Art at Kensington and the legacy of the Great Exhibition nurtured the credibility of naval architecture and emphasized its place within Britain's industrial enterprises. The cultural significance of the association connected the exhibition's celebration of Smilesian virtue, British 'modernity' and the naval architects who sought to make themselves indispensible to Britain's seaborne empire.[86] The creation of this new type of 'expert', a scientifically inclined naval architect, was dependent on the perception that the school continued the legacy of the exhibition.

The choice of professors and teaching texts demonstrate the control that the INA was able to exert over the new school. Virtually all the personnel involved in teaching courses were members of the INA who shared Russell and Woolley's views that mathematics, theory and practice could be harmonised in a matrix that prioritised science and experiment over art and experience. Similarly, the location of the new school further demonstrates the control and independence that the INA developed in order to exercise a new identity of expertise in ship design. The criticisms MPs aired in parliament and the press over the choice of Kensington as the location for the new school were underpinned by the perceptions of naval architecture that members of the INA wished to change. Jervis's view that 'The pupils did not want more theoretical knowledge, and they would no more learn shipbuilding at South Kensington than they

[85] 'Introductory Proceedings', p. xvii-xviii. For further details about the curriculum see William White, 'On the course of study in the Royal Naval College, Greenwich; with specimens of the work done by students of naval architecture', *Transactions*, 18 (1877), pp. 361-378.

[86] For the cultural significance of the Great Exhibition see Auerbach, *Great Exhibition*. For exhibitions as places that embody narratives of 'experience' and 'expectation' see Bernhard Rieger, 'Envisioning the future: British and German eeactions to the Paris World Fair in 1900', in Martin Daunton & Bernhard Rieger (eds.), *Meanings of modernity: Britain from the late-Victorian era to World War II* (Oxford, 2001), pp. 145-164.

could anything there', represented the matrix of working knowledge that was challenged at Kensington.[87]

2.4 A PLACE FOR SCIENCE
Independence and a new matrix of working knowledge

The choice of a non-dockyard site, and in particular a geographically central site (in as much as London is in the centre of the country), was key to the idea that the school was for the benefit of all England (and Scotland). But the promotion and protection of the type of naval architecture advocated by the INA also rested on location for both the literal and metaphorical separation from the dockyards of Woolwich and Chatham, and the association with Kensington's legacy concerning industrial power and the virtue of technical education.[88] Place, David Livingstone argues, affects the 'conduct of science' and the 'content of science'.[89] The parliamentary debates over the site for this new school demonstrate a serious concern regarding what students of naval architecture and marine engineering would be taught there.

The previous section argued that the location of Kensington gave members of the INA control over the curriculum. This final section builds on that analysis and examines how 'place' also provided the INA with the independence to establish a new matrix of working knowledge. The self professed 'experts' of practical matters who occupied the House of Commons made repeated criticisms that the connection between mathematics, science and ship design was marginal. Paget, as the parliamentary spokesman for the

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[87] 'Discussion of science and the School of Naval Architecture during a session on Navy Supply', *Hansard*, 29 February 1864:, p. 1309.
[88] These developed bare comparison with the efforts of natural philosophers to bring mechanics and engineering under the purview of a liberal education. William Whewell hoped that '[e]very roof, frame, bridge, oblique, arch, machine, steam-engine, locomotive carriage, might be looked upon as a vase to which every well-educated man ought to be able to apply definite and certain principles in order to judge of its structure and working': William Whewell, *The mechanics of engineering: intended for use in universities, and in colleges of engineers* (Cambridge, 1841), pp. v-vi.
[89] David N. Livingstone, *Putting science in its place: geographies of scientific knowledge* (Chicago, 2003), p. 1, 18-21. Also see Peter Galison and Emily Thomson, *The architecture of science* (Cambridge, MA., 1999).

Admiralty, defended the college and argued that the modern naval ship was a complicated scientific entity. Paget, in response to Jervis' criticisms, rebuked,

> if the hon. and gallant Member for Harwich had been in a ship draughtsman's office and seen the beautiful geometrical problems and the various calculations there worked out, he would know that it required a good deal more scientific acquirement than the mere mechanical building of a ship, in order to become a naval architect; one was mere mechanical art, the other one of the highest branches of science.[90]

Alderman Salomons, MP for Greenwich, joined in the criticism that it made no practical sense to place the school in the west of the city where there was no shipbuilding. Paget responding by telling Salomons that the Admiralty chose Kensington,

> because they did not wish the school to be too much under the shade of the Admiralty. Moreover, Kensington was chosen because there were eminent lecturers and masters already established there who would be very useful to the Students of the Schools, many of the subjects taught there being well adapted to the education of naval architecture.[91]

Salomon's responded by repeating his initial question, underlined by the above perception of naval architecture: '[w]hy not have the School at Woolwich? There is plenty of science there.'[92] Such criticisms, I have argued, were built on the presumption that ship design was a mere practical art – or a practical science in the rhetoric used by Saloman – and was thus practiced with practical skills and experience rather than scientific skills and experiment.

The disagreement between the members of the INA and the MPs who sought to uphold 'practical matters' hinged on the perceived importance of mathematics and experimentation to naval architecture – or as the Anglican minister William Sewell put it, the degree to which 'deep thinking' was out of place in 'a world of railways and steamboats'.[93] The majority of the INA members saw a clear connection, but they were opposed by sailors, administrators and MPs who placed their trust in tradition and the underlying assumption that the expert of naval architecture required experience of the ship at sea. The decision to locate the school in Kensington, geographically removed

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[90] 'Discussion of science and the School of Naval Architecture during a session on Navy Supply', *Hansard*, 29 February 1864, p. 1313.
[91] Ibid., p. 1309.
[92] Ibid., p. 1309.
[93] Quoted in Walter E. Houghton, *The Victorian frame of mind* (New Haven, 1957), p. 114.

from the practices of craftsman in the dockyards, physically and metaphorically draw distinctions between the teaching of theory and practice. In Woolley's curriculum students would spend the autumn and winter months at Kensington and the spring and summer months in a shipyard.

Woolley defended this decision and appealed to those who favoured practice by arguing that a clear division in the time and place of the education of naval architects would 'dispel ... the fears of those who may be disposed to think that practice is about to be sacrificed to theory by bringing the School to London, rather than establishing it in a seaport town.'[94] Woolley placed a great emphasis on the importance of knowing the materials and tools of construction but the focus was undoubtedly on orientating students with the science and theory of naval architecture.[95] Woolley advocated mathematics and theory as a means to 'open to the students the whole range of mathematical and theoretical studies so far as they could in any degree have a bearing on the problems to be solved by the naval architect'.[96] Woolley and the INA's agenda that science would have priority over craft was as evident in the content of education as it was in the place it was taught – in a metropolis full of scientific activity away from the physical and cultural control of the navy.

The course taught at Kensington placed greater focus on 'the higher branches of mathematics' than an apprenticeship orientated training in craft.[97] To this end, Woolley hoped that students at the school would be stimulated by the scientific networks and lectures in London, including, but not limited, to the INA. He also hoped that students' grasp of the mechanical dimension of naval architecture would also benefit from living in the metropolis where all around there were 'models of former patented inventions'.

[94] Woolley, 'Education of naval architects', p. 267.
[95] Ibid., p. 266.
[96] Ibid., p. 263.
[97] 'Discussion of science and the School of Naval Architecture during a session on Navy Supply', *Hansard*, 29 February 1864, p. 1308.

London was a visual feast where the student could 'make himself acquainted, readily and in the most effective manner with their several contrivances and uses – where he may, almost unconsciously, imbibe the best practical lessons in machinery, and the adaption of simple mechanical means to desired ends.'[98]

Kensington's proximity to the network of scientific experts that operated in London was also beneficial to the school's teaching, and the superintendent and principal took advantage of the available talent. During the school's first years of operation Woolley and Merrifield invited the Astronomer Royal George Airy to lecture on compass correction, William Fairbairn on the strength of iron ships, Captain Sir Leopold Heath on naval tactics and artillery, Rankine on propulsion and mechanics, Reed on 'practical shipbuilding', Barnaby, Barnes and J. Crossland on equipment and propulsion and Froude on stability and oscillation.[99] The Admiralty showed its willingness to support the school by paying lecturers' fees and making personnel available to the school, such as Thomas Moore and William Bridges who taught modelling at the school.[100] The Admiralty also provided professors and students access to their dockyards and the extensive model collections held at Somerset House. The use of the naval gallery at the Kensington Museum, which also held ship models, was paid for by the Department of Science and Art.[101]

Thus the Royal College of Naval Architecture and Marine Engineering was designed to be in touch with London politics, connected to metropolitan science and close to – but not under the social control of – the Admiralty. Just as importantly, naval

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[98] Woolley, 'Education of naval architects', p. 268.

[99] W.H. W[hite], 'Three English schools of naval architecture', *The Annual of the Royal School of Naval Architecture and Marine Engineering*, 4 (1874), pp. 7-26, esp. 15.

[100] 'Admiralty letter digests, section 1.a, 1866', Admiralty papers 12/788.

[101] Raymond Needham & Alexander Webster, *Somerset House: past & present* (New York, 1906), p. 241; 'Admiralty letter digests, section 1.a, 1865', Admiralty papers 12/762. In 1857 Cole had given a speech on the 'functions' of the Department of Science and Art in the Kensington which held countless collections of art, science and models. Cole stated that 'This museum will be like a book with its pages always open ... Its destiny is ... to become the central storehouse or treasury of Science and Art for the use of the whole kingdom.' Henry Cole, 'Extracts from an Introductory address on the functions of the Science and Art Department' (1857), Jonah Siegel (ed.), *The emergence of the modern museum: an anthology of nineteenth-century sources* (Oxford, 2008), p. 245-46, esp. 246.

architects negotiated the cultural symbolism and power of the space where the Great Exhibition had displayed Britain's industrial, artistic and mechanical spirit to forge new links with science and engineering, away from the interference of Admirals, administrators and politicians. Kensington, with its huge legacy and cultural significance, provided a place from which senior naval architects could control their identity as 'other' from the dockyard and the craft culture which had existed for centuries. The physical and cultural connection with Kensington provided the cushion which gave those naval architects time to establish their authority as scientific investigators, commonsense commentators and pivotal figures in the building and use of the ship at a time when the majority of shipbuilding activity took place in a craft culture. This independence, however, lasted for less than a decade.

The founders of the school had hoped that private shipbuilders and engineers would be drawn towards the idea of a 'national school' and support it financially through donations and sponsoring their own apprentices to take courses.[102] This never happened and the Admiralty grew concerned that they funded many students from commercial shipyards. The financial administration of the school came under attack as early as 1865 when the Lord President of the Council requested that 'if the school is to continue under the direction of the Science & Art Department', the Admiralty should not be required to provide any financial provisions except for Admiralty students. Reed, who was then Chief Constructor of the navy, objected but the Duke of Somerset followed the Lord President's suggestion.[103] This marked the beginning of a series of events through which administrators at the Admiralty brought the education of naval architects and marine engineers back under their control. But come the 1872, when the RSNA was

[102] William White, 'Scientific Education', p. 20-1.
[103] 'Admiralty letter digests, section 1.a, 1865', Admiralty papers 12/762.

moved to Greenwich, the public perception of what was important in a 'modern', iron, steam powered navy had significantly changed.

The navy came increasingly under attack for only teaching cadets 'practical' and 'professional' skills that were important to seamanship. The debates over what secured naval power surveyed in chapter 1 influenced the perception that the skills taught to naval cadets during the early 1870s were outdated. An editorial in *The Times* argued that naval education reflected an era when, 'Steam was not a motive power, Gunnery was not a science, Naval Architecture was a simple art, and battling with the winds and waves and closing with the enemy constituted almost the whole duty of seamen afloat.'[104] The editorial complained that the navy institutions spread from Portsmouth to Kensington produced small numbers of specialised experts (such as the RSNA), and that a modern navy required all officers to have a sound knowledge of a range of subjects.

In 1872, as part of the Admiralty's new scheme for naval education, the school was moved to Greenwich hospital.[105] The idea was advocated by George Goschen, First Lord of the Admiralty during William Gladstone's 1868-1874 liberal government, as part of a larger reform of naval education. The scheme promoted an integrated naval education which included relocating a number of Admiralty sponsored schools to Greenwich. Observers hoped that this would promote 'the theory of navigation, the principles of naval architecture, [and] the mastery of foreign languages' which were increasingly associated with naval power.[106]

Parliamentary debate on the new scheme for naval education focused on arrangements for seamen to gain practical experience. When Goschen came to the plan for removing the school of naval architecture to Greenwich he was not able to describe

[104] 'The Government Scheme for Utilizing Greenwich', *The Times*, 5 August 1872, p. 7.
[105] 'Admiralty letter digests, section 1.a, 21 October 1872', Admiralty papers 12/891.
[106] 'The Government Scheme for Utilizing Greenwich', *The Times*, 5 August 1872, p. 7. For education and the Royal Navy see H.W. Dickinson, *Educating the Royal Navy: eighteenth- and nineteenth-century education for officers* (London, 2007), esp. 131-151.

the specific educational provisions under the new arrangements, but stressed that it 'should meet with the support of the most enlightened naval officers'.[107] Members of the school were powerless to object to the scheme but aired their concerns regarding their independence and control over the curriculum. The editor of the school's annual 'look[ed] forward with confidence to obtaining a hearty support from the new Institution at Greenwich', but on the condition that the school would continue the work it had begun at Kensington.[108] Another member of the school, possibly White, contributed a paper which defended the school's record and reflected on the necessity of a technical education.[109]

The arguments used to promote teaching the science of naval architecture were numerous. Scientific skills and knowledge, such as those taught at the school, were presented as 'beneficial' and 'useful' to the ship design and building process. Actors used every occasion to stress the connection between the use of science and efficiency, safety and naval power. White, for example, used public anxiety over the loss of H.M.S. *Captain* to argue that 'High scientific training may be sneered at by those who have no pretension to its possession; but the fact is undisputed and undisputable that without it any great step on a new and untrodden path cannot be safely made.'[110] The following chapters examine a series of case-studies and episodes through which members of the INA advocated the integration of theory, mathematics, experimentation, practice and experience.

White, who entered the RSNA in 1866, was one of many naval architects trained at Kensington who after graduating took an influential position in the shipbuilding, naval and scientific communities and advocated closer links between science and ship design. White served as Reed's secretary, an instructor at Kensington, an assistant constructor

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[107] 'House of Commons, Thursday, March 21', *The Times*, 22 March 1872, p. 5.
[108] 'Introduction', *The Annual of the Royal School of Naval Architecture and Marine Engineering*, 4 (1874), pp. 5-6, esp. 5-6.
[109] W.H. W[hite], 'Three English schools', p. 26.
[110] W.H. W[hite], 'Three English schools', p. 10.

under Barnaby, manager of warship construction at Armstrongs, Admiralty Director of Naval Construction (1885-1902) and in retirement undertook consultancy work for commercial firms like Cunard (where he collaborated on the design of the *Mauretania*).[111] Among White's fellow students at the school were Francis Elgar who served as an assistant to Reed at the Admiralty and later became the first Professor of Naval Architecture at Glasgow University, John Harvard Biles who succeeded Elgar at Glasgow, Philip Watts who was director of the War Shipping department of Armstrong, Whitworth & Co. and then Admiralty Director of Naval Construction (1902-1912), H.E. Deadman who became an assistant Director of Naval Construction, William John who joined Lloyd's Register, Josiah Richard Perrett who assisted William and Robert Edmund Froude at the Admiralty test tank and Frank Purviss who also assisted the Froudes prior to helping William Denny establish the first commercial test tank facility at Dumbarton.[112] These individuals, together with their teachers, may usefully be identified as a coherent social network of British naval architects.

2.5 Conclusion

The social network of British naval architects, and specifically the founders and members of the RSNA at Kensington, successfully instituted a new tradition for the science of naval architecture. The decade of education provided in Kensington transformed the training of naval architects and reorientated the perception of what skills naval architects required. The cultural significance of Kensington and its physical separation from the navy's dockyards cemented the adjustments between theory and practice that members of the INA advocated. In the lecture theatre, the class room, the

[111] Manning, *Life of White* (London, 1923).
[112] 'Admiralty letter digests, section 1.a, 20 May 1871', Admiralty papers 12/868.

meetings of the INA and the Admiralty constructor's office social connections were formed that linked sites of theory, sites of manufacture and spheres of control within government and military institutions. As such, the most important contribution of the Royal School of Naval Architecture and Marine Engineering was the network of professional and professorial ship designers and engineers who graduated and took hold of institutions across the public and private sectors of shipbuilding up and down Britain.

This social network was both professional and personal. The social life of many working Victorians was bound up in the associational culture of employers and the church.[113] When Barnaby entered the School of Naval Architecture at Kensington he joined the Young Men's Mutual Improvement Society, for which he served as secretary, and attended Onslow Baptist church with some of his fellow students and Admiralty officials. White's early biographer ascribed the naval architect's 'practical ability and calculated daring' to a 'puritan or protestant zeal sometimes approaching fanaticism'.[114] In the church White joined Barnaby, with whom he grew close and succeeded as secretary of the church's Sunday school.[115] Barnaby, in turn, had a personal relationship with his predecessor through Reed's marriage to his sister.

Within this social network Froude's test tank also became an important node through which many RSNA graduates and commercial engineers passed.[116] These included Watts, Perrett, Purvis and I.K. Brunel's son Marc Henry Brunel, who for a short time was also engaged to Froude's daughter Isy before his family objected to her Catholicism. Froude also operated in close contact with men of science, including most importantly Rankine and William Thomson in Glasgow. This social network of British

[113] Ross McKibbin, 'Why was there no Marxism in Great Britain', *English Historical Review*, 99 (1984), pp. 297-331.
[114] Manning, *Life of White*, p. 1.
[115] Ibid., pp. 18-19.
[116] In early 1872 Froude corresponded with the school of naval architecture for a short-term assistant. Watts was allowed leave from his studies to work at Dartington for three months. 'Admiralty letter digests, section 1.a, March/April 1872', Admiralty papers 12/891.

naval architects and a host of supporting actors, I will show in Part II, operated in similar ways to the north-British network of physicists and engineers that shaped Victorian energy physics in academic and professional engineering institutions.[117] It also had common members, with Rankine and his links to Glasgow industry and Thomson who wielded authority in numerous government committees regarding the ship, scientific knowledge and technical education. Froude, although sometimes at odds with Rankine, felt a debt to the professor's work on hydrodynamics.[118] While in 1875, James Robert Napier and Thomson helped secure Froude's election as an honourable member of the Philosophical Society of Glasgow.[119]

This social network of mathematicians, engineers, ship designers and shipbuilders was key to the distribution of knowledge and the credibility of naval architects. Correspondents in the social network transmitted ideas and reports. For example, in 1874, Froude supplied Napier with copies of his Admiralty report on experiments with H.M.S. *Greyhound*. Napier, after reading the report, passed it on again. 'If I find my stock of *Greyhound* reports hold out, I will send you another copy,' Froude told Napier. 'I should like you to have one to keep for yourself, though I am of course glad that you should have distributed as you have done the two already sent to you.'[120]

The British social network of naval architects will be continually deployed throughout the following chapters as I examine how science, theory and experimentation were used and perceived in the Admiralty and naval community at large. Part II of the thesis will follow the science of naval architecture into the world of Victorian science and engineering, paying particular attention to local meanings of mechanics and practices of experimentation. Part III will return to the specific question,

[117] Crosbie Smith, *The science of energy: a cultural history of energy physics in Victorian Britain* (Chicago, 1998).
[118] William Froude to James Robert Napier, 15 November 1874, Glasgow University, Archive services, Napier papers 90/2/4/51.
[119] Froude to Napier, 4 April 1875, Napier papers 90/2/4/51.
[120] Froude to Napier, 19 April 1874, Napier papers 90/2/4/51.

'to what extent did the Admiralty, despite providing for the education of scientific experts, cling to the experiences, practical skills, expertises, roles, functions and identities that had prevailed for decades, even centuries?' I argue that craft was not pushed aside, but that its role in the design and production of large technologies like the ship was reconfigured, for example in Froude's invention of his mechanical hand (chapter 5) or White's design for a scientific middleclass management in Her Majesty's dockyards (chapter 7).

PART II

EXPERIMENT AND THE SCIENCE OF NAVAL ARCHITECTURE

[B]y possessing a class of shipbuilders trained in mathematical science, with the powers of their minds invigorated and strengthened by a profound and secure course of study, able to deal with questions to which altered conditions are continually giving rise, not by trial and error – which is most frequently but another name for failure – not with the hesitating and trembling hand of the superficial socialist, acquainted perhaps with the results of the labours of deeper enquiries, and able in fair-weather times to apply them under known conditions, but with the firm grasp and bold readiness of the man profoundly skilled in the scientific principles of all kinds which may be made available to the art of naval construction, who feels himself thoroughly at home in them, and has acquired such power as to enable him to apply his principles readily and exactly, without fear of failure or of overlooking one principle while anxious to give affect to another, which can only be the result of long-continued and severe study.

Joseph Woolley, 'On the education of naval architects', Transactions, 5 (1864), pp. 262-71, esp. 265.

3

Experiment in Victorian hydrodynamics and ship design

In the absence of first-rate naval architects, we have been obliged to avail ourselves of mediocre talents and mere assumption. Naval officers (!) who know *much* about building ships have spent hundreds of thousands of pounds of the public money, and at this hour we have line-of-battle ships that cannot keep their ports open in anything like a strong breeze and a sea to match. ... Perhaps by men at the Admiralty, who have no professional whims and favouritism of their own, some fostering care will be given to the rearing of scientific persons who shall be capable of understanding the true principles of ship-building.

An article in The English Gentleman (1846) calls attention to low-standing of scientific credibility in the navy and the need for scientific experiments.[1]

In this paper a thoughtful attempt was made for the first time, to exhibit *all* the essential principles that govern the motions of a ship rolling in a sea-way, and to draw from them, by aid of mathematical investigations, a number of inferences for the guidance of the naval constructor.

William Froude's paper on ship roll attracts interest from Fraser's Magazine (1863).[2]

[I]f we consider the actual character of problems to be solved, can we fail in seeing that a very considerable amount of mathematical power is needful for their solution?

Joseph Woolley reflects on Froude, W.J. Macquorn Rankine, and James Crossland's papers on the problem of rolling.[3]

In 1861, William Froude presented a paper to the INA that provided a theory of ship roll much at variance with common knowledge. The literary and philosophical publication *Fraser's Magazine*, edited by Froude's younger brother, the historian James Anthony Froude, dedicated an article to explaining Froude's paper for non-specialists, and emphasised the importance of mathematics and experiment to the Victorian navy and naval power. 'To the man of science it [the ship] presents many beautiful and profound problems for solution; to the commercial man it suggests novel and most facilities for enterprise; and upon the defenders of the State it lays responsibilities of an extremely weighty and momentous nature.'[4] This article, perhaps written by Froude, directed the

1 [Anon.], 'Naval architecture', *English Gentleman*, 18 July 1846, p. 10.
2 [Anon.], 'Naval architecture', *Fraser's Magazine*, 67 (1863), pp. 96-113, esp. 100.
3 Joseph Woolley, 'On the education of naval architects', *Transactions*, 5 (1864), pp. 262-71, esp. 265.
4 [Anon.], 'Naval architecture', *Fraser's Magazine*, p. 96.

magazine's readers to the discussion of naval architecture that was being promoted by the newly founded INA.

Chapter 1 introduced and examined the broad political and technical context in which scientific experts sought to make space for scientific knowledge and ways of working. Chapter 2 demonstrated the problems that members of the INA, the scientific community and constructors department of the Admiralty experienced as they sought to demonstrate the value of science, theory and experiment to the 'defenders of state' who controlled the craft-orientated culture of Victorian government-science relations. The present chapter builds upon this analysis of how 'science' was made credible, taking for its focus a series of case studies that describe the nature of experiment and demonstrate how knowledge of (and trust in) hydrodynamics was housed within a network of individual identities, social dynamics, institutional reputations, local concerns and object meanings. It is vital to understand these connections that reveal the character of hydrodynamics in order to locate this subject in the scientific, social and cultural context of Victorian physics, engineering, industry and navy.

Victorian hydrodynamics took shape in the meeting halls of scientific and engineering societies, the workshops of shipbuilders, on shipboard Britain's naval and mercantile fleets and in the drawing rooms of Victorian engineers like James Robert Napier and John Scott Russell. Within these settings the science of hydrodynamics was not merely 'applied' to technical problems, but was developed through culturally specific episodes.[5] This chapter examines a series of contributions to Victorian hydrodynamics that I cast in a social light to demonstrate the nature of experiment in this context. These include the epistemological limits and social identity of natural philosophers' contributions to hydrography and hydrodynamics; the experiments and local politics of Glasgow professional and professorial engineers; Russell's wave-line theory and personal reputation that he constructed through I.K. Brunel's *Leviathan*; and, finally, the social politics that gave Froude a space to discuss model experiments and build credibility into his mechanical approach to naval architecture (the significance of which will be demonstrated across this part of the thesis). It will become apparent that experiment was understood through a range of contexts, and that there were a number of approaches that diverged because social actors saw different ways to integrate mathematics with mechanics, observation with experiment, and the use of models with the authority of experience in ship design.[6]

3.1 OBSERVATION, IDENTITY AND THE LIMITS OF KNOWLEDGE

Hydrodynamics in early Victorian science

Early modern and Enlightenment philosophical studies of hydrodynamics shaped the observational focus of early Victorian work in the field. Since 1660, with the foundation

[5] For the limits of 'applied science' as an interpretative category see Ronald Kline, 'Construing "technology" as "applied science": public rhetoric of scientists and engineers in the United States, 1880-1945', *Isis*, 86 (1995), pp. 194-221. Contrast with Otto Mayr, 'The science-technology relationship as an historiographical problem', *Technology and Culture*, 17 (1976), 663-672. For recent debate concerning whether technology current primacy and the reasons for historicising the 'science-technology' debate see Paul Forman, 'The primacy of science in modernity, of technology in postmodernity, and of ideology in the history of technology', *History and Technology*, 23 (2007), pp. 1-152; and the responses. Of particular interest in this debate is Chunglin Kwa's observation that histories of knowledge, knowing, experiment and instrumentality still largely ignores their technological context, see Kwa, 'Shifts in dominance of scientific styles: from modernity to postmodernity', *History and Technology*, 23 (2007), pp. 166-176, esp. 170.

[6] Key essays that deal with the 'construction' of meaning in areas where science and technology are in combination, and the term 'applied science' has been used, include Donald MacKenzie & Judy Wajcman, 'Introductory essay: the social shaping of technology', in MacKenzie & Wajcman (eds.), *The social shaping of technology* (Buckingham, 1985, 2nd Edt. 1999), pp. 3-28; Ronald Kline & Trevor Pinch, 'The social construction of technology', in MacKenzie & Wajcman (eds.), *Social shaping*, pp. 113-15.

of the Royal Society, natural philosophers joined together to observe fluids and speculate on the ideal shape of the ship. Research on waves and bodies echoed Isaac Newton's examination of waves and the cosmic system in book two of *Philosophiæ Naturalis Principia Mathematica* (1687), and the Enlightenment reason that dictated that ships mimic the perfection of God's creations, neatly encapsulated in the shipbuilder's motto, 'cod's head and mackerel tail'.[7] Such research undertaken by natural philosophers existed in isolation from the craft-culture of shipbuilding. For example, Mark Beaufoy's model experiments for the eighteenth century Society for the Improvement of Naval Architecture made little impact on the mentality and working practices of the Admiralty and private firms.[8]

The separation of natural philosophy and craftwork in hydrodynamics continued into the nineteenth century. Academic research on waves and bodies was undertaken within a broader scientific project of hydrography: the charting of the seas.[9] Early-Victorian hydrography was shaped by the imperial concerns at the core of government-science relations.[10] The commercial and military community were convinced that mapping and measuring tides, waves and currents would give the British Empire knowledge of ports, rivers and ocean routes that directly corresponded to trading and naval advantages.[11] This interest in hydrography enabled the scientific community

[7] John Scott Russell, 'The wave-line principle of ship-construction, part III', *Transactions*, 2 (1861), pp. 230-245, esp. 232.

[8] Scholars of early-modern and eighteenth-century era hydrodynamics have tended to ignore the scientific, craft, naval and cultural impact of the ideas they have meticulously examined, see for example Larrie D. Ferreiro, *Ships and science: the birth of naval architecture in the Scientific Revolution, 1600-1800* (Cambridge, MA, 2007). Contrast with Simon Schaffer, 'Fish and ships: models in the age of reason', in Soraya de Chadarevian & Nick Hopwood (eds.), *Models: the third dimension of science* (Stanford, 2004), pp. 71-105, esp. 91-96.

[9] Simon Schaffer notes that the reputation of eighteenth-century France's shipbuilding was linked to their government sponsored academic hydrography, see Simon Schaffer, ' "The charter'd thames": naval architecture and experimental spaces in Georgian Britain', in Lissa Roberts, Simon Schaffer & Peter Dear (eds.), *The Mindful hand: inquiry and invention from the late Renaissance to early industrialization* (Amsterdam, 2007), pp. 279-305, esp. 299.

[10] For science and the imperial project see Sujit Sivasundaram, *Nature and the Godly empire: science and evangelical mission in the Pacific, 1795-1850* (Cambridge, 2005); Richard Drayton, *Nature's government: science, imperial Britain, and the 'improvement' of the world* (New Haven, 2000); Robert A. Stafford, *Scientist of empire: Sir Roderick Murchison, scientific exploration and Victorian imperialism* (Cambridge, 1989).

[11] Richard Drayton, 'Maritime networks and the making of knowledge', in David Cannadine (ed.), *Empire, the sea and global history: Britain's maritime world, c. 1763-c. 1840* (New York, 2007), pp. 72-82; Crosbie Smith & Ben Marsden,

access to funds and an army of observers who mapped tidal patterns, but also visually measured waves and examined their formation. This observational knowledge was central to work on hydrodynamics that men of science, chief among them Astronomer Royal George Biddell Airy and Cambridge-trained mathematician William Whewell, developed as they 'gave rise to a new conception of the ocean' as a space for science.[12]

Hydrodynamics was a component of this early Victorian hydrographical work that sought to understand the motion of the oceans and the behaviour of waves. Airy, for instance, examined the effect of ocean waves on ironclad ships and compass navigation in order to devise a system of magnetic corrections that served to compensate for the compass deviation experienced by ironclads in the Royal Navy and iron steamers in commercial service during ocean travel. His work brought him into conflict with William Scoresby, a well known ship's captain, natural philosopher, and evangelical clergyman, whose vivid and dramatic accounts of Atlantic waves contrasted Airy's scientific treatment of the ocean.[13] It was not unusual for sailors to describe waves 'mountains high' without any authentication from reliable ways of measuring.[14] As such Airy and other men of science tended to distrust the observations of sailors. Scoresby placed faith in captains and direct experience of waves upon a ship. Airy, in contrast, placed greater faith in the system he had developed, and often dismissed the "stupidity of the captains of ships".[15]

Engineering empires: a cultural history of technology in nineteenth-century Britain (Basingstoke, 2005), pp. 12-40; Rob Iliffe, 'Science and voyages of discovery', in Roy Porter (ed.), *The Cambridge history of science, vol. 4: eighteenth century science* (Cambridge, 2003), pp. 618-45.

[12] Michael S. Reidy, *Tides of history: ocean science and Her Majesty's navy* (Chicago, 2008), p. 9. For many of these debates see Jack Morrell & Arnold Thackray, *Gentlemen of Science: early years of the British Association for the Advancement of Science* (Oxford, 1981).

[13] Alison Winter, '"Compasses all awry": the iron ship and the ambiguities of cultural authority in Victorian Britain', *Victorian Studies*, 38 (1994), pp. 69-98, esp. pp. 77, 82, 83-87.

[14] [Anon.], 'Naval architecture', *Fraser's Magazine*, p. 275.

[15] Winter, '"Compasses all awry"', p. 75.

The Victorian audience of the Airy-Scoresby controversy identified the proponents through the oppositional categories of 'practical' and 'theoretical'.[16] Whewell, who like Airy approached hydrodynamics as a part of hydrography, also placed greater faith in the theories and observations of natural philosophers than the extensive direct experiences of sailors. Whewell contributed to the natural philosophical study of hydrodynamics with fourteen essays published in the *Philosophical Transactions* between 1833 and 1850.[17] Airy and Whewell's approach to hydrodynamics solicited credibility within the Royal Society and Section A (Astronomy and Physics) of the BAAS, but shipwrights and naval architects continued to trust in the experience of waves and nature and the work of 'practical men'. Trust in hydrodynamic theories often rested on the identity of the observer and the credibility they took from the spatiality of their observations - had they been at sea, in a laboratory or theorised from the accounts of witnesses?

Richard Yeo has noted that Whewell 'stressed the need to distinguish between knowledge and its application, between theory and practice, between science and art'.[18] This separation forced a wedge between self styled 'practical men' and 'theorists'. To understand this division we must distinguish what Whewell, as a representative of the natural philosophical tradition, meant by 'practice'. Whewell, in dedicating *The mechanics of engineering* (1841) to Robert Willis, Jacksonian Professor of Natural Philosophy, declared his admiration for 'the combination of practical knowledge and

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[16] Ibid., p. p. 86.

[17] For an overview of Whewell's work on hydrodynamics and tides see Isaac Todhunter, *William Whewell, D.D., Master of Trinity College, Cambridge: an account of his writings with selections from his literary and scientific correspondence* (London, 1876), pp. 75-88.

[18] Richard Yeo later suggests that Whewell's view of invention and, what he misguidedly refers to as 'technology', became more positive in the 1850s after the Great Exhibition. Richard Yeo, *Defining science: William Whewell, natural knowledge, and public debate in early Victorian Britain* (Cambridge, 1993), pp. 154, 228.

theoretical beauty which I know to belong to your work'.[19] This 'combination' suggests a more complicated relationship than that suggested by Yeo, and thus it may be helpful to consider the context in which Whewell worked. Whewell's understandings of mechanics and engineering must be localised to early-Victorian Cambridge where the study of those topics appealed to professorial, not professional, individuals.[20] There were, however, other men of science who sought to negotiate a common framework of observation and knowledge with the practices of professional engineers.

The 'science' in the above example of early-Victorian hydrodynamics was not easily 'applied' to designing and making material objects because social and cultural divisions existed that complicated any shared sense of 'practice'. Thomas Gieryn noted that 'experiment' and discovering 'causal principle' were a part of the cultural cartography of Victorian Britain that distinguished the scientist from the mechanic.[21] The members of the BAAS's Section G, mechanical science, sought to redefine the identity of the section through a belief that scientific theory and analysis could solve the problems of industry. The section supported numerous committees that pursued the project of putting naval architecture on a firm scientific foundation.[22] Sections G members, including Rankine, Froude and Russell – with the support of better known men of science like William Thomson – sought to mediate the tensions between theory and practice that had complicated relations between men of science and men of industry.

[19] William Whewell, *The mechanics of engineering: intended for use in universities and in colleges of engineers* (Cambridge, 1841), pp. iii-iv.

[20] Ben Marsden, '"The progeny of these two 'Fellows'": Robert Willis, William Whewell and the sciences of mechanism, mechanics and machinery in early Victorian Britain', *BJHS*, 37 (2004), pp. 401-434.

[21] 'Scientists acquire knowledge through systematic experiment with nature', Gieryn writes, '[and] because mechanicians and engineers rely on mere observation, unsystematic trial and error, and common sense, they cannot understand or explain their practical successes or failures.' Thomas Gieryn, *Cultural boundaries of science: credibility on the line* (Chicago, 1999), pp. 55-58, esp. 55.

[22] Ben Marsden, 'The administration of the "engineering science" of naval architecture at the British Association for the Advancement of Science, 1831-1872', *Yearbook of European Administrative History*, 20 (2008), pp. 67-94.

Between 1838 and 1870 no less than seven committees met to examine knowledge of hydrodynamics and marine engineering. Held together by the influential presence of Russell, Rankine and James Robert Napier, these committees commissioned an enormous number of small-scale experiments and made enquires with the BAAS and Lords of the Admiralty to institute experiments with H.M. ships and establish a more prominent role for experiment in shipbuilding, but largely without success.[23] The last of these committees began meeting in 1868 and examined the state of existing knowledge on the stability, propulsion, and seagoing qualities of ships. The committee was chaired by Charles Merrifield, a lawyer by training, who was principal of the RSNA and a prominent member of London mathematics and science societies. The committee's report surveyed past experiments and the state of knowledge on resistance and rolling. Merrifield, who wrote the committee's report, noted that there were 'very few facts' known about ship resistance and roll. But what, precisely, was the reason for the scientific and engineering community's limited knowledge?

Merrifield explained in his report that there was no established standard of good form, nor a 'generally recognized theory or rule for calculating the resistance of a ship.'[24] Merrifield stated that the behaviour of fluids and the shape of waves were important issues, and although he was confident that men of science like Airy and Whewell understood and could describe their features, he was concerned that there was little knowledge based on experiment or experience that described their effects on ship behaviour. For instance, in his synthesis of theories of ship resistance, Merrifield dismissed continental approaches to identifying resistance that relied heavily on mathematical theories loaded with assumptions that did not account for peculiarities of

[23] Tom Wright, 'Ship hydrodynamics, 1710-1880' (Ph.D. thesis, Science Museum/ University of Manchester Institute of Science and Technology, 1983), p. 97.
[24] Charles Merrifield, 'Report of a committee on the Stability, Propulsion, and Sea-going Qualities of Ships', *B.A.A.S Reports, 1869* (London, 1870), p. 20.

ship shape. This included Frederik Chapman and Leonhard Euler's work that made use of co-efficients and the sine squared of the inclination theory of resistance. Such theories made assumptions regarding engine power (which was difficult to measure with accuracy) and non-curved surfaces respectively.[25]

In 1869, Merrifield reported to the BAAS that such hydrodynamic theories had been 'applied promiscuously to the practical [concerns of the ship owner] ... [T]he proper mode of applying mathematical investigation is to start, not from the known principles of general mechanics, but from an advanced base of observations peculiar to the science itself.'[26] Merrifield continued, 'we are only able to observe effects in the gross; being thereby driven to a certain want of detail, both of observation and of reasoning, which allows us to trust our conclusions only when they have been made to rest on a broad experimental foundation.'[27] Merrifield's report also noted that there were limits to mathematical analysis, quoting Rankine's observation that '[t]he complete problem of a ship's behaviour ... is far too complicated even for statement in an exact mathematical form.'[28] It is important to note that Merrifield was not an opponent of mathematical analysis.

As a member of the Association for the Improvement of Geometrical Teaching, Merrifield believed that mathematics was a valuable tool but that there was a stigma attached to it in British industry.[29] Merrifield's 1869 report demonstrated this tension in Russell's wave-line theory. Broadly put, the theory sought to describe the 'relation between the length of the ship and the velocity of advantageous propulsion' (in principle lengthening the ship and replacing the wide, convex bow with a thin, long

[25] Ibid., p. 11-12.
[26] Ibid., p. 31.
[27] Ibid., p. 41.
[28] Merrifield quotes from Isaac Watts, F.K. Barnes, James Robert Napier & W.J. Macquorn Rankine, *Shipbuilding: theoretical and practical* (London, 1866). Merrifield, 'Report', pp. 33-34.
[29] Charles Merrifield to James Robert Napier, 26 December 1871, Glasgow University, Archive service, Napier papers 90/2/4/39.

concave bow). This relationship was based on the behaviour of ships in trochoidal waves.[30] Russell's work placed emphasis on observation and understanding the shape of waves, linking his approach to the natural philosophy tradition employed by Whewell and Airy.[31] There were, however, significant epistemological drawbacks for theories of resistance drawn and justified from experience and observation. There were literally thousands of individuals in the scientific, engineering, naval and mercantile communities who could also speak from experience about resistance. Unlike mathematically established theories, observationally derived theories had to stand the test of immediate and numerous cross-questioning, sometimes from critics possessing an untrained eye.

Merrifield's 1869 report demonstrated the power that could be taken from listing the criticisms of numerous observers who had negative experience with the wave-line theory. Rankine, for example, observed that the length of the bow could be longer than Russell prescribed without adversely affecting resistance.[32] Froude and Napier doubted the principle underlying Russell's theory, and believed ships could be built shorter without experiencing greater resistance. 'I go with you wholly', Froude wrote to Napier, 'in disapproving the extravagant length of modern ships.'[33] The wave-line theory was, however, still an important and widely trusted development in British hydrodynamics, despite the questions asked of it by men of science and engineers who were uncertain as to the specific 'best form' of a vessel designed to utilise the theory.

The desire for more exact ways to understand the behaviour of a ship at sea informed discussion of ship roll in Victorian Britain. The leading British authorities of

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[30] Merrifield, 'Report', p. 15.

[31] The early-Victorian focus on waves also represented a break from the natural philosophical tradition of focusing on the body under the water, which bore some relation to the similarly natural philosophical treatment of ships as fish. John Scott Russell, 'The wave-line principle of ship-construction, part I', *Transactions*, 1 (1860), pp. 184-195, esp. 186-87.

[32] Merrifield, 'Report', p. 16-17.

[33] William Froude to Napier, 15 November 1874, Napier papers 90/2/4/51.

ship roll, the reverend Henry Moseley, Rankine and Froude, approached the phenomenon as a mechanical problem. These men of science were specifically interested in the centre of gravity, the metacentre (where the forces of buoyancy pass when a vessel was heeled, and the critical point below which, if the centre of weight be kept, there will be stable equilibrium) and how their respective connections to the centres of buoyancy, weight and the oscillation of the ship could be analysed to measure the '*mechanical work* required to heel the ship, considered as concentrated at its centre of gravity, to a given angle'.[34] It was by no means clear, however, how that could be accurately and credibly done.

The issues I have outlined in this section demonstrate the range of uncertainty in, and limits of knowledge of, hydrodynamics in mid-Victorian Britain. Merrifield felt that exact theories of ship resistance and roll could be generated, or at least theories that made sense of centuries of craftwork and *ad hoc* observation. Merrifield was anxious that within the current knowledge of hydrodynamics 'it does not appear that any specific mathematical form is to be preferred in respect of its total resistance to a long, fine, fair ship, either drawn or modelled by eye by a practiced draughtsman or modeller.'[35] His statement was not meant to imply that science offered little to craftsmen, but that there was considerable ambiguity and doubt that required further enquiry before science could be made credible to craftsmen. The overarching theme of Merrifield's report was that 'exact experiment appears to be most urgently needed'.[36] Merrifield valued practical problems and observation in his definition of an 'experiment', but other prominent actors wanted, or in some cases needed, different types of experiment to examine hydrodynamic problems and possibilities.

[34] Merrifield, 'Report', p. 26-27.
[35] Ibid., p. 20.
[36] Ibid., p. 10.

3.2 PRACTICAL EXPERIMENTS

Napier and Rankine in Glasgow naval architecture

What we might call an 'experimental tradition' with the ship – meaning experiments with the properties of a ship to come to knowledge of hydrodynamics and ship design – developed on Britain's rivers and in shipbuilders' workshops. Of all the rivers and shipbuilding centres of Victorian Britain it was the Clyde in Glasgow that led the way in building innovative and reliable vessels for the navy and mercantile service.[37] There were at one time over thirty shipbuilders on the Clyde, the most notable of which were John Scotts of Greenock, John Browns and William Denny & Brothers.[38] The Clyde was home to some of the first trials with iron and steam shipbuilding. It was also where James Robert Napier and Rankine experimented with ship design and formed a new theory of ship resistance.

In the 1820s Robert Napier (manager of Robert Napier & Sons) purchased the Vulcan Foundry. With the help of David Elder, Napier built large marine engines and expanded the family stake in iron steamship building that David Napier had began with the *Vulcan* (note the mythic associations to Vulcan, God of the forge, examined in chapter 1). Napier, together with his son James Robert Napier, built for the British admiralty and a host of commercial companies including Cunard and the Pacific Steam Navigation Company.[39] The firm was widely accredited with forging a connection between scientific theory and craft-practice in its ships. For example, the *Practical Magazine* printed the following in 1873 about James Robert Napier.

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[37] Sidney Pollard & Paul Robertson, *The British shipbuilding industry, 1870-1914* (Cambridge, MA, 1979).
[38] For the Clyde and the Clyde-built shipbuilding industry see Crosbie Smith & Anne Scott, '"Trust in providence": building confidence into the Cunard line of steamers', *Technology and Culture*, 48 (2007), pp. 471-96; Paul Ingram & Arik Lifschitz, 'Kinship in the shadow of the corporation: the interbuilder network in Clyde River shipbuilding, 1711–1990', *American Sociological Review*, 71 (2006), pp. 334-52; John Shields, *Clyde built: a history of shipbuilding on the River Clyde* (Glasgow, 1949).
[39] For Napier, see Michael S. Moss, 'Napier, Robert (1791–1876)', *Oxford Dictionary of National Biography* (Oxford, 2004).

> It would, perhaps, be too much to claim for Mr. Napier the profound and incisive acquaintance with theoretical formulae that distinguished the late Professor Rankine, or the equally exhaustive practical familiarity with the art of ship-building that have made the names of Mr. Reed, the late chief constructor of the navy, and Mr. Laird of Birkenhead, "familiar in our mouths as household words [an allusion to the H.M.S. *Captain* catastrophe]." But while we would not maintain that in their special and peculiar walks Mr. Napier excelled these men, we do not hesitate to ascribe to that gentleman a combination of theoretical and practical knowledge ... that cannot be claimed in any other living man.[40]

James Robert Napier's most significant connection to the science of ship design was through Rankine, a practising engineer who sought recognition as a man of science. The relationship was mutually beneficial as both parties looked to promote a harmony of theory and practice in professional engineering. Napier pursued this end to gain engineering and commercial advantages while Rankine pursued it to gain the support of Glasgow industrialists. In 1851, Rankine moved his base to Glasgow, where he continued to build on his reputation as a civil engineer and a man of science.[41] In 1855 he successfully sought the vacant regius chair of civil engineering and mechanics, which had been in jeopardy following Lewis Gordon's resignation. Napier lent his support to Rankine's application, and Rankine thanked Napier for the testimonial supporting his application, 'both as a certificate of my qualifications, and ... to prevent the abolition of the chair.'[42]

Between 1853 and 1857 Napier and Rankine experimented with building an air-engine.[43] At the same time the professional and professorial engineers collaborated to examine hydrodynamics and ship design, producing a formula for ship resistance, designing the lines of the *Admiral* (a Napier built steam ship for a Russian company, lunched in 1859) and compiling a large volume on hydrodynamics and mechanics with Isaac Watts and Frederick Barnes entitled *Shipbuilding: theoretical and practical* (1866).

[40] 'The shipbuilding trade of the Clyde', *The Practical Magazine*, 1873, pp. 1-6, esp. 6.
[41] For Rankine see, Ben Marsden, 'Rankine, (William John) Macquorn (1820–1872)', *Oxford Dictionary of National Biography* (Oxford, 2004).
[42] W.J. Macquorn Rankine to Napier, 7 November 1855, Napier papers 90/2/4/38.
[43] Ben Marsden, 'Blowing hot and cold: reports and retorts on the status of the air-engine as success or failure, 1830-1855', *History of Science*, 36 (1998), pp. 373-420.

In 1856, Rankine contacted Russell, who was also experimenting with ship form, to enquire into the best shape for ships. Russell responded, noting the lack of experimental data on the subject of ship lines and structure, 'I fear you will not be able to find ready made any materials for a practical essay on the thoughts of the forms used in naval architecture.'[44] Thus Russell encouraged Rankine to undertake research into the subject, and noted that 'my friend Mr. Napier would assist you with the means of making such a series of experiments'.[45]

Rankine agreed with Russell that experiments into form and structural strength were desirable. But, as he wrote to Napier, 'I am pretty confident his proposal is impractical. The series of experiments he speaks of would cost a very large sum if done in such a style as to be of any service; would occupy a great deal of time, & *waste* a great deal of material & workmanship; and where is the money to come from?'[46] Thus Rankine experienced the limits of knowledge as the limits of his capital. However, he and Napier collaborated to treat the design and trials of the *Admiral* as an experiment on the large-scale of a commercial ship. Once the *Admiral* was built, Rankine was able to examine the ship's resistance with some Admiralty co-efficient calculations and a comparison between the resistance properties of the *Admiral* and Brunel's *Leviathan*, which Russell was building on the principles of his wave-line theory.[47] To Rankine, the design and trial of the *Admiral* served as a chance to make observations on ship behaviour, while the observations helped Napier to report back to the ship owners.

[44] Russell's initial letter was quoted verbatim in Rankine to Napier, 27 June 1856, Napier papers 90/2/4/38.
[45] Quoted in Ibid.
[46] Ibid. *Emphasis my own.*
[47] Rankine to Napier, December 1857, Napier papers 90/2/4/38.

Borrowing from Rankine's credibility as a scientific expert, Napier was able to confidently describe the qualities of the experimental ship.[48]

Rankine's report deserves special mention as an example of the less than precise culture of measurement that was common to ship trials. Rankine prefaced his analysis with a description of the currents and tide in the Frith of Clyde that affected the accuracy of his calculations. As with all ships the actual speed calculations for the *Admiral* were based on the time it took the ship to pass measured land markers. There was no mechanical or automatic way of measuring the variables that were used to calculate resistance. All was dependent on the bodily skill of a group of observers, which was not ideal for Rankine who was used to working with more precise mechanical ways of measuring force and motion. However, the lack of detailed data in the *Admiral* report suited her builder, Ben Marsden notes, because the results were 'commercially sensitive'.[49]

Rankine's general theory of ship resistance examined the problem at a molecular and mechanical level. He focused on water particles and their hydrodynamic behaviour, specifically with regard to the way the movement of bodies distorted them. For a 'well-designed ship', Rankine wrote, 'particles of water [will] glide over her surface through its whole length, and are left behind her with no more notion than such as is unavoidably impressed upon them through adhesion and stiffness'.[50] Rankine's approach thus reduced the subject of hydrodynamics to the matter of energy. Rankine concluded that every vessel had a specific speed at which the production of waves that

[48] *W.J. Macquorn Rankine, 'Report to the owners by W.J. Macquorn Rankine, Esq., C.E., Professor of Engineering in the* University of Glasgow, on the paddle steam-ship "Admiral," built by James Robert Napier, Glasgow', 12 June 1858, Napier papers 90/2/6/30.
[49] Ben Marsden, 'Rankine, (William John) Macquorn (1820–1872)', *Oxford Dictionary of National Biography* (Oxford, 2004).
[50] Merrifield quotes from Watts *et al*, *Shipbuilding*. Merrifield, 'Report', p. 18. Lord Robert Montagu, second son of the Duke of Manchester, also developed a theory on the path of every particle of water displaced by a vessel passing through it, see Robert Montagu, *Naval architecture: a treatise on shipbuilding* (London, 1852).

caused resistance was 'insensible'. When that speed, which we may call the 'efficient speed', was exceeded, energy was lost through the production of those waves.

Rankine's appropriation of a mechanical treatment for hydrodynamics reflected the broader trends in Victorian physical sciences, and more specifically the concerns of Scottish members of the north-British social network of men of science and engineers to whom themes of 'work' and 'efficiency' were acutely important.[51] The identity and interpretation of this type of mechanical hydrodynamics was strikingly different to the older tradition in which Whewell worked. Actors working within the emerging north-British tradition hoped that the union of theory and practice would utilise experimental and mathematical skills and expertise for the improvement of mechanical objects like steam engines, propellers and iron ship hulls – the last of which has been ignored in the historiography of physics, but deserves its place.[52] Rankine's work on ship resistance was therefore significant both in regard to how he conceptualised waves and how he interpreted the problem for others through the framework of 'mechanical work' and 'energy'.

Rankine's approach contained a great deal of uncertainty because he had been unable to provide substantial evidence to support his molecular theory.[53] His work also suffered because practising engineers such as William Denny, another Clyde shipbuilder, felt alienated by his 'overmathematical and algebraic explanation of the practical subjects he took in hand'.[54] Thomson also conveyed to Denny his belief that

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[51] For themes of work, entropy and efficiency in nineteenth-century physics and engineering see Crosbie Smith, *The Science of energy: a cultural history of energy physics in Victorian Britain* (London, 1998).

[52] For example see the chapter 'Mysterious fluids and forces', in Iwan Rhys Morus, *When physics became King* (2005) that ignores debates in hydrodynamics that represent an important feature of the Victorian debate between molecular and field theory physics. Iwan Rhys Morus, *When physics became King* (Chicago, 2005), pp. 156-191. Contrast with Marsden's observation that 'Rankine successfully combined considerations of the fluid flow and the geometry of actual ships with engine propulsion, hull resistance, and, most importantly, work'. Ben Marsden, 'Rankine, (William John) Macquorn (1820–1872)', *Oxford Dictionary of National Biography* (Oxford, 2004).

[53] Merrifield, 'Report', p. 21.

[54] William Denny to William Froude, 17 February 1873, in A.B. Bruce, *The Life of William Denny: Shipbuilder, Dumbarton* (London, 1889), p. 141.

'Rankine was very unintelligible to practical men'.[55] These criticisms were significant to Rankine's credibility among engineers and the authority of his theory of ship resistance, but they were arguably less important to his reputation among men of science.[56] The juxtaposition of the authority and unintelligibility in science-engineering collaborations ran through mid-Victorian naval architecture. A similar juncture can be seen in how the authority of Rankine and Napier was connected to the ship as a material object. The *Admiral*, I have argued, was important to Rankine as an opportunity to experiment, and his authority among shipbuilders rested on the success of the vessel. Rankine's reputation as a man of science, however, was not ultimately linked to the fate of the ships he worked with. Napier, in contrast, had much more to risk in experimenting with ship design. Ships equated to financial and personal capital. He laid his credibility on the line with every ship he designed.

The interwoven nature of theory and practice, experiment and production, pervaded all of Napier's shipbuilding endeavours. Napier readily accepted experiment and innovation as the role of the engineer, which was unusual in Victorian Britain. In a series of correspondence with the architect and theorist Edward Lacy Garbett, Napier complained that inventors/designers/architects ought to know the principles of building and production – in effect collapsing the boundaries between theory and practice, science and engineering. 'You speak [negatively] of architects knowing nothing of mechanics', Garbett wrote, '[n]ow, in the name of common sense, why *should* they know anything of mechanics[?]'[57] Napier rejected the traditional boundaries between science and engineering, and chose to work within an inventive tradition that made use

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[55] Denny quoted Thomson's opinion in a letter to Froude, see William Denny to Froude, 17 February 1873, in A.B. Bruce, *The life of William Denny: shipbuilder, Dumbarton* (London, 1889), p. 141.
[56] James Clerk Maxwell made a similar criticism of Rankine's thermodynamics despite being intellectually and culturally close, see Smith, *Science of energy*, pp. 140, 150, 165-66, 248, 264.
[57] Edward Lacy Garbett to Napier, 20 October 1873, Napier papers 90/2/4/39.

of science and generated knowledge that members of the scientific community could engage with. As such Napier established for himself a limited amount of kudos as a man of science. He was a member of Section G of the B.A.A.S., and one of the chief organisers of the 1876 Glasgow meeting. 'His inventions', the *Bailie* reported, 'are adopted by every shipbuilder on the Clyde.'[58] The periodical also pointed to Napier's gentility, noting his home in Blythswood Square, Glasgow, and printing the following caricature of his dress that did not suggest a mere mechanic.[59]

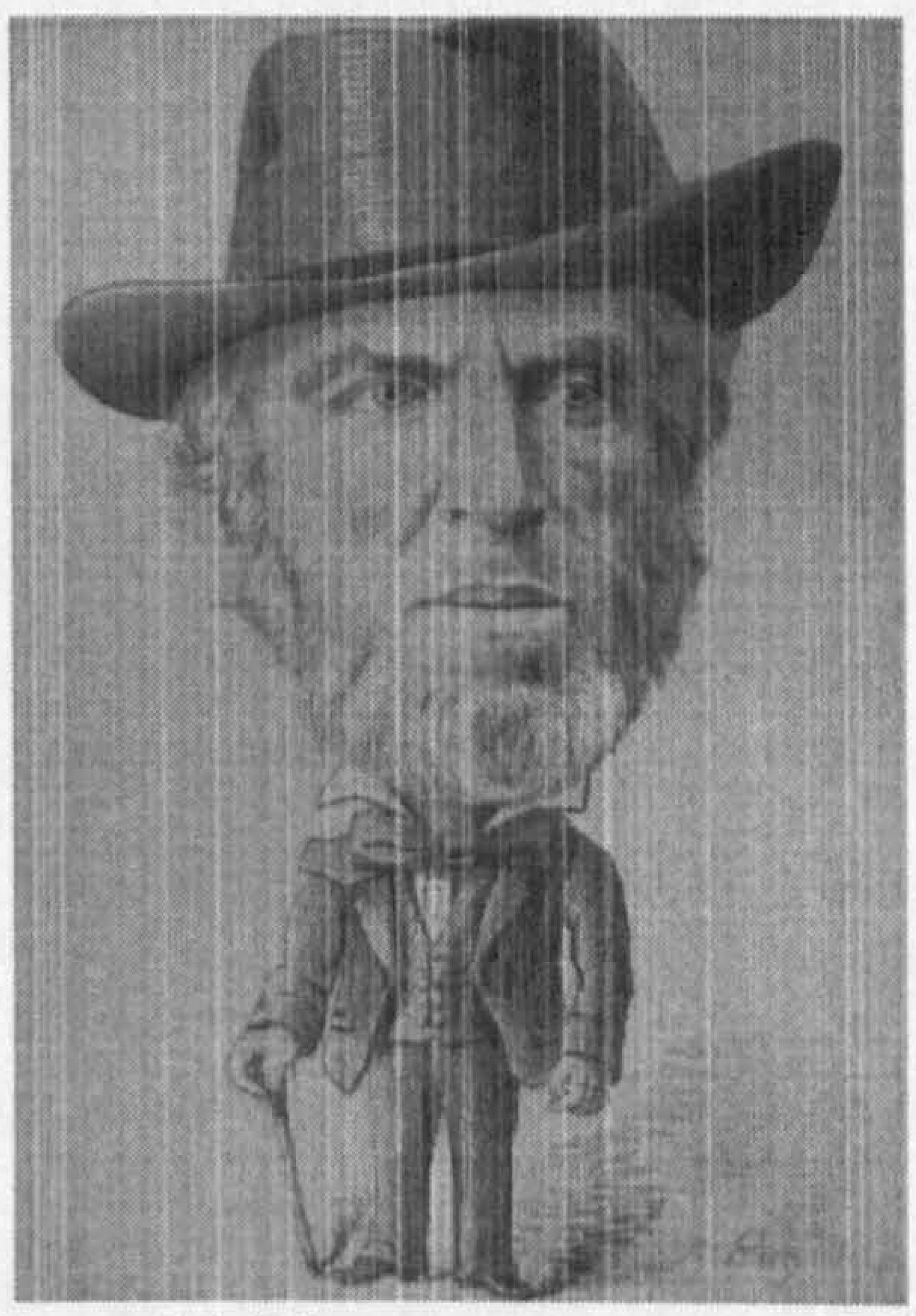

Figure 3.1 'Men you know – no. 202'.

Napier's combination of mechanical enterprise and practical experimentation was most clear to see in H.M.S. *Black Prince*, H.M.S. *Warrior*'s sister ship. The *Black Prince* attracted interest in mid-Victorian Britain as an experiment in shipbuilding. The construction of the *Black Prince* was fraught with technical and financial difficulties, particularly with regard to satisfying the novel specifications the Admiralty had set. To ease these difficulties the Admiralty copied to Napier letters on the design and work that took place on the *Warrior*. Letters from Clarence Paget described for Napier the delays experienced by the Thames Ironworks, and letters from John Ford of the Thames

[58] 'Men you know – no. 202', *The Bailie: My Conscience!*, 30 August 1876, pp. 1-2.

[59] Napier only developed this gentlemanly manner towards the end of his life, as indicated by Archibald Smith's 1854 account of Napier personal appearance and ease with which he moved around his ships by sliding on the tarred decks. Crosbie Smith & M. Norton Wise, *Energy & empire: a biographical study of Lord Kelvin* (Cambridge, 1989), p. 24.

company to Paget demonstrated the difficulties felt by the private firm. Ford compared the *Warrior* to another experiment in shipbuilding recently completed on the London river, Brunel's *Great Eastern.*

Ford stressed that 'a work of such novelty and magnitude requires more time for its execution'.[60] The difficulty concerned meeting the Admiralty's specification for iron armour, which Napier also experienced with the *Black Prince* – and which nearly bankrupted his company. The novel design of the *Warrior* and *Black Prince* were known to their builders. Ford used the novelty to excuse the Thames company's delay in production.[61] From the Admiralty's perspective these delays harmed the credibility of their trial with ironclads. Admiral Baldwin Walker, controller of the navy, explained to the Board of Admiralty that 'it is of great importance that one of these experimental vessels should be completed at as early a date as possible'.[62] If Napier had not already recognised the novelty of the *Black Prince* as a naval vessel and that the Admiralty's credibility was on the line, this correspondence surely did.

Napier's credibility was important to the Admiralty's early forays into ironclad shipbuilding. Napier wanted to prove that his firm could be trusted by the Admiralty to build these experimental ships that were a source of much public intrigue and scrutiny. To nurture his credit Napier turned to his friend Robert Spencer Robinson who, in 1861, took over from Walker as Controller of the Navy. In 1863, Robinson supported Napier by arranging to give a group of admirals a tour of the works.[63] Napier's relationship and credibility with Robinson, however, was not always assured. In 1863 their working and

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[60] John Ford to Clarence Paget, 9 June 1860, Napier papers 90/2/6/42. Also see Philip Banbury, *Shipbuilders of the Thames & Medway* (Newton Abbot, 1971).
[61] Ford to Paget, 12 October 1859, Napier papers 90/2/6/42.
[62] Baldwin Walker to the Board of Admiralty, 6 June 1860, Napier papers 90/2/6/42.
[63] Robert Spencer Robinson to Napier, 20 September 1863, Napier papers 90/2/4/28c

personal relationships collided when Napier responded to a Board of Admiralty note written by Robinson that had became public.

Robinson had been requested to consider the merits of iron over wood, and provided a report to the Lords of the Admiralty that pointed to the serious technical and administrative problems with iron shipbuilding. The Controller acknowledged that iron ships could be built larger and with better structural strength, but that they suffered from localised spots of weakness, fouling, the attraction of marine zoophytes, the poor quality of available iron, the danger of iron splinters that result from shot impacting on iron and a relative weakness under an armour belt.[64] In an inversion of the use of the French *La Gloire* to justify iron shipbuilding, Robinson stated that '[t]he most able designer of warships in Europe ... M. Dupuy de L'Ome ... constructs the ships that are to form the French line-of-battle of wood, in preference to iron.'[65] The Controller added that of all Her Majesty's dockyards only Chatham was equipped for iron shipbuilding, and thus the country either needed to make a large outlay for shipbuilding machinery or place faith in Britain's commercial shipbuilders. Robinson's support lay with the former proposal, which he defended to the Board by claiming that 'in no one instance have the [private] contractors kept to their agreements with the government, either as to time or cost.' He continued, alluding to the 'general slovenliness of the work performed by iron shipbuilders', and their 'uncertainty attending this mode of construction.'[66]

Robinson's report outraged Russell, who organised a petition on behalf of London iron shipbuilders to Parliament, requesting that a committee be formed to study

[64] Robinson's report was quoted in 'Iron or wood?', *The Times*, 11 March 1863, p. 11.
[65] Ibid., p. 11. It is noteworthy that these debates in the Admiralty's shipbuilding policy were in no way affected by the Admiralty's decades of experience funding the mail lines ran by commercial companies, many of whom had turned to iron in the late-1840s and early 1850s. I thank Crosbie Smith for pointing out this contrast.
[66] Ibid., p. 11.

Robinson's claims.[67] Russell also wrote to Napier and persuaded him to write a similar petition to be signed by Clyde shipbuilders – who had hitherto taken a prominent role in building the ironclads that the Controller attacked. 'I think you have a just right to complain', Russell wrote, 'you must not allow yourself to lie silently under the implication of bad workmanship, bad material and want of principle'.[68] Russell suggested that Napier act quickly to produce a rebuttal, lest 'it will be believed that you are silent because the accusations are true.' Russell, himself a Scotsman, concluded that unless swift action was taken the reputation of Glasgow shipbuilding would suffer before the eyes of European competitors and contractors: 'it is virtually saying to foreign nations "if you want good steam ships don't come here."'[69] Napier, as an influential member of the Institution of Engineers and Shipbuilders in Scotland, organised a committee to study Robinson's claims and send a complaint to Parliament. For Napier both his credibility and the credibility of the fragile union of theory and practice that he, his firm and Rankine advocated was on the line.

Napier and Rankine's work was attractive to members of the INA who believed that there were serious limitations in exclusively mathematical expressions and solutions to problems of naval architecture. In 1860, Woolley noted that 'late researchers in the science of hydrodynamics, to which some of our ripest mathematicians – Professor Stokes, for example – have paid much attention, have made little, if any, advance in this direction, and we are as far as ever from a sound theory of resistance.'[70] Napier and Rankine's experiments with hydrodynamics in the *Admiral*, ironclad shipbuilding with the *Black Prince* and publication of *Shipbuilding: theoretical*

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[67] Russell also used Robinson's remarks to support his views on maintaining a monopoly of commercial iron shipbuilders in building naval vessels, which justified his views on expertise and independence examined in chapter 1. John Scott Russell to Napier, 13 March 1863, Napier papers 90/2/4/36.
[68] Russell to Napier, 23 March 1863, Napier papers 90/2/4/36.
[69] Russell to Napier, 18 April 1863, Napier papers 90/2/4/36.
[70] Joseph Woolley, 'On the present state of the mathematical theory of naval architecture', *Transactions*, 1 (1860), pp. 10-38, esp. 15.

and practical were intended as instructive offerings to a community torn between the tense, intermingled cultures of practice and theory. The public trial of the *Black Prince* also demonstrates that for shipbuilders every ship became an object of experiment, the success of which carried with it the firm's (and their designers) credibility.

3.3 WAVE-LINE AND REPUTATION

Russell and Science in the *Great Eastern*

Isambard Kingdom Brunel's *Leviathan* (later *Great Eastern*) was recognised in many editorials, articles and open letters in Victorian newspapers and periodicals as a spectacular development. An editorial in *The Times* cast the *Leviathan* against the cultural authority of the Horatian myth, that providence governed travel across the oceans. The editorial claimed that the myth no longer had credence in the British maritime empire that was connected by iron and steam. In its place emerged a new myth about God's plan for the British:

> It will appear that the sea was made to alternate with the dry land, not that continents might be disconnected, but that man should have the opportunity of exerting his skill and invention in connecting them. The result of this great experiment in shipbuilding, if it answers, of which there is little or no doubt, will be a consolidation of the British Empire such as we have not yet seen.[71]

This new mythology celebrated a series of cultural reconfigurations, among which were the dominance of humankind over nature and the increasing credibility of mechanics. Thus the *Great Eastern* came to represent a new relationship between experiment and invention in industry.

Napier and Rankine were not alone in utilising commercial ventures as opportunities to experiment. Brunel took similar opportunities, albeit in a more spectacular way that celebrated the rhetoric of science, spectacle and improvement, to

[71] 'London, Saturday, April 18, 1857', *The Times*, 18 April 1857, p. 8.

experiment with ship resistance and roll.[72] Brunel was not himself scientifically sophisticated or notably learned in theory or mathematics, but he surrounded himself with people who were, like Russell, Froude and William Bell, who took care of experiments and the more complicated elements of design and science.[73] This section examines Russell's association with the design of the *Leviathan* to demonstrate the way in which the ship and experimental models became a fundamental part of the project of experimentation in hydrodynamics.[74] This case-study continues the theme developed in the previous section regarding how the authority of scientific theories and the credibility of experiment became intertwined in the material objects produced by industrialists.

Russell, son of a Scottish clergyman, was educated at Glasgow University. In the early 1830s he taught mathematics and natural philosophy at the University of Edinburgh prior to emigrating south, where he established himself with the shipbuilders of the Thames. Russell approached ship resistance through a similar framework of values to those of the north-British social network that he left behind. He associated the practice of the naval architect with 'work' and 'economy', putting the problem of finding the 'best form' in the following light: 'what is the way of least waste? Let us inquire how a ship, in moving through the water, shall avoid wasting power in causing unnecessary or useless movement.'[75] Thus, Russell's conception of waste was both mechanical and commercial. 'Power and money were wasted in vain attempts to make ships of unsuitable dimensions attain high speed', he noted, 'instances are well known, where a double amount of steam boiler had been provided to compel high speed

[72] For the *Great Eastern*, and especially its commercial failure, see Smith & Marsden, *Engineering empires*, pp. 102-107, 122.
[73] R. Angus Buchanan, *Brunel: The life and times of Isambard Kingdom Brunel* (London, 2002), p. 221
[74] For Russell see George S. Emmerson, *John Scott Russell: a great Victorian engineer and naval architect* (London, 1977).
[75] Russell, 'Wave-line, I', p. 186.

in an unsuitable vessel, and afterwards these boilers had to be removed, the higher speed being found impossible in that kind of ship'.[76] Russell also understood the nature and use of experiment through a commercial conception of economy, but only after a series of disappointing trials with a more expansive project that built experiment (particularly with models) into the working practices of engineers.

In 1860, Russell claimed that shipbuilders who incorporated the wave-line theory were able to benefit from the practical rules that the theory supposedly established. Russell believed that the wave-line theory 'gives us *the exact length of ship for every speed* at which we wish a ship to go'.[77] I have observed above that Rankine, Napier and Froude disproved the direct connection between increments of length and speed that Russell believed he had discovered. Russell responded to these criticisms by drawing back from his own personal stake in the wave-line and emphasising that ships reflect the skills and feel for 'economy' of their builders. 'Knowledge of the wave principle does not supersede the knowledge of other principles of naval construction', Russell later told the INA, '[i]t requires a man of fully as much wisdom and knowledge of his profession to turn the wave principle to account.[78] Russell's protestations are instructive of how he saw his credibility as the naval architect of the *Great Eastern*. Russell had frequently stated that 'the Great Eastern ... is a pure example of the wave form', and as such the credibility of his ideas were entwined with the success of the ship.[79] Prior to 1860, before the launch of the *Great Eastern* and the first signs of its disastrous career as a working ship, Russell's attitude to science had been more speculative.

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[76] John Scott Russell, 'The wave-line principle of ship-construction, part III', *Transactions*, 2 (1861), pp. 230-245, esp. 240.
[77] Russell, 'Wave-line, II', p. 205.
[78] Russell, 'Wave-line, III', p. 231.
[79] Ibid., p. 241.

In the 1850s, Russell was invited to design two mail steamers for the Australian Royal Mail Co., where he met Brunel, the company's chief engineer. In 1852, Brunel discussed a plan with Russell for a leviathan of the ocean, 600 feet long and of 20,000 tons, to be built in Russell's Millwall shipyard. The *Leviathan* was designed to follow Russell's wave-line principle of ship construction that he had first examined in the 1830s and 1840s with the support of the BAAS, which had given him funds to make observations of the resistance profile of ship shapes from the size of small models in canals to 200 foot seagoing vessels. At the same time Russell collaborated with Sir John Robison, an inventor and scientific administrator who was prominent in the Scottish scientific community and Section G of the BAAS, on another BAAS project to determine 'the varieties, phenomena and laws of waves, and the conditions which affect their genesis and propagation'.[80] Russell noted that there were two distinct types of experiments on ship resistance, 'those designed to advance our knowledge of the laws of hydrodynamics which govern the phenomena of resistance of fluids, and the other the experiments serving as a basis to the operation of the practical construction of ships, the *Experimenta Lucifera* and the *Experimenta Fructifera* of Lord Bacon.'[81] During these experiments Russell, who practiced the latter, observed how waves were formed along a ship's hull during motion.[82]

Russell wanted to make his experiments as instructive as possible, which included conveying to and convincing shipbuilders that models provided a trustworthy way to truth. He proposed a volume based on his BAAS experiments that would list illustrations of ship shapes and the corresponding resistance expected of that shape.[83]

[80] John Scott Russell, 'Report on Waves', in *Reports, 1844* (London, 1845), pp. 311-389, esp. 311.
[81] John Scott Russell, 'Notice of a report of the committee on the form of ships', in *Report, 1843* (London, 1844), pp. 112-115, esp. 113.
[82] Russell, 'Wave-line, I', p. 184; Russell, 'Wave-line, II', p. 201.
[83] Russell, 'Report of a committee on the form of ships', in *Report 1842* (London, 1843), pp. 104-105, esp. 104.

Russell, who was aware that previous failed model experiments had also been undertaken under the rhetoric of 'for the advancement of naval architecture', outlined specific reasons why they had been ignored by practical men. These reasons included the lack of interest among experimenters in 'the wants of the constructor', that the model shapes experimented on rarely reflected ship shapes and that the size of the models were 'too small to claim for these results, as applied on a large-scale, any considerable degree of confidence'.[84] Russell was keen to use the voluminous data he had collected to demonstrate to men of science and industry alike that he had discovered 'a remarkable law by which it appears that velocity has a corresponding form and dimension peculiar to that velocity': the wave-line theory.[85]

Russell used the numerous papers he delivered to the scientific community to demonstrate the connection between experiment and shipbuilding. In 1854, he addressed the BAAS meeting at Liverpool with a paper 'On the progress of naval architecture and steam navigation'. Russell described how superior lines, such as those of the *Leviathan* that were based on the wave-line theory, could be 'achieved by those who, like himself, had "consulted and "cross-question[ed] nature" through experiment.'[86] Russell frequently employed the rhetoric of science and experiment to describe the wave-line principle and Brunel's ship.[87] In these papers Russell also emphasised the importance of asking questions that were not necessarily consequential to the shipbuilder, such as 'where does the water go which is displaced by the bow? And how does it go?'[88] Russell used these questions to establish the importance of experimentally coming to knowledge of 'best form'. He further emphasised the

[84] Russell, 'Report of a committee', p. 104.
[85] Russell, 'Notice', p. 114.
[86] Smith & Marsden, *Engineering empires*, p. 103.
[87] This was also acknowledged in numerous national and local reports of Russell's work on the *Leviathan*, see for example, 'The Great Eastern steam ship', *Morning Chronicle*, 2 September 1857, p. 7.
[88] Russell, 'Wave-line, III', p. 230.

important role of science by contrasting the experimental culture he advocated with the rules of thumb he had been taught in the Thames craftwork culture: 'I was educated in the dogma that the great beam, or main breadth of construction, should be exactly one-third of the length from the stem, and exactly two-thirds of the length from the stern; making the after body double the length of the fore body.'[89]

Russell, unlike Brunel's other associates, actively promoted himself through his dealings with the *Great Eastern* in a Victorian press that was enraptured with the rhetoric of new mythologies and 'experiment' surrounding the *Great Eastern*. This was a dangerous activity because the rhetoric of experiment and spectacle were not easily made compatible with the persona of credit and trust that Russell sought as a naval architect and businessman. Russell slowly realised that public trust in the *Great Eastern* as a working object was destabilised by the unrelenting influence of press speculation and its representation of the *Great Eastern* as an experiment and shipbuilding monstrosity.[90] In letters to shareholders, Russell compensated by stressing how his own authority was at stake. 'You have been taught to suppose that you and I have opposite interests. Do not believe it! My interests can never be separated from those of the Great Ship', Russell explained, 'I expect yet to gain reputation by her; and I am, like yourselves, a large shareholder.'[91]

In the 1860s, following the commercial failure of the *Great Eastern*, Russell distanced himself from the optimistic statements he had made regarding the validity of models for practical purposes (that he had publicised as a part of his wave-line theory). Russell description of the wave-line principle for the INA (described over the course of three papers from 1860-61) contained a number of references to model experiments,

[89] Ibid., p. 239,
[90] See the account of the *Great Eastern* as an object of science, spectacle and personal credibility in Marsden & Smith, *Engineering empires*, pp. 102-7.
[91] [John Scott Russell], 'Report to the shareholders by the builder of the great ship', Napier papers 90/2/4/36.

but in the discussions that followed Russell's method was criticised by shipwrights like Thomas Joseph Ditchburn, superintendent of Fletcher, Son & Fearnall, a builder of steamships based at West India Docks, London. Ditchburn told members that, 'with reference to experiments in troughs or canals and in open water, the results are so different that no truth can be developed by such experiments'.[92] It seems that Russell agreed, in principle, with Ditchburn's criticism. 'I believe the man does not yet live who can tell, from what he observes with a little model in a little trough, anything about what a ship of full size will do in open water, or upon the sea. But, at the same time', Russell explained, 'a man who wishes to know a subject thoroughly will do well to study it upon any scale on which he may have the opportunity of studying it'.[93] Russell's response to Ditchburn suggests that he perceived a purely scientific value to undertaking scaled down experiments that lacked immediate practical benefit. He added that '[i]f there is anything I wish to guard them [young naval architects] against it is against making experiments with small models, and believing that they, or I, or any other students, have sufficient knowledge of hydrodynamics to be able to pass from them to the conditions of a large ship.'[94]

3.4 Making Meaning in Model Experiments

Froude and Model Debates

Russell's 1861 views on model experiments reflected the views of many practising and professorial engineers, but not all. Froude, who was also involved in building the *Great Eastern*, controversially suggested making use of small models. In 1861, Froude presented his ideas on the rolling of ships to the INA. Froude's paper described and

[92] Russell, 'Wave-line, II', p. 209.
[93] Ibid., p. 210.
[94] Ibid., p. 209-10.

analysed his observation that a vessel on a wave sat at a right angle to the wave surface, that rolling was often a result of *too much* stability (added weight below the centre of buoyancy) and that stability was linked to the period of a ship's roll (time taken and angle of a complete roll) and the shape of waves. Froude expressed a degree of trepidation when he began the paper, noting his relative inexperience in comparison to other members of the institution and that his paper would be 'markedly at variance with views which have been expressed by men whose authority deservedly ranks high on questions of Naval Architecture.'[95] Froude's anxiety was understandable. He recognised that his audience were not simply skilled analysts and mathematicians, but men like Russell who 'embodies the result of his experience and his investigations'.[96] This section examines how Froude sought to place models at the core of his experimental work, demonstrating the problems and debates that gave them meaning in Victorian hydrodynamics and ship design.

Froude spent most of his professional career working as a civil engineer on Brunel's Bristol-Exeter railway. Froude was one of a number of scientifically inclined engineers that Brunel surrounded himself with to lend theoretical, mathematical and scientific expertise to his projects. Unlike many of Brunel's assistants, Froude became a close social acquaintance. Angus Buchanan suggests this was facilitated by their mutual respect and Froude's position as a gentrified engineer of private means.[97] Likewise, Froude appreciated Brunel's clarity and the influence it had on him, later telling John Newman that he was 'a man of singular grasp of thought, and truthfulness and honesty of purpose'.[98] In 1844, Froude left Brunel's service and retired to Dartington to care for his dying father. Despite formally retiring, Brunel commissioned Froude to undertake

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[95] William Froude, 'On the rolling of ships', *Transactions*, 2 (1861), pp. 180-230, esp. 180, 187.
[96] William Froude, 'Remarks on Mr. Russell's paper on rolling', *Transactions*, 4 (1863), pp. 232-275, esp. 232.
[97] Buchanan, *Brunel*, pp. 162, 201.
[98] Froude to John Newman, 29 December 1859, in *Correspondence*, p. 118.

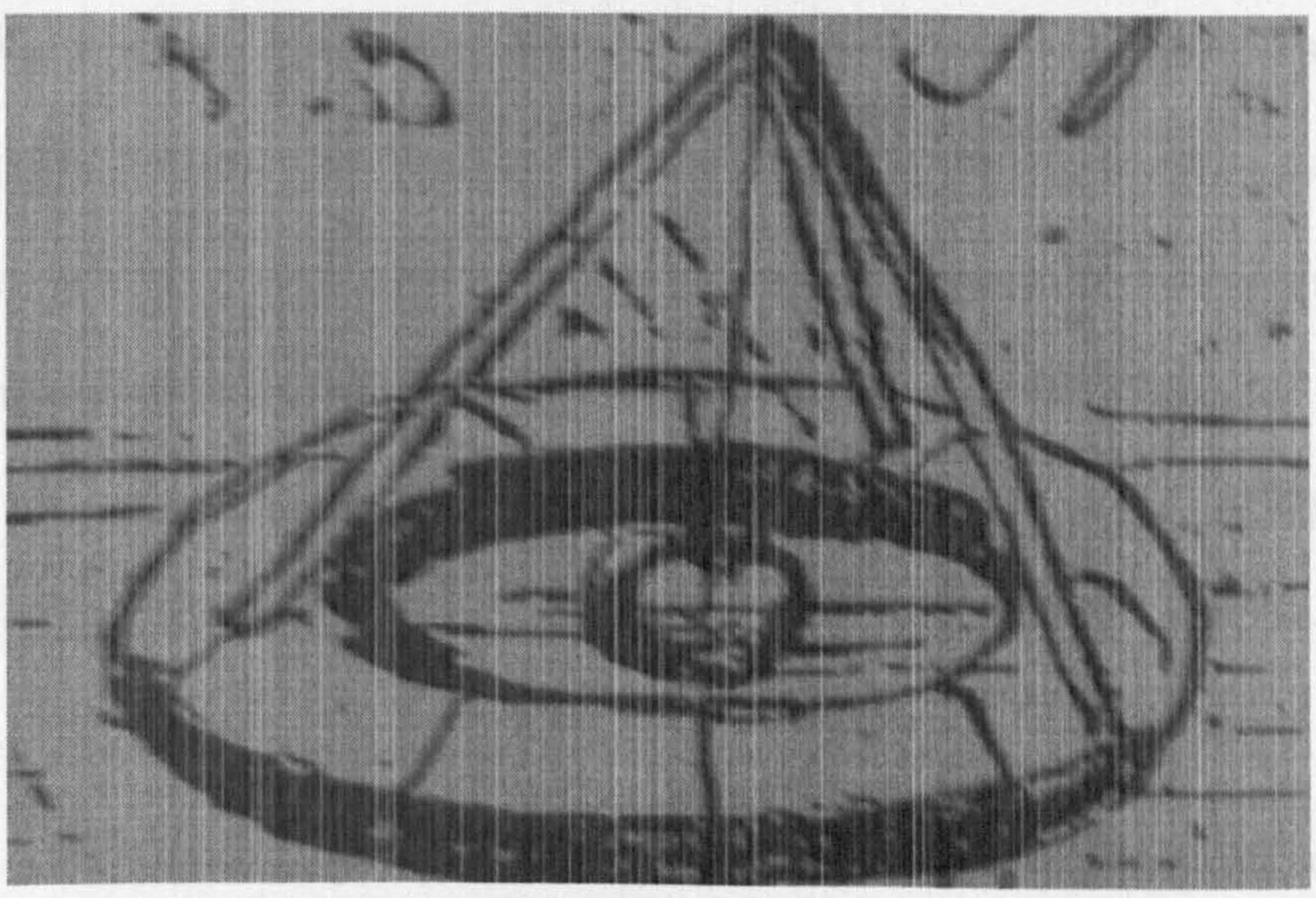
piecemeal engineering work in the vicinity of Devonshire, suggesting that Brunel placed a great amount of trust in Froude's ability.[99] In 1857, shortly prior to the launch of the *Leviathan*, Brunel, who wanted reassurance that the design was safe, commissioned his former assistant to undertake a series of experiments and mathematical analyses on the design of the ship, particularly with regards to stability and roll.

Froude performed experiments and calculations 'as to [the] position and distribution of weights in the Big Ship with a view to the calculation of moments in rotation.'[100] Froude compared his data from experiments undertaken by Bell, another of Brunel's assistants, and noted that his data differed from Brunel's own analysis. With knowledge of the ship's dimensions and weights, Froude performed a small model experiment, the results of which suggested that the ship's two centres of gravity were on different levels, causing the ship's stern to sit heavy in the water and the fore to rise out of the water. Froude expressed his concern to Brunel's assistants that he was 'anxious to know whether the difference indicates the existence of any error anywhere'. If not then there was a design fault in the ship.[101] Froude suggested that Brunel's staff perform the same model experiment he had performed as 'it would enable us to compare the results of our calculations with actual fact, in the case of the model, and thus in some respects to test their accuracy.'[102]

In another letter, this time to Brunel, Froude described in detail the experiments he had performed on ship roll (oscillation), and mentioned that he had discovered something that he felt was 'highly valuable'.[103] Froude had performed a series of tests using rafts and corks to observe the behaviour of a floating body on a wave. In one

[99] Isambard Kingdom Brunel to Froude, 22 July 1845, Bristol University, Special collections, Isambard Kingdom Burnel papers, Letter Books, 4; Brunel to Froude, 3 October 1846, Brunel papers, Letter books, 5.
[100] Froude to [one of Brunel's assistants], 1 June 1857, Brunel papers DM 1308/X1.20.xxii.
[101] Ibid.
[102] Ibid.
[103] Froude to Brunel, 16 August 1857, Brunel papers, Letter books, 4.

experiment he set a pendulum on top of a ring of corks, and observed the relationship between the surface of the wave, the surface of the cork and the centre of gravity displayed by the pendulum.[104] Froude observed that 'a body [that] floats on the surface of the wave will be ... *at right angles to the surface of the wave*'.[105] Froude also described for Brunel how he came to his conclusion 'by consideration of general dynamics', noted the engineer, and 'I think I may truly say I have already tested it by experiment.'[106] Froude felt that by attaching what he would later call 'an extremely delicate (I might almost say a perfect) self-acting apparatus, for recording by diagram, the degrees by which the oscillation of any given model declines', he could produce a line indicating the action of a rolling ship.[107] Froude performed such an experiment with a model of the *Great Eastern* and a series of other test models on the estuaries of Salcombe, Devon, and the results of which he took to the INA.[108]



3.2 Froude's 1857 cork experiment.

[104] Ibid.
[105] Ibid.
[106] Ibid.
[107] Froude, 'Remarks', p. 270.
[108] An early twentieth century biographer of Froude noted that 'Froude was frequently seen by the natives rowing about apparently playing with toy boats. When on one occasion two uniformed men (naval officers interested in the experiments) were seen at the oars, a story spread about the locality that William Froude was mad and had to be in charge of two "keepers."'. *Correspondence*, pp. 4-5.

Models had a long and multifarious relationship to the ship. They had been widely used by the world's navies and shipbuilders in artistic, decorative and ceremonial ways.[109] Robert Seppings, surveyor of the navy (1813-1832), nurtured this tradition by establishing the first national collection of models in Britain, housed in Somerset House for the instruction of shipwrights and sailors.[110] This new instructive mode did not include using models to explore the epistemological nature of hydrodynamics and shipbuilding, but as the models used by naval constructors became larger and more complex, their possible use in instruction and controlling the design of ships broadened. In the eighteenth century models took on a variety of uses such as training and experimenting. During the Enlightenment the model became a key tool in the 'precision management of society and nature.'[111] In the naval community the role of the 'solid maker', or model maker, was increasingly recognised in the years following the Napoleonic Wars. These craftsmen worked in the lofts of mould rooms where they made models that became the template for the drawings that served as guides for ship frames.'[112] The growing authority of using models to represent and examine natural phenomena also influenced engineers and men of science like Froude, Rankine and Russell, who all utilised models to varying extents in their research. This emerging tradition reflected the prominence of themes like 'the machine' and 'the mechanical' in nineteenth century science and society.[113]

Models, or rudimentary floats in the case of early experiments, were used by shipwrights to experiment with design features. John Fincham, whose contribution to

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[109] Brian Lavery & Simon Stephens, *Ship models: their purpose and development from 1650 to the present* (London, 1995), pp. 9-22.

[110] Raymond Needham & Alexander Webster, *Somerset House: past and present* (New York, 1905), pp. 240-41.

[111] Nick Hopwood & Soraya de Chadarevian, 'Dimensions of modelling', in de Chadarevian & Hopwood, *Models: the third dimension of science* (Stanford, 2004), pp. 1-15, esp. 5.

[112] Schaffer, ' "The charter'd Thames"', p. 296.

[113] Peter Dear, *The intelligibility of nature: how science makes sense of the world* (Chicago, 2006), pp. 115-136; Schaffer, 'Fish and ships', p. 71-105.

hydrodynamics I examined in chapter 2, undertook experiments with 'models of circular sections and triangular sections' of the ship to examine the conditions that affected resistance.[114] A larger and more systematic investigation of ship resistance through models was undertaken by Russell in the 1840s (see above). In 1863, a BAAS committee involving Rankine, Russell, Napier and Froude examined the resistance of water to floating and immersed bodies in a purely scientific study. This committee commissioned model experiments, broadly following the method used by Russell in the 1840s.[115] Two models of 4 feet were pulled at 2 knots, a speed chosen so that the models did not exceed the 'natural speed of the wave corresponding to the length of the model'.[116] These experiments were not developed further, and like previous examinations of hydrodynamics funding by the BAAS, had little authority outside the BAAS. The various unsuccessful attempts between the late-eighteenth and mid-nineteenth centuries to establish the credibility of model experiments disheartened many naval architects and engineers.

Rankine's approach towards models and science in ship design clearly demonstrates this attitude. Rankine was relatively open to the use of models but, as Marsden has argued, 'practical considerations of time and expense' shaped his intellectual environment. 'Carrying out small-scale experiments, or modelling, would be of no immediate commercial value, there being no guarantee of the applicability of a naive "scaling up" of results', writes Marsden, and 'experiments ... carried out simply to provide data for a "scientific" paper would be *wasteful* of time, labour, and money.'[117] This context made it difficult for Rankine to justify small-scale modelling. A keen

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[114] Froude, 'Rolling of ships', p. 229.
[115] W.J. Macquorn Rankine, John Scott Russell, James Robert Napier and William Froude, 'Interim Report of the Committee on the Resistance of Water to Floating and Immersed Bodies', in *Reports, 1865* (London, 1866), pp. 56-57.
[116] Ibid., p. 56.
[117] Marsden, 'Engineering science', p. 335.

commercial awareness and respect for 'prior "practical proof"' were prominent in Glasgow engineering science, examples of which included the design of the *Admiral* and the Rankine and Napier gaz engine.

Like many of his contemporaries, Froude questioned the worth of previous experiments with models, telling Napier that Russell's experiments were 'valueless'. But Froude's sense of what was 'practical' differed distinctly from Rankine's.[118] In 1873, Froude described some of his model experiments to Thomson concerning his notion of instantaneous equilibrium and the effective wave slope, indicating that accountability and practicality were not so consequential to the gentleman experimenter/engineer. 'That there is some approach to truth in all this I cannot doubt', Froude wrote, but 'that the proposition is of any practical value I cannot yet presume to say.'[119] Froude was at liberty to explore what he simply found interesting, without justification. Thus Froude told Thomson, 'Indeed I can only make the faintest guess as to how the same principles will work out when applied to more ship shape forms – but it is certainly interesting and instructive.'[120] Even during the 1870s, when Froude was working in the test tank, built with support from the Admiralty, he was not under institutional control and continued to follow his own research interests in tandem with any ship plans sent to him by his naval benefactors.

Debates concerning model experiments reveal the tensions between 'ship' and 'model', 'exact' and 'instructive', 'mathematics' and 'mechanics'. The ways Victorian naval architects, engineers and shipbuilders negotiated these categories offers a framework to differentiate the cultures of experiment that criss-crossed Victorian naval architecture and the identity of science and engineering. Woolley, for example, told

[118] Froude to Napier, 15 November 1874, Napier papers 90/2/4/51.
[119] Froude to William Thomson, 18 March 1873, Thomson papers GB 0247 MS Kelvin F48.
[120] Ibid.

members of the INA that 'experiments on small models are always less satisfactory than on vessels of the proper dimensions properly equipped, although something may be learned from them.'[121] The main fault that Woolley perceived was that the form of the models 'essentially [differed] from any actual form ever given to a ship', and that the proportionality between a model and a wave was not a credible reflection of 'a real vessel ... [and] the waves of the ocean.'[122] Thus Woolley (echoing Rankine's concern for practicality) did not want models to have any place in the experimental approach to ship design that the INA advocated from its foundation, quite possibly because models had come to represent a great failure in the instructiveness of science in practical projects.

The INA controversy that emerged over ship roll and the use of models in the early 1860s was the first major disagreement among members of the INA, and as such the manner in which its members discussed the issue provides an insight into how members of the INA saw their institution as a representative body of experts. This controversy was vital to the production of trustworthy knowledge about hydrodynamics, which had hitherto appeared to be an epistemologically problematic field of science.[123] Papers discussing and dissecting Froude's theory of rolling monopolised the programme at the third meeting of the INA. Woolley opened the first session by stating his opposition both to Froude's idea that the 'position of momentary equilibrium for a ship on a wave is that which places her mast at right angles to the

[121] Joseph Woolley, 'On the present state of the mathematical theory of naval architecture', *Transactions*, 1 (1860), pp. 10-38, esp. 30. Moseley expressed a similar attitude to models when he told the INA members that 'Whether the action of water upon a ship is like the action of water upon a little float is, I think, a question which admits of considerable doubt.' Froude, 'Rolling of ships', p. 229.

[122] Woolley, 'Mathematical theory', p. 37; Joseph Woolley, 'On the rolling of ships', *Transactions*, 3 (1862), pp. 1-7, esp. 6.

[123] Shapin noted that 'speech about natural reality is a means of generating knowledge about reality, of securing assent to that knowledge, and of bounding domains of certain knowledge from areas of less certain standing.' Steven Shapin, 'Pump and circumstance: Robert Boyle's literary technology', *Social Studies of Science*, 14 (1984), pp. 481-520, esp. 481. Also see David Locke, *Science as writing* (New Haven, 1992).

wave surface where she floats', and the use of model experiments to come to that conclusion.

Many of the responses to Froude's work took the form of gratification for Froude's endeavour, respect for his mathematical and theoretical abilities and then dismissal of his work. For example, Woolley praised Froude's 1861 paper, which 'possesses the high merit of being the first systematic attempt since the time of Bernouilli to grapple with the difficulties of this question. ... [I]t cannot be denied for a moment that his Memoire is a most valuable and suggestive contribution to the Science of Naval Architecture'.[124] 'I believe that some of his most important conclusions may be relied on as offering a near approximation to the truth', he continued, before abruptly remarking that 'no arguments, I think, can be deemed conclusive which are founded on experiments made either with small floats or with long thin boards.'[125]

Froude respected Woolley for having 'clothe[d] adverse criticism in ... friendly ... courteous language'.[126] 'I cannot better express the value I place on this non-controversial mode of treating the subject', he prefaced his response the next year, 'than by shaping all I have to say in exact harmony with it.'[127] This discursive mode reveals the manners and method of Froude's scientific thought, in which themes like doubt, modesty and open-mindedness were central (see chapter 4).[128] Froude believed it was important to avoid personal confrontation in scientific disputes as they detracted from the epistemological controversies that were vital to 'progress'.[129] This attitude

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[124] Woolley, 'Rolling of ships', p. 4.
[125] Ibid., pp. 4, 6, 7.
[126] W.J. Macquorn Rankine, 'Remarks on Mr. Froude's theory on the rolling of ships', *Transactions*, 3 (1862), pp. 22-45, esp. 35.
[127] Froude, 'Remarks', p. 232.
[128] For science and manners see, Paul White, *Thomas Huxley: making the "man of science"* (Cambridge, 2003), pp. 6-22; James A. Secord, *Victorian sensation: the extraordinary publication, reception, and secret authority of* Vestiges of the natural history of creation (Chicago, 2000), pp. 162-66;
[129] For manners and scientific objectivity see, Lorraine Daston & Peter Galison, *Objectivity* (New York, 2007), pp. 191-252; Steven Shapin, *A social history of truth: civility and science in seventeenth-century England* (Chicago, 1994), pp. 310-354.

characterised the course of scientific objectivity that he charted in a culture where craft practice, commercial rivalry and personal disagreements were widespread.

The politics of politeness that members of the INA engaged in were key to the open dialogue that was formed between naval architects, engineers, mathematicians and men of science (chapter 6 contrasts these dialogues with those in which members of the INA restricted the access of naval men who emphasised 'common knowledge' and 'manly simplicity').[130] Froude's dialogue with Woolley facilitated discussion across distinctly different approaches to hydrodynamics and experiments. Froude believed that Woolley's opposition to his notion of a position of momentary equilibrium was rooted in the orthodoxy practiced by Woolley that had well defined notions of specific technical terms and dismissed model experiments. Woolley told members of the INA that there was no such position.[131] Froude responded by telling members of the INA that '[i]t is possible that to one habituated to approach the question from a point of view and under impressions different from those which I myself followed in approaching it, the words do not convey distinctly the sense in which I used them, and in which the proposition enters into my subsequent reasoning.'[132] Froude suggested that differences were neither personal nor based on 'facts', but were instead habitual and manifested through methodology and vocabulary. Thus he sought to avert direct confrontation and establish a space for dissent and discussion. This was particularly important for Froude, whose work in the early 1860s was considered marginal.

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[130] John Tosh notes that the politics of politeness that had been performed by politicians in the eighteenth century was practiced more widely in Victorian Britain where it was also contrasted by the 'manly simplicity' of 'the business class and the "respectable" working class', see John Tosh, 'Gentlemanly politeness and manly simplicity in Victorian England', *Transactions of the Royal Historical Society*, 12 (2002), pp. 455-72, esp. 457-62. Also see Michèle Cohen, '"Manners" make the man: politeness, chivalry, and the construction of masculinity, 1750-1830', *Journal of British Studies*, 44 (2005), pp. 312-29. For the man of science as polite philosopher see Steven Shapin, 'The image of the man of science', in Roy Porter (ed.), *The Cambridge history of science, volume 4: eighteenth century science* (Cambridge, 2003), pp. 162-183, esp. 167-78.

[131] Woolley, 'Rolling of ships', p. 6-7.

[132] Rankine, 'Remarks', p. 35.

Russell also shrouded his 1863 response to Froude's work in this dialogue of non-direct confrontation. He remarked that 'we should entirely agree within the narrow limits of the hypothetical case set up by Froude ... where I differ from Mr. Froude is, that his theoretical float is not a ship, and his hypothetical waves are not a sea.'[133] Thus it was Russell's belief that Froude's research was restricted to hypothetical conditions and had limited practical credibility. Russell pushed this point further by emphasising the rhetoric of nature and natural habitat in which the ship exists. He considered what would happen to Froude's 'theoretical float' if it was in a 'true sea' when it 'becomes dangerous'.[134] Froude experienced great difficulty answering accusations as to the hypothetical nature of his work. Distrust of models, I have demonstrated, was significant, but so too was the fact that Froude's experiments had been hitherto undertaken in private, without institutional support or validation. Without witnesses or experimenters ready to replicate his work, Froude had a problem building credibility.[135] His ideas, that challenged a lot of common assumptions about both the behaviour of ships and how to study that behaviour, were largely left to rest on his own words.

The manners of the debate that took place in the INA were vital to the shape that hydrodynamics took in mid-Victorian Britain, first as it made space for Froude's work and second because it shaped the institution building, discipline formation and boundary work in which members of the INA were engaged. Edward Reed, chief constructor of the navy, commented that 'there is no doubt that this question of stability and rolling has become a most important one, and it will now require the most exact investigation which such men as our learned chairman, and Dr. Woolley, and Mr.

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[133] John Scott Russell, 'Postscript to Mr. Froude's remarks on rolling', *Transactions*, 4 (1863), pp. 276-283, esp. 278.
[134] Ibid., p. 278.
[135] For witnessing and replicability see Shapin, 'Pump and circumstance', p. 487-91; Simon Schaffer, 'Glass works: Newton's prisms and the uses of experiment', in David Gooding, Trevor Pinch & Simon Schaffer, *The uses of experiment: studies in the natural sciences* (Cambridge, 1989), pp. 67-104, esp. 68-70.

Froude, can bring to bear upon it, to put us in a position to handle it effectually.'[136] Indeed Froude was aware that uncertainty still ran through his work. He informed members of the INA that he had 'not yet been able to master the mathematical difficulties which this mode of treatment involves'.[137] Similarly, Froude told George Gabriel Stokes that these papers 'form a somewhat detached and perhaps almost incoherent series, since they were partly designed to meet such objections as were from time to time raised, and partly expressed a growing and perhaps in some respects a connected grasp of the subject by myself.'[138] To this end Froude desired to 'see my way to a method of applying a rigorous experimental test' to the problems of hydrodynamics and ship design.[139]

3.5 CONCLUSION

I have already argued in this thesis that the role of scientific ways of researching, thinking and working was not widely trusted in the navy or the craft culture that prevailed in Her Majesty's dockyards. All of the case studies examined in this chapter have highlighted that motions toward utilising 'scientific light' in everyday practices (the scientism with which some scholars find the roots of in this period) were governed by a range of non-scientific interests. These included wanting to build credible machines in the case of Napier, building reputation in the case of Russell and, as I will go on to argue, acting with moral responsibility and being dutiful to one's doubts in the case of Froude. Moreover, the ways in which the various actors surveyed in this chapter went

[136] Froude, 'Rolling of ships', p. 229.
[137] Ibid., p. 193.
[138] Froude to George Stokes, 6 April 1869, Cambridge University, Manuscripts room, Stokes manuscripts RS705.
[139] Froude, 'Rolling of ships', p. 193.

about forging such connections between science (theory and observation), experiment and practice has shown the active role of a wide-ranging network of objects and social gatekeepers that shaped Victorian hydrodynamics. These objects included the ships and models on which the credibility of ideas and craft-practices rested. The social gatekeepers included Robinson whose criticisms of iron shipbuilders like Napier threatened to derail practical experiments, the newspapers that speculated over the success of the *Great Eastern* and by association Russell's identity and reputation that he had established in tandem with the ship, or the social manners of debate that provided a space for Froude's ideas on hydrodynamics, models and experiment in a community of naval architects, men of science, engineers and mathematician who believed he was wrong.

Napier and Froude were on the wave of a new type of culture in which the scientist/engineer was given freedom and trust by institutions to perform experiments, but they were simultaneously carried along by the preceding waves that represented the long established ways of working, thinking and institutionally deciding whether science represented a useful way of working through material problems. Russell, who claimed that the authority of science and scientific ordering could solve many problems experienced by the Admiralty (see chapter 1), revealed that 'faith' and individual reputation were central components in engineering expertise. 'I have put away from myself all faith in experiments with little models', Russell told the INA, 'the only experiments I ever put faith in, as applicable to naval architecture, were made upon vessels from seventy to seventy-five feet long, and that they were the smallest experiments from which I ever deduced a theory; ... [and] if I cannot place faith in my results, we cannot place faith in anything at all.[140]

[140] Russell, 'Wave-line, II', p. 209-10.

4

William Froude, science and the culture of Victorian doubt

[Froude's work was] one of the most remarkable illustrations of the influence of scientific method. Where purely scientific investigation had proved futile, an association of experimental and mathematical processes has succeeded.

William White looks back on and distinguishes Froude's 'scientific method' from his contemporaries.[1]

[T]he usual way in which the self-evident method presents itself in historical practice is more subtle – not as a set of explicit claims about the rise, acceptance, and institutionalization of experiment, but as a disposition not to see the point of putting certain questions about the nature of experiment and its status in our overall intellectual map.

Steven Shapin and Simon Schaffer on making experiments authoritative.[2]

In 1860 John Newman, a mentor and lifelong friend of William Froude, asked whether there was a distinction between how men of science and theologians knew 'truth'. He claimed that 'the scientific proof of Christianity is not the popular, practical, personal evidence on which a given individual believes in it.'[3] '[T]heologians', Newman wrote to Froude, 'all affirm that Christianity is proved by the same rigorous scientific processes by which it is proved that ... the earth goes around the sun.' Newman demonstrated this by showing how even the most accepted scientific 'truths' depended on faith. He continued, 'I mean the proof is in this same line or order, for of course it is difficult to say whether we [can] be certain that ... the earth goes around the sun.[4] Newman examined this and numerous other examples in his correspondence with Froude in order to focus his ideas on the nature of 'faith' in British religious and intellectual society.

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[1] William White, *The influence of scientific methods on shipbuilding: an address delivered at University College, Liverpool, on 1st December, 1893* (London, 1893), p. 23.

[2] Stevn Shapin & Simon Schaffer, *Leviathan and the air pump: Hobbes, Boyle, and the Experimental Life* (Princeton, 1985), pp. 5-6.

[3] John Newman to William Froude, 18 January 1860, in *Correspondence*, p. 131.

[4] Ibid., p. 131.

In the 1820s and 1830s, Froude joined Newman and Richard Hurrell Froude, his elder brother, at Oriel College, where the Oxford Movement was building momentum. When Hurrell died in 1833, Newman took care of Froude and developed a close personal relationship. In 1845, Newman converted to Roman Catholicism and upon returning to Britain he began a mission to make influential converts to Rome from the sciences and humanities.[5] Writing to Sister Mary Gabriel in 1863, Newman told of his struggles with Froude. He 'has seen his children one after another, (this [Edmund] is the fourth) received into the Church; and he has borne it so gently, so meekly, so tenderly, (though it has given him a sense of desolation more cruel to bear) that I do trust God's mercy has the same gift in store for himself.'[6] Newman believed Froude 'would confess that her [the Catholic Church] authority is probable, but he cannot receive her absolute infallibility, and since she claims (as he thinks) what she has not, therefore the claim itself is a proof against her.'[7] The spiritual and intellectual differences between Froude and Newman, which I explore here through their discussions of spiritual and scientific knowledge, kept Froude from joining Newman's evangelical mission, but they also gave the mathematician a unique framework through which he conceptualised and practiced science.

Jack Morrell and Arnold Thackray's account of the early years of the British Association for the Advancement of Science (BAAS) highlights the frequently asked nineteenth century question: 'what was science?' The answers the BAAS suggested were various: 'science as value-free and objective knowledge; science as the key to economic and technological progress; science as the firm fruit of proper method; science as an

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[5] Newman believed that the conversion of high profile intellectuals would lend further credibility to Catholicism in Britain, see John Newman, *Apologia Pro Vita Sua, being a history of his religious opinions* (London, 1908, reprnt. 2005), pp. 155-184; Frank Turner, *John Henry Newman: the challenge to evangelical religion* (New Haven, 2002), pp. 527-641; Ian Ker, *John Henry Newman: a biography* (Oxford, 1988), pp. 337-75.
[6] John Newman to Sister Mary Gabriel, 7 April 1863, in *Correspondence*, pp. 152-3.
[7] Ibid., p. 153.

available, visible, and desirable cultural resource.'[8] Morrell and Thackray show that the notion of 'value-free' science belonged to a specific group of liberal Anglican men of science.[9] Froude, himself a liberal Anglican (when he was an Anglican), cited a 'love of the truth' throughout his hydrodynamic work and correspondence with Newman, but he also demonstrated a vigorous moral dimension to the pursuit of 'truth', shaped by his experience of religious and intellectual doubt.[10]

The individual and collective feeling of doubt in Victorian Britain has traditionally been the study of religious historians and literary critics.[11] Science has hitherto been explored as an 'influence' on doubt, and not as a localised construct of doubt defined by social networks.[12] This chapter examines Froude, his use of experiments in hydrodynamics and the authority of science through the concerns and curiosities of scientists and the culture they inhabited.[13] I begin by locating Froude in a social network of Victorian intellectuals, thus laying the foundations for connections between his scientific method and Victorian culture. Next I turn to a series of debates between Froude and members of the INA that took place in the early 1860s (preceding the

[8] Jack Morrell & Arnold Thackray, *Gentlemen of science: early years of the British Association for the Advancement of Science* (Oxford 1981), p. 224. Also see James A. Secord, *Victorian sensation: the extraordinary publication, reception, and secret authorship of* Vestiges of the natural history of creation (Chicago, 2000).

[9] The BAAS 'boasted its absence of religious barriers', yet 'represented Whiggery, Reform, and religious accommodation dressed in that most dangerous of disguises, the love of truth.' Morrell & Thackray, *Gentlemen of science*, pp. 227, 229.

[10] Evidence suggests that Froude turned to agnosticism at the end of his life. For Liberal Anglicanism see Richard Brent, *Liberal Anglican politics: whiggery, religion, and reform* (Oxford, 1987).

[11] For Victorian doubt and crises of faith see Timothy Larsen, *Crisis of doubt: honest faith in nineteenth-century England* (Oxford, 2006); Frank M. Turner, *Contesting cultural authority: essays in Victorian intellectual life* (Cambridge, 1993), pp. 73-100; David Newsome, *The Victorian world picture* (London, 1997); Bernard Lightman, *The origins of agnosticism: Victorian unbelief and the limits of knowledge* (Baltimore, 1987); Elisabeth Jay, *Faith and doubt in Victorian Britain* (London 1986); Jeffrey P. Von Arx, *Progress and pessimism: religion, politics, and history in late nineteenth century Britain* (Cambridge, MA, 1985).

[12] George Levine, 'Defining knowledge: an introduction', in Bernard Lightman (ed.), *Victorian science in context* (Chicago, 1997), pp. 15-23; George Levine, 'Scientific discourse as an alternative to faith', in Richard J. Helmstadter & Bernard Lightman (eds.) *Victorian faith in crisis: essays on continuity and change in nineteenth-century religious belief* (Basingstoke, 1990), pp. 225-261. It should be noted that the essays in Helmstadter & Lightman (eds.) *Victorian faith in crisis*, offer a more nuanced perspective than other contributions to the topic.

[13] For the relationship between science and religion, from which I will draw throughout this chapter, see David Knight, *Science and spirituality: the volatile connection* (London, 2004), pp. 53-91, 123-136; Aileen Fyfe, *Science and salvation: evangelical popular science publishing in Victorian Britain* (Chicago, 2004); David Lindberg & Ronald Numbers, 'Introduction', in Lindberg & Numbers (eds.), *When science & Christianity meet* (Chicago, 2003), pp. 1-6; John Brooke & Geoffrey Cantor, *Reconstructing nature: the engagement of science and religion* (Edinburgh, 1998), pp. 15-42; John Brooke, *Science and religion: some historical perspectives* (Cambridge, 1991).

Admiralty's decision to build the test tank) to demonstrate how themes of 'doubt' and 'certainty' informed his approach to hydrodynamics and use of experiments. Then, exploring the culture of Victorian doubt and the tensions between belief and science, I give these themes local meaning in Froude's social and intellectual world. Together with chapter 4, this analysis describes the values and attitudes embodied in Froude's conception of experiment, the test tank and his approach to naval architecture.

4.1 Cultures of doubt in Froude's social network

In the emblematic *Dover Beach*, Matthew Arnold gave a voice to all those who felt stranded from traditional authorities of truth, knowledge and social order. His use of phrases like 'confused alarms', a lack of 'certitude' and 'struggle', represented issues that were increasingly prevalent in Victorian intellectual experience.[14] Commercial successes, expanding empire, scientific developments, the growth of democracy and the decline of religion were as satisfying to Victorians as they were distressing. Celebration of post-Enlightenment scepticism and scrutiny, for example, undermined spirituality and the comfort of God.

> The Sea of Faith
> Was once, too, at the full, and round earth's shore
> Lay like the folds of a bright girdle furled.
> But now I only hear
> Its melancholy, long, withdrawing roar,
> Retreating, to the breath
> Of the night-wind, down the vast edges drear
> And naked shingles of the world.[15]

Froude's exposure to these issues began at home, growing up with his brothers Hurrell and James Anthony Froude (later Regius Professor of History at Oxford) under

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[14] Matthew Arnold, 'Dover beach', in L. Trilling (ed.), *The portable Matthew Arnold* (Harmondsworth, 1951), p. 166. Walter Houghton, *The Victorian frame of mind, 1830-1870* (New Haven, 1957).

[15] Arnold, 'Dover beach', p. 166.

the stern rule and 'High-Toryism' of Robert Froude, Rector of Dartington and Archdeacon of Totnes.[16] His mother, Margaret Froude *née* Spedding, was also an important intellectual influence. Her close family connection to James Spedding, literary editor and biographer, opened access to the high intellectual circle of Victorian Britain.[17] In 1859 Robert Froude died, William inherited the family wealth and built a new home at Chelston Cross, Torquay. There Froude was frequently visited by Arnold, John Ruskin and Isambard Kingdom Brunel.[18] Froude's social network also included the gentlemen of science William Thomson (later Lord Kelvin), Charles Lyell and W.J. Macquorn Rankine, various members of the Athenæum Club and numerous shipping industrialists.

In 1828, Froude joined Oriel College, where he took a first in Mathematics and third in Classics.[19] He was schooled in subjects from Euclid to Herodotus, and tutored by his brother until 1833, when Hurrell fell ill and Newman took over his cramming. 'I will promise to keep him in order', Newman wrote to Hurrell, 'and will make him write his fingers off – and when I come here to sleep, he shall come regularly to me and receive his periodical rowings as good as you could administer.'[20] Newman brought William into his social circle of Isaac Williams, Frederic Rogers, John Keble and Henry Wilberforce, the last of whom was said to be 'in exstasies [sic] at William Froude's

[16] The Froude's distrust of evangelical teaching came from their father and their years in Oxford, which taught them 'to look on Evangelicals as "weak, amiable, but silly persons, without learning or judgment, with accurate knowledge, and generally ridiculous."' Von Arx, *Progress and pessimism*, p. 175.
[17] This social network included, but was not limited to, John Ruskin, Kingsley, Leslie Stephen and William Makepeace Thackeray. Leslie Stephen, 'Spedding, James (1808–1881)', rev. W. A. Sessions, *Oxford Dictionary of National Biography* (Oxford, 2004); Louise Imogen Guiney, *Hurrell Froude: memoranda and comments* (London, 1904), pp. 2-12. Beyond the various social connections Margaret provided was a sense of godliness which she instilled in the Froude children at a young age, see Piers Brendon, *Hurrell Froude and the Oxford movement* (London, 1974), pp. 6-11.
[18] Gordon Huntingdon Harper, [Introduction], in *Correspondence*, pp. 1-32, esp. pp. 7-8.
[19] Richard Hurrell Froude to William Froude, 5 May 1828, in *Correspondence*, p. 218.
[20] Newman to R.H. Froude, 13 January 1832, in *Letters*, III:6.

inventions, and applications of his mathematics to mechanics.'[21] Froude remained at Oriel for a brief time after graduating, serving as the college chemist and mechanist.[22]

1830s Oxford was the home of Newman's Tractarian project. It was also the epicentre of intellectual doubt. The uncertainties expressed by Arnold and countless other Victorians stemmed chiefly from personal anxieties, responses to geological investigations into the age of the earth and the Higher Criticism.[23] In Oxford and Cambridge, where students were required to sign the Thirty Nine Articles and take Anglican orders in order to join the fellowship, doubt in the traditional authority of the church endangered the careers of young academics. James Anthony Froude, for example, expressed grave doubts when he signed the Thirty Nine Articles and joined the fellowship at Exeter College, Oxford. His anxieties did not stem from the geology-genesis debate, but from researching a project on English and Irish saints with Newman. James Anthony grew increasingly discouraged by the lack of 'attainable facts'. Frustrated, he turned to the latest biblical scholarship, the Higher Criticism, through which he explored the literary history of the Bible as a collection of texts, written two centuries after the time of Jesus, by a wide group of authors and open to a range of interpretations.[24]

James Anthony's internal struggle with the 'literal truth' of religion found form in *The Nemesis of Faith* (1849), a novel that explored his spiritual doubts. The narrative took the form of a collection of correspondence written by Markham Sutherland, an Anglican clergyman, who grappled with the ramifications of the Higher Criticism on his spirituality. '[I]n strength and weakness, it [the Bible] is alike human, and has followed

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[21] Mrs. Newman and Harriet Newman to Newman, 8 December 1832, in *Letters*, III:126.
[22] W. Abell, 'William Froude, M.A., LL.D., F.R.S.: a memoir', in A.D. Duckworth (ed.), *The papers of William Froude, M.A., LL.D., F.R.S., 1810-1879* (London, 1955), pp. xi-xiv, esp. p. xii.
[23] Many geologists were themselves either deeply spiritual or ordained ministers, see Morrell & Thackray, *Gentlemen of science*, p. 227.
[24] For the cultural resonance of biblical scholarship in Victorian society see Stefan Collini, *Public moralists: political thought and intellectual life in Britain* (Oxford, 1991), p. 92.

in its growth the common laws of human development', James Anthony wrote in the book's preface, 'it has grown and it has suffered, and it must be judged exactly as all other books.'[25] Froude wrote that 'Faith ought to have been Sutherland's salvation – it was his Nemesis – it destroyed him.'[26] Sutherland's struggle left him 'with his moral insight distorted, and with his spiritual constitution too shattered to enable him to face successfully the trials of life.'[27]

Loss of faith in traditional sources of authority defiled Froude's Anglicanism and imposed itself on his approach to history. He believed it was impossible to know the past with any certainty, and struggled for many years to understand the purpose of history. He only reconciled his doubts about history when he became a disciple of Thomas Carlyle's moralistic, national historiography. Froude's experience of doubt did, however, give rise to a new vocabulary to write a history that engaged with the lack of clear, established conventions of authority in Britain, thus giving the Victorians an active historical and social identity.[28]

William Froude felt similar doubts in religion, science and politics. He believed that anyone who claimed to profess 'the truth' was under a moral duty to convey both their certainty and their doubt. In 1859, he told Newman that adherence to this duty lay at the heart of progress. Advances in physical science and the mechanical arts, Froude argued, have been made possible 'by virtue of the wider and freer scope of action which

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[25] James Anthony Froude, *The nemesis of faith* (London, 1849), pp. x-xi. For Froude's intellectual thought see Von Arx, *Progress and pessimism*, pp. 173-9.
[26] J.A. Froude, *Nemesis*, p. xiv.
[27] Ibid., p. v. For the intellectual context of this novel see Maurice Cowling, *Religion and public doctrine in modern England: Volume III, accommodations* (Cambridge, 2001), pp. 12-4.
[28] Peter Mandler noted that the many literary projects of men like Kingsley, Froude, W.E.H. Lecky, James Bryce, Mandell Creighton and Lord Acton were unified through a sense of history because 'history was now seen as central to a proper understanding of the national character and its propagation as a crucial glue for social and political cohesion; and in certain cases because nationalist history had revived the claims of philosophic history to provide guidance for the immediate conduct of the polity.' Peter Mandler, *History and national life* (London, 2002), pp. 23-45, esp. p. 45.

this principle has conquered for itself'.[29] If there was an epicentre to all these doubts it was Oriel College - yet Oxford, on whole, remained a bastion of traditional authority. Fellows in Oxford vehemently attacked those whose responses to doubt took them outside establishment religious, social and pedagogical beliefs. The *Nemesis of Faith*, for example, was publicly burnt in James Anthony's college. Enlightenment scepticism was equally unpopular in Oxford, and Tractarian responses to scepticism were even less popular.[30] Hurrell Froude and Newman, who led the Tractarian movement (Oxford movement), came under constant attack in a public press deeply concerned with the threat of popery.[31]

The Tractarians petitioned for a series of reforms to restore Catholicity to the Anglican Church.[32] In contrast to the individualist philosophy of evangelicals, the Tractarians believed in 'reserve', in a spirituality of 'metaphor and imagination.'[33] For example, in 'Tract 87' (1840), Williams critiqued the 'simplistic' evangelical reading of Christ's sacrifice, arguing that the lesson had to be understood through the 'tone' of the act. Newman similarly emphasised 'tone' in his autobiographical *Essay in Aid of a Grammar of Assent* (1870).

> I am what I am, or I am nothing. I cannot think, reflect, or judge about my being, without starting from the point which I aim at concluding. My ideas are all assumptions, and I am

[29] Froude also noted that 'The principle is making some progress even in Politics. Bye and bye I hope it will master men's minds in the province of religion.' Froude to Newman, 29 December 1859, in *Correspondence*, p. 122.

[30] Thomas Arnold, headmaster of Rugby, had the following reaction to Edward Pusey's tract on fasting: "My dear Pusey, ... I am sure there must be many points of unison still between us, without ascending to the highest of all: though by the form in which your tract appears I fear you are lending your cooperation to a party second to none in the tendency of their principles to overthrow the truth of the gospel." Henry Parry Lindon *et al*, *Life of Edward Bouverie Pusey* (4 volumes, London, 1893-97), I: 282-83, quoted in Marvin R. O'Connell, *The Oxford conspirators: a history of the Oxford movement, 1833-1845* (Lanham, Maryland, 1991), p. 174.

[31] Hurrell was author of Tracts 9, 59, 63, a rough draft of 75 and possibly 8. For Froude's part in the origins of the Tractarians see John Newman, *Apologia*, p. 12. Also see O'Connell, *Oxford conspirators*, pp. 300-319; Michael Diamond, *Victorian sensation: or, the spectacular, the shocking and the scandalous in nineteenth-century Britain* (London, 2003), pp. 83-87

[32] This 'second reformation' of the church in England was characterised by intolerance for religion based solely on the Bible, an opposition to the literal-leanings of evangelical teaching and a desire to restore the aesthetics of spirituality and belief. O'Connell, *Oxford conspirators*, pp. 137-173; Turner, *Newman*; David Newsome, *The parting of friends: a study of the Wilberforces and Henry Manning* (London, 1966); *The mind of the Oxford movement*, ed. Owen Chadwick (London, 1960). For other Tractarian ideologies see Simon Skinner, *Tractarians and the 'condition of England': the social and political thought of the Oxford movement* (Oxford, 2004).

[33] Philip Davis, *The Victorians* (Oxford, 2002), p. 115.

> ever moving in a circle. I cannot avoid being sufficient for myself, for I cannot make myself anything else, and to change me is to destroy me. If I do not use myself, I have no other self to use. My only business is to ascertain what I am, in order to put it to use.[34]

This emphasis on the 'tone' of the believer is vital both to understanding the culture of Tractarianism and the controversy between Newman and William Froude.[35]

Froude criticised what he saw was as the conservative and immoral attitudes of many Oxonians to both religion and science. '[T]he general tone of Oxford teaching', Froude wrote, 'was at least as dogmatic in relation to sciences as in relation to Theology [,] and [this] had laid strong hold of me'.[36] Prominent popular attitudes to science and religion in Oxford at this time included those of William Sewell, who once proudly claimed that 'a nation of Newtons could no more produce a gentleman than a nation of infidels could create a Christian'.[37] Stefan Collini has argued that the decline of dogma – especially in Christianity – led to a surge of 'public moralists' who had to develop ways of trusting and understanding authority in a doubt-ridden culture.[38] Critiques made by establishment fellows like Sewell, that science was without 'honour' and moral responsibility, emphasises the moral struggle that Victorian intellectuals faced when making new configurations of trustworthy knowledge.

There was a fierce tension between the defenders and doubters of traditional, institutional authority, be it in the Anglican Church, the truth of history or the authority of traditional science. Sewell wrote,

> I would not give up one verse, the very simplest, of my Bible for all the knowledge of all generations; but I would not raise a finger to impede, I would strain every nerve to impel, the progress and extension of knowledge. I have no fear for Christianity or mankind from science in itself. It is its defects, its abuse, its false reasonings, its corruptions by the human heart, the atmosphere of conceit that surrounds it, the idolatry with which it is worshipped,

[34] John Newman, *Essay in aid of a grammar of assent* (London, 1870), p. 340.
[35] 'To the Tractarians, an individual is never right merely on the grounds of holding a general opinion which happens to be true, unless he holds it in a particular manner of being. What one must really and deeply *means*, as Newman insisted in his Apologia, is always autobiography': Davis, *Victorians*, pp. 115-6.
[36] Froude to Newman, 29 December 1859, in *Correspondence*, p. 119. For controversy in science and religion in Victorian Oxford see Pietro Corsi, *Science and religion: Baden Powell and the Anglican debate, 1800-1860* (Cambridge, 1988), pp. 106-140.
[37] William Sewell, *A second letter to a dissenter* (Oxford, 1834), p. 37 quoted in Corsi, *Science and religion*, p. 123.
[38] Collini, *Public moralists*, pp. 64-5.

> the miserable coldness it engenders, its selfishness, its dreams of vanity, its alienation from God, - that is what we ought to dread; and this is not science in itself, but science in man, - weak, wicked, contemptible man.[39]

Sewell's attack on pro-science pedagogical reforms in Oxford represented much of the traditional, establishment attitude towards those who practiced experimental science, and were believed to oppose traditional Anglican authority.[40] Froude did not agree with the thrust of Sewell's argument, but he did believe that science should be practiced within moral guidelines by responsible, honest, doubting experimenters.

4.2 SCIENTIFIC KNOWLEDGE

Certainty and duty

In order to unpack the local distinctions between Newman and Froude's understanding of scientific knowledge we must first examine the dynamics in their relationship. Newman's mission to convert reputable Victorians struck deep into Froude's family. Froude's wife and children, except Edmund, converted to Catholicism. In Froude's letters with Newman he took a fiercely adversarial position to Catholicism, calling it an 'intellectual tyranny' for silencing the capacity for doubt among its believers. Froude, however, held a different view of individual Catholics (notably his family), and even accepted that the system of belief had potential for personal tolerance.[41] 'My family', Froude wrote to the Scottish shipbuilder and marine engineer James Robert Napier, 'are sincere & not at all bigoted Catholics and don't fret with me or at me for going firm the other way.'[42] Froude's personal spirituality is much harder to categorise. His religious

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[39] Sewell, *Second letter*, pp. 5-6.

[40] Secord notes, for example, that in 1845 when fellows of Balliol attempted to remove Newman's friend and associate W.G. Ward for his views on Catholicism, the Tractarian Frederick Maurice wrote, "If the Heads of Houses may sit in judgment on Ward's book to day, they may try Buckland for his geology to-morrow." F.D. Maurice to J. Hare, 15 January 1845, in Frederick Maurice, *The Life of Frederick Denison Maurice chiefly told in his own letters* (2 vols., London, 1884, second edition), I:398-400, quoted in see Secord, *Victorian sensation*, pp. 223-4. Also see Turner, *Cultural authority*, p. 188.

[41] Newman to Froude, 9 April 1863, in *Correspondence*, p. 150.

[42] Froude to James Robert Napier, 14 March 1875, Glasgow University, Archive service, Napier papers 90/2/4/51.

upbringing was a mixture of Tory and puritan elements of Anglicanism. He was swept up by Hurrell's Tractarianism and caught up by Newman's Catholicism.[43] There is evidence Froude remained a dutiful Anglican, though his correspondence depict him as a doubting agnostic.[44] Froude's opposition to 'dogmatic truth' was probably shaded as much by the diversity of practicing Christians who surrounded him as by what we may call his 'scientific mentality' (which was also socio-cultural).

Froude believed that there were many religious practices that were inconsistent with each other. In this way, zealous belief and practice actually had the effect of laying the foundations of doubt.[45] Froude told Napier that 'the least reasonable' practice was the 'duty & efficacy of prayer', given that Christians were taught that there was a perfect, wise, powerful God. 'I can believe myself & the universe to be under the governance of a perfectly wise & perfectly good & perfectly powerful Being', Froude argued, but the role of prayer then, '[is to] wish to make Him change any purpose He has found, or to form one which He has not formed, is but another way of fuelling mistrust of His wisdom and goodness. ... [T]he notion that I could change His purpose involves the notion of changing it for the worse.'[46] Thus Froude contested the Catholic Church's conceived infallibility.

Infallibility, like scientific dogma, demanded assent without due scrutiny. Froude, however, felt that society, and specifically men of science, dealt with (even profited by examining) probabilities and uncertainties.[47] I will now demonstrate, with recourse to

[43] The Reverend Thomas Mozley noted that "William Froude has [sic] his heart in with his brother's work at Oriel, though his turn even then was for science." Thomas Mozley, *Reminiscences, Volume II* (London, 1882), p. 14. Froude was publicly recognised as one of Newman's few friends who remained close, but there is no evidence that his association with Catholics ever affected his public life.

[44] Abell, 'Froude', pp. xi-xiv.

[45] The predilection to challenge such forms of knowledge was common to the moral philosophy of Scottish common-sense philosophy and liberal-Anglican critiques of Evangelical readings of science, see Secord, *Victorian sensation*, pp. 61, 270-96. For science and common sense philosophy, see Roger L. Emerson, 'Science and moral philosophy in the Scottish enlightenment', in M.A. Stewart (ed.), *Studies in the philosophy of the Scottish enlightenment* (Oxford, 1990), pp. 11-36.

[46] Froude to Napier, 14 March 1875, Napier papers 90/2/4/51.

[47] Froude to Newman, 29 December 1859, in *Correspondence*, p. 118.

his correspondence with Newman, the concerns and curiosities that dominated Froude's pursuit of scientific knowledge. I will argue that, apropos of Newman's theories of knowing, Froude's conceptualisation of 'science' (and framework for his hydrodynamic theory and practice) was a moral construct, deeply embedded in the culture of Victorian Doubt.[48]

Newman's use of the word 'scientific' to denote religious and spiritual practices was a major sticking point in his relationship with Froude. 'Religion is not merely a science but a *devotion*', Newman told Froude, 'theologians affirm that Christianity is proved by the same rigorous scientific processes by which it is proved that we have an Indian Empire or that the earth goes around the sun.'[49] Newman believed that 'truth' in science and religion could be attained by believing and knowing – two separate but not mutually exclusive concepts. The first concept, belief, denoted a personal almost mystical way of knowing, traditionally defined within the Catholic Church as a product of grace.[50] Newman extended this concept to science. Just as a person can know faith by believing in God, they can know modern physics by believing in Isaac Newton (both the person and the authority). 'When then a certain proportion of our race are certain they have found religious truth, should we not feel as we might do, if while ignorant of mathematics, we found a number of educated persons simply confident of Newton's conclusions?'[51]

Newman's second concept was that 'there is a popular and personal way of arriving at certainty in Christianity as logical as that which is arrived at by scientific

[48] Froude frequently queried the 'truth' of hydrodynamic theories or the 'best form' for a ship, both of which had hitherto been based on traditional sources of authority, e.g. seamanship and artisan craft, and assumptive modes of thought, e.g. 'rules of thumb', see chapters 1, 2 and 3.
[49] Newman to Froude, 2 January 1860, in *Correspondence*, p. 127; Newman to Froude, 18 January 1860, in Ibid., p. 131.
[50] Newman to an unidentified respondent [possibly Frances Mary Ward], 1851 in Ibid., p. 88.
[51] Ibid., p. 86.

methods in subjects non-religious' (for example, the idea that Britain was an island).[52] To govern this second concept, and understand why and when individuals assented to facts, Newman devised a tool he called 'illative sense'.[53]

> There are those, who, arguing *à priori*, maintain, that, since experience leads by syllogism only to probabilities, certitude is ever a mistake. There are others, who, while they deny this conclusion, grant the *à priori* principle assumed in the argument, and in consequence are obliged, in order to vindicate the certainty of our knowledge, to have recourse to the hypothesis of intuitions, intellectual forms, and the like, which belong to us by nature, and may be considered to elevate our experiences into something more than they are in themselves. Earnestly maintaining, as I would, with this latter school of philosophers, the certainty of knowledge, I think it enough to appeal to the common voice of mankind in proof of it.[54]

At the core of this 'illative sense' was faith in the authority of facts and the 'practitioners of knowledge' who generated them. Owen Chadwick has argued that Newman sought to disconnect science from religion.[55] Newman, however, recognised that Victorians were 'apt to prize knowledge above holiness'.[56] I suggest, therefore, that he did want to separate science and religion, but reestablish the prominence of belief in the configuration of all types of knowledge. 'We are in a world of facts,' Newman noted, 'and we use them; for there is nothing else to use. We do not quarrel with them, but we take them as they are, and avail ourselves of what they can do for us.'[57]

Newman used his concept of 'illative sense' to challenge Froude's conceptualisation of scientific knowledge. Drawing from the tensions between essences of truth and specific truth, Newman argued, that 'when all scientific proof, even for the existence of India, is examined microscopically, there will be found [a] hiatus in the logical sequence so considerable as to lead to the question "are there no broad, just

[52] Newman to Froude, 18 January 1860, in Ibid., pp. 131-2.
[53] Newman to Froude, 29 April 1879, in *Letters*, 29: 115. Froude did not live to see the correspondence in which Newman specifically addressed 'illative sense', but the point was put to Froude in a more basic shape in 1860. It may well be argued that Froude's long correspondence with Newman stimulated many of the ideas in Newman, *Grammar of Assent*, in which he described the illative sense. Harper, '[Introduction]', pp. 1-32, esp. p. 2.
[54] Newman, *Grammar of Assent*, pp. 336-7.
[55] Chadwick, *Newman*, p. 89.
[56] John Newman, *Parochial Sermons*, Volume I, p.234, in Owen Chadwick (ed.), *The Mind of the Oxford Movement* (London, 1960), p. 103.
[57] Newman, *Grammar of Assent*, p. 339.

principles of knowledge which will protect us from scepticism in all reasoning about things external to us, both scientific and popular?"[58] Newman's illative sense emphasised the similarity in how an individual can know truth in science and religion.[59] Froude, however, did not accept Newman's notions of personal and scientific knowledge as applied to science and religion alike. Froude believed that if faith was measured 'directly as the *positiveness* of the Belief and inversely *as the strength* of the evidence', as he perceived Newman advocated, then 'measured Faith seems to be but another word for "prejudice"'.[60]

Froude's critique lay in his fundamentally different conceptualisation of 'science'. He accepted that religion was guided by 'instinct', but that the word 'science' intended something more distinct.[61] Froude claimed that 'science' was based on knowledge removed from instinct: knowledge produced through morally responsible experiment.[62] Therefore, when Newman claimed that there was a 'scientific proof' for Christianity, Froude took issue. 'Putting out of consideration for a moment the personal certainty arrived at without scientific proof,' Froude wrote to Newman, 'it seems to me that you attribute to scientific proof a cogency and completeness of conviction, which in the domain of "science" technically so call[ed], none of the higher minds which occupy that domain, attribute to such proofs.'[63] Because Froude's sense of science rested on the moral, mechanical and personal pursuit of knowledge through experiment and demonstration (see chapter 5), he rejected that anything more than a strictly 'personal' knowledge of Christianity was possible.

[58] Newman to Froude, 18 January 1860, in *Correspondence*, p. 132.
[59] Newman to Froude, 29 April 1879, in *Letters*, 29:114
[60] Froude to Newman, 29 December 1859, *Correspondence*, p. 122.
[61] Froude to Newman, 8 October 1864, in Ibid., pp. 181. This critique strongly resembles Faraday's opposition to 'popular prejudices' in science such as table-turning and mesmerism, see Geoffrey Cantor, *Michael Faraday: Sandemanian and scientist* (Basingstoke, 1991), pp. 144-51.
[62] For tensions in science and culture between assumptions, the observer and progress in knowledge see Secord, *Victorian sensation*, pp. 55-61.
[63] Froude to Newman, 25 January 1860, in *Correspondence*, p. 135.

Froude's opposition to Newman's ideas on knowledge and belief resonated with Victorian critiques of knowledge, specifically with regards to the public debate between Newman and Carlylean historians.[64] In 1877 Leslie Stephen, a disciple of Carlyle's nationalistic, moral historiography, and close ally of James Anthony Froude and Charles Kingsley, published a critique titled 'Dr. Newman's Theory of Belief' in the *Fortnightly Review*. Stephen argued that 'in the "Grammar of Assent," our belief in the uniformity of nature is regarded as an illogical conclusion of the imagination, a doctrine which he [Newman] shares with the purely empirical school'.[65] 'We can take nothing as proved', Stephen contended, 'but that which has stood the hard test of verification by multitudinous experience. ... No man can say, This is true because I think it; no man can hold that he has grasped the full and ultimate truth upon any subject.'[66] Kingsley had earlier described Newman's emphasis on 'faith', instead of tangible, attainable truth, through anti-catholic blinkers. 'Love of truth' was not a virtue Anglicans saw in Newman.[67] Newman reacted to this attack in his *Apologia pro vita sua*, a theological autobiography and defence of his conversion, published as a series of weekly articles (and later as a volume in 1864). Newman used this volume to explain the tenets of belief that took him from doubt in Protestantism to faith (and assent) in Catholicism.

The *Apologia* was widely read and well received. Froude, recalling a conversation with Charles Lyell, told Newman how the *Apologia*, 'has been very much read by men of Science with a feeling of great interest.' Froude specifically noted curiosity in how Newman 'substantiates the bridge by which he steps so freely from the state of doubt which (as they feel) inevitably attaches to these results of probabilities, to the state of

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[64] The union of scientists and agnostics against Newman represented a larger anti-Catholic polemic in Victorian discourse, see Turner, *Cultural authority*, p. 83.

[65] Leslie Stephen, 'Dr. Newman's theory of belief', *Fortnightly Review*, 22 (1877), pp. 680-697, esp. p. 686.

[66] Leslie Stephen, 'Dr. Newman's theory of belief', *Fortnightly Review*, 22 (1877), pp. 792-810, esp. 810.

[67] Charles Kingsley. 'Froude's history of England, vols. VII and VIII', *Macmillan's Magazine*, 51 (1864), pp. 211-224, esp. 217, quoted from Ker, *Newman*, p. 533.

absolute certainty'.[68] This 'bridge' unified Newman's two concepts of belief and represented a challenge to Froude's faith in science. Thus Newman urged on Froude 'that [there] is a sophism in (considering) the certainty of secular science so far superior to the certainty, or persuasion as you would call it, of the personal evidence for Christianity.'[69] The theologian substantiated this by claiming that scientific truth, like religious truth, was not based on the rationale of an idea, but the credibility of the knowledge holder.

4.3 'OUR "DOUBTS" IN FACT APPEAR TO ME AS *SACRED*'

Doubt in practice

Newman frequently challenged Froude's doubt in religious truth by testing his 'faith' in scientific method. Newman forced Froude to accept that science, like religion and secular life, depended on belief and assent. He argued that to 'know' science required the individual to have faith in men of science, their morals and the authority of their work. 'I was struck how table turning was put down', Newman wrote, 'by the authority of a great name, Faraday, presenting to the public one argument which was received on its plausibility by the man, or on his word without trial.'[70] Thus Newman used the example of table-turning to show that truth in scientific controversy was not based on superior reasoning but on the 'reputation' and 'character' of who witnessed natural phenomena.[71] Froude disagreed, and argued that Faraday's 'authority did little for him but to get him a hearing'.[72]

[68] Froude to Newman, 8 October 1864, in *Correspondence*, p. 180.
[69] Newman to Froude, 18 January 1860, in Ibid., p. 132.
[70] Ibid., p. 132.
[71] This belief was at the centre of Newman's notion of a social construction of scientific truth. Ibid., p. 132.
[72] Froude to Newman, 25 January 1860, in Ibid., p. 137.

Froude argued that Faraday's success depended on his 'mode of enquiry': the experiment as a process that separates 'facts' from opinions.[73]

> Faraday did not bring evidence against the facts, or properly speaking, argue against the theories – he only contrived a very simple experiment, which he induced several of the most enthusiastic table turners to try, which experiment showed them that the facts they thought they saw were not real facts – that their own unaided senses had misled them and that in part they had deceived themselves, that when they thought or persuaded themselves they were not pushing the table, they were in fact pushing it; and that when by a simple contrivance he enabled them to see whether they were pushing or not pushing, and in what direction, they no longer did push and the table no longer moved, so much for the *facts* of the table turning experiments.[74]

Froude possessed great faith in the authority of experiments that could be replicated and completed by various groups of experimenters.[75] Froude's views on doubt, certainty and authority lay at the core of his experimental practices. This section describes the practices, cultural symbols and sources of authority Froude drew from to establish 'certain' conclusions in his study of science, ship behaviour and design.

David Knight has rightly observed that historians of science have neglected threads in the discourse of doubt and certainty that were not overtly spiritual.[76] Treated as a religious attitude, doubt has traditionally been explored as a source of authority connected to the legitimisation of geological theories and the authority of scientific knowledge as 'systematic' and 'reliable'. But considered within wider cultural history, doubt was a historical product associated with post-Enlightenment scepticism and the moral significance of the 'fact' as developed by the Carlylean historiographical movement.[77] Therefore, doubt was a cultural force, neither intrinsically pro-science nor

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[73] Even Froude's conceptualisation and trust in facts owes much to Faraday: "FACTS ... ought not too hastily ... be confounded with opinion; for the *facts are for all time, whilst opinion may change as a cloud in the air*." Michael Faraday to Adolphe Quetelet, 25 February 1850, in L.P. Williams, R. Fitzgerald & O. Stallybrass (eds.), *The selected correspondence of Michael Faraday* (2 vols., Cambridge, 1971), 570-80, quoted in Cantor, *Faraday*, p. 200.
[74] Froude to Newman, 25 January 1860, in *Correspondence*, p. 137.
[75] For 'replication' and 'credibility' in experiment, see David Gooding, Trevor Pinch & Simon Schaffer, 'Introduction: some uses of experiment', in David Gooding, Trevor Pinch & Simon Schaffer, *The uses of experiment: studies in the natural sciences* (Cambridge, 1989), pp. 1-28, esp. 3.
[76] Knight, *Science and spirituality*, p. 125.
[77] A similar analysis can be made of 'science', which John Brooke has argued, did not mean anti-religion, but was a construct of a society's cultural exchanges and negotiation of various fields of knowledge. Brooke, *Science and religion*, pp. 5-7.

anti-religion; it was a source of authority to be negotiated in scientific controversies. 'Our "doubts"', Froude wrote, 'in fact appear to me as *sacred*, and I think deserve to be cherished as sacredly as our beliefs'.[78] To negate ones doubts was to be immoral in claiming to know the truth.[79]

Chapter 3 noted that Froude's theories of ship resistance and roll were at odds with prevailing knowledge of hydrodynamics and ship design in Victorian Britain. The stream-line theory, which broadly stated that most ships with fine lines would experience no resistance when passing through a 'perfect fluid', contradicted the commonsense view that a ship expended energy by pushing water out of its path. Earlier, when John Scott Russell formulated his wave-line theory, he asked 'where does the water go'? Using this question to frame the theory, Russell made observations and offered the answer that '[i]n the case of the fore body, the water must suit itself to the shape of that body which is forced into it. ... We must [also], therefore, fit the after body to the run of the water in the wake.'[80] Froude refuted the assumption that a vessel 'pushes' water out of the way by mechanically proving it to be a *prima facie* error - a visual illusion (see chapter 5). Instead, Froude claimed that resistance was caused by friction between the ship and the waves that formed around it.[81]

Froude acknowledged that the visual evidence of bow-waves and wakes at the aft of a ship gave the impression that water was pushed away from the bow. However, the

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[78] Froude to Newman, 29 December 1859, in *Correspondence*, p. 121. This use of religious language to express the importance of doubt in science reflects the Victorian cultural tensions between 'secular' and 'sacred' labels in the configuration of knowledge. Historians revising the 'conflict narrative' between science and religion have explored the meaning of these labels through the people who used them, through trust claims and through episodes when scientists and popular science authors complicated 'the medieval distinction between sacred and secular': Fyfe, *Science and salvation*, p. 68.

[79] Frank Turner noted that the conflict between science and religion in Victorian Britain 'involved controversy about the social structure of the intellectual nation as well as about the structure of knowledge and of the universe.' Far from being a marginal dispute, the discourse between these two, now distinct, fields of knowledge, 'represents one chapter in the still-to-be-written intellectual and social history of the emergence of the professionalized society in the West.' Turner, *Cultural authority*, pp. 199-200.

[80] John Scott Russell, 'The wave-line principle of ship-construction, part III', *Transactions*, 2 (1861), pp. 230-245, esp. 237.

[81] [William Froude], 'The British Association: address to the mechanical section', *The Engineer*, 20 (1875), pp. 191-92, esp. 216.

impression created in the eye was delusive. Froude identified the same problem of treating illusionary surface phenomenon as the foundation of a theory with regard to theories of ship roll. He wrote, in response to Russell's paper on rolling that the dynamical theory of roll was 'elegant and captivating' and 'altogether delusive'. Froude also rejected Russell's idea that roll, a phenomena universally experienced by sailors, could be eliminated. On this point Froude instead proposed that roll could to be measured and thus controlled, but only to the extent that a ship could be made safe or comfortable.[82] Thus Froude conceptualised the problem of ship resistance differently than Russell, Rankine and Joseph Woolley. Where Russell *et al* accepted the epistemological limits of observation in Victorian hydrodynamics (see chapter 3), Froude looked to find ways of bringing the problem under greater scrutiny, beginning with the foundational 'mode of enquiry' used to study the causal links in the theory.

In 1875, Froude discussed his approach to hydrodynamics with Napier. Froude specifically noted that he 'had to pull down a lot of work and ideas built up on these imaginary lines of thought', meaning theories based on abstract laws and *prima facie* observations. Froude decided to revise the subject 'by the light of working experience in a laborious though no doubt a bungling form', beginning by locating as many of the uncertainties and assumptions upon which the shape of the ship was made.[83] Froude dismissed both existing scientific theories and rule of thumb presumptions that he could not account for (this will be discussed further in chapter 5). He believed craftsmen often watched a newly launched ship 'with as anxious and uncertain an eye as if she were an animal he had bred ... not a work which he had himself completed, and

[82] William Froude, 'Remarks on Mr. Russell's paper on rolling', *Transactions*, 4 (1863), pp. 232-275, esp. 249.
[83] Froude to Napier, 22 February 1875, Napier papers 90/2/4/51.

whose performance he could predict'.[84] Thus Froude sought to place the science of the ship on firm, experimentally proven foundations.

There are three key aspects of doubt in Froude's experimental practices that I will examine: his self imposed duty to doubt conclusions; his aversion to the causal ties that dogmatic conclusions carried; and his rejection of tacit experience as a bridge to certainty. Froude's view on the first area reflected the brand of honest doubt with which Froude conceived scientific knowledge. Froude's conception of truth and scientific method was fuelled by his sense that there was a great human duty to doubt. 'The only way to truth,' Froude told Napier, 'is by doubting & fumbling, and correcting errors where we can.'[85] The 'mode of enquiry' that Froude thus found most meritorious was 'the temper which realizes as carefully as possible the exact degree of doubtfulness which attaches to its conclusions'.[86] He readily admitted that some of his theories and conclusions were only approximations. But he also recognised that an approximation of nature was better than any fallacy shrouded in the mist of dogma. 'In many cases,' Froude urged in response to Rankine's critique of his rolling theory, 'there is very great value in arriving at a conclusion, if only in such a way as but to indicate that the subject is not a mystery, but one which admits of a solution; and, but to sketch the nature of the steps by which it is to be approached, and to give some ideas of its character when found.'[87] This example serves to demonstrate how honest doubt manifested itself in Froude's work.

Two years previously, Froude had engaged in a similar dialogue with Newman. Newman had accused Froude of sitting back from judgment, in effect, to be unwilling to

[84] [Anon.], 'William Froude', *Nature* (12 June, 1879), pp. 148-150, esp. 148.
[85] Froude to Napier, 14 March 1875, Napier papers 90/2/4/51.
[86] Froude to Newman, 29 December 1859, in *Correspondence*, p. 122.
[87] W.J. Macquorn Rankine, 'Remarks on Mr. Froude's theory on the rolling of ships', *Transactions*, 3 (1862), pp. 22-45, esp. 34.

accept the gift of grace and the necessity of faith. Froude responded in like manner with a Biblical parable that taught 'objectivity': 'I say in reply "it was the four lepers who sat in the gate, afraid to take part in the trials of their fellow citizens, and ready to fall away to the Syrians for the bare chance of a meal, who discovered the siege was raised."'[88] From this we may cast the moral obligations and duties of the doubting man of science on to the practice and rhetoric of scientific enquiry. Such rhetoric was clear in many of Froude's public lectures. In his BAAS presidential address, for example, he demonstrated his doubting mentality by telling his audience that '[n]o one is more alive than myself to the plausibility of the unsound views [meaning anti-stream-line theory] against which I am contending; but it is for the very reason that they are so plausible that it is necessary to protest against them so earnestly'. Froude urged engineers to be critical of the intellectual bonds that tied sensorial experience to dogmatic theorising: '[i]n truth it is a protest of scepticism, not of dogmatism; for I do not profess to direct any one how to find his way straight to the form of least resistance.'[89]

Froude worried that engineers treated experience as scientific knowledge, or as reason to reject scientific knowledge. He saw just such danger in Russell and Woolley's rejection of his views on the position of momentary equilibrium and the validity of model experiments. Casting the controversy in terms of doubt and dogma, Froude observed,

> it not unfrequently [sic] happens, especially in the more elementary stages of the attempt to reduce into the form of a regular science, the principles of any art which embodies a large mass of valuable traditional experience, that the existence of some tendency which becomes soon apparent under scientific treatment of the subject, is found to tally more or less with some, perhaps, undeniable and important fact which has been empirically established. In such cases there is an almost irresistible impulse to connect the fact and the scientifically proved tendency, under the relation of cause and effect, with the confidence which the comparison does not really warrant; and in accordance with this impulse, the enunciation both of the empirical and of the scientific proposition, is very apt to be mutually moulded

[88] Froude to Newman, 25 January 1860, in *Correspondence*, p. 135. See Old Testament, 2 Kings 7:3-8.
[89] [Froude], 'Address to the mechanical section', p. 217.

> into an undue adaptation, and their relation becomes established as a *quasi* dogmatic truth.[90]

Froude believed Russell and Woolley were consumed by a dogmatism to see causal links where he believed they had not been proven. Froude's critique originated in his way of looking at scientific problems through a framework of doubt, moral obligation and honest faith. 'Propositions and relations thus established, if treated with undue delicacy or deference, became great obstacles to the progress of free enquiry, distorting the currents of fresh thought too determinately into old established channels', Froude told members of the INA.[91] Froude claimed that such a mentality 'hampered' trust in new theories of ship roll.

The third area of Froude's doubt concerned knowledge gained from experience through the body - sensorial receptors - and which was frequently cited by those who witnessed ships roll at sea. 'It is true that the improved results in shipbuilding have been obtained through accumulated experience', Froude told the audience at his BAAS presidential address, 'but it unfortunately happens that many of the theories by which this experience is commonly interpreted, are interwoven with fundamental fallacies, which passing for principles, lead to mischievous results when again applied beyond the limits of actual experience.'[92] Froude saw the same problem in religious questions where 'experience' was cited as a form of authority to govern intellectual bridges or leaps of faith to certitude. In both cases Froude felt that doubts were more important than claims of 'experience' - a kind of intuition - based on fallible senses. Experience of the ship at sea, or experience designing and building ships, could only take knowledge of hydrodynamics and ship design to a certain point. Froude believed that once that point was reached, a dangerous epistemological and sensorial complication occurred.

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[90] Froude, 'Remarks', p. 244-45.
[91] Ibid., p. 244-45.
[92] [Froude], 'Address to the mechanical section', p. 191.

Interpretations of sensorial knowledge could become so rigid that they negated other forms of knowledge. Froude personally preferred quantifiable knowledge, which he believed was rooted on more certain epistemological foundations by virtue of independent verifications and scrutiny. 'It may be perhaps said that it is childish to plead "tendencies" in reference to questions which ought to receive quantitative solutions; and this would be admitted if the quantitative solution were attainable, or if any great stress were laid on the alleged tendency.'[93] Numerical knowledge could offer certainty, yet that certainty itself had a context in the culture of Victorian mechanical thought and work (see chapter 5). For now I am interested in examining further how Froude used his doubts to conceptualise his work.

4.4 MORAL RESPONSIBILITY

Froude carried his conceptualisation of 'doubt' and 'certainty' into his scientific and mechanical works in a number ways that distinguished him and his practices from contemporary theorists, experimenters and naval constructors. In tracing and examining these distinctions I have examined the significance of Froude's private thoughts on doubt and scientific knowledge on his scientific work. I now turn to the language and rhetoric employed in his scientific work. A moral use of language was both central to Froude's pursuit of truth and a touchstone for persuasion and disseminating knowledge. When, in the late 1860s, Froude outlined his reasons supporting experiments on models, he expressed anxiety that only knowledge grounded in experiment could offer the certainty that so called 'rule of thumb' ship design lacked. 'We can have no ground for certainty that we have found even an approximation to the

[93] William Froude, 'On the rolling of ships', *Transactions*, 2 (1861), pp. 180-230, esp. 197.

best form,' Froude noted, 'unless we have gone experimentally over almost the whole ground and tested a very wide variety of shape.'[94] To Froude issues of certainty and experimental practices were wrapped up in his conceptualisation of doubt as a moral and positive force to resolve problems.

Historians have characterised Froude's views on model experiment as those of a genius who observed what no one else had seen.[95] But when we consider Froude's cultural and intellectual connections with doubt, Tractarianism and the 'public moralist' reconfiguration of knowledge in Victorian Britain, we are able to explore Froude's work (and ways of thinking) as a response to the intellectual concerns and curiosities of the era. Froude conceived that all scientific knowledge was a probability, and therefore if a statement was claimed true it was because 'the probability of ... [it] *is being* most continually tested and found to stand the test.'[96] Froude simply wanted to put as many possibilities to the test, just as he put his own way of conceiving 'facts' and 'truths' to the test. If certainty through grace was Newman's credo, then Froude's was 'Ever learning and never able to come to a knowledge of the truth.'[97] Froude perceived that 'a source of disagreement' between him and Newman, was 'seated in the very principle of "thinking" and of "concluding" and in the very nature of thoughts and of conclusions'. A disagreement founded on essential mental laws 'which govern the various states of mind including in the various senses of the term "belief," and which fix the duties attached to them.'[98] Froude told Newman that in his experience of solving mechanical problems, '[t]he force of the conclusion as *held* can never exceed the degree of

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[94] Charles Merrifield *et al*, 'Report of a committee on the Stability, Propulsion, and Sea-going Qualities of Ships', *Reports, 1869* (London, 1870), pp. 10-47, esp. p. 47.
[95] See David K. Brown, *The way of a ship in the midst of the sea: the life and work of William Froude* (Penzance, 2006); George Emmerson, *John Scott Russell: a great Victorian engineer and naval architect* (London, 1977).
[96] Froude to Newman, 29 September 1864, in *Correspondence*, p. 178.
[97] Froude to Newman, 29 December 1859, in Ibid., pp. 122-3.
[98] Ibid., p. 118.

probability'.[99] For Froude certainty in truth was not a matter of assent but moral responsibility. In this conceptualisation 'science' was a label for an attitude, practice and fragile union of dutiful work, mental preparation and moral use of language.

Froude recognised that a great duty weighed on anyone who produced knowledge. '[A]ny possibility however faint, may in its place make it a duty to *act as if* the conclusion to which it points were absolutely certain, yet that even the highest attainable possibility does not justify the mind in discarding the residuum of doubt'. '[T]o enhance or intensify the sense of the preponderance of the probabilities in either scale,' Froude argued, 'is distinctly an immoral use of faculties.'[100] Earlier in the 1850s, Faraday had made a similar statement to the Royal Institution, under the heading '*deficiency of judgement*', during a lecture on the mental education of the scientific observer. Faraday believed that '[M]ankind is willing to leave the faculties which relate to judgment almost entirely uneducated, and their decisions at the mercy of ignorance, prepossessions, the passions, or even accident.'[101] Froude specifically cited Faraday's lecture during his discussion with Newman about how the table turners were debunked.[102]

Froude repeated to Newman an anecdote about Dr. William Hyde Wollaston that Faraday had used to show the 'sportive behaviour' of some scientists.[103] Faraday 'had been discussing some question with Dr. Wollaston who, in support of his own view, said,

[99] Newman marked in the margin of the letter: 'I say it can with an *absolute assent*'. Froude to Newman, [early 1879], in *Letters*, 29: 109-10.
[100] Froude to Newman, 29 December 1859, in *Correspondence*, p. 120.
[101] Michael Faraday, 'Observation on mental education' in [Royal Institution], *Lectures on education: delivered at the Royal Institution of Great Britain* (London, 1855), pp. 40-88, esp. pp. 41-2.
[102] It must be noted that unlike Faraday, who read the book of revelations and the book of nature very literally, Froude rejected the absolute truth of the Bible. For Faraday and the book of nature see, Geoffrey Cantor, 'Reading the book of nature: the relation between Faraday's religion and his science', in David Gooding & Frank A.J.L. James, *Faraday rediscovered: essays on the life and work of Michael Faraday, 1791-1867* (Basingstoke, 1985), pp. 69-82, esp. pp. 70-73.
[103] For Wollaston see Williams, T.I., 'Wollaston, William Hyde (1766–1828)', *Oxford Dictionary of National Biography* (Oxford, 2004).

half sportively, "I will bet you three to one it is so and so"'.[104] Faraday disdained what he felt was an improper and immoral attitude to the 'scientific pursuit of Truth'. Wollaston defended himself, saying 'that he had intended in that way to express his measure of *preponderance* of the evidence in favour of the view he adopted'. Faraday felt that the scientists should be sober and responsible in every regard around the subject of their study. The attitude towards conclusions and the language used to construct them for dissemination ought to be empty of sporting language and behaviour. Froude, in his conceptualisation of trustworthy, moral conclusions, rejected both the instinctive impulse of artisans and the dogmatic tendency of scientists to over-extend their conclusions.

Froude believed that scientists prejudiced their experiments by speaking in dogmatic turns of phrase.[105] 'It seems to me that the tendency to say "*I will*"', wrote Froude, 'is characteristic not of scientific but of personal proof.'[106] There was in 'science', as conceived by Froude, a need to question dogmas, sporting certainties and any knowledge founded on 'personal proofs' (assumptions and instinct). To leave dogmatic or personal conclusions unquestioned was to cover up doubt, and to 'enhance or intensify the sense of the preponderance of the probabilities ... is distinctly an immoral use of faculties'.[107] Froude's awareness of doubt and the need to state the uncertainty as well as the certainty in conclusions can be seen in his scientific papers.

In 1874, Froude presented a paper to the Institution of Naval Architects, 'On experiments with H.M.S. Greyhound', in which he spent a considerable portion of his time discussing the limitations of his experiment.

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[104] Froude to Newman, 25 January 1860, in *Correspondence*, p. 138. For the original discussion see Faraday, 'Observation', pp. 72-3.
[105] Froude to Newman, 25 January 1860, in *Correspondence*, p. 135.
[106] Ibid., pp. 135-6.
[107] Froude to Newman, 29 December 1859, in Ibid., p. 120.

> To obtain a tolerably satisfactory determination of a ship's speed in the usual method on the measured mile, requires, for each speed, a succession of many mile runs, alternately with and against tide; and, from the variation which may meanwhile be occurring in the speed of the tide, some elements of doubt are even then involved in the final average.[108]

Froude believed that a moral scientist was responsible in both their attitude to experimentation and writing (disseminating) their conclusions. To satisfy his moral duty to the audience, Froude provided a detailed description of the instruments, the names of the instrument makers, details of independent testing of the instruments and descriptions of the task they were designed to do.[109]

The dissemination of knowledge was a deeply agonising process for Froude. '[I]t is so painful to him [Froude] to write,' Newman told Wilberforce, 'even when he has got himself to begin, he stops, puts his pen aside, and never takes it up again.' Newman continued, 'he sees things much more clearly than he can express them. And, when he puts his thoughts on paper, he is at once disgusted at their inadequacy to express his meaning, and so is led to give over.' [110] Froude's friend Ruskin wrote that '[a]ll the virtues of language are, in their roots, moral; it becomes accurate if the speaker desires to be true ... You can, in truth, understand a man's word only by understanding his temper.'[111] With a similar tone, Froude acknowledged that when scientists expressed ideas and evidence they did so within a framework of language and interpretation that was 'shaped into useful tools of investigation and stamped' by the experimenter, not the audience. Thus the auditor, 'however cultivated his general knowledge, however powerful his intellect, has nevertheless not become familiar with methods of thought and the special meanings of words'.[112]

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[108] William Froude, 'On experiments with H.M.S. Greyhound', *Transactions*, 15 (1874), pp. 36-73, esp. p. 37.
[109] Ibid., p. pp. 38-41. See Shaffer's description of Newton's experimental apparatus and use of replication, Simon Schaffer, 'Glass works: Newton's prisms and the uses of experiment', in David Gooding, Trevor Pinch & Simon Schaffer, *The uses of experiment: studies in the natural sciences* (Cambridge, 1989),pp. 67-104, esp. 68.
[110] Newman to Henry Wilberforce, 3 January 1869, in *Letters*, 24:200.
[111] John Ruskin, 'Writing and thinking [extracts from 'The relation of arts to morals', *Lectures on Art*]', in F. Aydelotte (ed.) *English and engineering: a Volume of essays for English classes in engineering schools* (New York, 1923), pp. 1-2.
[112] Froude to Newman, [early 1879], in *Letters*, 29: 109.

Newman had great faith in language, and told Froude that 'it "was a paradox to say 'we (people in general) could not express our thoughts to each other in words'"'.[113] Yet Newman's critics believed his faith in language to truthfully convey knowledge between individuals was part of his deception. An awareness of the moral use of language resonated in Froude's social network. "No man", Kingsley wrote, "knows the use of words better than Dr Newman."[114] For Froude the fragility of language, as a form of communication, was a cause of doubt and anxiety, but especially in 'practical science' where,

> all men are agreed in the desirableness of making language the instrument of exact thought, and in which they have the greatest and most complete means which can exist anywhere of verifying and comparing meanings of words, and of expressions which are intended to convey modes of thought.[115]

Froude's sense of the fragility of language can be seen throughout his work. He avoided responding to questions that took him beyond the constraints of the subject he had discussed, answering questions with quips like, 'I think that one of the things which one has to learn, is to know what are the limits of what one knows.'[116] Froude rarely spoke beyond the scope of his experience, which he believed was the only subject one could speak with exacting logic and accuracy. He observed that although men of science sometimes neglected this standard, and 'indulge[d] in ['loose talk'] about the certainty of the conclusions to which science leads', he knew that they '*all* treat their own conclusions with a skepticism [sic] as profound and as corroding as that with which they treat Theology.'[117] Froude closely associated self-indulgent conclusions with

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[113] Froude to Newman, in *Correspondence*, 1854, p. 97.

[114] Newman noted this passage of Kingsley's review of Froude's *History of England*, in a letter to Edward Badeley, see Newman to Badeley, 15 January 1864, *Letters*, 21:18, quoted in Ker, *Newman*, p. 535.

[115] Froude to Newman, in *Correspondence*, 1854, p. 97.

[116] Abell, 'Froude', p., xiii.

[117] Froude to Newman, 29 September 1864, in *Correspondence*, pp. 177-8.

dogma, and claimed that they both 'fail absolutely to convey definite meanings or ideas'.[118]

Froude believed that when the scientist makes and maintains a conclusion, it was,

> not less religiously his duty to keep before his eyes his knowledge of the fallibility of his processes of thought and those of advisers, and to maintain as vivid a recollection of the probabilities in favour of it - And instead of saying "this is my honest belief and so help me God it ever shall be" - he ought to say "this is for the present the best conclusion I can come to, but in the sight of God I declare that I shall be at all times ready to reconsider it, if reasonably called on to do so, either in the score of errors of fact, or errors of judgment.[119]

What is compelling about this statement, within the context of the decline of religious faith and rise of secular moral duty, is that the moral statement is made with reference to a higher power.[120] Froude conceived a morality in science, shaped by his awareness of the moral gulf that the culture of doubt had opened in Victorian intellectual pursuits.[121] Froude's response to this culture contained strong Tractarian and liberal-Anglican attitudes, much to Newman's disappointment. Froude's sense of certainty and experimental practice were shaped under the shadow of God, the arbiter of unprejudiced judgements, in a framework that acknowledged that responsible doubt was necessary for improvement.

4.5 CONCLUSION

Shortly before his death in 1879, Froude told Newman that 'science makes progress by being always alive to its own fundamental uncertainties'.[122] Mental preparation, moral obligation and a dutiful use of language stimulated enquiry. Knowing what was

[118] Froude to Newman, 1854, in Ibid., p. 97.
[119] Froude to Newman, 29 December 1859, in Ibid., p. 120.
[120] Victorian Doubt was frequently deployed to buttress the authority of scientific theory when it came into clear conflict with religion, but rarely did the engagement of science and religion exist within a basic 'conflict model'. Levine, 'Defining knowledge', pp. 16-7; Brooke, *Science and religion*, p. 5.
[121] Cantor, 'Book of nature', p. 73-77.
[122] Froude to Newman, [early 1879], in *Letters*, 29:111.

uncertain gave direction, progress and definition to what was certain. The individual's awareness of the moral duties implicit in producing knowledge, Froude argued, was beneficial within the broader scheme of knowing. 'Physical science and the mechanical arts, have of late, made progress with increasing rapidity and security ... by virtue of the wider and freer scope of action which this principle has conquered for itself in those districts of thought.' The 'principle', which Froude defined as 'the temper which, while realizes as carefully as possible the exact degree of doubtfulness which attaches to its conclusions, *acts* nevertheless confidently on the best and wisest conclusions it can form' had come to prominence within science (and politics). Froude urged experimenters to negotiate this line between doubt and acting confidently by following a moral compass, which Froude described in overtly religious language: 'the best and wisest use of every faculty we possess must be that use which will be most pleasing to Him by whom these faculties, whether perfect or imperfect, have been given us "to be exercised therewith."[123] Thus Froude's approach to science, that emphasised experimental work and doubt, did not exist in a vacuum but was the product of a personal experience of Victorian doubt: distrust in the authority of past knowledge, opposition to instinctive analysis and the rejection of dogmatic conclusions.

The theme of doubt runs throughout this thesis: doubt in the truthfulness of experimentation or experience, doubt in the expertise of naval architects and officers, and doubt in the authority of the test tank Froude built in the early 1870s. The doubts of actors were various and more often connected to anxiety in authority than the more focused culture of Victorian doubt as a religio-intellectual mode. This chapter has shown, however, that Froude may be connected with the latter, through his social network, his private correspondence with Newman and his rhetoric, conception and

[123] Froude to Newman, 29 December 1859, in *Correspondence*, p. 122.

experimental practices as a man of science. This sketch of cultural authority, doubt and the conceptualisation of 'scientific' method is essential to understanding Froude's approach to naval architecture. His contemporaries believed that he 'was incapable of using a word of exaggeration. He was an ideal observer.'[124] Such praise was central to Froude's reputation and authority as an 'expert'. The next chapter examines a series of case studies that demonstrate how the themes of doubt, dogma and experimentation were embodied in Froude's mechanical 'expertise' in the test tank.

[124] Nathaniel Barnaby, *Naval development in the century* (London, 1902), p. 245.

5

Models, mechanics and measurements

It is the Age of Machinery ... Nothing is now done directly, or by hand; all is by rule and calculated contrivance ... The living artisan is driven from his workshop, to make room for a speedier, inanimate one ... Not the external and physical alone is now managed by machinery, but the internal and spiritual also. ... The same habit regulates, nor our modes of action alone, but our modes of thought and feeling. Men are grown mechanical in head and in heart, as well as in hand.

Thomas Carlyle notes the spread of mechanical philosophy and ways of working.[1]

Our knowledge of physical constants and of the properties of materials, our units and scales and instruments and tester of all sorts, are for the most part offspring of the marriage of science with practice. They make science exact, and they allow engineers to be standardized. ... It was to meet the requirements of the naval architect that William Froude attacked the problem of ship resistance, devised the method of the experimental tank, and showed how measurements on the drag of small models might, through application of what is now called the principle of dynamical similarity, furnish data from which to determine the power required at any speed to drive the largest ships.

James Alfred Ewing looks back on Froude's unification of science and practice in the test tank.[2]

In 1872, C. Mitchell & Co. shipbuilders of Newcastle approached William Thomson for his opinion on the efficiency of their proposed transverse screw and rudder system. Thomson placed Mitchell in correspondence with William Froude, lending his support to the civil engineer's ideas.[3] Froude performed a series of experiments and calculations for the shipbuilders but complained in private to Thomson that there was a 'want of real vitality ... in the working rules of most mechanical engineers'.[4] Froude believed that commercial engineers like Mitchells worked to company rules and standards that limited the possibility for exploring alternative mechanisms and methods of working. Froude contrasted such ways of working with his own work in the test tank. In a letter to James Robert Napier he wrote, 'what we are doing here is a pleasant and wholesome

[1] Thomas Carlyle, 'Signs of the times', *Edinburgh Review*, 49 (1829), pp. 439-59, esp. 442-2.
[2] James Alfred Ewing, *An engineer's outlook* (London, 1933), pp. 38-9.
[3] William Thomson to Charles Mitchell, 12 November 1872, Glasgow University, Special collections, Thomson papers GB 0247 MS Kelvin M39.
[4] William Froude to Thomson, 13 December 1872, Thomson papers GB 0247 MS Kelvin F47.

mixture of mathematics and mechanical operations, which serves very well to encourage and draw out the faculties in both directions.'[5]

'Pleasant' and 'wholesome' are peculiar words to describe mathematics and mechanics. Why was Froude interested in loading mathematics and mechanics - two types of 'operating', to use his terminology - with such values? A possible answer, I argue, resides in how Froude wished to recast mechanical work and mathematical thought as *mechanical thought* and *mathematical work* by enlarging the role of mechanics in Victorian workshops, draught rooms, dockyards and learned society. Mechanics were widely perceived as an occupation for the working classes, although slightly better than the working class of labourers.[6] Froude wanted to instil a sense of gentility and civility into mechanical work, believing as he did that there was a vitality, virtue and truth in mechanical ways of thinking and working.[7] Similarly, Froude recognised that mathematics was still widely understood as an abstract form of thinking (let alone working) by many Victorian mechanics. Mathematics, unlike mechanics, had a strong link to classical learning, natural philosophy and the privileged inhabitants of Oxbridge parlours.[8] To call mechanics and mathematics 'pleasant' and 'wholesome' is strongly suggestive of Froude's approach to his work and the social network in which it took shape.[9]

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[5] Froude to James Robert Napier, 22 February 1875, Glasgow University, Archive service, Napier papers 90/2/4/51.

[6] Alastair Reid notes that mechanics were seen as artisans rather than labourers, superior to the latter. Reid also examined the 'intelligent artisan' of Thomas Wright's Victorian books, noting the discrepancy between Wright's often footnoted character and the period-uniqueness of Wright's literary construction. Alastair Reid, 'Intelligent artisans and aristocrats of labour: the essays of Thomas Wright', in Jay Winter (ed.), *The working class in modern British history: essays in honour of Henry Pelling* (Cambridge, 1983), pp. 171-186, esp. 173-177.

[7] Contrast with Ben Marsden, '"The progeny of these two 'Fellows'": Robert Willis, William Whewell and the sciences of mechanism, mechanics and machinery in early Victorian Britain', *BJHS*, 37 (2004), pp. 401-434.

[8] For mathematics, Oxbridge and associations with ancient learning see Andrew Warwick, *Masters of theory: Cambridge and the rise of mathematical physics* (Chicago, 2003), pp. 49-113; Robert Fox & Graeme Gooday (eds.), *Physics in Oxford 1839–1939: laboratories, learning and college life* (Oxford, 2005); Crosbie Smith & M. Norton Wise, *Energy & empire: a biographical study of Lord Kelvin*, (Cambridge, 1989), pp. 149-201.

[9] This context extends to the relationship between mind and body that historians such as William Lubenow have sketched with regard to the brand of liberalism that was simultaneously mental, material and emotion. William C. Lubenow, 'Mediating "the chaos of incident" and "the cosmos of sentiment": liberalism in Britain, 1815-1914', *Journal of British Studies*, 47 (July 2008), pp. 492-504.

This chapter concludes my analysis of the epistemological issues in naval architecture opened in chapter 3. I examine the culture of measurement and mechanisation in the ship design community and Victorian navy as exemplified in Froude's work with models. An article in *Fraser's Magazine* noted that 'until Mr. Froude's experiments were undertaken it was, to say the least, pretty much a matter of shrewd guessing on the part of the designer when he had to determine the engine power required in a ship of novel form and unprecedented speed.'[10] Chapter 2 demonstrated that most of the work involved in building a ship was guided by tradition, craft and approximations. Precision measurement was not a matter-of-fact way to truth. Like many tenets of scientific labour it had to be made a matter-of-fact.[11] The same was true of the practice of mechanics. *Tekhnë* has existed since the wheel and the first elementary tools and weapons, but throughout history there has been an unending reconfiguration of the role of the mind and the hand in this process.[12]

Tracing art, industry and science through the 'oppositional categories' of mind and hand - intellectual and manual - opens up areas of epistemology and practice that shed light on how actors defined knowledge, production and work.[13] Froude, for example, put machines and models into the heart of his mode of enquiry. He trusted the apparatus he built with his hands to measure phenomena more than he trusted his own mental

[10] [Anon.], 'The science of naval architecture', *Fraser's Magazine*, 99 (1878), pp. 269-276, esp. 272.
[11] For making matters of fact see Steven Shapin & Simon Schaffer, *Leviathan and the air-pump: Hobbes, Boyle, and the experimental life* (Princeton, 1985), pp. 3, 14, 18, 39-40. For Victorian measurement see Graeme Gooday, *The morals of measurement: accuracy, irony and trust in late Victorian electrical practice* (Cambridge, 2004); Simon Schaffer, 'Metrology, metrication, and Victorian values', in Bernard Lightman (ed.), *Victorian science in context* (Chicago, 1997), pp. 438-74; Simon Schaffer, 'Accurate measurement is an English science', in M. Norton Wise (ed.), *The values of precision* (Princeton, 1995), pp. 135-72; M. Norton Wise, ed., *The values of precision* (Princeton, 1995).
[12] *Tekhnë* is the etymological root in Greek of the art, craft or skill of someone who builds. For the various etymological roots of technology and technical work see Thomas P. Hughes, *Human-built world: how to think about technology and culture* (Chicago, 2004), pp. 2-5. For a recent critique and defence of the cultural constituency of defining technology and techniques see Paul Forman, 'The primacy of science in modernity, of technology in postmodernity, and of ideology in the history of technology', *History and Technology*, 23 (2007), pp. 1-152. Contrast with the response Ronald Kline, 'Forman's lament', *History and Technology*, 23 (2007), pp. 160-166, esp. 162.
[13] Lissa Roberts & Simon Schaffer, 'Preface', in Lissa Roberts, Simon Schaffer & Peter Dear (eds.), *The mindful hand: inquiry and invention from the late Renaissance to early industrialization* (Amsterdam, 2007), pp. xiii-xxvii, esp. xiii-xv. This framework opens many areas of interpretation that older models of technology-as-tool lack, for example, contrast with the evolutionary model in George Basalla, *The evolution of technology* (Cambridge, 1988), esp. pp. 27, 30-32, 50, 104, 137.

senses. A mind/hand framework offers a way of examining in close detail the culture of 'mechanical objectivity' that Lorraine Daston & Peter Galison have traced in Victorian science.[14] Moreover, the mind/hand framework emphasises what was particular about the 'practice' of mechanics at any given time. To proceed I ask 'how did actors in the naval and naval architecture communities mark the distinctions between head and hand?' And 'how was the credibility of measurement and mechanisation established?' These questions open my discussion of how the engagement between measurement, mechanisation and the ship shaped knowledge, production and social order in Part III of this thesis.

5.1 THE ADMIRALTY TEST TANK

Seeking support for model experiments

The 1869 BAAS committee on the 'Stability, propulsion, and sea-going qualities of ships' (introduced in chapter 3) surveyed the work of many leading authorities in hydrodynamics. Charles Merrifield's conclusion was that full-scale experiments were necessary to improve both theoretical and practical knowledge of hydrodynamics and ship design. This suggestion, supported by the whole committee except Froude, was sent to the Admiralty in the hope of securing support, state funds and the use of H.M. ships. Froude dissented, making a case for undertaking an extensive and systematic series of model experiments. At the time Froude was already in correspondence with Edward Reed, chief constructor of the navy, in an attempt to privately secure funds. This section examines how the Admiralty was persuaded to pay for scientific experiments, demonstrating the authority of the symbolic, social and aristocratic culture of the

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[14] Lorraine Daston & Peter Galison's notion of 'mechanical objectivity' as a union between head and hand provides a promising alternative to the traditional discussion of mechanical thought as simply an intellectual activity, see Lorraine Daston & Peter Galison, *Objectivity* (New York, 2007), pp. 43, 115-125.

Admiralty in which the character and influence of the experimenter was key to decisions about expertise.

Merrifield, who denied the credibility of model experiments, recommended that the BAAS petition the Admiralty to commission a series of experiments with two full-sized ships consisting of distinctly different dimensions and shape to allow for comparison. These ships would be taken to either the west coast of Scotland or Norway where there was deep inland water. Such a space would enable observation of deep sea waves from shipboard and the land, thereby lending the experimenters some control over the observational and test conditions.[15] Merrifield specifically stressed that the water 'should be clear enough to admit of being seen through to a considerable depth.'[16] Similarly with regard to rolling, the BAAS committee reported that they would need 'a large number of ships, of various classes, and under very varied conditions.'[17] Merrifield's recommendations reflected the view of the majority of the committee whose experimental method was to fuse visual observations and mathematical deduction.

Members of the BAAS committee recognised that Admiralty support was vital to both performing experiments on ships and making any new theories credible.[18] Merrifield did not, however, demonstrate how his optimism in the power of experiment would produce practical knowledge. The reoccurring motif in his rhetoric was instead that the results of any experiments be published for the use of naval architects, who could then interpret the information. '[I]t would be a good thing for the Government,

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[15] Charles Merrifield, 'Report of a committee on the stability, propulsion, and sea-going qualities of ships', *Reports, 1869* (London, 1870), pp. 25, 41.
[16] Ibid., p. 25.
[17] Ibid., p. 42.
[18] Ibid., pp. 25-6.

and other large shipbuilders,' Merrifield wrote, 'to keep in view as an ultimate object'.[19] This argument doubtless damaged Merrifield's standing with the Admiralty. As this thesis has demonstrated, the British Admiralty had little interest or intention to help naval architects address the limits of their knowledge, and the naval element generally rejected optimistic claims of men of science that experiment could be used for the *matériel* improvement of the navy.

Froude proposed the use of models to explore simultaneously the epistemological limits of hydrodynamics through experiment and examine the efficiency of Admiralty ship designs on a case-by-case basis. Froude's remarks for the BAAS were focused largely on disputing the views in the report regarding models and their inadequacy in predicting the behaviour of ships.[20] Froude's fellow committee members questioned the accuracy of model experiments, rightly noting that there was no evidence that a law of comparison existed. Froude responded to these criticisms by reconciling the areas where his ideas were in harmony with his associates.[21] He also concluded his remarks by suggesting that model experiments could offer men of science more precision.[22] Froude linked this narrative of precision to uncovering the mysteries shrouding efficient and economic ship design:

> we can have no ground for certainty that we have found even an approximation to the best form, unless we have gone experimentally over almost the whole ground and tested a very wide variety of shape. ... there is no really established principle of judgment on which reliance can be placed. Yet most weighty considerations affecting economy and efficiency are involved in the settlement of even that single question.[23]

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[19] Ibid., pp. 25-6.
[20] Ibid., p. 43.
[21] In a letter to the Board of Admiralty Froude specifically cited his disagreement with Rankine as helping to define and tackle the problem of scale comparison, and eventually coming to an adequate working mathematical model. Froude to Hugh Childers, 11 December 1868, London, TNA, Admiralty papers 116/167.
[22] Merrifield, 'Report', p. 46. Links can be drawn on the question of precision and observation with the controversy between George Airy and William Scoresby discussed in Alison Winter, '"Compasses all awry": the iron ship and the ambiguities of cultural authority in Victorian Britain', *Victorian Studies*, 38 (1994), pp. 69-98.
[23] Merrifield, 'Report', pp. 46-47.

Froude had a distinct advantage over Merrifield in that he was already in correspondence with Reed.[24] Froude had contacted Reed in 1868 with a request to undertake model experiments on behalf of the Admiralty. Froude described the practical implications of the proposed experiments, arguing that '(i) Experiments duly conducted on a small scale will give results truly indicative of the performance of full size ships. [And] (ii) There are very important defects and inaccuracies in the received views concerning the resistances of different forms.'[25] Froude also corresponded with Hugh Childers, first lord of the Admiralty, for whom he also presented his justifications in terms of waste and economy, alluding to the 'coal question' that had been an important narrative of authority in the process of making more efficient steam engines.[26] Froude's thus sought to borrow cultural authority from Victorian discourses of industrial economy and efficiency by portraying the hull of the ships as part of a technological system of propulsive power in the ship.

At this time Reed was also in contact with Canon Henry Moseley, vicar of Olveston, Gloucestershire, chaplain to Queen Victoria and author of *A Treatise on Hydrostatics* (1830) and *The Mechanical Principles of Engineering and Architecture* (1843).[27] Moseley's prominence in the scientific community as a fellow of the Royal Society and English religious society had been recognised by the largely Anglican Kings College London, where he was professor of natural and experimental philosophy until 1844. Moseley left the university after a series of provocations within his department, including his advocacy of the fusion of mathematical analysis and experimental enquiry

[24] However, we must keep in mind that Merrifield was also linked to the Admiralty through his role as Principal of the RSNA.
[25] Froude to Edward Reed, December 1868, Admiralty papers 116/167.
[26] Froude to Childers, 11 December 1868, Admiralty papers 116/167. William Stanley Jevons, *The coal question: an inquiry concerning the progress of the nation, and the probable exhaustion of our coal-mines* (London, 1866), pp. v-xxvi, 85-138, 370-6. For the coal question and the steam ship see Crosbie Smith, Ian Higginson & Philip Wolstenholme, '"Imitations of God's own works": making trustworthy the ocean steamship', *History of Science*, 41 (2003), pp. 379-426, esp. 405-417.
[27] B. B. Woodward, 'Moseley, Henry (1801–1872)', rev. R. C. Cox, *Oxford Dictionary of National Biography* (Oxford, 2004).

in experimental philosophy and practical science.[28] Moseley, who in 1868 drew his living from his pastoral duties, wanted Admiralty funding for a series of rolling experiments with models. Reed, who supported these proposals, sought to integrate Moseley's proposed experiments with Froude's proposal for funds when he took the matter to his superiors.

In 1868, members of the Board of Admiralty visited Froude to view the model experiments that he had hitherto performed in the local ponds and rivers. Froude proposed to develop the experiments by building a test tank: a waterway, in which the temperature, behaviour and volume of water was maintained, and in which exactly scaled wax paraffin models of ships would be propelled by a railway and monitored by a complicated and delicate system of mechanical, automatic measuring apparatus to record resistance, speed and power.[29] In the test tank Froude could control the variables that made observations of full-sized ships at sea untrustworthy. Froude, in his correspondence with Childers at the Admiralty, argued that the test tank experiments would be 'a mode of inquiry at once exhaustive, rapid and economical thus furnishing a marked contrast to what is in fact the only alternative, a system of full size trials.' Froude also advertised his specific credibility and skills to show why the Admiralty could trust him to independently perform the experiments. '[T]hough there are probably many men of science whose qualifications would be found in various respects superior to my own', Froude openly admitted, 'I have ... acquired a large stock of apposite knowledge and matured habits of experimental inquiry.'[30] He recognised that it was important to demonstrate his expertise with regard to knowledge, but also the

[28] Henry Moseley to Charles Babbage, January 1832, London, British Library, Babbage papers, vol. 5, add. ms. 37186, f. 206.
[29] Froude to Childers, December 1868, Admiralty papers 116/167.
[30] Ibid.

significance of his experience as a skilled worker. His argument also reemphasised that the problem of ship form was a mechanical one, neither solely practical nor scientific.

Froude's letter to Childers addressed the potentially problematic question of where the test tank might be built. Froude requested that 'on the score alike of efficiency and economy the work should be trusted to myself at my residence here.'[31] 'I have a good workshop in my own house', Froude continued, 'nowhere else could I approach it with the same mechanical advantages.[32] On this issue the Admiralty had little to say; suggesting that they had no long term plans for model testing and only saw Froude's work as a trial of experimental research. In the same way Childers made no objection to Froude's demand to appoint a staff of paid assistants. Froude closed his letter with a comparative analysis of the costs and benefits of instituting model experiments in a test tank, the cost of which was £2000. He argued that were the result to confirm that shorter ship were as fast and efficient as longer ships, 'beneficially taking 10 feet off the length of a single ironclad[,] the whole outlay would probably be recouped at once.'[33]

On 31 March 1869, Reed formally requested Admiralty support and funds for Froude's experiments (with Moseley's petition reemployed as a letter of recommendation for the proposal).[34] Moseley, as a former university professor and associate to the royal court, had the authority that Froude lacked, and thus brought extra weight to the test tank proposal.[35] The type of the authority that Froude and Reed looked to attach to their credibility is indicative of the aristocratic culture of decision making in the Admiralty and the brand of symbolic, social and cultural

[31] Ibid.
[32] Ibid.
[33] Ibid.
[34] Reed to Robert Spencer Robinson, 31 March 1869, Admiral papers 116/137. Moseley told Reed that he was 'delighted to be associated with Mr. Froude and it will be easy for me to visit Torquay, whenever it may be necessary.' Moseley to Reed, 27 January 1869, Admiralty papers 116/137.
[35] Reed to Robinson, 31 March 1869, Admiralty papers 116/137.

capital that induced those decisions. This capital came from individuals of reasonably high social standing and who were known to members of the Board of Admiralty. Few members of the Admiralty constructors department or the INA held this type of socio-cultural capital.

In private Froude and Reed stood together in advocating the test tank and considered how else they could influence Childers' decision to allocate funds. Froude felt that he and Reed had exhausted the science and engineering-based arguments in favour of the test tank and thus asked Reed 'whether it would do good if I were to bring to bear on Mr. Childers any collateral influence, to the extent of getting myself *extremely* guaranteed as a good man & true, who has long paid attention to this class of question.'[36] Froude used his extensive family social network to bring the Duke of Somerset, who two years previously had been First Lord of the Admiralty, to view his model experiments.[37] Somerset in turn suggested to Froude that he send to parliament a comparison of the cost of recent shipbuilding mistakes and the cost of the proposed test tank (as he had already sent to Childers). Somerset, who had been heavily criticised for neglecting the *matériel* condition of the Admiralty, became an eager advocate of Froude's experiments, and encouraged Froude to make the test tank an issue of parliamentary politics. Froude discussed his meeting with Reed, telling him that '[i]f the Duke of Somerset were now first Lord I think there would be little difficulty in obtaining sanction for the proposed system of experiment.'[38] Doubtless Reed's associates at the Admiralty were also privy to this correspondence.

Conscious of the authority of social networks and non-scientists, Froude further mobilised support from his cousin James Spedding, the editor of a widely published

[36] Froude to Reed, 20 January 1869, Admiralty papers 116/137.
[37] Froude to Reed, 27 December 1868, Admiralty papers 116/137.
[38] Froude to Reed, 20 January 1869, Admiralty papers 116/137.

edition of Francis Bacon and a contributor to many periodicals. Spedding was a personal friend of Childers and Lord Hampton (whose opinion was also held in high regard by the First Lord).[39] Spedding had also been 'an independent witness' to a number of Froude's experiments, and Froude believed that 'both on his own account & through Lord Hampton[, he] could & would make interest for me in the best sense of the word if that should be desirable.'[40] On 2 April 1869, Spedding contacted Childers with the following testimony.

> I believe you have under consideration a proposition from Mr. William Froude for a course of experiments to determine the best shapes of ships; and you will probably wish to know as much as you can about the character of the proposer. ... Of his professional qualifications as an engineer you will of course have from persons better qualified to speak. But few have had better means than myself of knowing how perfectly disinterested a man he is - what an immense amount of patience, pain and ingenuity he will spend upon the thorough investigation of one of these problems, and how entirely he is moved therein by scientific curiosity, and the love of a perfect machine (ally [like] a ship), and a sense of the immorality of wasted force and unnecessary friction.[41]

Spedding's ability to speak to Froude's character and mentality as an experimenter complemented Reed's input regarding the soundness of Froude's proposed experiments. The above passage also suggests how Froude's work was understood by non-experts.

In April 1869, William Baxter, MP for Montrose and parliamentary secretary of the Admiralty, examined the proposal. Baxter, a political appointee, advised Childers that having 'talked over this matter with Sir S. Robinson [and] having some doubt as to the wisdom of ... his opinion as noted[,] I come to the conclusion that perhaps some independent scientific authority, say the Royal Society, might be consulted say as regarding the *paramount* importance of these experiments.'[42] Baxter's letter to Childers reveals that leading members of the Board of Admiralty believed that their Chief

[39] Ibid.
[40] Ibid.
[41] James Spedding to Childers, 2 April 1869, Admiralty papers 116/167.
[42] William Baxter to Childers, 11 April 1869, Admiralty papers 116/167. At this point the Admiralty had not been contacted by Merrifield on behalf of the BAAS, and thus had no material against which to judge Froude's proposal.

Constructor, Reed, was not perceived to be 'independent' or a source of authority – Reed was at this time at odds with his superiors on the Board of Admiralty – while Robert Spencer Robinson, controller of the navy, was not believed to possess adequate knowledge of the science of shipbuilding. Thus Baxter perceived that there were no experts within the Admiralty to judge the scientific merit of a proposal. It is also noteworthy that Baxter identified the Royal Society, and not the newer BAAS or more specialised INA, as the appropriate body to judge Froude's proposal. This demonstrates the gentlemanly and traditional perception of science and expertise held by powerful decision makers within the Admiralty.[43]

Baxter's note halted progress on Froude's proposal. Only in December 1869, following agitation within the Admiralty from Reed and outside from Merrifield's BAAS committee, was the proposal resurrected. In July 1869, Merrifield wrote to the Secretary of the Admiralty in his capacity as secretary of the INA. The INA had been made aware that the Admiralty were considering a proposal from Froude, and the INA council wished to convey that 'any additional information in reference to the resistance encountered by vessels ... would, if reliable, be of the utmost importance to ship-builders.'[44] In September 1869, Merrifield was again in correspondence with the Secretary of the Admiralty, this time as the author of the 1869 BAAS report on ship design. Merrifield fiercely advocated 'exact experiment on vessels'.[45] Henry Brunel, who was close to Froude and later became one of his assistants at the test tank, was very sceptical about how Merrifield would handle the matter of competing with Froude for Admiralty support. He was a 'dirty little beast, blagard & snobbish', Brunel told Froude,

[43] For the Royal Society at this time see Marie Boas Hall, *All scientists now: the Royal Society in the nineteenth century* (Cambridge, 1984).
[44] Charles Merrifield to Vernon Lushington, 19 July 1869, Admiralty papers 116/167.
[45] Merrifield to Lushington, 28 September 1869, Admiralty papers 116/167.

encouraging him to 'treat Merrifield as an enemy ... be cautious, don't let kindness lead into mess'.[46]

Merrifield firmly painted Froude's views in opposition to the majority of the BAAS committee that supported experiments on full-sized ships.[47] However, Merrifield also told the Admiralty that Froude's model experiments 'can evidently be had in greater number and in larger variety at much less expense than on full scale'.[48] This statement demands further reflection. Merrifield opposed Froude's ideas but he did not publicly betray the possibility that if the Admiralty would not support full-scale experiments, it might support model experiments. This was a compromise, and it reflects the tensions felt by a social network of naval architects that was aware that they had little influence over the Lords of Admiralty and that scientific experts had little authority in comparison to the naval element in the navy.

Robinson and Childers now had before them a choice to follow the guidance of a BAAS committee of experts on hydrodynamics and naval architecture, support the experiments proposed by a single member of that committee, or, of course, ignore all the proposals as the Admiralty had ignored previous projects from the BAAS to investigate ship shape. Spencer Robinson consulted Reed, who specifically addressed the BAAS committee's report and noted that '[m]y assistants and myself have given consideration to these questions, and have come to the conclusion that the Report of the Committee neither sets forth sufficient reasons for undertaking experiments with full sized ships, at necessarily great expense, nor shows in what way the results of such

[46] Henry Brunel to William Froude, September 1869, Bristol University, Special collections, Henry Marc Brunel papers, Letter Book 10.
[47] Merrifield to Lushington, 28 September 1869, Admiralty papers 116/167.
[48] Charles Merrifield, 'Second report of the committee ... appointed to report on the state of existing knowledge on the stability, propulsion, and sea-going qualities of ships', *Reports 1870* (London, 1871), pp. 44-48, esp. p. 45.

experiments would be brought to bear upon the improvement of Her Majesty's Ships.'[49] In contrast, Reed remarked that Froude's model experiments 'would be of real value to science, and would probably develop results of service to ship construction.'[50] Reed then persuaded Woolley to support Froude. Significantly, Woolley had been at odds with Froude in the early 1860s over the use of models; additionally, Woolley's authority on naval architecture was well known to the Board of the Admiralty.[51]

In early February 1870, Vernon Lushington, Secretary to the Admiralty, informed Merrifield that 'My Lords Commissioners of the Admiralty ... are unable to give a general assent to the proposals of your Committee to conduct experiments upon Her Majesty's ships.' Lushington also took the opportunity to inform Merrifield that, quite apart from the petitioning of the BAAS committee, 'My Lords have been pleased to sanction certain experiments upon models, to be conducted by Mr. Froude, a member of the Committee, and will cause the results of those experiments to be communicated, when complete, to the Institution of Naval Architects, the British Association, and such other Professional bodies as to My Lords may seem desirable.'[52]

5.2 Mechanical knowledge

Certainty in theory and practice

Sir Henry Acland, Regius Professor of Medicine at Oxford University (1858-1894), wrote the following of Froude: "No workman in any art ever combined in juster proportion, few in so eminent degree, the three properties of culture, science and practice. His

[49] Reed to Robinson, 2 December 1869, Admiralty papers 116/167.
[50] Ibid.
[51] Joseph Woolley to the Board of Admiralty, 26 January 1870, Admiralty papers 116/167.
[52] Merrifield, 'Second report', pp. 45-46.

hands were as skilful as his creative brain was active."[53] The sophisticated union Froude sought between mechanics and knowledge in his test tank was a source of much of the 'vitality' that he believed many engineers lacked. This union was firmly located within his mental framework of doubt (chapter 4) and mechanical skill and rigorous and creative experimentation (chapter 3). Froude believed that a type of 'mechanical objectivity' could be utilised in a manner that reduced error in both the epistemology and practice of producing knowledge, thus addressing many of the criticisms Newman made regarding certainty in scientific knowledge.[54]

Froude greatly respected the work of mechanics. '[A] grand workshop *is* a most fascinating place,' Froude wrote to Napier. But he did not believe that mechanical work was an end in itself. Instead he saw mechanics as part of a more sophisticated, inquisitive mode of thinking and working. Continuing his thoughts on the 'grand workshop', Froude suggested that, 'its contents & its doings are attraction enough almost, to attract one's attention & bar ones higher progress'.[55] Froude's priorities were investigation and knowledge. In 1841, William Whewell argued that mechanics were the 'real life' manifestation of mathematics, and advocated that they ought to be taught to engineers for 'practical application'.[56] Froude, in advancing the inverse working matrix of mechanical thought, called for engineers to put the 'virtue' of mechanical knowledge into practice and pursue epistemological problems. Froude was determined to place certainty where mechanical engineers and theorists had formerly been content with 'instinct', 'belief' or 'abstract deduction'.

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[53] Quoted in Westcott Abell, 'William Froude, M.A., LL.D., F.R.S.: a memoir', in A.D. Duckworth (ed.), *The papers of William Froude, M.A., LL.D., F.R.S., 1810-1879* (London, 1955), pp. xi-xiv, esp. xiii.
[54] For cultural discussions of mechanics and Victorian frameworks of 'knowing' – religious being the most prevalent – see Boyd Hilton, *A mad, bad, & dangerous people? England 1783-1846* (Oxford, 2006), pp. 439-492; Ben Marsden & Crosbie Smith, *Engineering empires: a cultural history of engineering in nineteenth-century Britain* (Basingstoke, 2005), esp. pp. 245-254; Thomas Gieryn, *Cultural boundaries of science: credibility on the line* (Chicago, 1999), pp. 37-64.
[55] Froude to Napier, 22 February 1875, Napier papers 90/2/4/51.
[56] William Whewell, *The mechanics of engineering: intended for use in universities, and in colleges of engineers* (Cambridge, 1841), p. v.

Froude was not alone in separating instinct from logic and belief from knowing. Leslie Stephen was one of many Victorians who wanted to place knowledge on a firm, verifiable, almost tangible foundation.[57] Stephen, like Froude, also debated the dynamics of faith and knowing with Henry Newman. Their dialogue was, unlike Froude's, open to the public in the *Fortnightly Review*. Stephen addressed Newman's theory of belief and supposedly 'scientific treatment of religious, ethical, and political problems'. Stephen, who wrote in similar circles with James Anthony Froude and the Victorian community of doubters, wrote that, '[t]he logic of facts does not lie on the surface, to be picked up by the first observer who comes by, but requires a collateral process of preparing and testing, and a corresponding logical apparatus.'[58] Stephen argued that against such a standard Newman fell short, for he continually broke all the laws and theories of belief that he claimed were 'scientific'.[59]

Peter Bowler has observed that in Victorian Britain the search for knowledge was set within a conscious awareness 'of [a] transition from medieval to modern values - a transition that was often painful and that opened up massive uncertainties as to what modern values should be.'[60] Deeply engulfed in the experience of doubt, Stephen remarked that, '[w]e can take nothing as proved but that which has stood the hard test of verification by multitudinous experience. ... No man can say, This is true [because] I think it; no man can hold that he has grasped the full and ultimate truth upon any subject.' Stephen concluded that 'if the [human]race is to progress, men must not be content to bow to the first authority at hand, even if it shows signs of strong and

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[57] Jeffrey P. Von Arx, *Progress and pessimism: religion, politics, and history in late nineteenth century Britain* (Cambridge, MA, 1985), pp. 181-2.
[58] Leslie Stephen, 'Dr. Newman's theory of belief', *Fortnightly Review*, 22 (1877), pp. 680-697, esp. p. 687.
[59] Leslie Stephen, 'Dr. Newman's theory of belief', *Fortnightly Review*, 22 (1877), pp. 792-810, esp. 799.
[60] Peter J. Bowler, *The invention of progress: the Victorians and the past* (Oxford, 1989), p. 2.

prolonged vitality.'[61] Stephen and the community of Victorian intellectual doubters believed the medievalism of dogma, belief and instinct could not transcend the extensively more democratic intellectual frameworks of the nineteenth century, by which knowledge was catalogued, documented, made accessible to wider social groups, even suited for utilitarian purposes.[62] One way in which this was achieved in the scientific and engineering community was by making knowledge numerical, instructive and public.[63]

Many of these themes can be identified in Froude's 1875 presidential address to Section G of the BAAS. Froude chose to begin his paper with an appeal to *progress* and *purposefulness*. 'The address of the President of a section would year by year possess an appropriate interest,' Froude suggested, 'if it could always consist of an exposition of the progress made during the past year in the department of science which the section embraces.[64] In order to demonstrate the 'progress' he felt he had made, Froude explored alternative and mechanical ways of presenting knowledge to his audience. He operated experiments while he spoke, presented diagrams and exhibited his measuring apparatus. He told the audience that this 'innovation' in a presidential address was necessary 'in order to make my meaning clear'.[65]

Froude's believed that experimental knowledge constituted a higher, more credible, source of authority because it rested on mechanical and methodical experiences. Chapter 4 demonstrated that Froude was exposed to a lot of debate

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[61] Stephen, 'Newman's theory of belief', p. 810. Also see Asa Briggs, *The age of improvement, 1783-1867* (London, 1959), p. 401.
[62] Alan Rauch, *Useful knowledge: the Victorians, morality, and the march of intellect* (Durham, North Carolina, 2001), pp. 22-59.
[63] For dissemination and popularisation of science see Bernard Lightman, *Victorian popularizers of science: designing nature for new audiences* (Chicago, 2007); Geoffrey Cantor & Sally Shuttleworth (ed.), *Science serialized: representation of the sciences in nineteenth-century periodicals* (Cambridge, MA, 2004). For quantification and public knowledge see Theodore Porter, *Trust in numbers: the pursuit of objectivity in science and public life* (Princeton, 1995).
[64] [William Froude], 'The British Association: address to the mechanical section', *Engineering*, 20 (1875), p. 191.
[65] Ibid.

concerning the standards of certainty, especially the perceived limitations of traditionally 'protestant' notions of belief, but also the possibilities of certainty in logic and mechanics. The Reverend Thomas Mozley noted that 'William Froude has his heart in with his brother's work at Oriel, though his turn even then [in the 1830s] was for science.'[66] Froude frequently referred to 'the mental training I received from my Brother Hurrell', or the 'principles first cultivated in my mind by Hurrell' in his letters to Newman, but in 1859 he suggested that his experiences of how science 'mechanically' managed 'working' knowledge had begun to 'produce results which I fully admit to be at variance with Hurrell's'.[67] Froude continued, noting that his work with Isambard Kingdom Brunel had since opened the possibility that that certainty was not an inherent property of knowledge but part of the relationship between knowledge and the investigator.[68] Thus Froude came to his belief that certainty was based on probability and therefore if a statement was claimed true it was because 'the probability of ... [it] *is being* most continually tested and found to stand the test.'[69]

Experiments represented a way for Froude to negotiate his doubts in knowledge, and specifically hydrodynamics. This premise depended on three factors. The first concerned the ability to control the variables that plagued ship trials, the second rested on the credibility of mechanical objectivity and experiment in the physical sciences and the third, contrasting slightly the second, developed the belief that close observations and demonstrations made knowledge more trustworthy (as was common in the response to feelings of doubt). Froude's faith in model experiments thus rested on the

[66] Thomas Mozley, *Reminiscences, Volume II* (London, 1882), p. 14.
[67] Froude to John Newman, 29 December 1859, in *Correspondence*, pp. 118, 119, 122.
[68] Ibid., p. 118.
[69] Froude to Newman, 29 September 1864, *Correspondence*, p. 178.

ability to control phenomena and experiments.[70] He believed that with a model experiment 'we are not perplexed by a multitude of collateral functions such as in full size trials [that] ... intrude themselves into the result'. Experiments with models, in contrast, provided 'an exact and unmixed record of the resistance experienced by the form, disembarrassed from the questions of efficiency of engine power or of propulsive agency.'[71]

Froude's experience of practical science was physical, direct and experimental: his scientific subjects of study were tangible and, as he described to Newman, 'the principles and results of reasonings are confronted with the test of direct experiment, and were to be divested of prejudices and to arrive at truth simply, is the object most directly before the eyes'.[72] Froude believed that there was always recourse to 'verification of meaning by reference to tangible things, that is, things open to the direct action of the senses'.[73] Models provided just such a tangible thing, but more importantly their scale offered Froude the control which he lacked when experiencing an experiment from the bow of a ship. Models, Froude claimed, allowed for 'the facility of manipulation inherent in mere smallness of dimensions'.[74] The test tank thereby allowed the experimenting engineer to control and manage the variables that had previously been beyond the range of the mathematician or artisan.

Froude's approach to mechanically managed knowledge and the use of models was also shaped by his interactions with men of science like Thomson and W.J. Macquorn Rankine who were conscious of both the mathematical and applied

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[70] For issues concerning experiment see David Gooding, Trevor Pinch & Simon Schaffer, 'Introduction: some uses of experiment', in Gooding, Pinch & Schaffer (ed.), *The uses of experiment: studies in the natural sciences* (Cambridge, 1989), pp. 1-28.
[71] Froude to Reed, December 1868, Admiralty papers 116/167.
[72] Froude to Newman, 29 December 1859, in *Correspondence*, pp. 118-9.
[73] Froude to Newman, [early 1879], in *Letters*, 29:109.
[74] Froude to Reed, December 1868, Admiralty paper 116/167.

engineering issues involved in forming knowledge.[75] Thomson, who helped Froude construct some of the testing instruments and procedures used in the test tank, strongly believed he was 'never content until I have constructed a mechanical model of the subject I am studying. If I succeed in making one, I understand; otherwise I do not.'[76] In a similar regard, Froude believed that,

> models being cheap of construction and specially adapted to the purpose may be multiplied and varied in an almost indefinite extent, so as to direct the inquiry to any particular question that may be opened up, and to complete all the links in each chain of results from which any individual law we are in search of is to be deduced.[77]

Such mechanical models – theoretical and literal – could shed light on the dogmas of *prima facie* knowledge. For instance, it was common belief among shipwrights and sailors that the cause of resistance when a ship moved through water was that the ship had to push water out of its way. This *prima facie* knowledge seemed absolutely correct to observers who looked over the bow and watched the formation of small waves along the bow line, giving the impression of water being pushed to the side. Nathaniel Barnaby, an otherwise scientifically inclined naval constructor, admitted that that view had seemed 'an extremely natural one' to many sailors and shipbuilders.[78] Froude's stream line theory of ship resistance, however, suggested that in most ships the entirety of resistances was caused by surface friction that was not visible to the naked eye.[79]

Froude experienced difficulty building credibility for the stream line theory precisely because it could not be visually witnessed from the shipboard. Froude could only demonstrate his theory through small experiments that replicated the fundamental physical conditions experienced during ship resistance. In one such experiment Froude

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[75] For Thomson and inventions see relevant sections on the compass, sounding machine, marine engineering and telegraph in Smith & Wise, *Energy and empire*. For similar themes with Rankine see Ben Marsden, 'Engineering science in Glasgow: economy, efficiency and measurement as prime movers in the differentiation of an academic discipline', *BJHS*, 25 (1992), pp. 319-346. For the broader context of these issues see Kline, 'Construing "technology"', pp. 194-221.

[76] William Thomson, *Notes of lectures on molecular dynamics and the wave theory of light* (Baltimore, 1884), pp. 270-1, quoted from Smith & Wise, *Energy and empire*, p. 464.

[77] Froude to Reed, December 1868, Admiralty papers, ADM 116/167.

[78] Nathaniel Barnaby, *Naval development in the century* (London, 1902), p. 240.

[79] [Froude], 'Address', p. 191.

ran water through a suspended length of curved piping (taking the place of the side of a ship). Froude demonstrated that because the suspended pipe did not move there was an absence of resistance properties in fluid passing the side of a body. During his 1875 presidential address to Section G of the BAAS, Froude used this very experiment to demonstrate the stream line theory to his audience.[80] This was just one example of how Froude developed visual, mechanical and scaled-down ways to address epistemological questions concerning hydrodynamics and doubts regarding ship design.

Within this context of mechanical thought and work Froude found 'vitality' for his mechanical practice. Froude also derived 'vitality' from his skill and experience as a mechanic. Those who knew his work were struck by his skill. Henry Brunel, I.K. Brunel's son, testified that '[h]is skill as a worker in material was great, and resulted from the educated knowledge of what should be aimed at, rather than from any particular excellence in that kind of aptitude which artizans [sic] require from practice.' Brunel was impressed by the harmony of theory and practice in Froude's working practices. He was similarly impressed by his range of mechanical contrivances and his 'well directed refinements of measurement for saving time.'[81] Barnaby was another admirer who recognised Froude's ability both as a mindful mathematician and as 'an able workman'. '[W]ith his own hands he executed many most accurate pieces of work,' Barnaby wrote. 'His mechanical skill is shown by the design and details of the many beautiful machines he contrived for his various investigations.'[82] 'The tank, the house, the travelling machinery, the measuring and timing apparatus, the model making', Barnaby wrote, 'everything was original and efficient.'[83] Recognition of Froude's mechanical way of

[80] [Froude], 'Address', p. 191.
[81] [Henry Brunel], 'Obituary: William Froude', *Proceedings of the Institution of Civil Engineers*, 60 (1880), pp. 395-404, esp. 398.
[82] Originally written for *Transactions*, 20 (1880): Barnaby, *Naval development*, p. 293.
[83] Ibid., p. 244.

working and thinking also extended beyond his social circle. *Nature* noted that '[b]eing an excellent mechanic, and a most conscientious and ingenious experimentalist, Mr. Froude put all his theories and hypotheses to the most crucial and varied practical tests'. The science periodical also noted that where Froude could not prove the truth of his experiments, he was 'determined [to hightlight] the limits of error involved by them.'[84]

Froude's practical bent also provided a common ground on which he nurtured relationships with men of science who shared his attitude to theory and practice. Thomson, one of Froude's greatest allies in the scientific community, was a personal friend, source of information, confidante and an advocate.[85] With George Gabriel Stokes, Lucasian Professor of Mathematics at Cambridge, Thomson discussed 'seeing his [Froude's] experiments and work (which are quite splendid, and will give exceedingly valuable results)'.[86] Froude applied the standards and culture of measurements common in physical science to engineering. Froude was most frequently identified as an engineer or mechanic, but his involvement in the BAAS and friendship with men of science such as John Tyndall, Charles Lyell and George Stokes broadened his credibility as someone who applied scientific and mathematical methods to engineering problems.[87] Froude exploited his identity as a scientifically aware mechanic during his correspondence with Robinson and Reed concerning the building of the test tank. But Froude promoted more than his technical knowledge and prowess. He seemed to

[84] [Anon.], 'William Froude', *Nature*, 19 June 1879, pp. 172-3.

[85] There is evidence of their social closeness in their correspondence, such as an invitation to Froude to join Thomson onboard his boat. Froude to Thomson, 18 March 1873, Thomson papers GB 0247 MS Kelvin F48.

[86] Thomson to Stokes, 25 May 1872, in *The correspondence between Sir George Gabriel Stokes and Sir William Thomson, Baron Kelvin of Largs*, ed. David B. White (2 vols., Cambridge, 1990), II:372.

[87] For Froude's social connections see his obituary, [Anon.], 'William Froude', *Nature*, 12 June 1879 and 19 June 1879. This is supported by various correspondence between Froude, Thomson and Stokes. Interestingly Froude's work on hydrodynamics was valued highly by academic men of science and mathematicians, see for example Woolley's anecdote about Froude's work in Cambridge physics following a paper at the Institution of Naval Architects: William Froude, 'Experiments upon the effect produced on the wave-making resistance of ships by length of parallel middle body', *Transactions*, 18 (1877), pp. 77-97, esp. 87-8.

suggest he had a 'mechanical instinct'. This label – a necessary hyperbole conflating what I have already examined regarding instinct and knowing – captures what engineers meant when they cited their experience and mastery of machines, as if intimate familiarity with machines and skills of manipulation were necessary to make truths.

5.3 THE MECHANICAL HAND

Making precise measurement

To continue the themes of intuition and certainty, mathematics and mechanics, I now place the ship, model and the mechanised measuring apparatus Froude used in his test tank within the context of the oppositional categories of the mind and hand. Using these points of reference we can further examine how the ship and the model became objects of a disciplined, mechanically measured hand and scientifically orientated mind (as opposed to artisan craftwork examined in chapter 2). Examining Froude's mind and hand in this way I contextualise his approach to measurement, breaking down boundaries imposed on Victorian experimenters and engineers that marked their work in either a solely scientific or craft-orientated system of making knowledge.

In 1863, William Snow Harris examined the way ships were built and the skills of those who designed them. '[A] careful training in mechanical, physical, and mathematical science is essential to the Naval Architect; yet on the other hand we must in candour admit that many clever Naval Constructors have arisen solely by their own uncultivated natural talents', Harris noted, '[v]ery many fast and fine ships have been the result of a practical eye, a skilful hand, and good intellectual powers'.[88] Harris appreciated that the '*intuitive*' sense that guided 'rule of thumb knowledge' was good enough to build a 'working knowledge' of the ship, but he believed that there were alternative ways of making ships and knowledge that were more precise. Indeed, John Pickstone has argued that nineteenth century science stressed 'the relation between experiment and systematised invention; it concentrates on the creation and control of novelty.'[89] This was certainly the case with Thomson, who emphasised the materiality of knowledge. Crosbie Smith and Norton Wise traced in Thomson work a 'look and see' approach to understanding nature, noting in particular that the 'theorist, like the experimenter and the engineer, must "look" and "touch" in order to "see" and "feel", thereby to "understand" and "believe".'[90] These simultaneously scientific and material ways of measuring attracted Froude as he sought precision to ward off his doubts concerning certainty and accuracy.

Froude discussed with Thomson ways of discovering 'what, exactly, or pretty exactly, is *the effective wave* slope', as he sought to increase accuracy in his work with the Admiralty.[91] Thomson held that once phenomena could be seen and felt (mechanically at least) then they could be understood. Thomson was then able to proceed to examine phenomena through numbers.[92] 'In physical science a first essential step in the direction of learning any subject is to find principles of numerical reckoning and methods for practicably measuring some quality connected with it', Thomson

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[88] William Snow Harris, *Our dockyards, past & present state of naval construction in the government service. Its future prospects* (Plymouth, 1863), p. 9.

[89] John Pickstone exploration of the relationships between science and technology through the renaissance to modern technoscience highlights that 'mechanical philosophers liked to see organisms as "mechanism" – but that was mostly intellectual fancy', while the industrial revolution witnessed strong analogies between 'synthetic invention and synthetic experiment': John Pickstone, *Ways of knowing: a new history of science, technology and medicine* (Manchester, 2000), pp. 66, 136.

[90] Smith & Wise, *Energy and empire*, p. 464.

[91] Froude to Thomson, 18 March 1873, Thomson papers GB 0247 MS Kelvin F48.

[92] For scholarship on quantification see I.B. Cohen, *The triumph of numbers: how counting shaped modern life* (New York, 2005); Porter, *Trust in numbers*.

wrote.[93] Froude approached hydrodynamics through much the same process, thus demonstrating his connection, both socially and scientifically, with the esoteric culture and discipline of Victorian physics.

Measurement, or rather precision measurement, had particular resonance in Victorian scientific life. By the end of the nineteenth century, the ability to read mechanical work from a trusted instrument, such as a dynamometer which measured the work of reciprocating engines, was the only credible way of knowing physical activity.[94] These practices spread into the ways scientists worked, linking the practices of those who discovered and invented. These practices presented rhetorical opportunities to scientifically inclined engineers who sought to distinguish themselves from their fellow engineers who used craft work practices. Such boundary work was evident in the first scientific paper presented to the INA.[95]

At the inaugural meeting of the INA Joseph Woolley argued that because 'so much is inexact in the theory of naval architecture, and on so many points nothing but general considerations can be brought to bear, how very essential it is to naval architects to drink deeply of the well of scientific truth, and to be imbued largely with the spirit of philosophical inquiry.' 'Were the science of naval architecture more exact than it is, it might be better permitted to the professors of the art to be less of geometers and mechanicians', Woolley continued, noting that the traditional role of the naval architect

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[93] Thomson continued: 'I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind: it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science.' William Thomson, 'Electrical units of measurement' (1883) in Thomson, *Popular lectures and addresses* (3 volumes, London, 1889-94), 1:80-143, esp. 80-81.

[94] Graeme Gooday, *The morals of measurement: accuracy, irony and trust in late Victorian electrical practice* (Cambridge, 2004); Simon Schaffer, 'Late Victorian metrology and its instrumentation: a manufactory of ohms', in Robert Bud & S. Cozzens (eds.), *Invisible connections: instruments, institutions and science* (Bellingham, 1992), pp. 24-55. A historiography of 'reading' instruments also necessitates putting the body and spatio-temporality of the reader back into the picture, see Graeme Gooday, 'Spot-watching, bodily postures and the "practiced eye": the material practice of instrument reading in late Victorian Electrical life', in Iwan Rhys Morus (ed.), *Bodies/mchines* (Oxford, 2002), esp. 165-195; Otto Sibum, 'Reworking the mechanical value of heat: instruments of precision and gestures of accuracy in early Victorian England', *Studies in History and Philosophy of Science*, 26 (1995), pp. 73-106.

[95] For boundary-work see Gieryn, *Cultural boundaries*.

had been either to build ships or theorise. With these boundaries defined Woolley made his argument that a third role was required for naval architects so that the 'absolutely fixed on scientific principles [that] soon takes the form or rule which requires nothing beyond more experience for its correct application' may be reimagined within a more reflexive framework of 'working knowledge'.[96] 'Precision' measurements could be brought to bear against 'fixed scientific principles' and 'experience' to open new areas of research and work where practitioners could simultaneously discover and invent.

The culture of measurement and mechanics that Froude, Woolley and others advocated starkly contrasted with the traditions of artisanship that were still celebrated by many engineers. Even the *Engineer*, a journal for the engineering community that usually celebrated the integration of scientific standards and engineering practice, seemed to regret the loss of artisan and artistic skill that characterised many engineers of the early Victorian era.

> Twenty or thirty years ago there were those in the drawing offices of our large engineering factories who, with faultless delineation, could infuse a degree of feeling into their works sufficient to raise them into the region of art. Who does not remember the delicate, well joined lines, the soft and rich shadows, true to geometry, at least, if not true to nature, and the crisp and dainty surface which distinguished the better efforts of the leading hands! Either nobody knows how to do such work now, or nobody will take the trouble. There was [for example] ... Mr. David Kirkaldy's magnificent sections of the Cunard steamer Persia, the first and we believe the only engineering drawings which ever found a place upon the walls of the Royal Academy.[97]

The *Engineer* noted the end of art in ship design, but it would not be accurate to say an end to the use of the hand. In the framework of working knowledge proposed by the INA, the hand was still present but it was no longer attached to the body of the craftsman. The culture of mechanical knowledge and work that characterised Froude's work with the ship helps define how the hand was recast into a new association with mechanical thought, in essence to create a new mechanical hand.

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[96] Joseph Woolley, 'On the present state of the mathematical theory of naval architecture', *Transactions*, 1 (1860), pp. 10-38, esp. 38.
[97] *The Engineer*, 10 June 1864, p. 357.

Recasting the hand involved placing the role of 'craft' within a system of mechanical investigation. Such a reconfiguration can be seen in Froude's model making procedures. Froude used wax paraffin, which he cut to shape with a copying machine fitted with rotary-cutters.[98] Froude drew inspiration from machinery used by wood carvers – a link to artisan culture – the model was then finished by hand. When Froude needed to make slight alterations to shape during trials for the purpose of experimentation the model was again hand-carved.[99] Froude wrote to Napier that 'all this works very nicely and gives instructive results; which I am glad to show, and discuss, with all true men, with whom discussion is instructive. So if you come this way please give me a look.'[100] Thus, craft skills were still necessary but only in tandem with mechanical apparatus and mental openness to alternative ways of working in industry. These dynamics were similarly embodied in Froude's automatic, graphic measuring devices. These devices were central to how Froude tackled the epistemological questions of hydrodynamics and his doubts regarding ship design. Such mechanical and automatic apparatus became Froude's hands for 'touching' and 'feeling' phenomena. These devices, once made trustworthy, were central to the new ways the Victorians measured and mechanised the ship.

Froude, in his initial correspondence with the Admiralty regarding the test tank, made clear that 'at the outset it is essential for the sake of avoiding "personal error" that the results should be self-recorded'. To this end Froude used a 'very well arranged and successful dynamometric apparatus' in the tank.[101] The dynamometer was used to display the resistance of models. Froude recorded and graphically displayed resistance by tying a dynamometer into a larger system of measuring devices. One device

[98] Barnaby, *Naval development*, p. 260.
[99] Froude to Reed, December 1868, Admiralty papers 116/167.
[100] Froude to Napier, 21 September 1872, Napier papers 90/2/4/51.
[101] Froude to Reed, December 1868, Admiralty papers 116/167.

registered the 'rotation of the truck wheels [the rail truck suspended from the tank ceiling that propelled models]' and provided 'an exact measure of the distance as it is travelled by the model', while a 'time apparatus' synchronised the recordings made by the system.[102] These devices, Froude told the Admiralty,

> when duly combined in one apparatus will record by lines traced on a travelling sheet of paper the velocity and resistance of the model at each point of its course. Since, under this arrangement we have an exact record of the resistance, we may do away with the definite weight and delicate tow line; substituting for it an inexorable mechanical force, regulated by a chronometric governor which will ensure a uniform speed.'[103]

The self-recording apparatus plotted resistance on an early form of graph paper. Such paper containing precise and detailed marking was not common in the nineteenth century, so Froude also built a machine to print squared paper.[104]

Froude expressed to the Admiralty his faith in the precision accuracy of self-recording, together with the manageable conditions in the tank. His faith in the machinery used to provide exact precise measurements of model experiments contrasted with the criticisms he made of the scheme for full-sized ship experiments advocated by Merrifield *et al.* '[U]nder the above mentioned [Merrifield] arrangement', Froude wrote, 'it will be found that owing to various difficulties such as the elasticity of the tow line, the dangers of causing adventitious friction etc., it is not easy to satisfy this requirement [of avoiding "personal error"].'[105] Froude trusted his self-recording apparatus that embodied both his 'looking and seeing/touching and feeling' approach to experiment and his faith in mechanical enquiry with his 'mechanical hand'. Brunel observed that Froude,

> was free from superstitious belief in the automatic accuracy of machine tools, and preferred to trust principally in gauges and surface plates, having a maxim that any error which could be detected could always, with proper care, be corrected. At the same time he did not

[102] William Froude, 'Observations and suggestions on the subject of determining by experiment the resistances of ships', Henry Marc Brunel papers DM1986/4.9.
[103] Ibid.
[104] R.W.L. Gawn, 'Historical notes on investigations at the Admiralty experiment works, Torquay', *Transactions*, 83 (1941), pp. 80-116.
[105] Froude to Reed, December 1868, Admiralty papers 116/167.

> neglect to employ all the advantages that good tools could afford. His lathes were kept in perfect order; there was no slackness, nor, what he seemed still more to dislike, any unnecessary tightness.[106]

We must remember, however, that trust in Froude's mechanical hand was contingent on the success of his experiments in validating the law of comparison between models and actual ships.

5.4 MEASURING THE SHIP

Work in and out of the test tank

The Committee on designs for ships of war (1872), a group of politicians, admirals and scientists brought together in the wake of the loss of H.M.S. *Captain*, requested the Admiralty to generate full-scale experimental data on the conditions that affected ship resistance. Froude, who was a member of the committee, offered to undertake the experiments for the Admiralty on H.M.S. *Greyhound*.[107] Froude also used the opportunity to test the accuracy of his law of comparison and examine the accuracy of Rankine's theory of resistance.[108] Thus, prior to experimenting with the *Greyhound*, Froude performed the intended tests first with a model of the *Greyhound* in the tank.

The full-size experiments with the *Greyhound* largely followed the towing experiment described in Merrifield's report for the BAAS committee on stability, propulsion, and seagoing qualities of ships. Froude appreciated the novelty and importance of performing towing experiments on full sized ships, but he was also conscious of the problems of obtaining accuracy in such experiments. For instance, the various sources of resistance from the engine to the propellers made non-towing

[106] [Brunel], 'Obituary', p. 398.
[107] William Froude, 'On experiments with H.M.S. Greyhound', *Transactions*, 15 (1874), pp. 36-73, esp. 36.
[108] Ibid., p. 37.

experiments untrustworthy.[109] Froude also noted that the existing system of measuring a ship's speed during a trial, the measured mile, was similarly made untrustworthy ('doubtful' to use Froude's word) by 'the variation which may ... be occurring in the speed of the tide'.[110] Froude told the INA that he needed 'continuous and automatic' records of speed and force if the experiments were to be 'satisfactory and conclusive'.[111] Force could be registered by a dynamometer but speed was a more problematic variable to measure. Thus, in order to prove the accuracy of the law of comparison it was necessary that Froude found similarly precise, self-recording ways to understood resistance in an actual ship.

The log method Froude decided to use to measure speed had previously been used with success by George Bidder (another member of the Admiralty's 1872 committee), but Froude still wanted to provide a transparent record of how he went about validating his law of comparison. Thus, in an 1874 paper to the INA, he described the process in detail.

> It consisted in paying out a continuous length of twine attached to a log-ship of large area, the twine, as it ran, passing round and gripping a counting-wheel of definite circumference, which was geared so as to transmit the motion thus obtained to a revolving cylinder charged with a long sheet of paper, the length of which occupied the entire circumference of the cylinder. The circumferential travel of the sheet thus represented the ship's travel on a reduced but measurable scale; and on it the force-indications of the dynamometer, and a time-scale supplied by a piece of clock-work, were simultaneously and automatically marked.[112]

Pens marked the distance travelled against time, while another line indicated the towing strain. Barnaby later wrote that graphical representation was central to the credibility and transparency of Froude's measurements.[113] 'This curve', Barnaby wrote,

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[109] Ibid., pp. 36-37.
[110] Ibid., p. 37.
[111] A successful record of observations did not, however, simply rest on mechanical measurements. As with the mechanical hand in the test tank, accurate 'automatic' measurement on the actual *Greyhound* depended on the skill of a team of observers watching and testifying to the number of screw propeller revolutions per minute and checking on the engine room graphical readouts. Ibid., pp. 38, 41.
[112] Ibid., p. 38.
[113] For transparency in dissemination knowledge from experiments see Gooding, Pinch & Schaffer, 'Uses of experiment', p. 3

which is plotted from the various lines automatically drawn by the measuring apparatus, 'expresses for the model of that particular form what is in fact and apart from all theory the law of its resistance in terms of its speed.'[114] In the same vein of demonstrating transparency and credibility, Froude offered descriptions of what each instrument in the self-recording apparatus was designed to do, the names of the instrument makers and details of independent testing on the instruments thus guaranteeing trustworthiness and the possibility of replication.[115]

Froude next offered his findings, again with an awareness of transparency and credibility. As with his description of the instrument he used, Froude offered the preamble that the experiments 'cannot be insisted on as absolutely exact, because minor discrepancies in results were in some cases noticeable when an experiment was repeated with unchanged conditions.' Froude was happy, however, to conclude that the experiments were 'substantially correct', thereby demonstrating on one hand doubt in his work, and on the other hand transparency in his work. These rhetorical practices nurtured credibility for Froude's long awaited final conclusion, namely that at up to eight knots the resistance of a ship is 'almost exactly proportioned to the square of the speed ... [and that] Above 8 knots it [resistance] increases more rapidly'.[116] Froude also confirmed that his law of comparison worked.

Froude's data from the *Greyhound* model experiment compared accurately to the data from the *Greyhound* towing experiment, thus validating his work in the tank. Froude dwelt on this point, reaffirming his justification for dissent from the 1869 BAAS committee report and confirming that the 'results of the experiments with the models,

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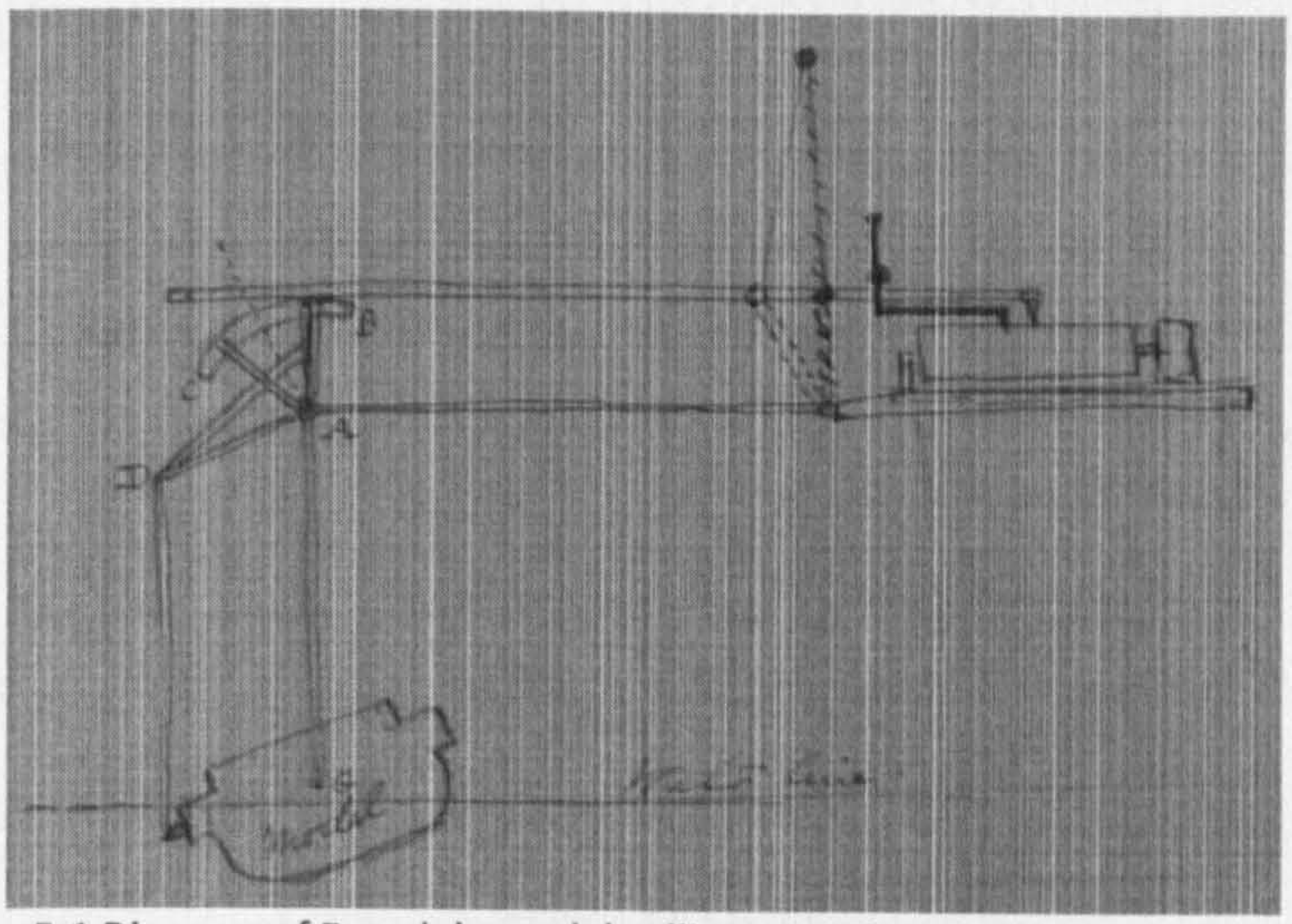
[114] Barnaby, *Naval development*, p. 248.
[115] Froude, 'Greyhound', p. 38-41. For a classic study of replication see Shapin & Schaffer, *Leviathan*, pp. 225-282.
[116] Froude also offered figures on the resistance and energy lost through the propellers, stating that anything up to fifty-eight percent of thrust was lost. The *Greyhound* experiments gave rise to another avenue of research for Froude in propeller design, during which he corresponded with Thomson and Mitchell's. Froude, 'Greyhound', p. 45.

being free from the prominent causes of error involved in the full-sized trials, were obtained with considerably greater accuracy' than those obtained from the *Greyhound*.[117] However, it would have been unusual had Froude not also dwelt on his lingering doubts. The law of comparison was not 'absolutely correct', Froude told the INA, because some resistance was experienced by ships that could not be replicated for models. '[I]ndeed, the differences that may be caused by difference in quality of surface being very considerable, the absolute resistance of any ship is an indeterminate quantity,' Froude noted, 'and thus the test of the law of comparison, which the full-sized trial affords proves less definite than might be wished, and it is desirable to trace out the limits of the indefiniteness.'[118] The transparency of Froude's conclusions was arguably rooted in his mentality of honest doubt, which in turn gave his conclusions an air of honest credibility.

Themes of automatic measurement, transparency and doubt similarly ran through Froude's experiments with ship roll. As with resistance, Froude began by undertaking a series of model experiments. His experiments were then scaled up in the mid-1870s for a series of high profile experiments with H.M.S. *Devastation* at the request of the Admiralty following the loss of the *Captain* (see chapter 6). Froude's apparatus used a pendulum to give a representation of the angle rolled. Attached to the pendulum was a pen that rested on a piece of paper 'travelling at a regulated speed at right angles to the swing of the pendulum'. '[I]t will be readily understood by all who are familiar with indicator diagrams and similar mechanical records,' Froude reported to the INA in

[117] Ibid., p. 52.
[118] Ibid., p. 53-54.

1873, 'that a line will be drawn on the paper, which will give an exact record of the relative angular position of the pendulum and the ship.'[119]


5.1 Diagram of Froude's model rolling experiment, 14 May 1871.

Froude described in detail the problems involved in measuring the horizontal line in ship roll, suggesting the various ways of recording the constant level from which rolls were measured. Froude's preference, we have established, was for automatic measurement. However he had some trouble devising a completely automatic process to record roll. 'In some experiments I have lately conducted on the rolling of ships at sea,' Froude informed the INA, 'an observer on the upper deck of the vessel kept level by pointing it [the pendulum] continually at the horizon. ... It is evident, however, that a method of this sort, depending on the skill of an observer, and which can be only employed in daylight, should, if possible, be replaced by some self-acting piece of mechanism.'[120] Froude considered alternatives, dismissing the gyroscope as unsuited to recording and the fly-wheel as being *too precise* and delicate. If any force was transmitted to a fly-wheel by a body, clothing or resistance incurred by an attached pen marking paper, the wheel ceased to accurately measure.[121]

[119] William Froude, 'Description of an instrument for automatically recording the rolling of ships', *Transactions*, 14 (1873), pp. 179-190, esp. 179.
[120] Ibid., p. 180.
[121] Ibid., pp. 180-82.

Complications also occurred in how Froude interpreted the graphical representations of rolling. Froude found that his trial ships 'rolled less deeply than the apparently effective wave slope as indicated by the pendulum, seemed to promise.' He speculated to Thomson 'that in using the pendulum diagram, we were in fact calculating on waves of greater effective steepness than the waves which had been actually causing the oscillation.'[122] 'It is possible', he continued, 'that it may be some analogous agency in virtue of which as appears from our automatic diagrams of rolling in a seaway, the resistances (of whatever sort) appear to be there more vigorously developed than in artificial oscillations in still water.'[123] Together with his specific findings from rolling experiments, Froude was able to compare roll in a seaway to artificial roll and identify certain discrepancies that shed light on the role of resistance under seas waves and how waves formed.

Froude's apparatus for measuring roll received praise and acceptance from engineers and sailors alike in the INA. At the 1873 meeting, Merrifield testified to the accuracy and orderly working manner of Froude's roll recording apparatus. '[I]t is well known that the principles on which his machine is arranged are scientifically correct', Merrifield told members of the INA, 'he derives immense advantage from being not merely a good theoretical mathematician but a thorough mechanical engineer, accustomed to work with his own hands to such an extent that when he requires accurate work he prefers to do it himself instead of trusting it to workmen.'[124] Admiral Edward Belcher provided a less technical testimony of Froude's 'valuable invention', but his comments carried the authority of fifty years making observations on the rolling of ships.

[122] Froude to Thomson, 18 March 1873, Thomson papers GB 0247 MS Kelvin F48.
[123] Ibid.
[124] Froude, 'Automatically recording', p. 185.

Froude's audience at the INA was not wholly supportive of his work. The Earl of Lauderdale, who declared himself a 'seaman', was struck by the 'sensitive' nature of Froude's apparatus, but declared that no mechanical device was more sensitive to the behaviour of a ship than the body of an experienced sailor. '[F]rom my experience at sea, any very sensitive instrument of that sort is very highly tested. There are such jerks when a ship is steaming or sailing against a head sea that no man but a seaman who has been in a ship can possibility tell what the motions are.'[125] In contrast, Robinson, formerly Controller of the Navy, placed greater faith in Froude's ability to build an instrument better capable of capturing the behaviour of the ship in the midst of the sea than a jack tar. '[I]t is a machine which will, if successful, record accurately all the motions of the ship,' Robinson told the INA, 'and enable sailors and naval architects to supply science to the practical work which they have to do.'[126] Robinson thus made the vital distinction that experience might guide sailors, but that professional, scientifically trained designers (and perhaps sailors) preferred to produce and utilise mechanically made, numerical reductable and applicable knowledge to build ships.

Lauderdale was arguably more connected to and representative of the culture of naval experience and authority that taught that the sailor ultimately made and understood the ship through their actions. Robinson, who had been keen to establish strong links between sailors and men of science in the Royal Navy, told the INA that 'I feel grateful ... and I am sure we must all agree that the gratitude of the scientific world is due to Mr. Froude for the care and patience with which he has observed these phenomena, and for the extraordinary skill, precision, and cleverness, with which he records them.'[127] Testimonies such as these suggested to outsiders the value of Froude's

[125] Ibid., p. 186.
[126] Ibid., p. 189.
[127] Ibid., p. 189.

work. The way in which that perceived value was turned to practical value, and the reception of Froude's work within the naval community at large, is more difficult to trace and will be given further attention in Part III of the this thesis.

One of the most significant contributions that Froude made to naval architecture was that his work in the test tank and on the seas eroded the notion that there was one single perfect ship design. In his presidential address to Section G of the BAAS he showed that 'general laws' were misleading. He used the example of the contradictions between his stream-line theory and John Scott Russell's wave-line theory, noting that '[i]n order to reduce wave resistance we should make the ship very long. On the other hand we should make her comparatively short, so as to diminish the surface of wetted skin.'[128] Thus Froude sought to educate engineers that single 'lessons' from experiment, as were perhaps more common to 'learning from experience', were less common in a culture of mechanics, measurement and numerical reckoning. Engineers needed 'exact qualities' that could be automatically and credibly calculated and used to make more efficient designs.[129] 'We have sufficient general data from which the skin resistance can be determined by simple calculation', Froude explained, 'but the data for determining wave resistance must be obtained by direct experiments upon different forms to ascertain its value for each form.'[130] In effect, experimental data could be produced that suggested the preferable shape of a ship only if the experimenter knew its proposed dimensions and the approximate conditions of its intended use (an extension of Russell's criticism of Admiralty shipbuilding policy and treatment of ship designers examined in Chapter 1).

128 [Froude], 'Address', p. 217.
129 Ibid., p. 217.
130 Ibid., p. 217.

Froude did not believe his experiments suggested a single, perfect design, rather a way of improving the designs that came to him. This left him at odds with his masters who served on the Board of Admiralty. The destruction of the *Captain* and public anxiety over the Admiralty's shipbuilding programme had given urgency to finding 'the path forward' in ship design that was craved by the naval commentators and Boards of Admiralty who lived by public support and accountability. George Hamilton (First Lord of the Admiralty 1885, 1886-1892) noted that Board policy to ship design during the 1860s and 1870s was neither long term nor strategic but a response to the inherent uncertainty regarding how naval architecture and marine engineering might develop. Thus the Board, 'endeavoured to surmount this difficulty by building various different types of warship ... in the hope that something might be evolved out of this heterogeneous mass of inconsistency which gradually be accepted as the ship of the future – a very dangerous and costly method of arriving at the truth.'[131] Unsure which way pointed forward, Froude's test tank further diminished the ideal of the perfect ship. The only general lesson that Froude felt could be learnt from his experiments was that the assumptions and misleading experiences that suggested that short ships had certain benefits and long ships others did not survive experimental scrutiny – and that only experimental enquiry could guarantee efficiency and safety in Royal Navy ships.

Reflecting on nineteenth century engineering science, James Alfred Ewing wrote that 'Our knowledge of physical constants and of the properties of materials, our units and scales and instruments and tester of all sorts, are for the most part offspring of the marriage of science with practice.'[132] Ewing was a student of Thomson, one of the first professors of engineering at Cambridge and from 1903 Director of Naval Education at

[131] Frederic Manning, *The lfe of Sir William White* (London, 1923), p. vi.
[132] Ewing, *Engineer's outlook*, p. 38. For Ewing see, E.I. Carlyle, 'Ewing, Sir (James) Alfred (1855–1935)', rev. W.H. Brock, *Oxford Dictionary of National Biography* (Oxford, 2004).

the Admiralty, appointed at the behest of Admiral Jackie Fisher who wanted to increase naval cadets' knowledge of engineering. Ewing (quoted at the top of the chapter) wrote that the marriage of science and practice was a fitting description of Froude's work. He felt that Froude was the embodiment of this trend to marry science and practice, a trend which made 'science exact', offered precision and prediction to naval architects and enabled 'engineers to be standardized.'[133] What, however, were the broader consequences of this marriage that in the case of ship design relocating the ship in a sphere of controlled measurement and mechanical scrutiny? How did sailors understand and respond to these developments? And how did the identity of the ship change during this period?

5.5 Conclusion

This chapter has charted the ways in which the 'hand that makes' was detached from the artisan and grafted onto the man of science and engineer. The new hand that emerged in late Victorian Britain was mechanical, thoughtful and detached (but still borrowed authority and modes of practice) from the working classes of craftsmen who 'built' by experience. Froude's mechanical hand can be interpreted in the light of his belief that mechanics offered practitioners control to manipulate the variables of an experiment. Such control was vital to how Froude negotiated his doubts. My exploration of Froude's mechanical hand has thus highlighted that the 'scientific' ways of thinking, experimenting and working that the test tank represented were not in opposition to, but actually drew extensively on cultures of religious doubt and craft-practice (mechanical art).

[133] Ibid., p. 38.

This chapter has also demonstrated that the institutional and administrative bonds of the Admiralty were still largely controlled by gentlemanly professional men who were swayed by the authority of naval officers. Froude's manoeuvring to secure support the test tank, during which his social circle highlighted his credibility and capital as a 'disinterested' experimenter, demonstrates that social position and moral character were important to how the Admiralty judged scientific projects. Such a code reminds us more of the aristocratic nature of early modern science than modern 'big science' and science-military relations of the early-twentieth century. In conclusion, the growing mechanical treatment of the ship in Victorian Britain (introduced in chapter 1) was not simply a sign of 'modernity' or 'inevitable progress' but a process deeply entwined with how a group of Victorians like Froude thought, worked and ordered systems of production around the ship. These systems were imbued with values, such as Froude's sense of 'vitality' and mechanical objectivity and, as I will go on to argue in chapter 7, William White's focus on local, scientific collaboration and management, and Barnaby's notion of ethical improvement and technological change.

PART III

EXPERIMENT, EXPERIENCE AND EXPERTISE IN THE NAVY

Nothing would be more fatal than for the Government of States to get in the hands of experts. Expert knowledge is limited knowledge, and the unlimited ignorance of the plain man who knows where it hurts is a safer guide than any rigorous direction of a specialized character.

Winston Churchill to H.G. Wells, 17 November 1902, quoted in Harold Perkin, The rise of professional society: England since 1800 (London, 1989), p. 169.

6

Officers, constructors and the authority to shape the ship

Were we obliged to admit that this [the test tank and the work of scientists] was but the usual course of the trial and error which we are obliged to submit to in the progress towards truth – that these things were but the necessary or even occasioned results of scientific operations – it would be one of the most humiliating obligations in the whole range of mechanical science; but happily it is not so. The system, the working out of which has led to these disastrous results, is contrary to sense and to science. It fails to represent the facts in relation to the behaviour of ships at sea, it is opposed to the experience of sailors, and it is contrary to the views of the most approved writers on naval architecture and of living naval architects. This system, without any tentative process, and without the concurrence of persons of competence and experience, has been smuggled wholesale into our Navy, at a great expense to the country, only to do great damage to our ships.

Admiral Edmund Fishbourne asserts that sailors know the most about the behaviour of ships and the 'science' of the ship.[1]

[I]t is wonderful how slowly the true knowledge of things spreads ... showing that knowledge is but a viscous fluid.

William Froude compares the movement of 'truth' to the inertia of a body of water.[2]

In the 1870s, one of Britain's most prominent men of science, William Thomson, became a trusted advisor to the admiralty. The Admiralty drew on his knowledge of navigation, instrumentation and naval architecture, placing increasing trust in his expertise and authority to judge between scientific proposals. In 1872, Thomson shared with William Froude an account of a conversation he had with a captain in the Royal Navy who had trouble understanding his scientific perspective on the behaviour of the ship. Froude responded by telling Thomson that he had met the same captain a long time ago, and recalled that '[h]e was then industrious and anxious to know about things but it did not seem to me that he any real grasp of them.' Froude continued,

> Perhaps as he has learned more and risen higher in the service (by his merits I believe chiefly) he has grown more self-confident, and the atmosphere that a Captain R.N. breathes

[1] Edmund Fishbourne, *A Letter to the Rt. Hon. G.J. Goschen, M.P., First Lord of the Admiralty, etc. etc., on our Ironclad Fleet* (London, 1872), p. vi.
[2] William Froude to James Robert Napier, 7 July 1876, Glasgow University, Archive services, Napier paper DC90/2/4/51.

> must greatly discourage the idea that perhaps others understand any part of his [surroundings] better than he does. ... [But e]ven about ropes a sailor does not always know best, especially if he is a Captain R.N., of which I have occasionally had funny proof.[3]

Froude's sketch of a Royal Navy captain underlines and illustrates the contrasting socio-cultural setting of knowledge and authority in the navy.

Naval officers understood their surroundings through a very different interpretative matrix than men of science, engineers and naval architects. There were strain between sailors, men of science and engineers over the epistemology of ship behaviour and ship design, broadly definable as a tension between experience and experiment and a controversy over whether 'scientific enquiry' made ships efficient. Froude demonstrated the socio-cultural nature of these distinctions in a letter to James Robert Napier concerning the possibility that the Admiralty would undertake experiments into the 'exact' conditions affecting steering in screw propelled ships, noting his fear that 'the Admiralty folk will "pooh pooh" the enquiry as relating to a matter *practically well understood* already.'[4]

This chapter examines the strains and tensions that existed in how naval officers and constructors (and more broadly men of science and engineers) respectively thought and worked. I explore a series of public controversies in which the ship became a contested object of the authority between these two divergent social groups, through which their respective claims to authority and 'expertise' took shape. Throughout the nineteenth century sailors claimed that the knowledge they gained from tacit experience of the ship at sea was superior to the knowledge held by shipwrights and engineers concerning ship behaviour.[5] A group of naval officers carried the claim

[3] Froude to William Thomson, 12 December 1872, Glasgow University, Special Collections, Thomson papers GB 0247 MS Kelvin F47.
[4] The emphasis is my own. Froude to James Robert Napier, 20 May 1876, Napier papers 90/2/4/51.
[5] Naval officers' resource to tacit experience made their claim to expertise more powerful than that of non-specialists and 'folk wisdom', the notion that a social actor instinctively knows if something is good or not. Harry Collins & Robert Evans, *Rethinking expertise* (Chicago, 2007), p. 119.

further and asserted their superiority over shipwrights, engineers and the emerging social network of naval architects to design ships.

The case studies explored in this chapter present a counter-narrative to the attempts of naval architects to turn ship 'trials' into experiments, a movement that reflected broader aims in engineering science to equate 'technological' and experimental enquiries.[6] This chapter contextualises the claims that naval officers made, identifies the values and priorities that underlined them and examines how they shaped the relations between naval officers and constructors, the public discipline formation of naval architecture, the institutional authority of naval architects and science, the influence of scientific experts, and the identity of the ship in Victorian Britain.

6.1 SAILOR AS DESIGNER

Tacit experience versus mechanical measurement

In 1832, William Symonds became the navy's chief ship designer. Symonds, a naval officer, had designed ships for the Duke of Portland and Duke of Clarence in the 1820s. He had sought to replace Robert Seppings as the Chief Constructor at the Admiralty and, just prior to the Whig abolition of the navy Board, leaned on his political connections, including Portland, Lord Vernon and Sir James Graham (who abolished two schools of naval architecture), and was given Seppings' duties. Henry Chatfield, master shipwright and an associate of Seppings, claimed that Symonds disagreed with a lot of 'received

[6] Ben Marsden, 'Blowing hot and cold: reports and retorts on the status of the air-engine as success or failure, 1830-1855', *History of Science*, 36 (1998), pp. 1-48, esp. 34-40.

opinion' concerning naval architecture and could not design a safe ship.[7] Indeed H.M.S. *Vernon*, Symonds' first frigate built for the navy, experienced poor stability on its maiden voyage and was ordered to return to port for correction. Symonds' position at the Admiralty depended on political patronage, as naval historians have argued, but I argue it was also rooted in the socio-cultural authority of experience, expertise and credibility that gave power to naval officers over constructors.[8] Using a series of public discussions I trace the values and resonances of that authority and draw out wider conclusions regarding the intersecting cultures of expertise in the Admiralty and the communities of sailors and shipbuilders.

Chatfield, the anonymous author of 'An apology for English shipbuilders' (1834), made the argument that Symonds was unqualified to be Surveyor of the Navy.[9] Chatfield specifically drew attention to the failure of Symonds' ships, such as the *Vernon*, and recommended the navy to place their faith in the 'scientifically trained' students of the School of Naval Architecture to guarantee the safety and efficiency of the fleet. Chatfield accused the Whig government that appointed Symonds of distrusting technical and 'scientific' experts (also see John Scott Russell's criticism of that government examined in chapter 1). Chatfield's essay also responded to an article in the *Metropolitan Magazine*, a radical liberal magazine edited by Frederick Marryat, that had defended Symonds from criticism by casting aspersions on his predecessor, Seppings, and the skills and honour of the students of the School of Naval Architecture.

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[7] [Henry Chatfield], 'The school of naval architecture: in reply to the "Metropolitan Magazine;" by the author of "An apology for English shipbuilders"', *The United Service Journal, and Naval and Military Magazine*, 1 (1834), pp. 227-30, esp. 227.

[8] Andrew Lambert, *The last sailing battlefleet: maintaining naval mastery, 1815-1850* (London, 1991), pp. 67-87.

[9] [Chatfield], 'School of naval architecture', p. 227-30.

Marryat, who wrote the article in question, had served in the Royal Navy, rising to the rank of captain before resigning in 1830 to become an author.[10] He wrote a series of popular sea novels, including *The Naval Officer, or, Scenes and Adventures in the Life of Frank Mildmay* (1829), *Midshipman Easy* (1836), and *Japhet* (1836), that portrayed wholesome and masculine sailors steeped in and glorifying Britain's naval tradition. Marryat's article in the *Metropolitan Magazine* cast Symonds as a standard bearer of the school of thought that claimed that the sailor, through his intuition and tacit experience of the ship at sea, knew how a ship should handle and consequently how it should be built (this reflects the issue of practical knowledge explored in chapter 2). He also claimed that students of the school of naval architecture lacked the moral credibility of naval officers. Marryat claimed that 'out of the whole only two are respectable', and that '[s]ome of them cannot legally make claim to any father!!!'[11] In contrast of course, naval officers were seen to be the paradigm of British nobility and honour.[12] In this fashion Marryat referred to Seppings as a mere 'dockyard matey', thus demonstrating the brand of symbolic, social and cultural capital that was credible in the culture of expertise and authority in the Royal Navy.[13]

Marryat, who believed that advances in mechanical art were rarely made by engineers (see introduction), portrayed Symonds as both a naval expert and an engineering expert, noting that he 'had the powers of deep calculation'.[14] Symonds, however, saw himself as a mathematician. It was solely Marryat who publicised the

[10] Marryat's work was respected by later authors like Joseph Conrad and Ernest Hemmingway who wrote about naval life, see J. K. Laughton, 'Marryat, Frederick (1792–1848)', rev. Andrew Lambert, *Oxford Dictionary of National Biography* (Oxford, 2004).

[11] F.M[arryat]., 'School of naval architecture', *Metropolitan Magazine*, 8, November 1833, pp. 225-232, esp. 231.

[12] On the gentleman image of the officer class see Mary Conley, *From Jack Tar to union jack: representing naval manhood in the British empire, 1870-1918* (Manchester, 2009); Quintin Colville, 'Jack Tar and the gentleman officer: the role of uniform in shaping the class- and gender-related identities of British naval personnel, 1930-1939', *Transactions of the Royal Historical Society*, 13 (2003), pp. 105-29. For the navy and the patrician class see David Cannadine, *The decline & fall of the British aristocracy* (London 1990, penguin edition 2005), pp. 264-80.

[13] M[arryat], 'School of naval architecture', p. 227.

[14] Ibid., p. 227.

claim. He and other writers used Symonds as an icon for the practically minded naval officer in their arguments with shipwrights and engineers. That this discursive tactic found support in Britain's naval and political communities, I argue, reveals the perception of an influential social group that science was not a domain of specialised knowledge sustained by men of science, but a set of empirical techniques and rhetorical claims. The actors who used this tactic frequently concluded that the sailor was more expert because he could master the 'science' but also boast experience and tacit knowledge.

Chatfield, in response to Marryat, recognised that 'it has been the fashion to deride the idea of applying pure mathematics and experimental philosophy to naval architecture, and to hold out the doctrine, as F.M. does, that sailors "feel practically that they are right;" ... We cannot repress a smile at so empirical a notion.'[15] Chatfield, in a series of short papers delivered at the Royal United Service Institution (RUSI), contrasted Marryat's image of Symonds with one of technical ignorance and experimental stubbornness. Chatfield argued that constructors needed to be able to measure behaviour and not speak from experience, for only then could they 'improve naval architecture as all other physical sciences are improved.'[16] Chatfield's response to Marryat resonated with naval constructors. Augustin Creuze, another student of the School of Naval Architecture, gave evidence to a House of Commons select committee on expenditure in the navy regarding Symonds' 'absurd' and 'costly' experiments in shipbuilding, arguing that they were 'not founded on correct principles'.[17] Joseph Woolley used Symonds' ships, particularly H.M.S. *Vanguard*, as examples of the

[15] [Chatfield], 'School of naval architecture', p. 230.
[16] Ibid., p. 230.
[17] Passage quoted in, [Financial Reform Association], *Financial reform tracts: No. 10, The Navy* (London, 1848/9), p. 2. The Financial Reform Association highlighted Symonds as an exemplar of the inexperienced 'expert' in the navy whose activity caused great waste to the nation's treasury, see Ibid., pp. 2-9

misleading value of visual observation.[18] Meanwhile, the phrases 'Symondite ship' and 'Symondite fashion' became labels for ships that rolled dangerously at sea.[19]

The debate over the skills and expertise needed to secure Britain's naval supremacy continued in the 1840s, still focusing Symonds and his ships. *Facts versus fiction* (1845), a pamphlet by the anonymous author 'One Who Has Served', promoted Symonds' 'practical experience', 'practical knowledge' and 'naval spirit'.[20] The author also employed positive experiential knowledge of the trial cruises of an experimental squadron that had returned to Davenport in late 1845 to accuse Symonds' opponents of falsifying the results of other cruising trials to attack Symonds' 'intuitive system' (a term used by Symonds' opponents).[21] The author criticised naval constructors who kept naval officers from the dockyards so that they were free, the author claimed, to bring 'forward their own theories to oppose facts'. 'It was in vain to tell them that he who governed and directed the whole fabric [the naval officer] was really the practical man', the author continued, '[t]heir narrow minds and interestedly limited vision could not embrace this truth, and ... [t]he bricklayers declared themselves your only architects'.[22]

In 1846, 'A Naval Architect' responded with *The present shipbuilding controversy; or, which is the misrepresented party*? This author criticised the 'personally loathsome' mode of debate and the discreditable 'spirit of party-feeling' that pervaded 'One Who Has Served's' pamphlet.[23] 'A Naval Architect' recalled Marryat's treatment of scientifically minded constructors, noting that '[t]hey are now designated, "aspersors

[18] Joseph Woolley, 'On the present state of the mathematical theory of naval architecture', *Transactions*, 1 (1860), pp. 10-38, esp. 27.
[19] See for example William Froude, 'Remarks on Mr. Scott Russell's paper on rolling', *Transactions*, 4 (1863), pp. 232-275, esp. 235; William Froude, 'On the rolling of ships', *Transactions*, 2 (1861), pp. 180-230, esp. 187.
[20] 'One who has served', *Facts versus fiction; or, Sir William Symonds' principles of naval architecture vindicated* (London, 1845), pp. vi, xi, xiv, xv.
[21] Ibid., p. v.
[22] Ibid., p. xxi.
[23] The author also began by repeating a phrase used by Chatfield in 1834, 'the war of controversy is better than the peace of ignorance': 'A naval architect', *The present shipbuilding controversy; or, which is the misrepresented party?* (London, 1846), pp. 7-8. It is possible that Chatfield was 'A naval architect'.

[sic]" – "calumniators" – "intriguers" – "slanderers" – "reckless falsifiers" – "libellers of high-minded honourable men" – "doers of everything that is mean and base in principle" – "ephemeral insects" – "venomous reptiles" – "overpaid mechanics"'.[24] 'A Naval Architect' flatly refused the claims that naval constructors were disingenuous and that the products of their labours were failures. The author specifically examined the results of a series of cruising trials to show that ships 'built after long experience in testing an experimental mode of construction' (namely by Seppings) performed better than Symonds' ships.[25] It was clear, placing the social politics of this controversy aside, that debate on ship behaviour rested on the authority of experimental squadrons as a mode of enquiry.

These experimental squadrons comprised ships built by the various factions of 'constructors' in the Royal Navy. These squadrons were sent out on sailing trials, on which the speed and manoeuvrability of the ships were gleamed from experience and observation. The trials were used to single out which ship was fittest for service in the navy, the result of which were brought before the public in newspapers and pamphlets. The experimental squadrons also constituted social events at which the aristocracy and Admiralty observed the squadrons leaving and returning to port, even taking yachts to accompany the cruises.[26]

Commander Alfred Ryder, with the assistance of another junior officer Edmund Fishbourne, published the results of an experimental cruise of battle ships in 1845. Ryder believed that such experimental cruises were vital to understanding the relative merits of the Royal Navy's ships. 'The knowledge of the architect must receive increase from the practical information and experience of the sailor,' Ryder wrote, '[a]rguments

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[24] Despite the similarity, the author dismissed the possibility that Marryat was 'One who has served'. Ibid., p. 10.
[25] Ibid., p. 47.
[26] Lambert, *Last sailing battlefleet*, pp. 40, 50, 81-3.

can be grounded only on facts that are *deserving* of *credit* from the *accuracy* with which they have been registered.'[27] Ryder, while not seeking to become a constructor like Symonds, drew distinct lines around the authority and influence of sailors as witnesses and experts. John Fincham, in contrast, argued that the broad observations on which the reports of experimental squadrons rested did not warrant such conclusions, with regard to both knowledge of the ship and the 'expertise' of naval officers.[28] Similarly, an article in *The Times* noted that '[i]t requires no great judgment to be aware that whatever may be the merits of the officers, a ship cannot be well worked with bad seamen; and that the majority of the crews of the Experimental Squadron are bad'.[29] Such problems led Victorian shipbuilders to read mistrust into other shipbuilders' successes on experimental squadrons.

A number of ship wrights, including Fincham, advocated the end of experimental squadrons as a way of finding the 'fittest' ship. Fincham was particularly concerned that the practice of cruising trials reinforced an elementary notion of visual experience as the means of interrogating any given design. He claimed that the cruises encouraged naval officers to form opinions of ship design 'much more in that [manner] of disjointed notions, than as parts of a system exhibiting their dependence and relation to regular order.'[30] Fincham argued that because sailors did not understand how individual elements of ship design interacted they were unable to 'remedy defects'.[31] Fincham concluded that until the Admiralty cease to 'experiment' through the means of rivalry and competition at sea, mobilising old admirals to command squadrons of under-

[27] Ryder's italics. Alfred Ryder, *A pamphlet on the experimental cruizes of the line of battle ships, in 1845* (London, 1846), p. 19.
[28] John Fincham, *A history of naval architecture: to which is prefixed, as introductory dissertation on the application of mathematical science to the art of naval construction* (London, 1851), p. 246.
[29] 'The experimental squadron: the continuance', *The Times*, 7 July 1845, p. 6.
[30] Fincham, *Naval architecture*, p. 246.
[31] Ibid., pp. 246-47.

manned ships, naval constructors would have little idea what *specific* features of the ship contributed to speed and manoeuvrability.

The adoption of a 'scientific' mode of enquiry in the naval service involved more than sponsoring and performing experiments. It required a social and cultural reconfiguration. Captain Edward Pellew Halsted, for example, situated the negative attitude of naval men towards knowledge, experiment and engineering within the naval mentality that was engrained in captains and admirals from their first days in the service. 'It has ever been the prominent characteristic of every true Seaman to look his enemy "face to face," and maintain his own traditional superiority by open effort of superior pluck and daring', Halsted told the RUSI.[32] Daring and courage were encouraged in the naval service. Enquiry and experiment were not. Similarly, as an anonymous gunnery officer argued in an 1867 pamphlet, experience made a sailor, not experiment in the dockyard or mathematics in the schoolroom. '[T]heir mathematics and navigation may be well enough,' the author noted with regards to cadets, 'but they have not had the opportunity of becoming seamen ... Experience gives a seaman a sort of intuitive faculty for meeting difficulties. *Experientia docet.*'[33]

Naval officers believed that experience gave them power over the ship – and doubtless it did to an extent. In the discussion of Froude's 1862 INA paper Sir Edward Belcher described the control that he, as a captain, had over the physical phenomena of ship roll (contrasting the debates examined in chapter 3). '[W]hen my ship rolled particularly, I rang the bell and ordered her not to roll', Belcher told the INA regarding his experience with H.M.S. *Samarang*, '[s]he had never been known to go more than seven knots before a wind [or] ... five on a wind. She had too much ballast. I took 96 tons out of her bottom, and she did everything; she sailed 10.6 knots on a wing and 13 before

[32] Edward Pellew Halsted, 'Iron cased ships', *RUSI Journal*, 5 (1861), pp. 121-269, esp. 228.
[33] [Anon.], *A few words about our navy, by a gunnery officer* (London, 1867), p. 5.

the wind. That is the difference which command effects.'[34] Russell acknowledged that lightening ballast was a 'very useful dodge' but that command alone could not solve problems of naval architecture. The engineer also wryly remarked, 'I am happy that there is a gentleman here so strong as to be able, by his word, to control the rolling of a ship', mocking the tone and attitude of naval officers toward ship behaviour.[35] Throughout Victorian Britain, members of the naval community exerted the sentiments, signs and symbols of a naval mentality toward the ship and its behaviour. Naval officers found numerous occasions to publicly express their superiority as experts of ship behaviour and to direct ship design. The next section examines in closer detail the 'science' (or science of practical experience) that sailors developed.

6.2 SAILORS SCIENCE
Or against the mathematics of control

In 1863, Edward James Reed, a founding member of the INA, was appointed to the office of Chief Constructor of the Admiralty. He held the post for seven years and during that time had many dealings with naval officers. Reed recalled one particularly striking episode during an 1886 lecture at the Worshipful Company of Shipwrights. A naval officer had come to him to ask whether it was dangerous that his ship had taken on such weight to bring her 'down to her "bearings"'. Unsure what the officer meant,

> I assured him that the ship was all right; that she had so many tons per inch of displacement at and near her load draught, and that a ton taken on board would only immerse her to the extent of a ton, neither more nor less, whether she had got her "bearings" or not. He declared that this was all wrong. It might, he said, be science, but it was not fact, for in truth each ton now taken on board sank her six times as much as a ton had previously. If he had no science of his own, I could have hoped to convince him that a ship's displacement in still water, and when she is unrestrained by lashings and otherwise, is an exact counterpart of the weight of herself and all on board, and that whether it was a pound, or a ton, or a

[34] W.J. Macquorn Rankine, 'Remarks on Mr. Froude's theory on the rolling of ships', *Transactions*, 3 (1862), pp. 22-45, esp. 41.
[35] Rankine, 'Froude's theory', p. 42.

> hundred tons, that was added to her, no matter what her shape or her draught of water, her immersion would be exactly increased correspondingly by a pound, or a ton, or a hundred tons. But it was his science that stood in the way of my science, and that worthy officer probably believes as stoutly as ever in the doctrine of "bearings," of which I avow myself wholly and absolutely ignorant. He no doubt regarded me as a theorist, and himself as a sound practical sailor down to the present hour.[36]

Reed concluded that the 'practical knowledge' of sailors was firmly entrenched by years of experience, observations at sea and tacit experience. Such entrenchment made the ships Reed designed for the Admiralty, the ideas Froude developed in the test tank and the science of hydrodynamics and ship design appear untrustworthy to naval officers. This section examines how sailors understood 'science' by exploring the threat that officers believed naval constructors posed.

If the INA was the hub of scientifically orientated shipbuilders, the RUSI was the forum in which sailors could confidently express their scepticism over ship designs and the work of scientific orientated shipbuilders. Unlike the INA, RUSI had a royal charter and an extensive list of aristocratic and government patrons including the Prince of Wales, William Gladstone, Edward Cardwell, George Goschen, Charles Beresford and Lord Charles Napier. The vice-presidents and council members were generals, colonels and Admirals. Reed strongly believed that 'the United Service Institution itself has ... been made the channel of spurious science and dangerous doctrine', but clearly there is a more interesting narrative to be told about the nature of RUSI's authority and its role in Victorian science.[37]

RUSI had been founded in 1831 by the Duke of Wellington to study the 'professional art' and 'science' of naval and military topics. Colonel the Honourable James Lindsay, on opening the 1857 annual meeting, encouraged members to 'discuss professional and scientific questions'. 'All the other professions have establishments for

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[36] Edward Reed, 'On the value of technical education to the shipwright and shipowner, 25 November 1886', in [The Worshipful Company of Shipwrights] (ed.), *The Worshipful Company of Shipwrights Lectures* (London, 1886-87), pp. 3-28, esp. 19-20.
[37] Edward Reed, 'Naval science: editor's introduction', *Naval Science*, 1 (1872), pp. 3-8, esp. 7.

imparting professional knowledge and general information', Lindsay observed, but '[i]n the learned and scientific societies of the country, naval and military science has been hitherto unrepresented and unrecognised; it is the province of this Institution to fill that vacancy and become to the services what the museum in Jermyn Street [Museum of Practical Geology] is to Geology, and that of Kew to botany.'[38] Thus Lindsay understood 'science' as a vital way of ordering knowledge and developing inventions, but as I have argued, many naval officers also thought of 'science' as a counterforce to practical knowledge. These many meanings of 'science' require further examination.

'Science' embodies systems of knowledge and enquiry. The 'image of science' in the nineteenth century was often equated with the broad 'possibility of intellectual certitude' that became increasing bound to the language of 'scientific method' as the conviction grew that truth could be identified if 'proper rules of enquiry were followed'.[39] Thus there could be a 'science' of anything, from cricket to cooking (even Catholicism according to John Newman). Men of science used this notion of science to disseminate the vital rules of enquiry, thereby enforcing their mastery over both nature and 'amateur investigators'. Francis Elgar, who in 1883 became the first professor of naval architecture in Britain, confirmed that 'common sense' and 'practical knowledge' were essential to be a naval architect, but that 'these qualities can no longer be regarded sufficient, by any one competent to judge, to the exclusion of the scientific knowledge it is now possible to obtain.'[40] 'Scientific knowledge' was deemed more complicated than mere observation and experience. It was based on refinement and the ability to order facts and understand the relationships between them. Moreover, the rules governing

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[38] James Lindsay, 'Chairman's address', *RUSI Journal*, 1 (1857), pp. 1-6, esp. 4.
[39] Richaard Yeo, 'Scientific method and the image of science, 1831-1891', in Roy MacLeod & Peter Collins (eds.), *The parliament of science: the British Association for the Advancement of Science, 1831-1981* (London, 1981), pp. 65-88, esp, 65-67. Also see Walter E. Houghton, *The Victorian frame of mind, 1830-1870* (New Haven, 1957), p. 13; John Brooke, *Science and religion: some historical perspectives* (Cambridge, 1991), pp. 6-7.
[40] Francis Elgar, 'The science of naval architecture' in *Proceedings of the International Engineering Congress, Division of Marine and Naval Engineering and Naval Architecture* (2 vols., New York, 1894), pp. 1-29, esp. 24.

that knowledge were controlled by professional and professorial naval architects.[41] For example, W.J. Macquorn Rankine sought to use the INA as a forum where 'gentlemen who are constructors' would profit from 'gentlemen who are sailors [and] would collect actual experience for us'.[42] This type of social control was potentially threatening to naval officers who did not want to lose their power to shape the ship.

Within the RUSI the various conceptions of science criss-crossed with actors like Lindsay advocating a scientific system of naval and military knowledge, John Knox Laughton establishing a scientific study of naval history and Admiral Edmund Fishbourne promoting the 'sailor's science' of naval architecture.[43] RUSI tended not to invite members of the INA to give papers and took little interest in experimental or mechanical approaches to the ship or naval matters (although significantly Barnaby became a regular contributor following the loss of H.M.S. *Captain*). RUSI members tended to share the general view of scientific naval constructors described by the author of *Fact versus fiction*, that they hid their failures and errors 'beneath the dignified mantle of science. If they [the naval architect] were told by the united voice of a whole ship's crew that a vessel sailed badly, pitched heavily, and was deficient in Weatherly qualities,' the author continued, 'the facts were immediately answered by a number of mathematical lines, dully marked *a, b, c,* &c. &c. and by a few algebraical [sic] calculations, in which the changes on *plus* and *minus* were rung, till the faculties of the majority of readers were confounded'.[44]

RUSI welcomed a steady stream of papers on hydrodynamics and ship design written by officers of the Royal Navy who sought to confirm sailors in their supremacy

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[41] Ibid., p. 1.
[42] Rankine, 'Froude's theory', p. 43.
[43] For Laughton see John Knox Laughton, 'The scientific study of naval history', *RUSI Journal*, 18 (1874), pp. 508-527; Andrew Lambert, 'The development of education in the Royal Navy: 1854-1914, in Geoffrey Till (ed.), *The development of British naval thinking: essays in memory of Bryan Ranft* (Oxford, 2006), pp. 34-59.
[44] 'One who has served', *Facts versus fiction*, pp. xx-xxi.

over the ship. These papers ranged in content and partisan rhetoric. An 1867 paper on the laws governing the transition of curves delivered by Commander B. Sharp provided a very dense survey of contributions to the topic from Augustin Creuze to Russell. Sharp approached hydrodynamics through a molecular framework and examined the causes of friction involved in pushing water out of the way of the ship (in contrast to the theory Froude was advocating in the INA at that time).[45] Sharp's intention in addressing this 'confessedly difficult subject' to his audience was to demonstrate 'the entire absence of any reliable rules for producing the actual form of the vessel'.[46] Fishbourne, who chaired Sharp's paper, thanked the speaker for having 'very justly shewn that owing to the lines of ships not being drawn according to any definite law, all calculations, whether for contents or any other objects, are but approximations'.[47]

Fishbourne was a Vice-President of RUSI and one of the most vocal opponents of the ideas and ships produced by scientifically orientated constructors. He thought a purely mathematical and experimental approach to the problems of ship design, such as Froude's, was flawed. He told members of RUSI that 'Mr. Froude has made an experiment in a tin-dish; to this exceptional kind of experiment he has applied to mathematics, and he had got a result which really means nothing.'[48] Fishbourne distinguished himself from his fellow officers because instead of criticising science as an empty source of authority he suggested his own theories and calculations to prove Froude and the scientific community wrong. Through the 1860s, 1870s and 1880s the Admiral presided over RUSI meetings, offered papers on ship design and naval catastrophes, and served as the institution's *de facto* expert on naval architecture.

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[45] B. Sharp, 'Naval architecture, as affected by the laws governing the transition of curves', *RUSI Journal*, 10 (1867), pp. 109-122, esp. 117.
[46] Ibid., p. 121-22.
[47] Ibid., p. 122.
[48] Fishbourne in discussion following Barras, 'Armour-plated ships, and the stability of ships in a sea-way, considered in relation to the principle of the lever and the laws of motion', *RUSI Journal*, 8 (1864), pp.199-216, esp. 214.

Fishbourne was in a small minority section of the officer community that engaged with mathematics, yet he still shared the general naval view that men of science and naval architects of mathematics, science and theory were not to be trusted. Fishbourne told an audience at RUSI that '[m]athematics are very powerful, something like a dentist's instrument, which if not rightly applied, pulls out the wrong tooth; and then the dentist has to convince the patient that he has not got the tooth-ache.'[49] Mathematics were thus seen as a tool or language through which the 'truths' that sailors 'knew' from tacit experience could be covered up. Yet Fishbourne believed that there was some authority in mathematical discourse, and encouraged naval officers to become fluent in it.

Why did Fishbourne think sailors should learn mathematics? Fishbourne observed that sailors had been inclined to go in the 'opposite direction' and say 'because I have been at sea and have got practical experience, I do not need any architectural knowledge'.[50] Fishbourne thought that naval officers were wrong to fashion their 'expertise' as something that was oppositional to mathematics and 'scientific method'. Fishbourne used his influential podium at RUSI to advocate 'a combination of two things, mathematical knowledge, and common sense, or practical knowledge applied to that.'[51] The increasing authority of 'scientific' discourses in everyday and industrial life was such that Fishbourne felt that the naval community could no longer simply offer an alternative type of expertise, rather they had to show the public that they were better than recognised mathematicians. He made this argument at RUSI, echoing existing notions that scientific 'mistiness often passes for profundity', and assuring young

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[49] Ibid., p. 215.
[50] Ibid., p. 215.
[51] Ibid., p. 215.

officers that naval architecture was not 'too abstract' for them to understand, while their experiences gave them an advantage over naval constructors.

Fishbourne argued that if sailors were to remain authorities – experts of ship behaviour and ship design – then they had to enter the mathematical game and change its rules. Naval officers had to reclaim authority to shape the ship by taking ownership of its science. Fishhbourne warned that 'if that be not done, and we are to be led away by the great mathematical talents and knowledge of such persons as Mr. Froude, we shall be landed in the greatest absurdities, and our ships will be utter failures.'[52] Fishbourne revealed his own dedication to playing the game of mathematics and science by writing a book utilising mathematical analysis of ship behaviour and design, *Our ironclads and merchant ships* (1874).[53]

At the core of Fishbourne's naval notion of science was a tacit experience of the ship at sea that he and others called 'practical experience'. This type of experience and expertise could not be attained by naval constructors who were, as sailors called them, 'men of theory' and 'landsmen'. This was a powerful argument, which I will show in sections 3 and 4 were credible to Victorian politicians and publics. For now I will simply outline a frame in which to examine how naval constructors responded to the naval community's faith in a notion of science based solely on practical experience.

Naval officers and men of science differed on how they understood the physical behaviour of a ship as it rolled, with sailors frequently reporting more dramatic and uncomfortable rolling than theorists calculated. Those who witnessed phenomena directly and visually have historically been the most trustworthy group of experts. In this regard, naval officers had an advantage over men of science. But since the seventeenth century men of science had developed tactics to negotiate the testimonies

[52] Ibid., p. 215.
[53] Edmund Fishbourne, *Our ironclads and merchant ships* (London, 1874).

of witnesses that contradicted scientific theories without bringing the authority of the witness into question (thus avoiding personal controversy).[54] Victorian men of science similarly cast doubt on the testimonies of naval officers by discrediting the illusionary nature of visual experience.

In Victorian Britain the sea was a wild, romantic entity understood through tacit experience, religious superstition and sailor's stories.[55] The cultural resonances of these themes mystified the sea. Thus Froude suggested that 'the scenery, so to call it, which surrounds the phenomena of rolling motion (especially when these are developed on a very large scale), is for the most part so very striking, and appeals so forcibly to the imagination'.[56] The violent sea and gale conditions that surrounded ship roll gave the experience of more roll than actually took place. Moreover, years of experience did not necessarily acclimatise the sailor. Those 'whose life is spent among such phenomena, and who have become familiarized to them by habit', Froude argued, 'have become accustomed chiefly to regard them under their impressive aspect'. Froude continued, noting that even the 'phraseology' sailors used to describe waves and the practices through which they ensured safe passage through a rough sea reinforced the delusory

[54] In a series of seventeenth-century debates over the physical causes of icebergs Robert Boyle defended the 'precise quantitative experimental hydrostatics' that he had helped shape in Oxford against the observations made by seafarers of Arctic icebergs that defied the experimentally established nature of the underwater dimensions of icebergs. Steven Shapin has noted that to avoid questioning the reliability of the witnesses (thus casting doubt on any similarly founded testimonies) or suggesting that there were different orders of nature in Oxford and the Arctic, Boyle sought to discredit the testimonies by examining what they omitted. Without questioning the internal facts of a testimony, its accuracy could still be opened to considerable doubt. Steven Shapin, *A social history of truth: civility and science in seventeenth-century England* (Chicago,1994), pp. 253-258.

[55] For culture and the sea, see Christopher Harvie, *A floating commonwealth: politics, culture, and technology on Britain's Atlantic coast, 1860-1930* (Oxford, 2008); Felipe Fernandez-Armesto, 'Britain, the sea, the empire, the world', in David Cannadine (ed.), *Empire, the sea and global history: Britain's maritime world, c. 1763 - c. 1840* (New York, 2007), pp. 6-21; Bernhard Klein, 'Introduction: Britain and the sea' in Bernhard Klein (ed.), *Fictions of the sea: critical perspectives on the ocean in British literature and culture* (Aldershot, 2002), pp. 1-12.

[56] Froude, 'Rolling of ships', p. 181. Froude also offered a domesticated example of the delusory quality of visual observations of ship roll: 'In the *Great Eastern*, on a passage to America and back, I found that the angles indicated by a pendulum were always much in excess of those thus observed, and thus the chandeliers suspended on the cabin ceiling conveyed to the passengers who watched them a very excessive notion of the angles obtained.' Discussion following Rankine, 'Froude's theory', p. 41.

sensation of roll.[57] Thus, men of science established that naval officers were not credible witnesses, not because their skills of observation were inferior but because their experiences were made invalid by the environment in which they took place.

6.3 THE PUBLIC CONSTRUCTION AND COURT-MARTIAL OF H.M.S. *CAPTAIN*

The loss of the *Captain*, which I introduced in the prologue, became a focal point for debates surrounding experiment, experience and expertise in the Victorian navy. The episode was one of the most controversial moments in nineteenth century naval history, for a time dominated Victorian newspapers and threatened to destroy the credibility of either naval officers or naval constructors. Historians have agreed that the ship was unsafe, leaving much of their debate to focus on why the ship was allowed to go to sea.[58] A number of interpretations have been offered ranging from a 'professionals' vs. 'amateurs' argument to overtly partisan explanations for the ship's design. Nicholas Rodger called the *Captain* 'the Liberal's answer to Tory naval architecture ... she was designed to show the naval world the enlightened spirits of scientific progress at sea'.[59] More recently a historian of technology sought to show how the supposed self-evident knowledge of the ship's instability was lost within the navy bureaucracy.[60]

This scholarship is arguably too concerned with Whiggish notions of 'scientific progress' and 'what went wrong' in the design of the *Captain* to examine why Captain

[57] Froude, 'Rolling of ships', p. 181.
[58] Stanley Sandler, 'The emergence of the modern capital ship', *Technology and Culture*, 11 (1970), 576-595, esp. 578-585; John Beeler, *British naval policy in the Gladstone-Disraeli era, 1866-1880* (Stanford, 1997), pp. 111-40.
[59] Nicholas Rodger, *The Admiralty* (Lavenham, 1979), p. 110.
[60] See the thoroughly researched PhD on the controversy surrounding Coles, Reed and the *Captain* that argues that the 'collapse' on the design process lay in the inadequate size of the constructors department in the Admiralty, David B. McGee, 'Floating bodies, naval science: science, design and the Captain controversy, 1860-1870' (Ph.D. thesis, University of Toronto, 1994).

Cowper Coles was given the authority to design the ship in the first place? Or even why naval officers trusted him over the staff in their own constructor's department? Why on the initial trials the *Captain* was found to be a safe ship? And how the social antagonism between naval officers and naval constructors shaped the technical, institutional and effectively socio-cultural controversy that the *Captain* catastrophe represented? I argue that the loss of the *Captain* and the disputes that followed can more insightfully be examined through the contextualised framework of authority and experience at sea that I have established. As sections 1 & 2 of this chapter show, sailors were not seen as 'amateurs' of what we may broadly call 'naval science', but had a specific culture in which they understood the ship and the technical dimensions of ship design. Utilising the contextual framework I have established I will examine the *Captain* catastrophe not to identify 'what went wrong' but why what happened might not seem unexpected given the culture of expertise in the Admiralty.

British interest in the power of turret ships was fuelled by reports from America of the naval engagements of the Civil War. Newspapers reported accounts of the Battle of Hampton Roads (1862), during which the C.S.S. *Virginia* and U.S.S. *Monitor* inflicted massive damage on wooden ships and flotillas.[61] Following the 1865 Union attack on Fort Fisher, during which monitors successfully bombarded the Confederate Fort, Coles stressed the need for the Royal Navy to add monitors to its own fleet. Writing open letters in *The Times*, he reminded readers of the Siege of Sevastopol, a similar scenario to the Union attack on Fort Fisher, where the Royal Navy lost numerous wooden walls armed with broadside cannons trying to attack a land position.[62] Coles also promoted his own turret ship designs as the way forward.

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[61] David A. Mindell, *War, technology, and experience aboard the USS Monitor* (Baltimore, 2000).
[62] Cowper Coles, 'The Federal Attack on Fort Fisher [letters to the editor]', *The Times*, 14 February 1865, p. 6.

In April 1865, the Admiralty appointed a committee to examine Coles' proposal that concluded that 'it [was] most desirable that a conclusive trial should be given to the system in a sea-going ship'.[63] The committee, however, rejected Coles' proposal that the ship should only have one turret, choosing instead to follow Reed's recommendation that the ship been fitted with two, to which Coles responded by publicly attacking the design of Reed's ship, H.M.S. *Monarch*, and personally criticising Reed for opposing turret ships. Coles' attacks on Reed mobilised social networks of naval officers and politicians that threatened Reed's authority at the Admiralty, and which, I will demonstrate, was already tenuous at best. In 1866, John Pakington sanctioned Lairds of Birkenhead to build a ship to Coles' specification. This decision had as much to do with the trust that naval officers and officials had in Coles as the distrust that they had in Reed.

Historians who have examined the *Captain* controversy as a dispute between 'professionals' and 'amateurs' have failed to appreciate that a 'professional naval architect' was not an office that guaranteed universal respect and authority in the Victorian navy. Reed, for instance, was treated with suspicion within the Admiralty. He was allied closely with Robinson, but other officers treated him with mistrust as an outsider. Reed had trained as a naval architect at the Central School of Mathematics, a short-lived institution that had been attached to the Portsmouth dockyard, but left the Royal Navy at the end of his studies. He managed a private shipyard and then edited the *Mechanics Magazine*.[64] When he was appointed Chief Constructor at the Admiralty MPs criticised the government for overlooking older shipwrights such as Oliver Lang who

[63] 'Summary of Correspondence relating to the design and construction of the late "Captain", 26 September 1870', London, NMM, Milne papers 161/18 p. 1.
[64] David K. Brown, 'Reed, Sir Edward James (1830–1906)', *Oxford Dictionary of National Biography* (Oxford, 2004).

had worked themselves up the craft-tradition through apprenticeships.[65] Reed responded to what he called 'this slander' and 'personal abuse' by writing personal letters to the MPs in question, further agitating the situation and inducing further criticism for indiscretion, ungentlemanly conduct and even calls for his resignation.[66] Reed was a forthright character, and as a servant of the state he neither deferred to his superiors in parliament nor formed amicable relationship with admirals.

On 15 January 1867, Reed wrote to Robert Spencer Robinson to describe his concerns regarding the progress of Coles' *Captain*. Reed noted that the freeboard of Coles' design would be '5 feet 6 inches only. I shall be glad to learn whether such a ship will be considered satisfactory', Reed continued, '[i]n my own opinion this ship of about 3000 tons could not be effectually fought or worked as a sailing ship with so low a freeboard'.[67] In 1868, Reed advised the Admiralty to withhold final payment to Lairds until his worries regarding the low freeboard and questionable cruising qualities of the ship had been examined, but Lairds were paid and on 27 March 1869 and the *Captain* was launched.[68] At the same time Reed expressed a desire to leave the Admiralty. He told the Board that '[t]he Admiralty have, in my humble opinion, made a grave mistake in not giving me proper recognition & support.'[69] Reed believed that his position as a technical expert in the government machinery was not valued, and in July 1870, four months prior to the loss of the *Captain*, resigned. The reason he gave for leaving was

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[65] 'The Navy – Appointment of Mr. Reed. – question', *Hansard*, 20 Feb 1863, pp. 572-73; 'The Navy – Estimates', *Hansard*, 23 Feb 1863, pp. 705-706.
[66] 'Breach of Privilege', *Hansard*, 26 Feb 1863, pp. 800-802.
[67] Edward Reed to Robert Spencer Robinson, 15 January 1867, Milne papers 148/1.
[68] 'Summary of Correspondence relating to the design and construction of the late "Captain", 26 September 1870', Milne papers MLN/161/18 p. 13.
[69] Reed to Alexander Milne, 20 April 1868, Milne papers 165/11.

'the very low estimate which all Governments put upon mechanical and scientific skill in this country, as compared with its value in private life'.[70]

The limited confidence that naval officers had in Reed and his criticisms of the *Captain* were counterbalanced by the faith that sailors had in experimental squadrons and the testimony of their fellow officers. Following its launch the *Captain* joined the *Monarch* in Rear-Admiral Thomas Symonds' (the son of William Symonds) channel squadron for firing and rolling trials.[71] 'Sir Thomas gives it as his opinion', Robinson conveyed to the Board of Admiralty, 'that the low freeboard of the "Captain" does not in any way inconvenience the turrets in a seaway ... though considerable quantities of water came over the upper deck.'[72] Symonds' report was just one of many positive testimonies of the *Captain*'s safety, stability and success that dismissed concerns regarding freeboard. Rear-Admiral Cooper Keys, who also witnessed the trials, declared the *Captain* safe, even superior to the *Monarch* with regards to how she handled.[73] A similar testimony was provided by the ship's own captain, Hugh Burgoyne.[74]

These reports, drawn from tacit experience, were deemed the most credible sources of information in the Admiralty regarding the *Captain*. They appealed to the signs and symbols of authority in direct witnessing highlighted above. Captain J.E. Commerell, for example, testified that '[f]rom what I have observed of the "Captain", I should consider her rather a stiff vessel under sail, a very easy and slow roller, perhaps

[70] 'Navy – Resignation of Mr. Reed', *Hansard*, 18 July 1870, pp. 413-14. Following the loss of the *Captain* Reed claimed that Childers had driven him out of the Admiralty by seeking to appoint Coles to a permanent position to rival his own. See Edward Reed, 'The loss of the Captain [letter to the editor]', *The Times*, 21 December 1870, p. 12.
[71] Vernon Lushington to Milne, 26 November 1869, Milne papers 143/4.
[72] 'Copy "of reports of the Admiral in command of the Channel Squadron as to the Trials of the Ships "Monarch" and "Captain" after joining the Fleet in May last; with any reports received from the Captains of the respective Ships made either to the Lords of the Admiralty or the Admiral in Command"', Milne papers 161/11.
[73] 'Observations of Rear-Admiral Cooper Keys, CB, respecting ships of the combined squadrons (1870),' Milne papers 143/4.
[74] 'Summary of Correspondence relating to the design and construction of the late "Captain", 26 September 1870', Milne papers 161/18, p. 17.

in this respect having a slight advantage over the "Monarch".'[75] Significantly, Commerell believed that easy, slow roll was a sign of a smooth and stable ship. However, to Reed, Froude and other members of the INA, long and slow arches of roll were a sign of a dangerous ship. It may have seemed more violent for a ship to oscillate quickly and a lot when unbalanced, but the INA members believed it was safer than experiencing long, slow rolls that were more likely to tip the ship to a position where it could capsize.

On 7 September, after over a year at sea and many trials that provided evidence for naval officers to declare the *Captain* a success, the ship sank off the west coast of Spain. The social dimension of the controversy surrounding the *Captain* exploded as witnesses, reputations, authorities and skills were publicly attacked. Members of the *Captain's* court-martial board soberly listened to evidence and concluded that the *Captain* capsized due to the unfortunate combination of her low freeboard, top-heavy superstructure, large canvass and heavy wind that culminated in the *Captain* rolling to a point at which its stability was insufficient to recover.[76] But in public there was large political fallout and a witch hunt for someone to take the blame. Captain Coles had died onboard the *Captain*, thus in the absence of a scapegoat (and with Admirals concerned for both their authority to shape the ship and the credibility of the turret system) numerous officers blamed Reed for the loss.

The immediate political fallout was fuelled in part by Childers and the Earl of Northbrook who both lost sons in the disaster. Childers initially blamed the previous Conservative Board of Admiralty led by Pakington for ignoring the advice of Robinson

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[75] 'Copy "of reports of the Admiral in command of the Channel Squadron as to the Trials of the Ships "Monarch" and "Captain" after joining the Fleet in May last; with any reports recived from the Captains of the respective Ships made either to the Lords of the Admiralty or the Admiral in Command"', Milne papers 161/11.

[76] [Lord Commissioners of the Admiralty], *Court Martial. H.M.S. "Captain". Minutes of proceedings, &c., &c., 27th September to 8th October, 1870* (London, 1870).

but soon shifted the blame to Reed after hearing his testimony at the court martial.[77] Reed had explained that upon hearing the ship was lost he suspected that it was probably because of pressure on the sails causing the ship to exceeded its stability. Childers accused the former Chief Constructor of keeping his fears from his superiors.[78] The First Lord then published an Admiralty minute that specifically blamed Reed for not calculating the *Captain*'s curve of stability before the ship left for her trials.[79] Childers noted that when the calculations were made by Frederick Barnes, an assistant constructor, the ship had already set sail.

The calculations Childers mentioned had only recently been devised by Barnes. Moreover, Reed's assistants felt that it was pointless to force their calculations and theoretical considerations on practical seamen. Experience, Barnaby acknowledged at the court-martial, was king to officers. 'I should not have presumed to press those calculations in the face of the officers who tried the *Captain*. It would be presumptuous to do so,' Barnaby testified, furthermore 'so far as I am aware no one predicted from them that the *Captain* would turn over.'[80] In the *Gentleman's Magazine*, William White supported his associates remarks, reiterating that '[b]efore the calculations were made the vessel had been tried at sea, and had, as we have seen, been reported upon most favourably as respected her "seaworthiness".'[81]

If Reed's assistants sought reconciliation, Reed sought controversy. It may be useful to think of the debates that took place after the loss of the *Captain* as simultaneously about assigning blame, protecting reputations and establishing expertise for the present and future. In *The Times*, Reed responded to Childers'

[77] Hugh Childers to Charles Wood, 15 November 1870, York University, Borthwick Institute, Halifax Collection A4/90 Part I.
[78] [Lord Commissioners of the Admiralty], *Court Martial. H.M.S. "Captain"*, p. 40.
[79] Ibid.
[80] Ibid., p. 158-59.
[81] William White, 'The story of the Captain', *Gentleman's Magazine*, 5 (1870), pp. 700-714, esp. 713.

'extraordinary minute', explaining for the public that the Admiralty had given Coles and Lairds entire responsibility for the *Captain*, despite his protestations before and during the construction.[82] Reed had noted in an earlier letter that the *Captain*'s construction had been based on the Board's 'assumption that the opinions of Sir S. Robinson and myself were not to be trusted'.[83] In making this statement Reed further fuelled the discussion that was emerging regarding who was trusted to have the expertise to safely design a ship. Reed's assertion is particularly curious as the 1866 Board of Admiralty he criticised was led by Pakington, the first President of the INA, of which Reed was a founding member.

Pakington privately discussed Reed's public letters with Milne with the intention of drafting a public response to protect themselves. 'I never felt that their [Reed and Robinson's] opinions were not to be trusted,' Pakington wrote, while suggesting that his intention was to give Coles 'a fair trial' for his 'invention which had attracted so much attention'.[84] Pakington certainly acknowledged that he had given Coles a free rein, implying that he believed that naval officers could be experts of ship design. Milne, in response, offered a slightly different perspective. He also denied that Reed and Robinson had made 'any special representation of want of stability in the Captain', rather that 'they did not approve the "plan" and Coles did not approve of "them".'[85] Milne also recalled that Coles had been given a freehand and that adverse criticism of his design could spark further undesirable public dispute: 'if the Admiralty interfered in any manner with Coles views it would be considered that he had not his own plans carried out.'[86] Thus Milne acknowledged the public and political pressure Coles

[82] Edward Reed, 'The loss of the *Captain* [letter to the editor]', *The Times*, 21 December 1870, p. 12.
[83] Edward Reed, 'The court-martial on the Captain [letters to the editor]', *The Times*, 5 October 1870, p. 6.
[84] John Pakington to Milne, 11 October 1870, Milne papers 165/10.
[85] Milne to Pakington, 13 October 1870, Milne papers 165/10.
[86] Ibid.

controlled, and that he was personally anxious not to question Coles' plan. Milne did not, however, excuse Reed from potential public controversy: 'it was his [Reed's] duty to have written to the Controller' if he had any concerns with the *Captain*.[87]

It was of course possible that both sides in the dispute were correct, i.e. Reed and Robinson did not explicitly state that if the freeboard was too low the ship would be unsafe (and that administrators and admirals were ignorant of the connection), but that the reason why Reed and Robinson were not confrontational during the ship's construction was because Pakington told them not to interfere with Coles' work. One way or another, there were organisational problems and questions of expertise that complicated charging anyone with overall responsibility for the ship (even the ultimate responsibility of the first ford was made ambiguous as three different politicians held that office during the ship's construction). Nevertheless, the prospect of public dispute seemed to appeal to Reed, who fuelled the debate by repeatedly posing public questions relating to matters of expertise.

In parliament the Earl of Lauderdale and the Duke of Somerset came to Reed's defence, but they were very much a minority in the political community.[88] The Earl of Northbrook, whose interest in the loss of the *Captain* stemmed overtly from the personal loss of his son onboard, did not believe that the findings of the court martial got to the heart of the matter. Northbrook asked Edward Cardwell to transmit to William Gladstone, then prime minster, a request to reopen the investigation. He even offered to lead the enquiry, 'however painful and at whatever personal sacrifice' it would be.[89] Northbrook felt that 'the terrible responsibility, which appears from Mr.

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[87] Ibid.
[88] 'Parliamentary Intelligence', *The Times*, 17 June 1871, p. 6.
[89] Northbrook to Edward Cardwell, quoted in Cardwell to Gladstone, 16 October 1870, London, British Library, Gladstone Papers, vol. xxxiv, British Library add. ms. 44119, f. 166 & f. 168.

Reed's evidence to exist somewhere, should be brought home'.[90] The Earl soon attracted support from naval officers who disliked Reed. Sidney Dacres, first sea lord, encouraged Northbrook to build a platform to investigate Childers' claim that Reed had acted with malice.[91] Dacres noted that '[y]ou must take Mr. Reed's evidence with a great deal of dilution[;] he never in his life expressed fears of the Captain's safety to any one ... if there has been even a hint of such a thing I would not have sent my greatest enemy to sea in her.'[92] These correspondences demonstrate the contempt with which Northbrook, a senior politician, and Dacres, a senior Sea Lord, viewed Reed, Robinson and the Admiralty's leading technical officials.

As public debate increased, particularly criticism of Reed's expertise, suspicions developed that the fleet Reed had designed during his time as Chief Constructor contained further disasters like the *Captain*. Childers thus recommended forming a committee to examine the design of war ships. He advised the Board of Admiralty that the committee should examine the 'present state of the science of naval architecture' and the 'requirements of naval warfare' that were brought together in ships of war.[93] Given the committee's dual purpose Childers sought to name Froude, Rankine and Woolley to join a selection of naval officers and experts under the direction of Lord Dufferin. Childers also appointed Thomson to the committee, indicating the reputation he had developed as a scientific expert with the Admiralty.[94] Childers' desire to bring naval officers and men of science together underlines that the *Captain* dispute and the proceeding controversy regarding the use of science rested on personal credibility –

[90] Northbrook to Algernon West, 8 October 1870, Gladstone Papers, vols. clxxxi, add, ms. 44266, f.7
[91] Northbrook to Sidney Dacres, 6 October 1870, Gladstone Papers, vols. clxxxi, add, ms. 44266, f. 13
[92] Dacres to Northbrook, 5 October 1870, Gladstone Papers, vols. clxxxi, add, ms. 44266, f. 15.
[93] Admiralty Memorandum enclosed in Childers to Wood, 15 November 1870, Halifax Collection A4/90 Part I.
[94] Ibid. For Thomson and his work and authority with the Admiralty see Crosbie Smith and M. Norton Wise, *Energy and empire: a biographical study of Lord Kelvin* (Cambridge, 1989), pp. 735-786.

credibility that Childers believed that naval officers and men of science possessed, and naval constructors did not.

6.4 SCIENCE ON THE LINE

The Committee on designs and H.M.S. *Devastation*

As the *Captain* catastrophe continued to be discussed in the British press and learned societies the debate increasingly engulfed the longstanding question 'could 'science', as practiced by men of science and naval architects, guarantee a safe, efficient and powerful ship?' At the 1870 meeting of the British Association for the Advancement of Science in Liverpool, Reed addressed Section G with the argument that '[i]f we value the [naval] property of the country and our national security we should bow down to the altar of science.'[95] Reed's address caught the attention of Vice-Admiral George Elliot, a close ally of Alfred Ryder, who responded in *The Times* to defend seamanship and practical knowledge. The admiral argued that 'those who have to handle the tools are the best judges of their merits, and that seamanship is a science which enters largely into shipbuilding'. Elliot resented Reed for trying to phase out masts and sails, and rejected that a low freeboard and a heavy superstructure contributed to the loss of the *Captain*. Eliot concluded his letter, 'Mr. Reed will yet have to perform the same act of homage to practical experience which he proposes ... admirals ... to do [to] ... "science".'[96] The post-*Captain* debate became increasingly about experiment, experience and expertise, thus providing a public pulpit for the naval officers, constructors and administrators who had developed conflicting models of 'science' since the 1830s to fortify their respective authority and the identity of science.

[95] Passage quoted from George Elliot, 'Mr E.J. Reed, C.B., on the loss of the Captain [letters to the editor]', *The Times*, 28 September 1870, p. 12.
[96] Ibid., p. 12.

In 1871, Frederic Rogers, a prominent civil servant and former student of Hurrell Froude, wrote to his sister to say that,

> W. Froude is up and down here, about an Admiralty commission on which he is sitting. It is to discuss, as far as I see, ship-building in general, shapes, armour, sizes, etc. etc. He seems to like it much and says that the sailors and men of science it is composed of work well together. It is to be hoped they will keep us straight, and make our ditch impassable to Prussians or any one else.[97]

Froude joined Admirals Elliot, Ryder, four other naval officers, and Woolley, Rankine, George Bidder, Thomson (who together with Froude formed a scientific subcommittee), Thomas Lloyd and three commercial shipbuilders. In the wake of the loss of the *Captain* the Admiralty suspended work on all the ships Reed had designed and cancelled all the proposed ships Reed had planned.[98] Thus the committee was also asked to examine ships under construction, including H.M.S. *Devastation*, and, 'with reference to the present state of the science of naval architecture and the requirements of naval warfare', make recommendations on their form.[99]

Much of the committee's discussion focused on the *Devastation*. Reed and Robinson had made a number of public statements suggesting that the ship design was not ready, fuelling public anxiety that the ships of the Royal Navy were not to be trusted. Barnaby testified in defence of the ship, stating that with slight modifications it was safe. Meanwhile Thomson, using the parameters of the worst ocean wave observed by William Scoresby, calculated that the *Devastation* had the stability to avoid the fate of the *Captain*.[100] Thomson also reported that Froude's bilge keel design, derived from rolling experimenting with models, steadied the ship.[101] Dufferin, who reported back to the Admiralty, supported Thomson's statements and declared that 'the "Devastation"

[97] Frederic Rogers to his sister, 30 January 1871, quoted in George Eden Marindin (ed.), *Letters of Frederic Lord Blachford: under-Secretary of State for the Colonies, 1860-1871* (London, 1896), p. 293.
[98] Frederic Manning, *The Life of Sir William White* (London, 1923), p. 53.
[99] [Lords of the Admiralty], *Design of Ships of War: Copy of the Instructions given by the Admiralty to the Committee on Designs for Ships of War* (London, 1871), p. 2.
[100] The committee also concluded that the *Captain* would have been safe if it had not been fitted with sails, and 'comparatively safe' had the vessel been built as designed but with 8 feet of freeboard. Ibid., pp. xxxi-xxxii, xlvii.
[101] Ibid., pp. 8, 47.

class represents in its broad features the first-class fighting ship of the immediate future.'[102]

Dufferin's report drew the Admiralty's attention to the 'important investigation' undertaken by Froude into the conditions that effected resistance. The committee requested that Froude be allowed to perform experiments with ships, mirroring his model tests, to which the Board of Admiralty had previously assented.[103] Dufferin also advocated the Admiralty take seriously Froude's larger bilge keels and experiments on roll. The chairman cautioned against complete trust in models experiments at this stage, yet he and the committee believed that Froude's work 'may be applied to the benefit of the Navy.'[104] Dufferin also believed that it would be wise for the Admiralty to discontinue its arbitrary guidelines for ship designers, such as setting the maximum angle of vanishing stability at 50°.[105] In its place Dufferin suggested that more independence be given to constructors to use experiments and calculations to find every ship's distinct points of instability. The committee's report also advocated a series of mechanical reforms to all naval ships, including fitting apparatus to measure trim and speed, so that officers had quantifiable data regarding the behaviour of their vessel.[106]

Ryder and Elliot did not share a number of the views and suggestions expressed in Dufferin's report. Ryder and Elliot prefaced their dissenting report by noting that 'the [members of the] "Scientific" sub-committee ... are not familiar with ships and their behaviour at sea and in action'. Their minority report also echoed the concerns that naval officer had regarding the *Devastation*'s armour and offensive qualities.[107] In 1872, Ryder and Elliot took their arguments public. In a memorandum by Elliot on the 1872-3

[102] Ibid., p. xiii.
[103] Ibid., p. xi.
[104] Ibid., p. xii.
[105] Ibid., p. xix.
[106] Ibid., p. xix.
[107] Ibid, pp. xxxvi-xxxvii.

navy estimates the admiral complained that the committee of designs consisted of too many civilians and government officials and that 'it cannot be said that the recommendations of the majority of the Committee are any practical guide for the Construction Department of the Navy.'[108] Again, the shape of the ship became subject to broader discussions of authority and control.

Elliot's plea for practical shipbuilding, guided by the experience and advice of naval officers, was shared by Fishbourne, who used his prominent position at the RUSI and a series of publications to express his views on naval architecture. Fishbourne published three works on naval architecture in the 1870s, in which he brought suspicion on the safety of the fleet of the Royal Navy and levied fierce criticisms of the 'radically erroneous systems of design and of calculation' perpetuated by Reed and Barnaby thereafter.[109] Fishbourne reiterated many of the arguments I examined in section 2, specifically citing Froude as the originator of the system of naval architecture responsible for the loss of the *Captain*. '[T]here doubtless is a superstructure of superior mathematics built up by him', Fishbourne wrote of Froude's theories, 'yet as it is *baseless*, his conclusions could not be otherwise than erroneous, and proportionately deceptive, and the adoption of them could only lead to the damage of our ships, and danger to the lives, if not also to the death of some of our seamen'.[110]

Fishbourne rejected Froude's theory of roll, *i.e.* that rolling was often the result of too much stability (added weight) and that stability was linked to the period of a ship's roll (time taken and angle of a complete roll, the sharpness and quickness of which indicated dangerous behaviour) and the shape of waves. Fishbourne's disagreement lay in the contrasting frameworks of observation and experience discussed in section 2.

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[108] George Elliot, 'Remarks on vote 100, navy estimates, for 1872-3', Milne papers 148/4, p. 1.
[109] Fishbourne, *A letter*, p. iv. Also see Edmund Fishbourne, *The loss of H.M.S. "Captain", illustrating a new principle of naval architecture for the first time enunciated* (London, 1870); Fishbourne, *Ironclads and merchant Ships*.
[110] Fishbourne, *A letter*, p. 6.

Froude saw the roll of the ship as a sign of stability and not, as the naval element saw it, as a sign of instability and danger to life. A vertical oscillation, for example, 'seems rather a matter of personal discomfort than of mechanical stress'.[111] Fishbourne rejected Froude's conceptualisation of stability as a force of motion designed to right the ship, stating '[s]tability ... is not, nor can be the cause of instability, or of rolling motions'.[112] Fishbourne also referred to the experiments Froude used to demonstrate his ideas, in which a suspended dish of water was swung without the contents spilling (see chapter 5), as a 'milkmaid's trick'.[113] Conversely, Fishbourne stated that his own authority came from being 'an amateur architect, who am also a sailor, having therefore a double qualification for understanding the subject which is largely a sailor's question', echoing controversies from the 1830s.[114]

The press controversy that Fishbourne continued to fuel heightened public awareness of the *Devastation*'s construction and trials, and increased public anxiety over the issue of how much authority ought to be given to science – especially when it threatened to dramatically alter the appearance and social order of the ship (as noted in the case of the *Devastation*, see figure 1.2). In 1874 Henry Watkin, MP for Hythe and a prominent railway speculator, took Fishbourne's concerns into parliament, where he asked whether scientific advisors like Thomson, 'a distinguished man of theoretical science', were 'safe advisors' in practical matters regarding the art of ship design.[115] Watkin specifically compared Froude's skills and authority to Fishbourne's, noting that the former's theories had been rejected by his peers. Watkin quoted from the INA model debates, specifically Russell's belief in the early 1860s that 'the cure [Froude offered for

[111] Froude, 'Russell's paper on rolling', p. 244.
[112] Fishbourne, *A letter*, pp. 12-13.
[113] Ibid., p. 3.
[114] Ibid., p. 31.
[115] 'Naval Construction of Ironclads', *Hansard*, 18 May 1874, p. 409.

stability] is worse than the disease', to discredit Froude and his work on 'experimental models in a fishpond.'[116] Fishbourne, in contrast, was painted as an expert who had 'spoken and written on the result of a life of practical experience.'[117]

Fishbourne and Watkin's appeal to practical knowledge and tacit experience resonated with many Victorians because they were more easily understood than experiment and hydrodynamic theory. Watkin sought to persuade the Commons' of Fishbourne's authority by asking MPs to remember a familiar childhood experience.

> We had our little boats in childhood, and what was our experience? We cut out a piece of wood in the form of a boat, and we put in masts and sails. We launched it on the Serpentine, and it toppled over at the first puff of wind. Learning by experience, we then nailed a bit of lead upon its keel. It stood then valiantly upright and resisted its enemy, the wind.[118]

Watkin, echoing the debates surrounding the foundation of the Royal School of Naval Architecture, rejected Froude's conceptualisation of stability in his theory of roll and denied that special knowledge and skills were required to become naval architects. '[I]n one sense we all have been naval architects', Watkin told the House.[119] Watkin's concluded his speech by urging the Commons to legislate on where the centre of gravity in a ship should be placed. This legislation would limit the influence of Froude and Barnaby by making their calculations, model experiments and inclining tests redundant, thus returning naval architects to the sole function of building what the Board of Admiralty told them build.

By 1873, public distrust in the *Devastation* had become an embarrassment to the Board of Admiralty. Launched 12 July 1871, the ship had been removed from the active list while the committee on designs sat to consider its safety. In Parliament John Hay and Henry Corry questioned the secretary of the Admiralty whether ships lately constructed and in construction at the Admiralty would be examined. In the public

[116] Ibid., p. 410.
[117] Ibid., p. 410.
[118] Ibid., pp. 405-406.
[119] Ibid., p. 405.

sphere a stream of pamphlets written by Fishbourne claimed that to deploy 'such mastless things as "Glatton," "Devastation," and "Cyclops," and others devoid of sea-going qualities ... is to waste public money, ... jeopardize ships of enormous value, imperil numerous lives, and in time of war to court national disaster.'[120] Goschen even had to address the Commons to deny reports that sailors on the *Devastation* constantly wore cork jackets in case of emergency.[121] With material safety and trust in the Royal Navy on the line, the Admiralty were keen to end public intrigue and rebuild faith in the fleet.

Henry Marc Brunel, who had nurtured a good working relationship with the constructors department while assisting Froude in the test tank, told Froude that Barnaby believed the board had become more concerned with pleasing the public than scientifically proving the credibility of the fleet.[122] However, leading scientific authorities including Thomson, Rankine and Froude had been very supportive, publicly refuting the claims of officers that the *Devastation* was unsafe. Men of science and naval constructors were eager to help the Admiralty and demonstrate the fleet's safety. Their interest in the matter was doubtless shaped by wanting to support the Admiralty constructors department, led by Barnaby, which was anxious to prove the *Devastation*. Barnaby, who had succeeded Reed at the Admiralty, conveyed to Brunel his concern 'that if they [the constructors] do not establish the position of this type of ship in the eyes of the general public, and of their own unscientific superiors as a success', the mastless ship – together with the authority of science – would severely suffer.[123]

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[120] Fishbourne, *A letter*, p. 26.
[121] 'House of Commons, Thursday, March 21', *The Times*, 22 March 1872m p. 5.
[122] Henry Marc Brunel to Froude, 14 July 1873, Bristol University, Special collections, Henry Marc Brunel papers, Letter book 14.
[123] Barnaby quoted in Ibid.

In 1874, Froude approached the Admiralty to formally request permission to undertake the ship rolling experiments that Dufferin had recommended in 1872. A successful series of 'experiments' with the ship would nurture trust in the class, while also validating Froude's model experiments and scale comparisons.[124] '[I]t should I think go far to establish in the minds of many who still hesitate to place confidence in it,' Froude wrote to Vernon Lushington, secretary to the Board of Admiralty, 'and it might induce their Lordships to place [model experiments] on a less restricted basis ... [and] with a somewhat larger scale of expenditure'.[125] Froude was given permission to proceed, but the continuing criticism of naval officers threatened the experiment. 'The entire navy, outside the Admiralty, and highly placed persons at Court', Barnaby later wrote, 'held that to send such a ship to sea, would be criminal.'[126] Even as Froude was ready to get underway he was held back. '[T]there is reason to fear that "their Lordships" are getting frightened by the clamour of unscientific naval officers', Froude told Napier. The mathematician considered asking Thomson to 'fire a shot at them [the Lords]' to galvanise the Board's support.[127]

Froude successfully took the *Devastation* to Gibraltar, where he performed the same rolling experiments as he had with a twelve foot model of the controversial ship. Simulating roll on 12 foot model was a comparatively easy mechanical task, but to simulate roll on the ship Froude ordered 400 men to run back and forth across the deck till the boat rocked to the necessary degree. The results of Froude's experiments supported the Committee on design's claim that the *Devastation* was safe. The experiments also provided Froude with demonstrable evidence that the behaviour of a

124 Froude to Vernon Lushington, 16 October 1874, Bristol University, Special Collections, Isambard Kingdom Brunel papers DM1986/2.5. Froude had previously complained that Thomson that he had not had an opportunity to undertake rolling experiments at sea. Froude to Thomson, 2 October 1872, Thomson papers GB 0247 MS Kelvin F46.
125 Froude to Lushington, 16 October 1874, Isambard Kingdom Brunel papers DM1986/2.5.
126 Nathaniel Barnaby, *Naval development in the century* (London, 1902), p. 75.
127 Froude to Napier, 15 November 1874, Napier papers 90/2/4/51.

rolling model corresponded with the behaviour of a rolling ship. Froude's rolling experiment also turned out to be a minor spectacle, thus helping news of the event spread. The King of Portugal had learnt of how Froude was causing the *Devastation* to roll, and requested to board the ship and see the process and view Froude's measuring apparatus.[128] On his return to England Froude provided a lengthy description of the measuring instruments and the tests at the Institution of Naval Architects, gaining praise from officers and constructors alike. The success of the *Devastation*'s trial, and Froude's work, was widely publicised, much to the disappointment of Fishbourne, Elliot, Ryder and Watkin. The full-scale tests had provided a type of proof which was demonstrable and visual, and that took Froude's ideas out of the domain of test tanks and into the arena previously dominated by sailors who could stress that they had experience and solid evidence on their side.

6.5 Conclusion

The controversies presented in this chapter demonstrate that 'experience' represented a matrix of knowledge, through which naval officers found personal assurance and public authority in their struggle to shape the ship. Members of the naval service and their partisan associates in parliament did not oppose naval constructors or their scientifically shaped ships because they were reactionaries or antiquated, as historians have noted with regards to the authority given to officers like Symonds. Naval officers distrusted scientifically trained and working engineers – together with the objects they designed – because they were produced outside of the nexus of technical,

[128] David K. Brown, 'William Froude and "the way of a ship in the sea", *Reports and Transactions of the Devonshire Association for the Advancement of Science, Literature and the Arts*, 124 (1992), pp. 207-231, esp. 216.

epistemological and socio-cultural associations through which they understood the ship and their naval service.[129] These partisans were held together by a common faith in *prima facie* observation, practical knowledge, tacit experience and the honourable word of the naval officer.

Froude's experiments with the *Devastation* were, however, powerful in silencing the concerns of naval officers. The ship's success suggested that naval architecture was not just a mathematical construction, that science could guide and guarantee naval power and that scientific experts could be trusted to judge whether a ship was safe - without the risk of testing against nature's elements in an experimental squadron. The *Devastation*'s success gave credibility to Dufferin's report and the Admiralty made stability tests mandatory for ships prior to launch. The Admiralty also encouraged naval officers to understand the 'Statements of Stability' that constructors produced, rather than dismiss them as the work of 'theorists'.[130] These reforms shifted the authority from experience to experiment and cultivated expert status for naval constructors.

Come the 1880s, naval officers like Admiral of the Fleet Thomas Symonds, William Symonds' son, had no ambition to dictate ship shape. Symonds was as argumentative as his father, but the only parties in the controversies he discussed were Chief Constructors and Controllers like Reed and Robinson. 'Mr. Robinson prefers Mathematics ... to experiment; while Sir E. Reed, the emperor of English scientific construction, recommends what is "proved experimentally,"' Symonds wrote to the editor of *The Times*. 'Doctors differ &c. I leave you and your readers to judge between these two scientific constructors, my faith being beyond all question in Sir E. Reed, and common sense - actual experiment before all argument.'[131] The nature of the

[129] Barnaby, *Naval development*, p. 75.
[130] William White, 'The Austral Judgement', *Nature*, 15 November 1883, pp. 49-51.
[131] Thomas Symonds, 'To the editor of *The Times*', *The Times*, 15 January 1885, p. 12.

controversy had changed. The final chapter of this thesis will examine how naval constructors asserted and nurtured their authority by marking their expertise, professionalising their craft and developing their discipline.

7

The culture of expertise revisited

[Admiral George Elliot] foretold that the trials of the two ships [of the Devastation class] would result in the triumph of the "sailor element" over "naval science" (*sic*); he claimed for the Dicey ship that she would be able to realise the full power of her engines on all occasions, and he contended that "the twin canoes of the Indian seas afforded abundance of proof of "the efficiency of this system of designing for obtaining the minimum of motion from the action of the waves." Now, if Admiral Elliot were a scientific officer, or if he cultivated a scientific method of thought, he would see how seriously statements like these operate against public confidence in a man.

Edward Reed uses his journal Naval Science *to promote scientific expertise in the Royal Navy.*[1]

If, as I have before stated, the extensive and growing adaptation of mechanical contrivances to the construction and the working of ships will, for the future, entirely reverse the conditions which existed during the last century and first half of the present, and give less scope in naval warfare for superiority to be gained by nautical skill and indomitable courage working through inferior instruments - if, consequently, the naval supremacy of this country must be seriously damaged, unless we are quite on a level with other nations in the excellence of our ships, whether as regards form and behaviour, or workmanship and best adaptation of mechanical appliances.

The Reverend Joseph Woolley speculates that future naval supremacy will be decided by professional engineers and mechanical inventions.[2]

An anonymous 1887 article in *Blackwood's Edinburgh Magazine* brought down a crashing criticism on the Admiralty and the many commentators who shaped public opinion of the *matériel* of the navy. Admiral Edmund Fremantle, the anonymous author, argued that the naval community was woefully ignorant of the best use of *matériel*, the management of 'science' and the role of naval constructors in shaping the military strategy that would secure Britain's position in global politics.[3] Fremantle's essay, 'Are ironclads doomed?', was written in response to public and private speculation that the invention of fast torpedo boats would make large gun vessels obsolete. Fremantle believed such opinion characterized British public anxiety that the empire was not safe unless it had a fleet containing all new ships equalling the number that constituted the

[1] Edward Reed, 'Three recent critics of naval architecture', *Naval Science*, 3 (1874), pp. 429-438, esp. 436-7.
[2] Joseph Woolley, 'On the education of naval architects', *Transactions*, 5 (1864), pp. 262-271, esp. 268.
[3] [Edmund Fremantle] Anon., 'Are ironclads doomed?', *Blackwood's Edinburgh Magazine*, 141 (1887), pp. 519-533.

fleets of it two biggest rivals – regardless of knowledge of whether, and in what way, those ships were efficient or powerful.[4]

Fremantle complained that the ignorance exhibited in discussions concerning torpedo boats and battleships revealed that the 'science' of naval strategy – how objects of naval power were designed and deployed – was a mystery to naval officers and commentators. 'Our naval constructors are themselves called upon to supply many of the tactical considerations involved in the design of a ship', the author acknowledged.[5] Fremantle, in contrast to the admirals discussed in chapter 6, believed that naval constructors could be trusted to guarantee naval power, peace and prosperity. Thus a distinguished naval officer accepted that sailors were not in control of shaping their surroundings, and urged naval officers to work in harmony with constructors.

This final chapter examines how naval architects and engineers understood their expertise and authority over the ship in late-Victorian Britain. I focus on how scientific expertise was increasingly entangled with the production of knowledge, *matériel* and social order within the naval community and the Admiralty. These processes took place within the context of the decline in the authority of naval officers and their skills to judge ship behaviour, the transition in the shipbuilding industry from a craft-orientated practice to a mechanical one, and the changing nature of Victorian professionalization. I close this analysis by exploring how naval constructors and officers understood the socio-cultural shifts that took place as the wooden wall was replaced by a machine.

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[4] In 1873, William White had made a similar argument, claiming that Victorian naval commentators fetishised what they thought to be most powerful or progressive without regard for the 'aggregate force' of the Royal Navy. William White, 'Our unarmoured ships', *Colburn's United Services Magazine*, 538 (1873), pp. 1-11.

[5] [Fremantle], 'Are Ironclads Doomed?' p. 519.

7.1 RECOGNISING EXPERTISE

Issues of expertise are part of almost every institutional relationship in society and yet the construction of that expertise is often invisible. Thus cultures of expertise are linked closely to trust, credibility and authority. This thesis has observed that 'experience' and 'practical knowledge' were vital to the credibility of experts in early and mid-Victorian Britain. Naval officers, for example, found that their claims to expertise were most readily trusted because they could appeal to those themes.[6] However, these cultures changed over time. The 'modernity' notion that 'science', as both a means and an end, was a force of good had not been constructed in Victorian Britain. Few people in the first half of the nineteenth century equated advances in physical science with strong national defence, healthcare or economic might.[7] This chapter traces the reconfiguration of Victorian expert culture in order to provide a backdrop to help explain why the increasing technicality and specialisation in naval architecture – and more broadly Victorian engineering – was trusted.[8]

Since the late nineteenth century, societal trust in experts has been increasingly bound to trust in institutions with clear bodies of profession, work and authority.[9] Within these institutions 'invisible technicians' worked to form connections between actors, objects and sites in their social networks.[10] Chapter 2 identified a social network of naval architects, engineers, mathematicians and men of science that quietly gained institutional power through the support of a small group of naval and professional patrons. Constructors like Edward Reed, Nathaniel Barnaby and William White used the office of the Chief Constructor at the Admiralty to expand their social networks of

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[6] Harry Collins & Robert Evans, *Rethinking expertise* (Chicago, 2007), p. 23.
[7] Frank M. Turner, *Contesting cultural authority: essays in Victorian intellectual life* (Cambridge, 1993), p. 177.
[8] For a broad study of how modern physical science became 'technical' see Theodore M. Porter, 'How science became technical', *Isis*, 100 (2009), pp. 292-309.
[9] Steven Shapin, *The scientific life: a moral history of a late modern vocation* (Chicago, 2008), pp. 1-46.
[10] Collins & Evans, *Expertise*, p. 20.

expertise through sites of experiment and commercial dockyards. Reed and Barnaby, for example, nurtured a close working relationship with William Froude, drawing his test tank into the working practices of naval architects and using their authority to legitimate his activity and *vice versa*. Such connections demonstrate that expertise was made through social processes, and by tracing it through social networks I have been able to highlight the sometimes invisible nexus of science, technology and power through which *matériel* change in the Victorian navy was undertaken, negotiated and understood.

The formation of centres of expertise within the Admiralty was vital to the social network of naval architects. The union of the INA, the RSNA and the office of Chief Constructor made it possible to develop a centre of institutional power and a pool of experts within the officer culture of the Admiralty and the craftwork systems that prevailed in H.M. dockyards (as shown in chapters 1, 2 and 6).[11] This way of marking expertise was key in the 1860s as the students of a modern mathematical education entered into a naval service that was generally suspicious of their methods and intentions. '[T]hey were treated with suspicion and dislike by the uneducated members of the profession, who unfortunately had too much influence at head quarters', Woolley explained at an early meeting of the INA, 'the old cry of want of experience was raised against them, and the values of their services, were for many years – the best years of their lives – lost to the country.'[12]

The authority of invisible technicians contained certain restrictions. Invisible technicians had little authority in conflicts with other experts whose skills resonated in the public sphere. In 1874, Froude testified to a committee on scientific education, during which he alluded to the *Captain* catastrophe to demonstrate that sailors were more trusted than men of science because non-experts could associate more with their

[11] In the same way, the marking of expertise through social and institutional processes was vital to the process of excluding actors who the social network of naval architects felt did not share their skills and knowledge.
[12] Joseph Woolley, 'On the education of naval architects', *Transactions*, 5 (1864), pp. 262-271, esp. 262.

narratives of visual observation and tacit experience. 'Mr. Reed's strongly urged objections to the ship,' Froude told, 'though based on scientific grounds, were overborne by ideas which relied simply on seamanship and traditionary knowledge.'[13] The institutional and public struggle for authority between naval constructors and naval officers was only settled when Barnaby and Froude were able to demonstrate publicly their ideas and the value of experiment in their trials with H.M.S. *Devastation*.

Froude encouraged the government to establish a distinct sphere of influence for scientists and engineering experts, especially in industries like shipbuilding that were 'carried on on traditionary principles'. The mathematician suggested that a standing committee of scientific advisors could dispense their wisdom on the application of scientific knowledge to industrial problems.[14] Froude did not secure government recognition for the scientific community at large, but he personally became a single, socially connected expert that the Admiralty could call on to respond to technical problems as they developed.

Froude's brand of expertise was demonstrated when, in 1872, the Admiralty asked him to investigate a proposal for a polysphenic rocket ship. The reverend Charles Meade Ramus caught the attention of the Board of Admiralty and members of parliament when he claimed to have invented a ship capable of reaching 40, 50 even 60 knots. Ramus had undertaken a series of model experiments that he believed demonstrated that if a polysphenic ship (a hull shape of two inclined steps, like two scalene triangles in sequence) reached a specific speed, it would lift out of the water, reducing the resistance profile of the vessel and then skim on the water surface.[15] Ramus was educated at Cambridge, had a gentlemanly living as a Rector, performed experiments in a local pond

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[13] *Royal Commission on Scientific Instruction and the Advancement of Science. Minutes of evidence, appendices, and analyses of evidence* (1874), II:105.
[14] Ibid., II:149. Froude's opinion was shared by Thomson and many other Victorian men of science. Ibid., II:105.
[15] Charles Ramus to the Lords of the Admiralty, 12 April 1872, in [Lord Commissioners of the Admiralty], *Correspondence between Admiralty and Rev. C.M. Ramus on certain experiments (relating to Hull Designs)* (1874), pp. 3-4.

and alleged to have experimental data to substantiate his arguments. If the Admiralty considered a surface comparison between Froude and Ramus they would doubtless have appeared similar. Ramus, however, fell victim to the discipline formation, institutional power and actors networks through which Froude was raised to the authority of a scientific expert.

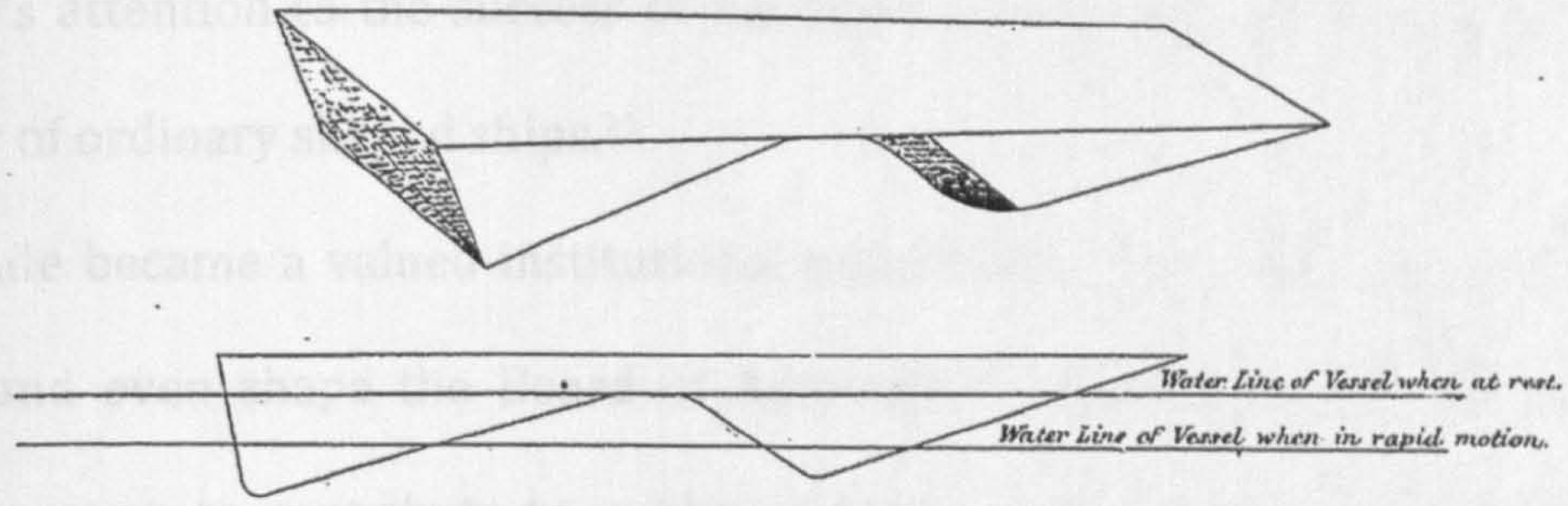

Figure 7.1 Ramus' polysphenic ship

The Admiralty, wishing to maintain secrecy and retain possible patents, ordered Froude to study Ramus' proposal.[16] Froude used the test tank system to manufacture and test the models Ramus prescribed. His report on the polysphenic ship noted that although the idea seemed plausible from visual examination and prima facie analysis, the reality of 'obliterating resistance at extreme speed is altogether illusory.'[17] Froude demonstrated that Ramus had miscalculated the power needed to propel an actual ship and that his scale-comparison was flawed. A speed of approximately 250 knots was required before the ship's resistance profile was lower. Ramus publicly responded to Froude's report in which he deferred to Froude's general skill but maintained that there were specific miscalculations in his method and that the results originally speculated in the polysphenic ship model were achievable in an actual ship.[18] 'I am convinced', Ramus wrote in a published paper, 'that no such exorbitant amounts of power as those

16 Vernon Lushington to William Froude, 12 April 1872, in Ibid., p. 3.
17 [Report of] Experiments to determine the resistance at various speeds of a ship of 2,500 tons, designed by the Reverend C. Meade Ramus, in Ibid., p. 24.
18 Ramus to Lushington, 20 December 1872, in Ibid., p. 29.

mentioned by Mr. Froude will even be required'.[19] Ramus continued to suggest ship shapes, inventions and model data to the Admiralty for investigation, and Froude was continually consulted to examine their accuracy.[20] As with his report on the *Devastation*, Froude used a situation that attracted the interest of hopeful admirals to demonstrate again the accuracy and authority of his model experiments, directing the Board of Admiralty's attention to the success of his system to use models to predict the actual behaviour of ordinary shaped ships.[21]

Froude became a valued institutional expert with the power to resolve technical disputes and even shape the Board of Admiralty's appreciation of 'science'. He was unable, however, to contribute to public understandings of the value of 'science', but public debates following the loss of the *Captain* and trials of the *Devastation* moved the question of expertise into the public sphere. The public marking of expertise constituted a very different process, dependent on a much larger audience being needed to recognise expertise (trust in authority). Froude was aware that he did not have a stock of credibility and authority with the naval element when he began his test tank experiments. In 1869, he told Reed of his 'doubt whether I have *name* enough (you see I don't doubt my merits) to be trusted with such an important job by the public.'[22] The wider public recognition of expertise brings our attention both back to debates surrounding the rhetorical use of words like 'science' and 'experience' to nurture

[19] Charles Ramus, *The Polysphenic Ship: or, the possibility of a greatly increased speed at sea proved by new experiments with an appeal to the government to publish the experiments made by the Admiralty to test the inventor's proposals* (London, 1874), p. 7.
[20] These inventions included a polysphenic ship propelled by rockets that Froude found would not skim but launch out of the water, spinning around as it elevated. *Engineering* followed the developments, noting, 'Mr. Froude wouldn't like to say how or with what result the ship would come down again.' See Charles Ramus to the Lords of the Admiralty, 15 February 1877, London, TNA, Admiralty papers 166/167; 'The Ramus Experiment', *Engineering*, 29 January 1875, p. 90; 'Admiralty Alternative', *Funny* Folks, 108 (1879), p. 108.
[21] Froude to Lushington, 13 April 1872, in *Admiralty and Ramus*, p. 5.
[22] Froude to Edward Reed, 20 January 1869, Admiralty papers 116/137.

authority (see chapter 6) and issues surrounding audiences, popular perception and the popularisation of the skills of naval architects like those who led the INA.[23]

This thesis has traced various public definitions of 'science'. Naval officers like George Elliot and Edmund Fishbourne persuasively conceived of a 'science' that was contrary to the ideas of Froude, Reed and William Thomson. John Newman conceived of a 'scientific' proof for Catholicism that played on the limitations of 'scientific' and 'personal' certainty. Meanwhile, naval architects sought to define 'science' as a collection of specific knowledge, theories and practices. In each of these examples 'science' was understood through the cultural terrain on which it was laid – and only credible and authoritative if that terrain was trusted.[24] To demonstrate this I will explore how the 'scientific' bureaucracy formed after the 1854 Northcote-Trevelyan government reforms lost credibility and was replaced by administration through 'scientific' experts in the wake of a public enquiry into the wreck of H.M.S. *Megaera* (1871).

The Northcote-Trevelyan reforms aimed to replace the gentlemanly traditions of the British civil service with a 'scientific' bureaucracy that reflected the economic themes of efficiency and economy common to early- and mid-Victorian politics.[25] The new bureaucracy was termed 'scientific' due to its underlying empirical system – not by virtue of the authority of scientific experts who had been recognised as such by the scientific community.[26] The soundness of this empirical system came under attack following the shipwreck of the *Megaera*, a naval troop ship carrying almost four-hundred sailors to Australia that was beached when its crew discovered large holes in

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[23] For recent reflections on these issues, see Bernard Lightman, *Victorian popularizers of science: designing nature for new audiences* (Chicago, 2007), pp. 1-38; James A. Secord, *Victorian sensation: the Extraordinary publication, reception, and secret authorship of* Vestiges of the natural history of creation (Chicago, 2000), pp. 155-298.
[24] Thomas Gieryn, *Cultural boundaries of science: credibility on the line* (Chicago, 1999), pp. 1-36, esp. 4.
[25] For the Northcote-Trevelyn reforms see Jon Agar, *The government machine: a revolutionary history of the computer* (Cambridge, MA, 2003), pp. 45-74. For the culture of economic thought and practice see G.C. Peden, 'From cheap government to efficient government: the political economy of public expenditure in the United Kingdom, 1832-1914', in Donald Winch & Patrick O'Brien (eds.), *The political economy of British historical experience, 1688-1914* (Oxford, 2002), pp. 351-80.
[26] John Scott Russell's criticism of Victorian government, examined in chapter 1, demonstrated this point.

its iron hull. A government commission examined why the *Megaera* had been put to sea in a state of disrepair, discovering evidence of widespread administrative incompetence, neglect of technical issues and under spending at the Admiralty.[27]

The Admiralty was widely represented in the Victorian public sphere as a traditional and old fashioned department run more on upper class social connections. The evidence heard by the *Megaera* commission supported those claims. It also gave rise to concerns that the governmental sense of empiricism rested on the managerial skills on administrators rather than on the merits of professional officers and technical experts.[28] These criticisms were given a label when the secretary to the Board of Admiralty, Vernon Lushington, described Childers' board as a 'phantom board'. Lushington described a series of bureaucratic failures, among which were letters left unopened or unregistered, little communication between Admiralty departments (specifically communications involving matters of ship maintenance), lack of departmental supervision and no regular board meetings.[29]

[27] Norman McCord, 'A naval scandal of 1871: the loss of H.M.S. *Megaera*', *Mariners Mirror*, 57 (1971), pp. 115-34.
[28] For the system of administrators and secretaries whose influence steadily grew within the Admiralty see C.I. Hamilton, 'Expanding naval powers: Admiralty private secretaries and private offices, 1880-1945', *War in History*, 10 (2003), pp. 125-156.
[29] 'The Megaera commission', *The Times*, 19 January 1872, p. 6.

THE "PHANTOM BOARD."

MR. BULL. "GHOSTS, BY JINGO!"

[*What else did he expect to see at the Admiralty, after* MR. VERNON LUSHINGTON'S *awful Revelation?*

Figure 7.2 'The "Phantom Board"'.

The phrase 'phantom board' caught public attention as an apt description for Childers' board. A verse in *Punch*, inspired by Lushington's condemnation of his own Board read,

> Behold, the phantom "my lords"
> Who sit upon phantom Boards,
> Conducting, with dimness and dizziness,
> An empty shadow of business.
> Their senile imbecility
> Ruins our fleet's utility,
>   And they gnash their gums
>   At whose comes
> To expose their lack of ability![30]

The popular presentation of the *Megaera* commission's condemnation of the Admiralty also highlighted the recent loss of the *Captain* (see the scrolls and skeleton sailor in figures 7.2 and 7.3 respectively) and emphasised the perception that Admiralty administrators were not prepared, or to be trusted, to handle the shipbuilding programme upon which British national security and commercial prosperity depended.

[30] 'The "Phantom Board"', *Punch*, 3 February 1872, p. 48.

Figure 7.3 '"The Phantom Board"'.

Change came in 1872, when George Goschen replaced Childers as First Lord and closed the book on many of his predecessor's administrative practices.[31] On 15 May 1872, a minute from the First Lord ordered that letters would be read every day at a meeting attended by the Sea Lords, but not the Controller.[32] Most significantly, however, an order at the end of 1872 established a council of construction, consisting of the chief naval architect, the engineer in chief, the surveyor of dockyards, two constructors and the professional assistances to the surveyor. The council was presided over by the chief naval architect, Barnaby, who would have overall control to resolve conflicts between the individual offices that comprised the council. Barnaby's control over the constructors department (with the exception of the Controller) was thus formerly recognised, and in turn he was officially made responsible for all

[31] For Childers' reforms see C.I. Hamilton, 'The Childers Admiralty reforms and the nineteenth-century "revolution" in British government', *War in History*, 5 (1998), pp. 37-61.

[32] 'Minute of First Lord dated 15 May 1872', London, NMM, Milne papers 146/2; 'At the Court at Windsor Castle, the 19th day of March', 1872, Milne papers 146/2

designs, repairs and alterations to naval ships, limiting the chance of another *Captain*, while tightening the internal management of maintenance.[33]

7.2 PUBLICISING NAVAL SCIENCE

Edward Reed, Nathaniel Barnaby and William White

The processes of making 'expertise' that I have examined tended to be private so not to arouse suspicion, but they could also be publicly negotiated and managed when it was advantageous. By utilising the tools of media representation and social control, which in the history of discipline formation have been as valuable as the fruits of experiment and experience, scientific experts billed themselves as the final arbiters of what was safe, efficient and good. I now develop this further by examining a series of case studies that reveal how Britain's three leading naval architects between 1863 and 1902 negotiated the issues of expertise and authority as they publicised naval science. These actors had the difficult task of describing their work in a complicated branch of physics in order to establish their expertise in the eyes of a naval community largely uneducated in science and mathematics (until the foundation of a new pedagogical paradigm at the Greenwich Naval College in 1872 and subsequent motions towards engineering training for naval officers).[34] Reed, for example, lamented that the 'practical sailor' resisted 'the beautiful science of the late Mr. William Froude' because it appeared to be too theoretical.[35] The case studies I draw on identify two different approaches to publicising naval architecture.

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[33] Navy (Controller's department), 'Copy of an official memorandum issued at the Admiralty on the 16t day of December 1872, relating to the duties of the Constructive and Engineering Department', Milne papers 146/2.
[34] H.W. Dickinson, *Educating the Royal Navy: eighteenth- and nineteenth-century education for officers* (London, 2007), esp. 131-151, 177-198.
[35] Edward Reed, 'On the value of technical education to the shipwright and shipowner, 25 November 1886', in *The Worshipful Company of Shipwrights lectures* (London, 1886-87), pp. 3-28, esp. 20.

Reed, following his resignation from the Admiralty in 1870, became a director of Earle's shipyard in Hull where he worked with his former superior, Robert Spencer Robinson, who was the firm's chairman. Reed used his public profile following the *Captain* catastrophe to promote simultaneously his expertise as a naval architect and redress the criticisms that the naval community had made against him. White believed that the reason for Reed's constant stream of letters to *The Times* 'is to be found in his desire to keep himself before the public as an authority on naval affairs ... Mr. Reed's ultimate object is no doubt to get into Parliament'.[36] Indeed Reed unsuccessfully contested Hull as a Liberal in 1873. In 1874, he was elected in Pembroke, and then in Cardiff in 1880. As a parliamentarian Reed portrayed himself as the resident expert of naval architecture, even naval affairs in general. In 1874, he repudiated Edward Watkin's criticisms of the *Devastation* and in 1886 he offered himself to William Gladstone as secretary to the Admiralty.[37]

> On the opposition side of the House will sit Lord G. Hamilton, Messrs Ritchie & Bartlett (in no very amiable mood probably) ... & other members likely to give no little trouble on naval subjects, and I cannot doubt that you will regard it as reasonable to afford your First lord (who I must respectfully hope will this time be in the Commons) such assistance as my life-long career in & on behalf of the navy may have fitted me to render.[38]

Reed served briefly as a Lord of the Treasury in Lord Ripon's Board, during which he sought to establish himself and former assistant, Francis Elgar, as a powerbase within the Admiralty in opposition to the constructors' department (see below).

In 1872, Reed established *Naval Science*, a periodical 'for the purpose of diffusing a knowledge of naval science, in the broadest sense of the words, throughout the world at large.'[39] Reed, who prior to serving the Admiralty had edited the *Mechanics Magazine*, noted that the *Captain* and *Megaera* affairs had excited the Victorian public's interest in

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[36] William White to Jane White, 2 November 1872, quoted in Frederic Manning, *The Life of Sir William White* (London, 1923), pp. 46-47.
[37] 'Naval construction of ironclads', *Hansard*, 18 May 1874, pp. 414-426.
[38] Edward Reed to William Gladstone, 28 January 1886, London, British Library, Gladstone Papers vol. ccccix, add. ms. 44494, folio 87.
[39] Edward Reed, 'Naval science: editor's introduction', *Naval Science*, 1 (1872), pp. 3-8, esp. 3.

the subject.[40] The periodical only ran for four years, but during that time it attracted some key authors, including Joseph Woolley and Froude, and its articles were noted in other publications.[41] In aiming at a wide audience Reed hoped that *Naval Science* would shape public discussion of naval science. He specifically remarked that '[w]e shall not deprive ourselves of the pleasure, or our readers of the advantage, to bring to account some of those gentlemen who make the Navy a stock subject of their extravagant attacks and misrepresentations.'[42] Thus Reed saw his new publication as helping to instruct the public to judge between 'experts', be they naval constructors or officers, so to mark the boundaries of the naval constructor's authority.

Reed's publishing project conveyed a strong belief that the next war would be decided by scientific knowledge and mechanical skill.[43] Thus he used his periodical to mark who were those men of science whose skills were vital to Britain's naval security.[44] In reporting developments like Ramus' polysphenic ship, Reed focused on the skills and expertise of a social group of engineers, men of science and naval officers connected through the INA. In reporting these events Reed, who had been instrumental in establishing Froude's position at the Admiralty, paid more attention to the methods Froude used to dismiss the validity of Ramus' idea than the idea itself. Such reporting helped describe what Froude did with his models and demonstrate 'the very high esteem in which Mr. Froude is deservedly held by the Admiralty and by the country at large as an investigator of Naval Science.'[45]

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[40] Ibid., p. 3.
[41] Froude to James Robert Napier, 18 October 1872, Glasgow University, Archive service, Napier papers 90/2/4/51.
[42] Reed, 'Naval science', p. 6.
[43] Ibid., p. 6.
[44] For the power and duties of the editor in transferring knowledge and techniques by 'monitoring', 'digesting', 'abstracting' and 'translating' specific sciences for wider audiences, see William H. Brock, 'The making on an editor: the case of William Crookes', in Louise Henson, Geoffrey Cantor, Gowan Dawson, Richard Noakes, Sally Shuttleworth and Jonathan R. Topham (eds.), *Culture and science in the nineteenth-century media* (Aldershot, 2004), pp. 189-198.
[45] 'Admiralty experiments upon forms of ships and upon rocket floats conducted by Mr. Froude', *Naval Science*, 4 (1875), pp. 37-51, esp 51.

Reed similarly used Froude's expertise to attack Fishbourne's works on naval architecture. In 1874, Fishbourne published *Our ironclad and merchant ships*. This was a detailed discussion of hydrostatics and hydrodynamics, written with the use of algebraic representations of theories and diagrams. Fishbourne even sought a foreword for the book from George Stokes, Lucasian Professor of Mathematics at Cambridge.[46] The technical press devastated Fishbourne's work, together with his attempt to cast aspersions on Froude and the safety of the Victorian navy. One article in *Engineering* compared the admiral to Don Quixote in his 'vain, prideful opposition to authority'.[47] Reed similarly helped to mock Fishbourne. 'The whole book from beginning to end,' *Naval Science* noted, 'forms the funniest volume which has ever fallen under our notice.'[48] Reed's periodical aligned Fishbourne with the RUSI and noted the credibility the admiral had among sailors. For that reason numerous articles in *Naval Science* sought to 'correct' Fishbourne and 'all the violence which these novel theories offer to sound science'. This was partially attempted by explaining in laymen's' terms the work of 'experts' like Froude, Reed, Barnaby, Woolley and Russell.[49] With these tactics Reed simultaneously excluded Fishbourne from the social domain and networks of technical expertise that the engineering and naval science commuunities sought to develop in the 1860s and 1870s, and offered himself and his social network as experts to instruct inexperienced, unknowing naval officers.

Reed's style of publicising naval science carried a heavy notion of mastery and subservience regarding the naval constructor-officer relationship. He painted Fishbourne, Elliot, Ryder and the RUSI members who followed them as unaware and unready to deal with technical issues, leaving many naval officers offended and their

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[46] Edmund Fishbourne to George Stokes, 19 January 1877, Cambridge University, Manuscripts Room, George Stokes papers F182. Stokes declined the offer, but Fishbourne continued to privately stress to Stokes the need for the public to be made aware of the 'the danger of following Mr. Froude's views.' Fishbourne to Stokes, 14 March 1877, Stokes papers RS1275.
[47] 'Sir Edward Watkin on naval architecture', *Engineering*, 22 May 1874, p. 373.
[48] 'Admiral Fishbourne on naval architecture', *Naval Science*, 3 (1874), pp. 138-144, esp. 144.
[49] 'Admiral Fishbourne on Naval Architecture', *Naval Science*, 1 (1872), pp. 366-384, esp. 366.

superiors at the Admiralty aggravated. Reed suggested in his editorial introduction to *Naval Science* that,

> There is many a captain at this moment in command of an important iron-clad, costing from a quarter to half-a-million sterling, who is ignorant even of the thickness of his ship's armour ... This ought not to be; it hurts the spirit and sense of responsibility of our officers; it lowers their respect for the sea lords of the Admiralty, who ought, as they reasonably think, to understand the value and necessity of such knowledge to those in command of ships; and it would impose needless risks[.][50]

George Hamilton, first lord of the Admiralty to Lord Salisbury (first for 1885-86 and again for 1886-92 following the formation of a new government) believed Reed was 'a man of considerable ability' but after failing as a commercial shipbuilder 'became a bully of the Admiralty.'[51] Hamilton's point was well received when Reed's approach to publishing the skills of naval architects was compared to Barnaby and White's.

Barnaby balanced Reed's antagonism towards the naval community by actively encouraging naval officers to examine the state of naval architecture. In two papers presented at RUSI, Barnaby utilised a shared knowledge between the officer and constructor to establish a forum between the two social groups. In 1874, Barnaby presented a sketch of 'developments' in ship design since H.M.S. *Warrior*, emphasising that no naval commentator could say with accuracy what direction design was heading. The naval architect acknowledged that the armour of vessels such as the *Warrior* was inadequate protection against the guns employed in the 1870s. Admitting these problems, Barnaby sought to examine how 'efficiency' in ship design was a construct of many design features, not just protection. Citing the example of the *Devastation* class, Barnaby praised the spirit of 'boldness' lately employed by the Admiralty in testing new modes of design and shapes. He illustrated his points with reference to the extensive collection of ship presentation models (not like Froude's models) held by the institution,

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[50] Reed, 'Naval science', p. 6.
[51] Manning, *Life of White*, p. vi.

with which RUSI members were familiar.[52] The following year, Barnaby used the much publicised Hotspur-Glatton ramming experiment to examine the value of rams as part of a ship's offensive system and discuss the knowledge produced by experiment. Barnaby's paper clarified the belief of naval architects that the only adequate proof for certain conclusions in naval architecture was through scientifically managed experiments, while keeping open a dialogue with the concerns of naval officers over offensive and defensive power.[53] Barnaby's strategy of open discussion and reaching out to the RUSI established a fresh relationship between constructors and officers.

White employed a similar strategy to reach out to naval officers and engage with their concerns in a way that did not antagonise, but quietly shaped their appreciation of technical and engineering problems. Key to this process was White's extensive output of articles on ship design and naval matters for the major Victorian periodicals, including *Westminster Review, Gentleman's Magazine, Nineteenth Century* and *Fortnightly Review*.[54] White's articles provided a space to distribute a perspective on the ship from the point of view of the architect. Such a perspective had hitherto been absent, or limited to criticism of Reed's aggressive pursuit of his own agenda. White's first articles concerned the design of American monitors and the *Captain*. He dealt with the technical complexities that these subjects embodied in a way in which general readers could understand and appreciate, popularising a scientific view of ship design.[55] In 1914, Admiral Lord Charles Beresford commended White's role in popularising the role of naval architecture in naval matters, and for restoring 'to the ship of war the symmetry and beauty of design which had been lost during the transition from sail to steam.'[56]

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[52] Nathaniel Barnaby, 'Modern ships of war, as illustrated by the models in the Royal United Service Institution', *RUSI Journal*, 16 (1873), pp. 58-77, esp. 60, 63-64.
[53] Nathaniel Barnaby, 'Lessons from the "Hotspur-Glatton" experiment', *RUSI Journal*, 17 (1874), pp. 294-309, esp. 294-95.
[54] White also published work for the scientific community in *Philosophical Transactions of the Royal Society* and *Nature*, and the naval community in *RUSI Journal* and *Colburn's United Service Magazine*.
[55] William White, 'The story of the Captain', *Gentleman's Magazine*, 5 (1870), pp. 700-714.
[56] Charles Beresford, *The memoirs of Admiral Lord Charles Beresford* (2 vol., London, 1914), 2: 350-52.

The key to Barnaby and White's conciliatory approach to publicising and popularising naval science was that they simultaneously taught content and context. Barnaby and White, unlike Reed, reached out to naval officers to instruct, inform and implicitly mark their expertise. Explanations of technical issues like stability, resistance, armour protection and propulsions were based on the same sources and authorities discussed by Reed in *Naval Science*; but where Reed fortified himself within the engineering community, dismissed sailor's experiences and preached that the next war would be won on scientific knowledge and mechanical skill, Barnaby and White addressed sailors at RUSI, listened to their concerns and actively, even directly, shaped their appreciation of science and mechanics. If naval constructors could shape the attitude of young naval officers to the science of naval architecture and the expertise of constructors, then perhaps they could shape long term naval and shipbuilding policy.

When the RSNA was moved to Greenwich in 1872, and the educational establishment for naval architects placed within the training system for all naval officers, White, who lectured at the school, found he had an opportunity to reach out beyond young naval architects. In 1875, he designed and delivered a series of lectures on 'The behaviour of ships' that attracted naval officers. Influential admirals like Astley Cooper Key encouraged White to turn the lectures into a book, *Manual of naval architecture* (1877).[57] Years later, in a letter to a naval officer, White explained that the '"Manual of Naval Architecture" ... was written, as far as was possible, in popular language for the benefit of naval officers, yachtsmen and others.'[58] 'Writing largely for the information of seamen, it was my endeavour to awaken in their minds an intelligent interest in the observations of deep sea waves and the behaviour of ships', White wrote

[57] White to John Murray, 17 May 1875, quoted in Manning, *Life of White*, pp.63-64.
[58] White to Captain Robinson, 16 May 1911, [miscellaneous letter attached to a 1900 edition of William White, *Manual of naval architecture for the use of officers of the Royal Navy, officers of the mercantile marine, yachtsmen, shipowners, and shipbuilders* (London, 1877, Fifth Edition, 1900)], London. National Maritime Museum.

in the book's preface.[59] White's *Manual of naval architecture* was made a required textbook for students at Greenwich and placed onboard every H.M. ship.[60]

The book covered a range of issues concerning waves, the ship, armour, armaments and engines. The chapters on resistance provide a particularly useful way to appreciate how the major Victorian ideas on hydrodynamics were conveyed to the reading public. White described Rankine's stream-line theory and the elaborate experiments with models that Froude undertook in the test tank. An article in *Fraser's Magazine* emphasised that a 'notable feature of the book is the full explanation of the *modus operandi* of making experiments on the qualities and performances of ships, as well as of the purposes for which such experiments are undertaken', reflecting the significance of teaching a context for naval architecture.[61]

White's literary activity and public papers opened, examined and explained technical debates surrounding ship design for a wider audience. They also established his reputation with naval officers as an authority on the ship. In 1885, Captain (later Admiral) Gerald Noel wrote that 'I should be exceedingly pleased to see you appointed in his [Barnaby's] vacancy ...and [I] feel confident that the department will much benefit by the vigour and ability you are able to bring into it.'[62] Noel added, 'I trust that you will recognise how necessary it is for the welfare of the Service, and the good of the country in general, that the Constructive Department and the Navy (as represented by naval officers) should pull together, and not permit any breach to be made between them, by those who may be under the influence of petty jealousies.'[63] White's reputation with naval officers was invaluable against this backdrop of jealousies and personal disagreements (see chapter 6) that tainted the status of science and mechanics in the

[59] White, *Manual of Naval Architecture*, p. vi.
[60] The book was also translated into Italian, German, Russian, French and Japanese at the request of foreign navies who also wished to use the *Manual* as a textbook for officers. Manning, *Life of White* (London, 1923), p. 61.
[61] [Anon.], 'The science of naval architecture', *Fraser's Magazine*, 99 (1878), pp. 269-276, esp. 275.
[62] Gerard Noel to White, 1885, quoted in Manning, *Life of White*, p. 182.
[63] Ibid., p. 182.

navy. Admiral Philip Colomb underlined this when he wrote, '[w]e all know you pretty well from your writings and lectures, and there is no doubt that you will take with you into office a large amount of purely naval support.'[64] Like Noel, Colomb underscored his letter with the hope that 'we shall look for and expect to find the good of your designs, and you will look for and expect to find the good of our experience.'[65]

7.3 DESIGNING LABOUR AND SHIPS
William White and the Royal Corps of Constructors

In an 1881 volume of the *Westminster Review*, White singled out Rankine and Froude as having 'done more original work during the last twenty years than any other investigators at home or abroad', but at the same time recognised that neither of them were naval architects.[66] This was a concern to naval architects, like White, who recognised that if the 'science' of naval architecture was to flourish, the sophisticated scientific knowledge investigated in Britain ultimately had to be embodied in ships rather than scientific journals - thus demonstrating the promise that science could guarantee naval power. The mechanisation of the ship - and its association with 'science' and 'modernity' - was shaped by work and labour organisation in Her Majesty's dockyards and shipboard activity.[67]

Issues of expertise are clearly wrapped up in the culture of authority, professionalization and social status. Chapter 2 showed that craft-orientated systems of work and knowledge predominated in the dockyard for much of the nineteenth century. Engineering science, in contrast, was a young profession full of actors concerned with

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[64] Philip Colomb to White, 1885, quoted in Manning, *Life of White*, p. 182.
[65] Ibid., pp. 182-83.
[66] William White, 'The progress of shipbuilding in England', *Westminster Review*, (1881), quoted in Ibid. p. 11.
[67] For technology and modernity in Britain see Bernhard Rieger, *Technology and the culture of modernity in Britain and Germany, 1890-1945* (Cambridge, 2005). For debates surrounding how the Victorian's understood modernity as a steady and continuous building on tradition and the present see essays in Martin Daunton & Bernhard Rieger (eds.), *Meanings of modernity: Britain from the late-Victorian era to World War II* (Oxford, 2001).

their 'social mobility on both personal and professional levels'.[68] The building of expert status for scientifically trained naval architects was thus part of building social and institutional power. This section examines how scientifically trained constructors asserted institutional control over both designing ships and building them, thereby enlarging the authority of 'science' beyond the limited sphere it occupied in a craft-orientated system.

In 1880, White, then assistant to Barnaby, devised a new system for the training of ship builders and designers, the organisation of the Admiralty constructors department and the management of dockyards through the foundation of a Royal Corp of Constructors. The organisation of labour in the dockyards had tended towards a craft-work culture that provided, White wrote, 'for the entry of *workmen*'. As such, students who had attended the Kensington school or the Royal Naval College were still required to enter the dockyards as 'shipwrights': as assistants to dockyard draughtsmen and dockyard foremen. If graduates were fortunate, however, they were sent to the Chief Constructor to become one of his professional or personal assistants, but only a small number of men were employed in that service.[69] The usual form for advancement through the labouring positions at dockyards to the Constructors office was by competitive examination. The exams were based on the practical experiences of craftwork and not 'for any display of the advantages of the special training received at the [Royal Naval] College.'[70]

The limited number of authoritative, well-paid jobs in the Admiralty for naval architecture graduates deterred many from remaining in service to the state. Opponents of advanced training at the Royal Naval College claimed it should be disbanded because

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[68] Ben Marsden & Crosbie Smith, *Engineering empires: a cultural history of technology in nineteenth-century Britain* (Basingstoke, 2005), pp. 254-255.
[69] White to Nathaniel Barnaby & Dr. Hirst [Inspector of Naval Studies at Greenwich], '[Memorandum recommending the formation of a Royal Corps of Naval Constructors], 2 February 1880, quoted in Manning, *Life of White*, pp. 89-93, esp. 89.
[70] Ibid., p. 89.

the State did not gain from the education provided. White believed that was a falsehood and that 'the transfer of the services of these gentlemen from the Admiralty to the private establishments does not involve a real loss to the country'. White was certainly on the defensive as both a student and then instructor at the school, and his response reveals his belief that an enlarged community of scientifically trained experts spread across private and public service was beneficial to the country. '[I]t simply involves a change in the department of the national service', he wrote, and his 1880 plan for a Royal Corps of Naval Constructors reflects this.[71]

The establishment of the Royal Corps of Naval Constructors was conceived to change the status, authority and number of naval architects in relation to the less educated dockyard workers and foremen, and the bureaucratic administrators who had come under attack during the *Megaera* affair. In effect, the scheme aimed to establish naval constructors as institutional superiors to shipwrights and draughtsmen, and educated experts within the Admiralty machinery. The RSNA had given naval architects and marine engineers the collective organisation that a number of emerging middle class professions had sought for themselves. Such symbols of professional organisation distinguished the upper middle class from the lower, members of which tended to take advantage of the mechanics institutes, polytechnics and Workers Educational associations established by their social superiors.[72]

White's Royal Corps of Constructors was designed to establish scientifically trained, socially superior members of the middle class at the top of what Harold Perkin referred to as the emerging 'vertical career hierarchy' that was at the core of the late

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[71] W[illiam].H. W[hite], 'Three English schools of naval architecture', *The Annual of the Royal School of Naval Architecture and Marine Engineering*, 4 (1874), pp. 7-26, esp. 23.

[72] Harold Perkin, *The rise of professional society: England since 1880* (London, 1989), pp. 85, 96-99. It is essential to establishing the broad social features of Victorian professional culture to compliment the more internal processes of specialisation and disciplinary expansion that an older historiography of science professionalization emphasises. See for example, W.H. Brock, 'Advancing science: the British Association and the professional practice of science', in Roy MacLeod and Peter Collins (eds.), *Parliament of science: the British Association for the Advancement of Science, 1831-1981* (Northwood, 1981), pp. 89-117.

Victorian professional society. The need to establish a dominant position in the new professional society was driven by the necessity to hold status and power, especially in occupations intrinsically linked to government and in industries that had undergone swift transformations (such as the emergence of iron, steam and the skills needed to negotiate them).[73] The Admiralty only had a limited number of well paid, authoritative, jobs for educated naval architects. As such applicants for the handful of constructor jobs available in the Admiralty were required to go through extensive and extended competition. White believed that this status quo deterred men from higher social standing from entering the dockyard as 'only the sons of working men or persons in necessitous circumstances will submit to the severe competition, the rough life, and ultimate uncertainty of promotion.'[74] Similarly, the Civil Lords who traditionally administrated the public works, dockyards, storehouses and naval barracks sat on top of a glass ceiling that blocked 'craftsmen' from taking on management roles. Offices like the Director of Works were seen as apprentice positions for young MPs. Lord Clarence Paget, who was himself a Civil Lord at the Admiralty, noted that 'when Admiralty works were unimportant, this system worked well enough; but in these days about two millions are thus annually expended.'[75]

White believed the existing system of entry and promotion in the dockyard hindered the establishment of a professional class of experts – trained and educated professionals – in the dockyard. He petitioned his Admiralty superiors to reform the system 'so that the sons of persons in a good social position might be attracted into the Shipbuilding Department of the Admiralty'. To cement the reorientation from craft to scientific knowledge and management, White recommended that the Admiralty devise a new system for gaining knowledge and experience in the dockyards, different from the

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[73] Perkin, *Professional Society*, pp. 9, 17.
[74] White to Barnaby & Hirst, 2 February 1880, quoted in Manning, *Life of White*, pp. 89-93, esp. 90.
[75] *Autobiography and journals of Admiral Lord Clarence E. Paget, G.C.B.*, ed. Arthur Otway (London, 1896), pp. 364-5.

traditional apprenticeship schemes. Such a scheme should let socially superior and scientifically aware naval architects 'become Constructors, without passing through the lower grades of workmen, leading men, draughtsmen, and foremen'.[76]

The system White proposed involved making alterations to both the entry and promotion criteria and the labour organisation and divisions in the constructors department and dockyards (which had been distinctly separate Admiralty departments up until Robinson's tenure as Controller). White's proposal brought the two departments closer through the establishment of a class of 'assistant constructors', charged with supervising, but not with control over, dockyard foremen and the ranks below.[77] These assistant constructors were to be under the control of the Director of Naval Construction (presently Chief Constructor) who would continue primarily in the designing of ships but, under the proposed arrangements, would have a series of connections with the regional dockyards and eyes over the work of the foremen and draughtsmen who built the ships.[78] White's proposal responded to the criticism that the Royal Naval College was training (and the government paying for the training of) more naval architects than there were positions for. But more significantly, the proposal created a sphere of influence for naval architects over the entire shipbuilding process. If accepted, promotion and advancement through the dockyards would be based on scientific knowledge and management, rather than craft skills and experience.

White's proposal required extra funds for the proposed group of assistant constructors, which he justified through a series of suggestions to Barnaby and T. Archer Hirst. First, White argued the merits of placing naval architects in the dockyards to monitor and guarantee the work of labourers. Second, he suggested that regional

[76] White did not want this new system to exclude dockyard apprentices and workmen with ability to rise through the ranks, but under the new rules governing the path of graduates through the higher officers craft-workers were doubtless placed at a disadvantage. White to Barnaby & Hirst, 2 February 1880, quoted in Manning, *Life of White*, pp. 89-93, esp. 90.
[77] These assistant constructors were required to go to sea for two years after finishing their studies, so to experience the ship at sea and observe ocean waves.
[78] White to Barnaby & Hirst, 2 February 1880, quoted in Ibid., pp. 89-93, esp. 90-93.

dockyards might take on some designing work and in effect compete with each other to design ships much like private firms did when the Admiralty tendered ship contracts. Third, he noted that the Admiralty would be able to make use of all the students they funded through the naval college (this was admittedly a circular argument). And fourth, perhaps more interestingly given White's conscious awareness of the need to establish institutional expertise, he suggested that from time-to-time an assistant constructor could be detached from either the dockyard or the constructor's department and assigned to 'special services' that their unique standing and experience enabled. For example, an assistant constructor could be placed on 'the staff of an Admiral in command as professional adviser – a very necessary office in many types of modern ship', or on 'the inspection of works being done in foreign dockyards, taking up part of the duties regarding *matériel* usually performed by *naval attachés*' (such as Paget's clandestine survey of *La Gloire* described in chapter 1). Alternatively the assistant constructors could be appointed, as needed, to the staff of Royal Naval College instructors or sent to observe and testify to the results of trials with experimental ships.[79] Through these various suggestions White sought to justify the proposed Royal Corps of Naval Constructors as a professional body, spread across the ship design and build process, with an eye on the various divisions of labour from design to launch.

The corps would serve as an institutional control but also as an institution of knowledge. White proposed that any assistant constructor who left the Admiralty for employment in private industry would keep their title and serve as consultants to the Admiralty, thus retaining their expertise when necessary. Similarly, by putting assistant constructors on special assignment to the staff of naval officers the corps of constructors could demonstrate their expertise to the naval community.

[79] White to Barnaby & Hirst, 2 February 1880, quoted in Ibid., pp. 93-95, esp. 95

White's proposal was favourably received by Lord Northbrook's Board of Admiralty. White had an ally in the First Sea Lord Admiral Cooper Key and the Civil Lord Thomas Brassey, who was a keen populariser of naval matters and *matériel* reform. R.G.C. Hamilton, Accountant General of the Navy, also lent his support to the proposal, but was anxious to warn the Board that the scheme 'will call for the exercise of much delicacy and patience to overcome or avoid frictions between the present and future holders of professional appointments' – noting the shift from apprentices of a craft-orientated system to naval college graduates in a 'scientific-management' system.[80] Hamilton also recognised that the role of the assistant constructor as a non-controlling supervisor in the dockyard would require further definition. The corps was established on 23 August 1883, just after White had handed in his resignation to the Admiralty and joined Sir William Armstrong, Mitchell & Co as manager of warship design.

In 1885, Barnaby's health began to fail and he was ordered to take medical leave. Lord George Hamilton, who was appointed First Lord in Lord Salisbury's 1885 government, invited White to return to public service as Barnaby's replacement. On 28 July 1885, Hamilton sent White the following proposition:

> There are a number of reforms which I believe can be advantageously carried out, both in the dockyards and the Admiralty itself, and I shall personally be glad to do all I can to expedite and support any arrangements which your varied experience, in dockyards and private establishments, would advocate as tending to economy and expedition and efficiency.[81]

'[E]conomy and expedition and efficiency', the combination of these words in a seeming harmony presents a curiosity. There is nothing inherent in the notion of 'efficiency' that dictates that it was the most economical or quickest option.[82] There are benefits and costs to efficiency, the tensions between which have historically been negotiated to construct notions of efficiency. Hamilton's combination of these three 'values' in fact offers an insight into the culture of efficiency in which White was expected to work, and

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[80] R.G.C. Hamilton remarks on the proposed Royal Corps of Naval Constructors, quoted in Ibid., pp. 99-100.
[81] George Hamilton to White, 28 July 1885, quoted in Ibid., p. 179.
[82] For example, a waterwheel running at seventy-percent would be regarded as a measure of efficiency. Jennifer Karns Alexander, *The mantra of efficiency: from waterwheel to social control* (Baltimore, 2008), pp. 1-14.

in which he sought to build institutional expertise for naval constructors. In 1885, White returned to the Admiralty as Director of Naval Sonstruction, armed by Hamilton with a mission to reform the dockyards.[83]

Work in the dockyard had traditionally fallen under two heads, civil (or technical) and naval. The civil was undertaken by shipwrights and supervised by naval officers, while the naval, which included the work of the dockyard arsenals, was solely under the purview of naval officers. White wanted to reform the system of control and appoint a member of the corps of constructors to supervise the civil division and organise the work, distribution of labour and use of machinery.[84] White's credibility in bringing these reforms had been greatly improved by his activities during the five years he spent in private service at Armstrongs. During those years Reed had made a number of public criticisms of the stability of the *Admiral* class. White, who had been active in the design of the *Admiral* class, joined Reed in public but to provide a defence of the class and the Admiralty's shipbuilding policy. White acted with civility to Reed and helped the Admiralty maintain credibility and public support. White's letters to *The Times* carried favour with the naval officers and administrators. Hamilton even noted that with White in post he looked forward to sending him publicly and officially to dismiss Reed's frequent criticisms.[85]

White proposed that the Director of Naval Construction (DNC) be given the title of Assistant Controller in the hope of bringing a more formal relationship between the DNC and Controller, showing the DNC to be second in control of shipbuilding and recognising the centrality of ship design in the *matériel* concerns of the navy. The DNC was also to be given the direction of the experimental works at Haslar. The most controversial part of

[83] Hamilton later noted that 'Both White and Armstrong behaved with patriotism and promptitude', seeing as White gave up a substantial salary and Armstrong allowed the most respected naval architect of the era to terminate his contract.' Quoted in Manning, *Life of White*, p. 178.
[84] White, [Memorandum on dockyard organisation], 1885, quoted in Ibid., p. 191.
[85] Quoted in Manning, *Life of White*, p. 175.

White's scheme was the appointment of a Director of Dockyards (DoD) who would supervise work across the royal dockyards and be under the authority of the DNC.[86] The scheme was examined by Charles Ritchie's committee on dockyard organisation and approved on 1 February 1886. On the same day Lord Salisbury's government came to an abrupt end and Gladstone was invited to form a ministry. Gladstone appointed the Earl of Ripon to replace Hamilton at the Admiralty and invited Reed back to the service as a Lord of the Treasury.

Ripon's first business was to respond to the scheme Hamilton's board had taken under consideration. Ripon opposed the reorganisation as he felt that 'one of the first steps required to place our Dockyard management upon a sound footing is to establish a clear separation between the Designing and the Building Branches of the Controller's department ... I am inclined to believe that the more nearly we can treat the Dockyards as we treat private contractors the better'.[87] Ripon stressed his desire that regional dockyards compete against each other for a 'contract' to build a DNC's design. The First Lord believed that open competition in private industry was more efficient than government administration.[88] Ripon's approach was not historically favoured by naval architects and engineers. Beyond the supposed economic incentive of competition was what Russell had diagnosed as a dangerous tendency of contractors to tell builders what to do. The logic appeared to be that competition guaranteed efficient and economic ship design and construction – a claim that embodied the Victorian attitude that private industry and 'economy' was analogous to high standard design and construction. Ripon and White's respective ideals of 'efficiency' and 'economy' differed in a fundamental

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86 White, [Memorandum on dockyard organisation], 1885, quoted in Ibid., p. 193.
87 Lord Ripon, [Board minute on dockyard management], 8 march 1886, quoted in Ibid., p. 195.
88 For Victorian interest in open commercial competition as an economic, industrial and administrative model see Martin Daunton, *Wealth and welfare: an economic and social history of Britain, 1851-1951* (Oxford, 2007), pp. 115-120. Sidney Pollard and Paul Robinson suggest that the nature of competition and entrepreneur endeavour in shipbuilding, although a factor in economic and industrial practices, was conservative in contrast to other Victorian industries. Sidney Pollard & Paul Robertson, *The British shipbuilding industry, 1870-1914* (Cambridge, MA, 1979), pp. 6-8.

way. Where White advocated scientific oversight and localised collaboration, Ripon wanted competition and cost cutting.

Ripon's suggestion regarding control over the dockyard would have reversed the plans the Hamilton Board had under consideration. But more concerning to White was that Ripon wanted to appoint Francis Elgar to the post of DoD. Elgar had been Reed's closest ally at the Admiralty, and his return to service as DoD was doubtless connected to Reed's return as Lord of the Treasury. Elgar's appointment may be interpreted as Ripon and Reed's attempt to establish their own authority in the ship building process – particularly as Ripon intended for the DoD to be independent of the DNC. White's early twentieth century biographer writes that Ripon and Reed took a series of measures to make White's position untenable, leaving the position of DNC open to a rival, such as Elgar. These measures included questioning the relationship between White and Armstrongs, the nature of the consultancy work White performed for his former employer and dropping innuendo as to White's repute.[89]

White responded tactfully but forcefully to Ripon with a memorandum that defended managing the dockyards individually, but under the supervision of a Director of Dockyards who took orders from the Controller and Assistant Controller. White urged 'that the greatest hope for economy and efficiency in the Dockyards is to be found in the development and strict enforcement of *local responsibility*.' Aware that Ripon had shrouded his proposal in the rhetoric of private enterprise, White stressed his 'experience outside the public service, in creating and organising one of the largest shipyards in the country'.[90]

White believed '[a] centralised system of management is hopeless', and 'economy and expeditiousness and efficiency' was to be found through closely managing the work of labourers, utilising the role of the DoD as a 'high [quality] technical officer' overseer.

[89] Lord Ripon, [Board minute on dockyard management], 8 march 1886, quoted in Manning, *Life of White*, pp. 204-212.
[90] Ibid., p. 199.

To lend further weight to his defence of the system White offered testimony to the Admiralty's policy of sending officers to oversee the work of private firms building for the Admiralty. White also explained that there was no such system within the Admiralty's dockyards, and that the DNC hitherto relied on his social network and contacts within the individual dockyards. Moreover, White put his own credibility on the line, and told Lord Ripon in no uncertain terms 'that if there were to be any variation in present practice in the foregoing particulars, I should decline to accept any responsibility for the realisation of the intentions of the designs on ships building in the dockyard.'[91]

White successfully halted the First Lord's proposed rejection of the dockyard reform, but was not able to avoid the problem which arose from Ripon's appointing Elgar to the post of DoD. Ultimately White's protestations were unnecessary as, in August 1886, Gladstone's government came to an end after only eight months. Hamilton returned to the Admiralty and reemphasised his support for White and his reform agenda.

7.4 CONTROL OVER THE MECHANICAL SHIP

Nathaniel Barnaby and the morals of a mechanical navy

I close this chapter, and the body of the thesis, with a unique episode in the public writings of naval architects that, unlike any other, captures the co-productionist idiom that this study has traced from the early Victorian era, namely, that Victorians made their ironclad fleet while their ironclad fleet simultaneously remade their identities and social order. In *Naval development of the century* (1902), Barnaby placed the narrative of political, naval, social and technical 'development' within a framework of ethics. He

[91] Ibid., p. 200.

considered the following questions: 'what was Britain's right to the sea?' 'What was the best preparation for maintaining peace?' 'And was war righteous?' Barnaby shed his personal Christian perspective on many of these questions, frequently asking whether 'technological' developments were just and how unprecedented destructive force ought to be understood.[92]

W.H. Davenport Adams began a chapter of his *Famous ships of the British navy* (1878) with the following quotation from Carlyle's *Signs of the times*, 'It is said that ideas produce revolutions; and truly they do – not spiritual ideas only, but even mechanical.'[93] It suggests that in the nineteenth century 'mechanisation' was one of the greatest factors that affected social order. Adams' book charted naval history through the ships that entered maritime memory as living objects, personifying English values and symbiotically hosting famous commanders like Horatio Nelson. Barnaby, who assisted Adams in compiling his volume, understood, from his unique position as a designer, how mechanics destabilised the nostalgic perception and the cultural identity of the ship. In 1902, looking back on his career and the past century of naval development, Barnaby offered a perspective of the ship that traced the morals, ethics and social co-production of technological change.

Modern naval and military historiography has tended to consider 'modern' technologies as somehow sterile or removed from their corresponding physical destruction, emotional turmoil and philosophical considerations.[94] Discussion of successful technologies – destructive technologies – has tended to take place through a

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[92] For technology and socio-cultural relations surrounding weapons see William H. McNeill, *The pursuit of power: technology, armed-force and society since A.D. 1000* (Chicago, 1982); Michael Adas, *Machines as the measure of men: science, technology, and ideologies of Western dominance* (Ithaca, 1989), esp. 345-357.

[93] Thomas Carlyle, 'Signs of the times', *Edinburgh Review*, 49 (1829), pp. 439-59, quoted in W.H. Davenport Adams, *Famous ships of the British navy: stories of enterprise and daring* (London, 1878), p. 278.

[94] This is especially true of the majority of work concerning the desensitization of the soldier from the enemy especially during the era of mass warfare. See Ian F.W. Beckett, *The Great War* (Harlow, 2007), pp. 214-281. A more nuanced, although restricting, picture is painted in Robert O'Connell's account of affection and emotion to battleships, see Robert L. O'Connell, *Sacred vessels: the cult of the battleship and the rise of the U.S navy* (Oxford, 1991).

vocabulary of efficiency, effectiveness or even the self-sterilising label 'clean kill'.[95] Barnaby's account provides a wonderful corrective to such scholarship. Barnaby, who was born in Chatham to the craft-orientated culture of shipbuilding and the naval culture of Britain's dockyard towns, witnessed a series of reconfigurations in the science and culture of the ship during his lifetime. He entered a shipbuilding industry centred on wood, craftsmanship and tacit knowledge taught through experience and apprenticeship. He was a member of the Admiralty Department of Naval Construction that designed the first Royal Navy ironclad, H.M.S. *Warrior* (1860). Barnaby died in 1915 during a time of war that witnessed the spectacular and controversial deployment of science and naval power in the form of the super-Dreadnoughts. Throughout his life Barnaby advocated for stronger links between shipbuilding and science, and yet he showed a conscious awareness of how the British naval community perceived the cultural resonance of science and mechanics.

Barnaby characterised ship designs during the time he entered the navy as distinct by their width and height out of the water. For example, Barnaby referred to warships like Isaac Watts' H.M.S. *Minotaur* as an 'extravagance' in design.[96] In *Naval development of the century,* Barnaby contrasted the *Minotaur* with the *Devastation*, the navy's first mastless ironclad launched in the wake of the *Captain* catastrophe of 1871. The *Devastation* was visually and materially a different type of ship. 'It was so novel', Barnaby wrote, and 'before the ship was tried at sea it was universally distrusted by the navy, and held to be unsafe.'[97] But what made the *Devastation* especially distinct was the

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[95] Science and Technology Studies scholarship offers a more social perspective of the constructed nature of (and standards for appraising) technological effectiveness, see the historiographical synthesis in Brian Rappert, Brian Balmer & John Stone, 'Science, technology, and the military: priorities, preoccupations, and possibilities', in Edward J. Hackett, Olga Amsterdamska, Michael Lynch & Judy Wajcman (eds.), *The handbook of science and technologies studies* (Cambridge, MA, 2008), pp. 719-740. See also Harry Collins & Trevor Pinch, *The Golem at large: what you should know about technology* (Cambridge, 1998), pp. 7-29; Keith Grint & Steve Woolgar, *The machine at work: technology, work and organisation* (Oxford, 1997), esp. pp. 140-168.

[96] Nathaniel Barnaby, *Naval development in the century* (London, 1902), p. 68.

[97] Ibid, p. 73.

cultural and social network and associations that were intrinsically linked to it as a symbol of a 'modern', 'scientific', 'mechanical' ship (see Chapter 6).

There were political and cultural considerations to this new symbolism of the ship that Barnaby, as a builder of ships, understood through an older, medieval notion of warfare. 'While injustice and unrighteousness exist in the world,' he wrote, 'the sword, the rifled breechloader and the torpedo boat become part of the world's evolutionary machinery, consecrated like any other part of it.'[98] The 'consecration' of weaponry suggests Barnaby's overtly religious interpretation of 'force' and the technical development and use of that force, while the term 'evolutionary machinery' to describe weapons of destruction suggests the Victorian framework through which Barnaby understood the ship and 'naval development'.[99]

Barnaby's ethical treatment of naval development centred on the question 'what was righteous?' Barnaby considered that force could be used to bring peace and righteousness: 'Lasting good is only evolved in this world through strife and bloodshed. The song of the Angels was out of the Latin, and we were made to believe that the promise was unconditional and was on the cessation of war and bloodshed.'[100] Yet righteousness was not found only in the victory or the maintaining of order, rather in the ways that countries engaged with each other. 'Righteousness must come before clean-hearted Peace,' Barnaby wrote, 'and the omission of this thought from the English authorized version of the Angel's Song has wrought lasting mischief.'[101] Barnaby proceeded to reference British military and diplomatic actions in Armenia and South Africa which he believed irrevocably changed the perception in the British imperial

[98] Ibid, pp. 1-24, esp. 3.
[99] For evolutionary frameworks in Victorian culture see Martin Fichman, *Evolutionary theory and Victorian culture* (Amherst, 2002); Gillian Beer, *Open fields: science in cultural encounter* (Oxford, 1996).
[100] Barnaby, *Naval development*, p. 2. The song of the angels here refers to Luke 2:14: 'Glory to God in the highest heaven, and on earth peace among those whom he favours!'
[101] Barnaby, *Naval development*, p. 2.

mindset that peace could be maintained by force.[102] Thus Barnaby understood the nexus of power and technology through part of a more widespread Victorian moral critique of the 'righteousness' of imperialism.[103]

British relations with imperial dominions and countries outside the Empire had always been understood through distinctly different sets of values and were treated separately by the Victorians. However, Barnaby extended his moral concerns to the centuries' old rivalry between Britain and France – a rivalry Barnaby had experienced primarily through naval and technical matters. Barnaby observed that traditional mentalities of 'mis-trust' still presided, and noted that the British Admiralty continued to demand that 'the evolutionary machinery is daily perfected by the engineers and practiced by the seamen in preparation for the day when France ... may at any rate wage war with her upon the seas.'[104] Barnaby's concern, as an actor within the machinery that enabled imperialism and empire building, was that against the backdrop of imperial 'mischief' and pan-European 'mis-trust' the ship and the sailor were painted as agents of immorality. Barnaby wanted to revise the public perception of the battleship and the Jack Tar. He alluded to the criticisms of pacifist groups like the Society of Friends and cultural critics such as Leo Tolstoy who condemned the military and naval services as immoral. Barnaby believed the British sailor had a higher moral character than a stockbroker, lawyer or merchant – he 'would back the sailors against an equal number of clergymen for unselfish, manly living.'[105]

Aware and supportive of the moral critique of imperialism, but defensive over his role as an 'empire builder', Barnaby sought to ascribe an older concept of righteousness

[102] See Arman J. Kirakossian, *British diplomacy and the Armenian question: from the 1830s to 1914* (Princeton, 2003); Bernard Porter, *The lion's share: a short history of British imperialism, 1850-2004* (Harlow, 2004).
[103] Karuna Mantena, 'The crisis of liberal imperialism', in Duncan Bell (ed.), *Victorian visions of global order: empire and international relations in nineteenth-century political thought* (Cambridge, 2007), pp. 113-135; Jeffrey Paul Von Arx, *Progress and pessimism* (Cambridge, MA, 1985), pp. 206-208;
[104] Barnaby, *Naval development*, p. 3.
[105] Ibid., p. 8.

to the new machines of war and their operators.[106] He defended the ship from the accusation that it was solely an object of war, and that 'War has made its weapons as destructive and as appalling as was possible'.[107] He instead offered a revised moral/religious framework to understand ships and sailors:

> There is a Christianity which evolves an unselfish God-fearing life on shipboard and in the din and smoke of battle, and it is a nobler thing than the Christianity which seeks to make the best of both worlds and takes part in no battles save those of personal self-interest. Ruskin says in his *Crown of Wild Olive*: "I found that all great nations learned their truth of word, and strength of thought, in war; that they were nourished in war, and wasted by peace ..."[108]

To what extent was ship building a noble cause? Was Barnaby's motive noble if his craft or science promoted or enabled a destructive war that was not 'righteous'? Barnaby appropriated Ruskin's moralism as it related to religious sensibility in order to examine the extent to which sailors and designers functioned as a microcosm of that kind of moral social community.[109] Barnaby valorised war and validated himself, a ship designer, as a participant in some noble cause, not of British expansionism, which was by itself unrighteous, but British strength, vitality and virtue.[110] These issues take on greater significance still when we consider how the agency of who gave the ship its shape and identity swung increasingly from sailors to designers and engineers.

Barnaby's ethical treatment of the ship and the sailor in Britain's naval development reveals the perspective he shared with many Victorian naval architects – and towards the end of the century Admirals too – that the ship was becoming a mechanical object not of individual masculinities, order and control but systems of scientifically based/ordered power wrought by trained engineers. Barnaby recalled Ruskin's famous quotation on the qualities that humanity put in the ship (*The Harbours of England*, 1856) and remarked that,

> Ruskin has appealed to our pathetic sense of favour of the line-of-battle ship with its ribs and sides of strenuous oak, which will writhe and bend and splinter under attack before it will

[106] For engineers as 'empire builders' see Marsden & Smith, *Engineering empires*, pp. 1, 11.
[107] Barnaby, *Naval development*, p. 10.
[108] Ibid, p. 9.
[109] For Ruskin's moralism see J. Abse, *John Ruskin: the passionate moralist* (New York, 1980).
[110] Mark Girouard, *The return to Camelot: chivalry and the English gentleman* (New Haven, 1981).

> submit. But the treacherous iron or steel, which looks so strong and submits to perfection so easily, has no such pathetic claims.[111]

What struck Barnaby most was not the changing *matériel* but the changing human interaction between sailor and ship associated with the ship's reconfiguration from organic object to a machine.

Barnaby increasingly believed that '[t]he ship in which he [the 1902 sailor] serves is a mere instrument, not easily made interesting'. As such '[t]he man who has spent his life in a ship propelled by sails will have aptitude and abilities which cannot be acquired in a steamer.'[112] The values that the ship acquired as an instrument or machine drew on nineteenth century attitudes that machines could order society with greater speed and control.[113] Barnaby wrote throughout his career on how the introduction of mechanics, metallurgy and exact measurement into the ship and ship operations altered how sailors and scientists understood the behaviour of ships in the sea and reconfigured the romance of seamanship and seafaring for the sailor. He wrote the following regarding ships under construction in 1902:

> The new ships we propose to build will be equipped in all respects in the most perfect manner which knowledge or scientific possibilities suggest. They will receive all those accessories of which we have heard a good deal lately. They will be provided with the cordite charges and with the telescopic sights. They will be provided with electric hoists, and their torpedoes will receive the gyroscope.[114]

Such 'scientific possibilities' fundamentally altered the designs, operations and identity of ships but also the design (training), operations and identity of the sailors who sailed – if that was any longer an accurate phrase rather than naval nostalgia.

There were two main consequences of the transformation of the ship into a machine. Barnaby believed that the most dramatic naval development of the nineteenth century for the sailor was how he worked and identified himself in a mechanical ship.

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[111] Barnaby, *Naval development*, p. 25. Ruskin saw the 1856 heart of oak in the tradition of humanity of the handmade emphasised in the the Nature of Gothic, in 'The Stones of Venice' (1853), in E.T. Cook & Alexander Wedderburn, *The works of John Ruskin* (39 volumes, London, 1906), 10:180-217.
[112] Barnaby, *Naval development*, p. 25.
[113] Thomas P. Hughes, *Human-built world: how to think about technology and culture* (Chicago, 2005), pp. 45-75, esp. 52-53.
[114] Barnaby, *Naval development*, pp. 411-12.

Barnaby suggested that the late nineteenth century 'decline in the character of the British seaman' had been brought about 'partly by the suppression of sails'.[115] Here the decline referred as much to the Jack Tar as the gentlemanly officer.[116] As the majority of sailors spent the majority of their time at work at machinery the naval profession, those people who made the ship's final identity through use, simultaneously remade their identities as well the ship's.[117] At the same time the press and parliament grew concerned by the 'steady degradation of the personnel of "The Shipping of England,"' and yet other commentators, like Barnaby, placed faith in the ability of the shipbuilder to build big.[118] 'The exceptional ship of 1852, the "Leviathan," or "Great Eastern," can no longer be regarded as a monster', Barnaby wrote, 'The needs of commerce have now brought us up to her great length.'[119]

Connected to that development was the more alarming relationship between the social power of the machine as a way of control and the 'machine context' in war - the 'righteousness' of which the designer may not know. Sociological theories of technology have stressed the role of end users as the group who receive and make meaning for objects, but there is a significant role for the actors-network that made an object in defining the limits of that meaning.[120] Such a process was evident as naval architects and engineers imposed systems of measurement and mechanisation on the ship, thereby limiting the symbiotic relationship sailors felt they had with the wooden walls by designing mechanical systems and apparatus that were operated by a user. Where a sailor previously had to use his experiences and physical skill to help the ship sail

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115 Ibid., p. 26.
116 For Jack Tar see Mary Conley, *From Jack Tar to union jack: representing naval manhood in the British Empire, 1870-1918* (Manchester, 2009). For the English gentleman see Marcus Collins, 'The fall of the English gentleman: the national character in decline, c.1918-1970', *Historical Research*, 75 (2002), pp. 90-111; Quintin Colville, 'Jack Tar and the gentleman officer: the role of uniform in shaping the class- and gender-related identities of British naval personnel, 1930-1939', *Transactions of the Royal Historical Society*, 13 (2003), pp. 105-29.
117 Barnaby, *Naval development*, p. 26.
118 Ibid., p. 315.
119 Ibid., p. 316.
120 See Grint & Woolgar's work on configuring the user, Grint & Woolgar, *Machine at work*, pp. 65-94.

smoothly in its battle with the oceans, he now had a mechanical system of measuring instruments and tools at his fingertips to tame nature and fight enemies. As chapter 6 demonstrated, the rules for understanding the ship and its behaviour were altered; as were the dynamics between ship and sailor.

Barnaby's perspective on the ethics of shipbuilders were doubtless peculiar to him, but in examining them I have demonstrated some significant connections between how Barnaby, the most influential naval architect in Britain during the 1870s and early 1880s, conceived the transformation of the ship into a mechanical instrument. The values through which Barnaby interpreted naval development and the changing professional activities of a mechanised navy were by no means unfamiliar to his contemporaries. In 1864, Woolley had addressed the INA with a vision of how the mechanisation of the navy would alter the identity of the sailor and his profession. '[T]he extensive and growing adaptation of mechanical contrivances to the construction and the working of ships will, for the future,' Woolley wrote, 'give less scope in naval warfare for superiority to be gained by nautical skill and indomitable courage working through inferior instruments'.[121] In 1864 that position was only held by a minority in the naval community but, as this chapter showed, new connections between naval officers, constructors and engineers were forged following a series of catastrophes, public redrawing of the use and perception of science and private - institutional - shifts following the loss of the *Captain*.

Admiral John Fisher, who was very much a product (and builder) of these newly forged connections that equated 'science' with 'modernity', the 'future' and 'progress', advocated engineering training for cadets. 'In the old days it sufficed if a Naval Officer were a seaman', Fisher wrote, '[n]ow he must be a seaman, a gunner, a soldier, an

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[121] Woolley, 'Education of naval architects', p. 268.

engineer, and a man of science as well'.[122] Fisher fought relentlessly to improve the character, quality and status of technical education in the navy. Yet years after the launch of the first ironclads, he still had to contend with the influence of traditional views of seaman craft and of taming nature not with machinery but individual skill. This example serves as a reminder that the values and identity that designers and builders gave ships had a limited range of transmission, beyond which they again contested by users and wider publics. Only shipbuilding projects, controversies and public discourses in the wider naval community could maintain the strength of those values and identities beyond the drawing room or the site of experiments, reshaping the ship in popular culture as a machine.

7.5 CONCLUSION

The establishment of the Corps of Naval Constructors, together with the social status of its members as authoritative, credible and trustworthy, marked a shift in the culture of expertise from an aristocratic and craft-orientated authority to a technical and mechanical authority. This chapter has specifically examined a series of public and institutional strategies employed by actors in an effort to have contemporaries recognise their expertise. The contrast between Reed, Barnaby and White's approaches to building authority demonstrates that 'expertise' was contingent on successfully establishing for non-specialists the context in which to understand the substance of expert knowledge and skills. For example, the belief that mechanical power would be decisive in any future naval engagement (and that engineers were the gatekeepers to employing such power) was firmly established within the engineering community, but it

[122] This quotation was connected to Fisher's new scheme for Admiralty rank and status of the early 1900s. Quoted in R.F. Mackay, *Fisher of Kilverstone* (Oxford, 1973), p. 274.

required social processes and media representation to convince the naval community that their tacit knowledge alone may no longer be sufficient to meet naval and mechanical challenges.

I have shown the social processes of establishing expertise that took place in public forums between naval constructors, officers and administrators. These processes reconfigured the authority of 'expertises' and the social structures on which they were grounded. White's design for a model of management separated knowledge and labour, a social distinction between designer and builder. White's system of localised supervision by scientifically literate designers contrasted the traditional systems of knowledge production through experience that had been carried on in the craft-practice culture of dockyard self-governance and apprenticeships. White's Corps of Naval Constructors also demonstrated the social nature of building 'expertise', as the institutionalisation of scientific knowledge and management in Victorian Britain increasingly went hand-in-hand with the rise of the professional middle class.

The knowledge and skills required to shape the Victorian navy were increasingly found in the domain of engineers and men of science. As engineers gained expert status and institutional authority, the role and identity of sailors was altered. This thesis has shown how the ship entered the domain of mechanical knowledge, restricted the authority of naval frameworks of understanding and experience through which the naval officer exerted control over the ship. While the mechanisation of the ship has been only briefly sketched, I have suggested that the simultaneous building of mechanical expertise and mechanical ships also rebuilt the identity of the sailor (the final technological user).

Many engineers claimed that naval officers needed to learn and value naval architecture, if only because doing such would mean that officers would recognise the expertise of constructors. At the inception of the INA, Russell expressed his belief that '[t]he *sailor* is even more deeply concerned, if possible, than the shipbuilder [in the theory and practice of ship design and behaviour]. The admiral even more than the architect.'[123] Charles Merrifield, who occupied the office of principal in the RSNA, was particularly aware that changes in expertise, *matériel* and authority were connected. In 1872, he wrote that '[i]t is idle to talk of good naval designs so long as a topman is looked upon as the ideal of a sailor, and cruising as the duty of the fleet. The sailor we now want should be boatman, gunner, and stoker, rather than reefer.'[124]

Merrifield's frustrations rested on the perception that sailors did not tend to view ships as machines that embodied scientific and engineering problems, but the loss of the *Captain* and success of the *Devastation* contributed greatly to a change in the order of knowledge and social authority within the naval establishment. Come 1887, Fremantle, with whom I opened this chapter, felt that it was wise and helpful to admit publicly that both the value of naval *matériel* and expertise in the navy had altered. Although admirals still ran the Board of Admiralty and construction policy of the navy, they recognised that only naval architects had the technical knowledge and credibility to design ships.[125] As Fremantle made this statement, a new generation of officers were taking control of the navy, officers like himself, Noel, Fisher and Henry Jackson who had great respect for constructors like Barnaby and White. These officers recognised the expertise and potential role in decision making of those who invented and constructed machines of war.

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[123] John Scott Russell, 'On the professional problem presented to naval architects in the construction of iron cased vessels of war', *Transactions*, 2 (1861), pp. 17-37, esp. 22-3.
[124] Charles Merrifield, 'Review of the present conditions of naval design for commerce and for war', *The Annual of the Royal School of Naval Architecture and Marine Engineering*, 2 (1872), pp. 29-36, esp. 34-35.
[125] [Fremantle], 'Are Ironclads Doomed?', pp. 519-533.

Conclusion

A perfect ship of war is a desideratum which has never yet been attained, and is now further than ever removed from our reach. Any near approach to perfection in one direction inevitably brings with it disadvantages in another.

Lord Dufferin states that the qualities of a ship had to be a compromise, emphasising that the social groups surrounding the ship had first to decide what qualities were valued in the shape of the ship.[1]

This thesis has followed the ship as it passed from the domain of craftsmanship and gentlemanly officer control to mechanical 'objectivity' and engineering experts. I have examined both the dramatic *matériel* changes and the cultural reconfigurations in the nexus of ship, shipbuilder, naval officer and the skills that supposedly guaranteed Britain naval supremacy in the age of empire. Specifically, I have focused on how the 'hand that makes' was detached from the artisan and labourer and grafted onto the man of science and the engineer. The new hand that emerged in late Victorian Britain was mechanical, thoughtful and detached (but continued to borrow authority and modes of practice) from the working classes of craftsmen who 'built' by experience and 'rules of thumb'. This hand also shaped the emerging modern science-industry-government nexus.

Part I of the thesis explored discussions regarding science, craft and material change within the broad culture of naval supremacy. The issues I developed, namely financial management, mechanics, aesthetics, economics, efficiency and naval rivalry, provided the context for an insightful study of the skills that naval architects promoted as they sought to define a role for scientifically-orientated experts in a naval community occupied by craftsmen and naval officers who claimed authority over ship design. Part II

[1] [Lord Commissioners of the Admiralty], *Report of the committee appointed by the Lord Commissioners of the Admiralty to examine the designs upon which ships of war have recently been constructed, with analysis of evidence* (London, 1872), p. viii.

took a more detailed look at the cultures of experiment and science in Victorian naval architecture, focusing on the ideas and working practices of a group of naval architects, engineers, men of science, mathematicians and naval officers that I identified as a coherent social network. I have used this social network to focus my analysis of the identity of naval architecture, attitudes toward science, craft and mechanics, and the systems of production in which knowledge and authority were rooted (thereby ensuring that key concepts and ideas have not been left disembodied from actor's working practices). Part III returned to the broad Victorian perspective to examine the authority and public understanding of the skills promoted by the social network identified in Part II. I followed members of this British social network of naval architects through their disputes with naval officers and administrators over the use of science in making ships. I closed by examining the social and cultural concerns of naval architects and naval officers as they came to terms with the ship's identity following its reconfiguration from wooden wall to machine of war.

Victorian naval architecture and attitudes to the ship were at the intersection of an important theme in Victorian Britain: the changing nature of expertise and administration during the era of aristocratic decline and rise of technical education. The link between this shift and science was developed by social networks whose private (and embodied) knowledge, localised concerns and material objects shaped new understandings of mechanical expertise. To understand this process I have focused on the spaces, structures and social processes that lay between sites of private knowledge (Part II) and public reception (Parts I & III).[2] This thesis has specifically examined the

[2] Peter Mandler has argued that it vital to examine such sociological 'mechanisms of production, circulation, readership and the value of production media' through which interpretations are made. Peter Mandler, 'The problem with cultural history', *Cultural and Social History*, 1 (2004), pp. 94-117, esp. 113-16. This also reflects a broader turn towards the reflexive in the engagement between the humanities and social sciences, see Pierre Bourdieu & L.J.D. Wacquant, *An invitation to reflexive sociology* (Oxford, 1992), pp. 3-7, 36-7, 97.

politics at play in the social spaces where actors mapped various meanings of the 'scientific' to demonstrate the broader cultural meanings and authority of 'science' in Victorian communities.[3] The insights I have developed regarding the 'use of science' contributes to the historiography on popular science (and engineering) in the public sphere that has hitherto focused on natural sciences.[4]

I have examined how ships were simultaneously sites and objects of technological and cultural change. This perspective is vital to revising the overtly social interpretation of 'technological change' that predominates in the history of technology.[5] Technologies (or technological systems) such as ships have long histories, during which they entered into the specific cultures of their users and wider spheres of cultural iconography.[6] Technologies, as social historians have recognised, become social objects as well as material objects. But through being 'social' they were also mapped on to cultural terrain, taking on entrenched values and readings of history.[7]

Ships were icons of Britain's past. They had a historically entrenched function and a familiar aesthetic. A Victorian writer on naval aesthetics examined this through the iconography portrayed in the painted image of the ship: 'a ship must be old-fashioned, quaint of form, or battered and grimy. Spick-and-span newness is almost as much out of place on canvas as thorough efficiency.'[8] This sentiment resonated with naval architects,

[3] For example when a word or idea is traced beyond the context of a personal correspondence to other social networks and publics its meaning is re-interpreted, revised and transformed, see David Livingstone, *Putting science in its place: geographies of scientific knowledge* (Chicago, 2003), pp. 135-178.
[4] See, for example, Bernard Lightman, *Victorian popularizers of science: designing nature for new audiences* (Chicago, 2007).
[5] Donald Mackenzie & Judy Wajcman, 'Introductory essay: the social shaping of technology', in MacKenzie & Wajcman (eds.), *The social shaping of technology* (Buckingham, 1985, 2nd edt. 1999), pp. 3-28, esp. 23-24.
[6] Wooden sailing ships were certainly objects of romantic memory and affection, see for example Henry Wadsworth Longfellow's 'The building of the ship' with its strong threads of patriotism and paternal relationships between the ship and the master shipwright, see Longfellow, *The building of the ship and other poems* (Honolulu, 1920, orig. 1950). Steam and iron did not end the romanticism of the ship, but reconfigured it, for example see the organic metaphors in Rudyard Kipling's 'The ship that found herself' in Kipling, *A Day's Work* (Oxford, 1987, orig. 1898). I thank Laurie Ferriero for pointing me to the second of these literary texts.
[7] Scholarship on 'exhibiting' technology recognises these issues, see Ben Marsden & Crosbie Smith, *Engineering empires: a cultural history of engineering in nineteenth-century Britain* (Basingstoke, 2005), pp. 232-234.
[8] W.J. Fletcher, 'The aesthetics of naval architecture', *Nineteenth Century and After: a monthly review*, 52 (1902), p. 293.

who believed that much of the controversy surrounding H.M.S. *Devastation* lay in 'her odd appearance, and her unusual power as an engine of war'.[9] Nostalgia was a powerful source of cultural authority in matters of 'technological change'. It celebrated an imagined material culture of the past, but it was also a resignation to obsolescence. Nostalgia was therefore an important tool to negotiate change, available to all the social groups concerned, and yet its historical function in relation to 'technological change' is poorly defined.

The authority of nostalgic observations demonstrates a broader problem that this thesis has explored, namely, the nature of 'modernity'. Historians of expertise have argued that the spread of scientific knowledge and expertise was intrinsically linked to Victorian social, cultural and governmental reforms.[10] Historians of modernity, however, have rejected such monolithic interpretations, leaving the nature of 'scientific expertise' uncertain.[11] Indeed, I have identified the continuing credibility of the skills of craftsmen indoctrinated in 'rules of thumb', naval officers entrenched in tacit experience and administrators schooled in 'empiricism' and 'practical knowledge' through early and mid-Victorian Britain.

This thesis has constructed a frame in which the expertise of many groups could be examined as they crisscrossed and came into conflict, demonstrating the continuing authority of craftwork and practical experience. With this contextual frame in place, Part II scrutinised how experiment and science was understood in shipyards, the Admiralty and a series of public forums. My analysis of William Froude's test tank

[9] W., 'H.M.S. *Devastation* and her trials: by one who accompanied her during her late cruise', *Annual of the Royal School of Naval Architecture and Marine Engineering*, 4 (1874), pp. 27-45, esp. 27.
[10] Roy MacLeod, 'Introduction', in MacLeod (ed.), *Government and expertise: specialists, administrators and professionals, 1860-1919* (Cambridge, 1988), pp. 1-26, esp. 11; R. Angus Buchanan, 'Engineers and government in nineteenth-century Britain', in Roy MacLeod (ed.), *Government and expertise: specialists, administrators and professionals, 1860-1919* (Cambridge, 1988), pp. 41-58.
[11] Martin Daunton & Bernhard Rieger, 'Introduction', in Daunton & Rieger (eds.), *Meanings of modernity: Britain from the late-Victorian era to World War II* (Oxford, 2001), pp. 1-21, esp. 4.

emphasised two important ways in which this context shaped the content of science. First, my description of the Admiralty's decision to fund William Froude's test tank demonstrated the traditional socio-cultural capital that engineers and naval architects did not possess, but required in order to enter the government sphere as 'experts'. Second, my examination of Froude's working practices in the test tank highlighted that Froude's peculiar response to the prevailing authority of craftwork and trust in practical knowledge actively shaped his activities. Froude's scientific knowledge and authority as an expert was dependent on a wide range of social, cultural and moral contingencies that were by no means 'modern' in the monolithic sense, but an active negotiation with the continuing problematics of older concerns and epistemologies.

The nature of Froude's expertise was arguably representative of a more widespread culture of expertise within the government, science and war nexus. Engineers required the patronage of the traditional governing class just as much as they needed to organise themselves as a social and technical community. During the middle of the nineteenth century, members of the British social network of naval architects successfully established a school of naval architecture, quietly manoeuvred into positions of authority, formed new rules and languages through which ships were designed and understood, created powerful sites of experiment in which knowledge was held and, where possible, demonstrated their skills to naval officers and administrators. These developments slowly produced a new social order of knowledge and expertise in which science became analogous with efficiency, safety and power, effectively redefining the processes through which the Pax Britannica was maintained. Meanwhile in public, the well known members of this social network, John Scott Russell, Edward Reed, Nathaniel Barnaby and William White, developed their personal reputations, and in consequence, a public familiarity with the skills that the naval architect embodied.

Members of the British social network of naval architects have long been absent from histories of Victorian naval supremacy and the history of science, technology and war. This thesis has thus made an important two-fold contribution to these areas of scholarship. First, it has brought to light the activities, backgrounds, concerns and skills of a group of engineers who literally and culturally made the Victorian Navy, one of the most historically significant and yet singularly neglected institutions in the history of technology and war.[12] Second, it has responded to the conceptual limitations of previous studies on science, technology and war, namely the separation of those who made objects from those who made knowledge, the neglected theme of technological experience, the interaction between supposed 'specialists' and 'non-specialists', and the authority on which scientific knowledge and technical expertise relied.

The spread of 'scientific' knowledge and technical expertise in Victorian Britain had important social and cultural connotations for the traditional administration of government and the power of those individuals who in the past had been identified as 'mere mechanics'.[13] How did actors negotiate these connections between science, engineering, government and the moral authority of power?[14] This question remain one of the most important facing historians of science, technology and Victorian Britain interested in the formations of institutionalised science and the modern state. It is a question too expansive for a thesis, but I have examined some of the major issues,

[12] David Mindell makes this point in his skilful study of technology and war in the American Civil War navy, see David A Mindell, *War, technology, and experience aboard the USS Monitor* (Baltimore, 2000), pp. 7-12.
[13] For a broader cultural and social reading of how inventors became embroiled in political, economic and scientific discourses see Christine MacLeod, *Heroes of invention: technology, liberalism and British identity, 1750-1914* (Cambridge, 2007), pp. 1-26.
[14] Boyd Hilton, 'Moral disciplines', in Peter Mandler (ed.), *Liberty and authority in Victorian Britain* (Oxford, 2006), pp. 224-245; S.J.D. Green & R.C. Whiting, 'Introduction: the shifting boundaries of the state in modern Britain', in Green & Whiting, *The boundaries of the state in modern Britain* (Cambridge, 1996), pp. 1-14.

specifically the identity of experiment, experience and the culture of expertise. My analysis suggests that any response to this question must acknowledge two important issues. First, that the answer will be as much about social order and the culture of the Victorian state as it will about science. And second, that the identity of science-government relations were not only shaped by scientists and politicians, but by craftsmen, engineers and end-users.

Appendix A

Officers and council of the Institution of Naval Architects, 1860

President

Sir John Pakington[1]

Vice-Presidents

The Earl of Ellenborough, G.C.B.
The Earl of Hardwick, D.C.L., F.R.S.
Sir Francis Baring, Bart., F.R.S.
Sir James Graham, Bart., G.C.B.
Sir John Pakington, Bart., D.C.L.
Lord Clarence Paget, C.B.
The Right Hon. H.T.L. Corry
The Right Hon. Sidney Herbert
R. Abethell, Esq.
T. Chapman, Esq., F.R.S.
Duncan Dunbar, Esq.
J. Laird, Esq.
T. Lloyd, Esq.
Rev. H. Moseley, M.A., F.R.S.
J. Penn, Esq.
J. Scott Russell, Esq. F.R.S.
Isaac Watts, Esq.
Rev. Joseph Woolley, LL.D., F.R.A.S.

Members of Council

J. Bennett, Esq.
H. Chatfield, Esq.
H. Cradock, Esq.
J. Edwards, Esq.
W. Edye, Esq.
J.I. Fincham, Esq.
J. Graff, Esq.
J. Grantham, Esq.
W. Henwood, Esq.
S. Reed, Esq.
W. McP. Rice, Esq.
W. Ritchie, Esq.
W.B. Robinson, Esq.
J. D'Aguilar Samuda, Esq.
O.W. Lang, Esq.
J. Luke, Esq.
F. Martin, Esq.
J. Martin, Esq.
W. Moody, Esq.
A. Moore, Esq.
J.R. Napier, Esq.
J. Peake, Esq.
T. Pretious, Esq.
A.B. Sturdee, Esq.
P. Thornton, Esq.
G. Turner, Esq.
J. White, Esq.
J. Williams, Esq.

Associate Members of Council

Sir W. Armstrong, C.B.
Captain E.P. Halstead, R.N.
J. Macgregor, Esq.
J. Maudslay, Esq.
Captain Sulivan, R.N., C.B.
Captain W.H. Walker, H.C.S.

Treasurer

J. D'Aguilar Samuda, Esq.

Secretary

Edward James Reed

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[1] Pakington was raised to the presidency after the Duke of Northumberland rejected the position.

Appendix B

Cabinet and Admiralty Administrations, 1860-1880

	Government	Prime Minister	First Lord of the Admiralty	First Sea Lord	Controller of the Navy	Chief Constructor of the Navy
1859	LIBERAL	Palmerston	Edward Adolphus Seymour	Richard Dundas		
1860						Isaac Watts
1861				Frederick Grey	Robert Spencer Robinson	
1862						
1863						E.J. Reed
1864						
1865		Palmerston/ Russell				
1866		Russell				
	CONSERVATIVE	Derby	Pakington	Alexander Milne		
1867			Henry Thomas Lowry Corry			
1868		Derby/ Disraeli		Sydney Dacres		
	LIBERAL	Gladstone	Hugh Childers			
1869					Robert Spencer Robinson	
1870						Nathaniel Barnaby
1871			George Goschen		Capt. Richard Hall	
1872				Alexander Milne	Rear-Admiral William Houston Stewart	
1873						
1874			George Ward Hunt			
	CONSERVATIVE	Disraeli				
1875						
1876				Hastings Yelverton		
1877			W.H. Smith	George Wellesley		
1878						
1879						
1880						

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