The Scientific and Management Revolution in Shipbuilding on the "Two Clydes," 1880-1900

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by Stuart A. McKenna and Larrie D. Ferreiro

Introduction

The introduction of metal construction and steam propulsion into marine design during the 1800s provided shipowners and mariners with ever-more reliable vessels to ply the oceans. The study of the technology and infrastructure that enabled those vessels to be created has been of recent interest to maritime historians. In particular, the twenty-year period from 1880 to 1900 was a critical time, when marine design underwent a transformation from using "rule of thumb" principles to a more systematic, scientific approach. Our study investigates this transformation in detail through examining archival company records along with existing literature in order to determine the true causes for this monumental change of design approach and examine the impact this period has had on marine design today. This research will focus on the shipyards of Great Britain and the United States of America (and specifically on the "Two Clydes") for the reason that, during this period, these two nations dominated the merchant shipping world. In the 1890s, for example, British shipbuilders were known as "the naval architects of the world;" its yards accounted for seventy-five percent of the world's ship construction, and the tonnage it built for foreign owners alone almost equalled the rest of the world's shipbuilding combined. Two-thirds of British-built ships were launched on the Clyde River in Scotland, around the city of Glasgow. The United States was in distant second place, building ten percent of the world's tonnage, of which half was built along the Delaware River near Philadelphia, earning it the nickname "The American Clyde." Together the two nations had built seven out of every eight ships plying the world's oceans and waterways. (Hall 1884, 260; Pollard, et al 1979, 44-45; Gardiner 1993, 10; Matsumoto 1999, 76)

Background

In order to investigate and analyse the underlying reasons behind the shift in marine design practices in the time period 1880-1900, we examined the largest and most innovative shipyards from the "Two Clydes." The River Clyde and its Firth were once the location of over 300 shipbuilding firms and has seen the construction of over 25,000 ships over three centuries. The term "Clyde-built" became known as an industry benchmark of quality and this was, in part, down to the pioneering and high quality workmanship of the following shipyards selected by the researchers of this paper:

- William Denny & Brothers was opened by William Denny in Dumbarton in 1844 and was regarded as one of the most technologically advanced yards in the world. It built ships until 1963. (Figure 1)
- J & G Thomson was founded near Clydebank by pioneering brothers John and George Thomson in 1871; it later was absorbed into the John Brown Company. In

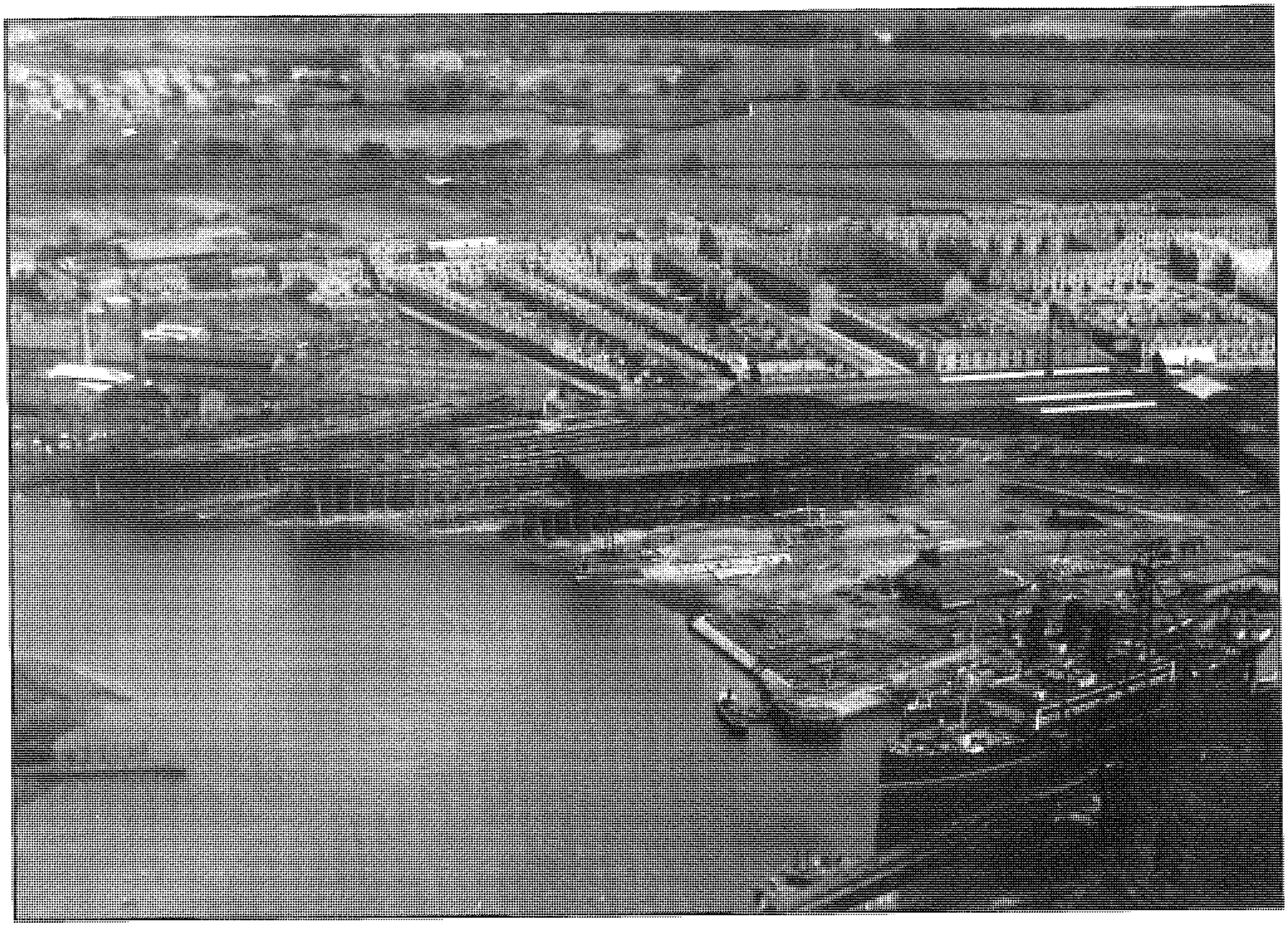


Figure 1. View of Denny yard from the Castle. Courtesy of the Scottish Maritime Museum.

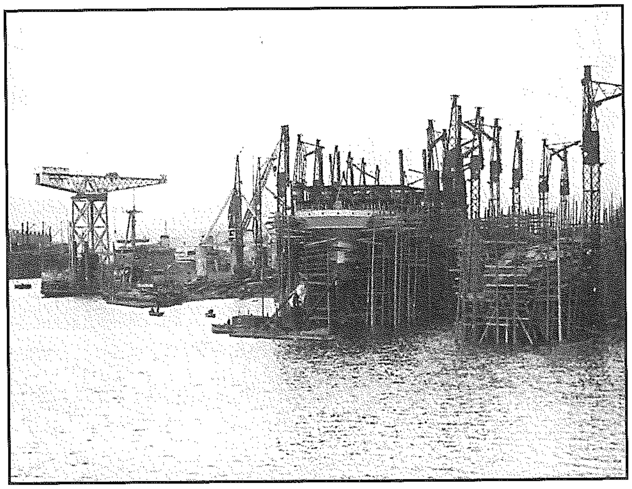


Figure 2. J & G Thomson yard in 1907. Courtesy of the Scottish Maritime Museum.

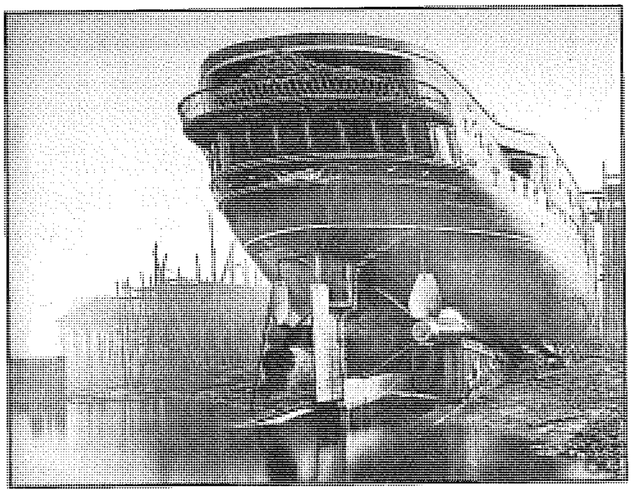


Figure 3. HMS *Northampton* ready for launching at Robert Napier's yard, 1876. From the editor's collection.

1847 the Thomson brothers had both worked for "The Father of Clyde Shipbuilding," Robert Napier, and it was surely Napier's influence that led to the brothers' shipyard gaining the reputation of a prestigious and record-holding shipbuilder. (Figure 2)

- Robert Napier & Sons was opened in 1841 on the banks of the Clyde in Glasgow near an area known as Govan by Robert Napier. Napier's firm was another pioneering shipyard and was responsible for producing some of the first iron vessels for the Royal Navy, worked with eminent scien-

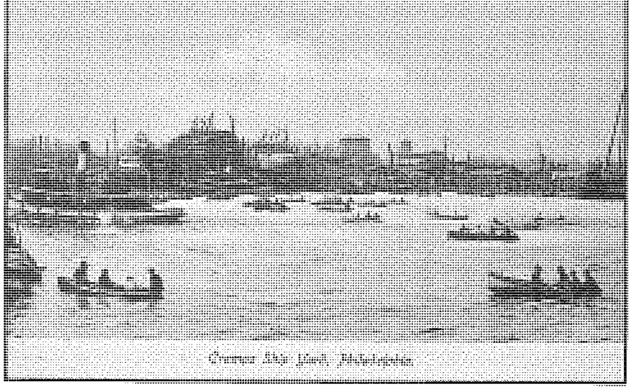


Figure 4. Cramp's shipyard in Philadelphia. From the editor's collection.

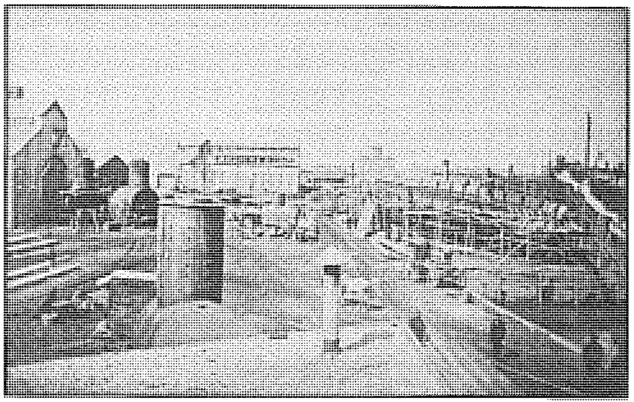


Figure 5. The Roach shipyard in the 1890s. From the editor's collection.

tists such as William J.M. Rankine, and provided for the education of some of the most famous naval architects and marine engineers, including John Elder and the Thomson brothers, before being taken over by the William Beardmore Company in 1900. (Figure 3)

In the United States of America, the Delaware River near Philadelphia, known as the "American Clyde," was home to some of the most important and innovative shipyards in the nation:

- William Cramp & Sons was founded in 1825 and built ironclad warships during the Civil War, later becoming one of the United States Navy's most important suppliers of battleships and destroyers through World War II. (Figure 4)

- John Roach & Sons was founded in 1864 and, between 1871 and 1885, was the largest ship building company in the United States. The Navy turned to Roach in 1883 to build its first modern, all-steel warships. (Figure 5)

- Harlan & Hollingsworth was originally founded in 1837 as a railroad car manufacturer but soon moved into shipbuilding, specializing in destroyers, ferries and coastal steamers, before being absorbed into Bethlehem Steel. (Figure 6)

By examining these innovative shipbuilders, we can compare and contrast the various organisational, science, engineering and design changes that occurred over this remarkable twenty-year period, which brought shipbuilding into the modern

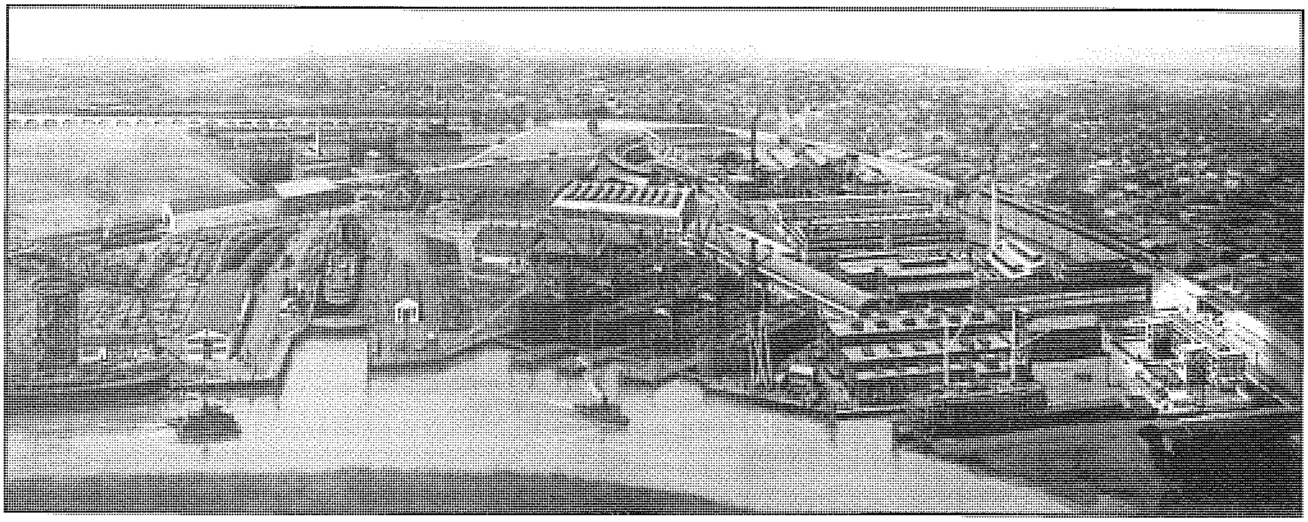


Figure 6. Panorama of the Harlan and Hollingsworth yard. From the editor's collection.

industrial age and professionalized role of the naval architect.

The Scientific and Managerial Revolution in Industry

Before 1880, most industrial firms were family-owned or partnerships, and could be described as single-unit enterprises, employing a small number of men and creating one (or just a few) products. There was usually little in the way of corporate specialization, so (for example) the owners might be responsible for design, production, quality, receivable accounts and marketing, all at the same time. Most of the processes were developed by careful trial and error over long periods, resulting in effective (but often inflexible) rules of thumb for guidance.

The last two decades of the nineteenth century saw two revolutions, a managerial revolution and a scientific revolution, that together created a new type of industrial enterprise,. The managerial revolution led to the vertically-integrated, hierarchical firm that brought many units under its control. This was marked by the growth of specialised divisions within the firm; for example, separate branches for accounting, engineering, production, and so on. Each of these divisions was led by middle managers, a new breed of worker who was neither an owner nor a labourer, but a salaried professional responsible for the people, material and processes in his division. The coordination of the activities of these divisions, and of the entire company, was carried out by upper-level managers, who themselves often rose up from the middle ranks. (Chandler 1977, 1-12)

In conjunction with this was a revolution in the application of scientific knowledge. The modern, hierarchical enterprise demanded increasingly standardized processes; and as the customer and supplier networks grew, the creation of standardized products as well. Industrial standardization was based upon scientific standardization: the ability to specify and predict the characteristics and performance of the technology while still in the design stage; to precisely control the production processes; and to accurately measure the results. Middle and upper-level managers of engineering firms were increasingly men who did not come up from the shop floor, but rather had a solid academic background in addition to practical training. In short, the period from 1880 to 1900 marked a major transition of industries, in both Britain and the United States, from small-scale family-owned and partnership firms, to the modern, vertically-integrated business enterprise. (Noble 1977, 5-6, 69-83)

Several innovations had come together since the beginning of the Industrial Age (circa 1800) to give rise to this new type of hierarchical, science-driven enterprise. Reliable power in the form of steam; reliable transportation in the form of railroads; and reliable communications by telegraph all contributed to the expansion of trade networks that reduced risks and encouraged large capital investments. At the same time, the professionalization of the engineering disciplines was in full swing, including the rise of professional bodies (the Institution of Civil Engineers, for example), the growth in engineering universities (such as the University of Glasgow), and the gradual elimination of the apprentice-based technical education in favour of an academic model that eventually incorporated scientific research. (Wengenroth 2000)

One of the first to undergo this sweeping change was the railroad industry. From around the 1850s, railroads in both Britain and the United States evolved into modern, vertically-integrated organisations, with salaried middle managers in charge of internal coordination of the various parts of the firm—rolling stock, fixed stock, coal, and so on—arrayed across a wide area. (Gourvish 1980, 10; Chandler 1977, 145) By the 1880s, railroad firms had developed something of a modern engineering organisation to oversee the design and testing of components, and creation of standards and specifications for rail shapes, composition of alloys, and other technologies. During this period, many firms, such as Burlington and Baldwin, established drafting rooms and laboratories overseen by engineers, who were increasingly university-educated and who belonged to professional societies. Both universities and professional societies were themselves becoming highly integrated in the establishment and coordination of industrial standards and practices. Locomotive design became more and more informed by theoretical developments in metallurgy and thermodynamics. (Usselmann 2002, 205-206, 227-230; Duffy 1983, 68-69; Brown 1995, 88-89; Noble 1977, 71, 79; Chandler 1977)

During the period 1880-1900, the vertical integration of organisations, and professionalization of its management, quickly spread to other manufacturing industries, which often borrowed talent from the railroad industry. The steel manufacturer Carnegie Company, for example, hired former railroad men who brought into the firm the engineering and management practices that made railroads so successful. Former railroad engineers working for architectural firms gave the newfangled skyscrapers their light steel skeletons, based heavily on railroad truss bridges. (Chandler 1977, 267-273; Misa 1995, 64-66)

During this era, many other industries were also becoming vertically integrated and were increasingly employing university-trained scientists and engineers to oversee the internal workings of their plants. For example, chemical-based industries such as petroleum distilleries, alkali producers such as glassmakers, even breweries began using ever more sophisticated chemical processes and laboratory analyses to improve production flow and quality, as well as to develop new products. (Noble 1977, 14-19; Chandler 1977, 243, 257; Anderson 2005)

The integration and professionalization of the maritime industries was "particularly complex," notes economic historian John Hutchins, during which time both shipping companies and shipyards progressed from an "unorganized, competitive system" to a "highly organized, rationalized and concentrated type of organisation." (Hutchins 1941, xx-xxi) The process of incorporating scientifically-based naval architecture into the design of ships was a critical part of this transformation.

Transforming the Shipyard on the British Clyde

Innovations in iron, steel and steam shipbuilding developed more quickly in the Clyde region than in many other parts of Britain, due both to its proximity to Atlantic trade routes and to the network of universities and engineering industries in the region. (Schwerin 2004) For the purpose of identifying and analysing the various factors involving the transformation of marine design through the scientific and managerial revolution that took place on the River Clyde, we used the archival records from the University of Glasgow. As ship building declined on the Clyde leading to the shipyards going out of business the records, plans and administrative paraphernalia was gathered by the University in order to preserve this unique and important period of history. By using this unique and invaluable snap shot of the past along with other key developments and events at this time, this research was able to put together a detailed picture of the factors leading to the change in the marine design approach.

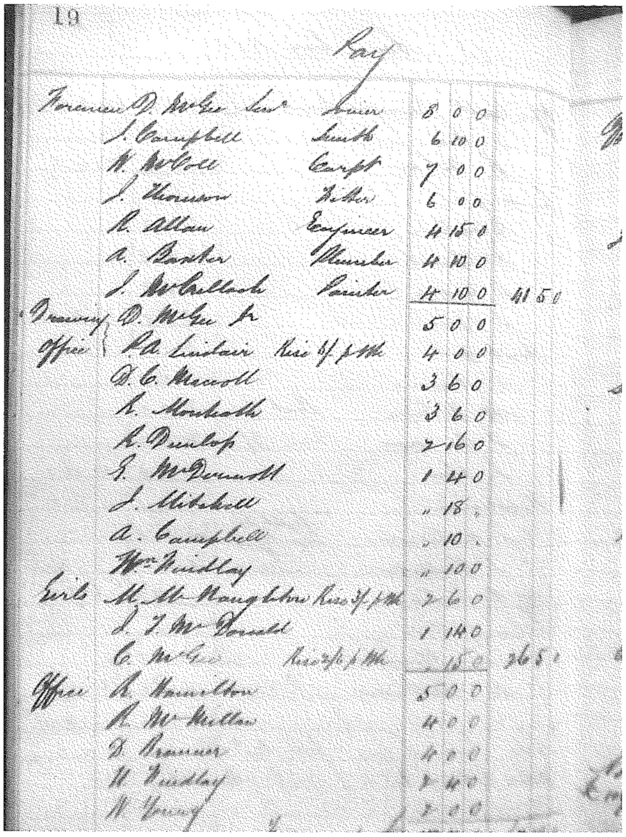
Figure 7. The Denny yard in 1963. Courtesy of the Scottish Maritime Museum.

William Denny & Brothers
(Figure 7)

Denny's shipyard was a leading force in the development and practical use of theoretical naval architecture. In 1883, William Denny (the son of the founder) erected an Experiment Tank in his Dumbarton shipyard to test hull forms and propellers, based on the one developed by the civil engineer, William Froude, in Torquay. (Bruce 1932, 192-205)

The Denny shipyard's salary books cover the period 1877-1907, providing an invaluable record of all office staff, including secretaries, tracers, telephone/telegraph operators in addition to the engineering and design based roles. This information, such as dates for commencement and termination of employment, salary information, pay increases and pay terms of apprenticeships, allows us to establish the various hierarchies of the organisation, track the progression and development of certain employees and even witness a change in terminology in relation to the job titles used as the profession of the naval architect is established.

For example, the title of Charles Henry Johnson (Figure 8), who had begun as a draughtsman at Denny's circa 1870, was changed from Chief Draughtsman to Chief Designer circa 1882, apparently reflecting both a change in the company structure as well as the role of what is regarded as a modern day naval architect. Johnson had been admitted to the Institution of Naval Architects (INA) in



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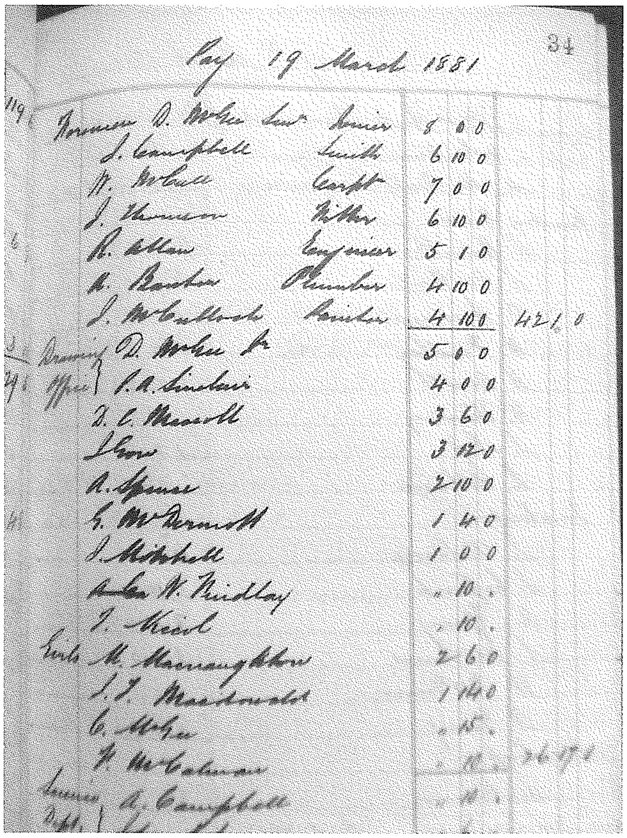
Pay

Foreman	D. McGee Senr	Joiner	8 0 0	
	J. Campbell	Smith	6 10 0	
	W. McColl	Carpt	7 0 0	
	J. Thomson	Fitter	6 0 0	
	R. Allan	Engineer	4 15 0	
	A. Baxter	Plumber	4 10 0	
	J. McCulloch	Painter	4 10 0	41 5 0
Drawing Office	D. McGee Jr		5 0 0	
	P.A. Sinclair	[illegible]	4 0 0	
	D.C. Macoll		3 6 0	
	R. Monteath		3 6 0	
	R. Dunlop		2 16 0	
	G. McDermott		1 4 0	
	J. Mitchell		" 18 "	
	A. Campbell		" 10 "	
	Wm Findlay		" 10 0	
Girls	M. McNaughton	[illegible]	2 6 0	
	J.T. McDonald		1 14 0	
	C. McGee	[illegible]	" 15 "	[illegible]
Office	R. Hamilton		5 0 0	
	R. McMillan		4 0 0	
	[illegible]		[illegible]	
	W. Findlay		[illegible]	
	W. Young		[illegible]	

Figure 8: Salary records for Charles Henry Johnson (Denny Archives). Courtesy of the University of Glasgow.



Pay 19 March 1881

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Foreman	D. McGee Senr	Joiner	8 0 0	
	J. Campbell	Smith	6 10 0	
	W. McColl	Carpt	7 0 0	
	J. Thomson	Fitter	6 10 0	
	R. Allan	Engineer	5 1 0	
	A. Baxter	Plumber	4 10 0	
	J. McCulloch	Painter	4 10 0	42 1 0
Drawing Office	D. McGee Jr		5 0 0	
	P.A. Sinclair		4 0 0	
	D.C. Macoll		3 6 0	
	[illegible]		3 12 0	
	[illegible]		2 10 0	
	G. McDermott		1 4 0	
	J. Mitchell		1 0 0	
	W. Findlay		" 10 "	
	[illegible]		" 10 "	
Girls	M. Macnaughton		2 6 0	
	J.T. Macdonald		1 14 0	
	C. McGee		" 15 "	
	[illegible]		[illegible]	[illegible]
[illegible]	A. Campbell		[illegible]	

Figure 9: Salary records for James Thomson (Denny Archives). Courtesy of the University of Glasgow.

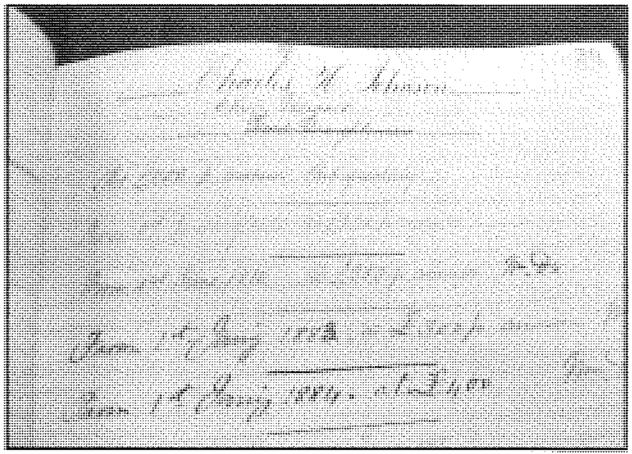
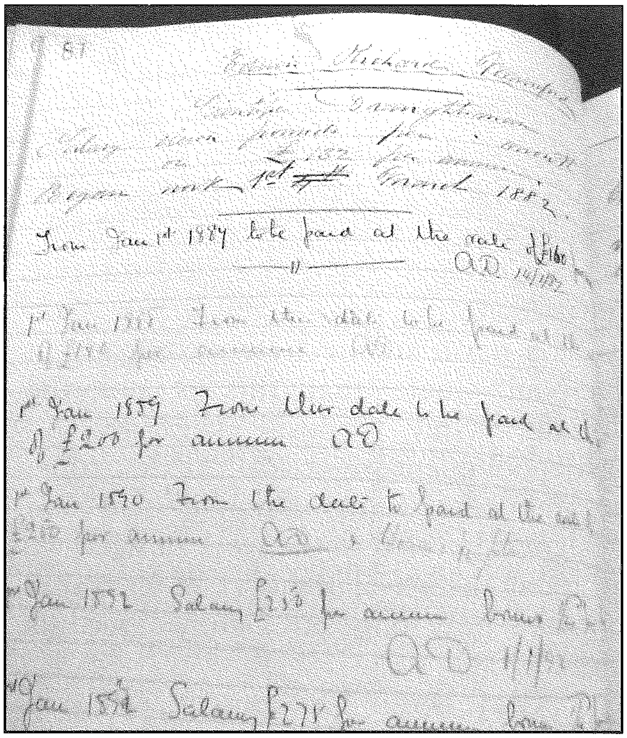


Figure 10: Salary records for Richard Mumford (Denny Archives). Courtesy of the University of Glasgow



From Jan 1st 1884 to be paid at the rate of £160

1st Jan 1889 From this date to be paid at the rate of £200 per annum AD

1st Jan 1890 From the date to be paid at the rate £2[illegible] per annum AD

1st Jan 1892 Salary £250 per annum [illegible]

1st Jan 1894 Salary £275 per annum [illegible]

Figure 11: Salary records for William Gray (Denny Archives). Courtesy of the University of Glasgow.

1880 (*TINA* 1880, xiii) His assistant, Frank P. Purvis, was, at the same time, also "promoted" from Draughtsman to Assistant Designer, and soon becoming the superintendent of the Experiment Tank. Both their salaries nearly doubled in the space of two years. Similarly, from 1880 to 1882, the firm hired two Scientific Draughtsmen (a term embodying both drawing and calculations), James Thomson and Richard Mumford. (Figures 9 and 10) These records indicate a substantial change in both design and managerial practices: that the "rule of thumb" building practices (which required only drawing skills) were being superseded by a new revolutionary scientific approach that demanded both designers and calculators; and that these roles were being staffed by well-salaried, technically skilled professionals in order to deal with the increasing complexity of the organisation and its products.

This assertion is further validated through the investigation of salary records of a former Denny's shipyard employee, William Gray. (Figure 11) Gray started his employment at Denny's in 1884, serving a five-year apprenticeship at the Experimental Tank. In 1892 he became Head of the Scientific Department and in 1896 was promoted to "Head Draughtsman of the Scientific Department." In 1902, Gray left the firm "to be a naval architect for a company in Liverpool" (note that this is not the William Gray whose shipyard in Hartlepool opened in 1874). At that time, the ambiguous terms 'Draughtsman' and 'Designer' referred to the work of what we call today the 'naval architect,' a term that appeared only once in Denny's records before 1900.

Gray began his apprenticeship in the scientific environment of Denny's Experiment Tank, signalling both a new breed of marine designer, that is, the naval architect, and indeed a new scientific approach to marine design. This was part and parcel of a novel management approach to design, one of specialization and vertical integration, as the design offices became separated into the technical department (steelwork), arrangements and scientific department. In particular, the appearance of the scientific department charged with "calculations as to weights, capacities, displacement, stability, speed, trim, etc.," demonstrates the rise of the new middle manager class; a worker with both academic and practical experience driving the organisation and new innovative marine design approaches. (Denny 1894, 280; Walker 1984, 118-119) This development coincided with the specialization and vertical integration of the production side of the shipyard, which was producing and installing high-efficiency triple-expansion engines and newfangled electrical generating and distribution systems. (Denny & Brothers 1932, 27-30)

Denny's often led the way among commercial shipbuilders in the use of scientific naval architecture. As early as 1869, the shipyard was computing displacement of its ships, a rare practice at the time for commercial shipbuilders, although the calculations were sometimes inaccurate. Stability calculations first appeared in ships' plans in 1880. In 1884, William Denny was the first to develop and use "cross-curves of stability," a method of quickly establishing stability conditions at various draughts and angles of heel, which came on the heels of the sinking on launch of the steamship *Daphne,* built by Alexander Stephen & Sons in 1883. Denny's attention to detail led them to develop a complete set of rules that standardized each part of the design and production process, from specific calculations that had to be completed for each ship, to the flow of materials in the production yard. (Denny 1884; Denny & Brothers 1932, 65-70, Lyon 1975 vol. 1, 11)

J & G Thomson

(Figure 12)

In 1880, Thomson hired John Harvard Biles, a graduate of the Royal Naval College Greenwich, as its first naval architect, "a reflection of the growing influence of scientific ship design." (Johnston 2000, 69) This evolution in scientific design and management is further evidenced by the compa-

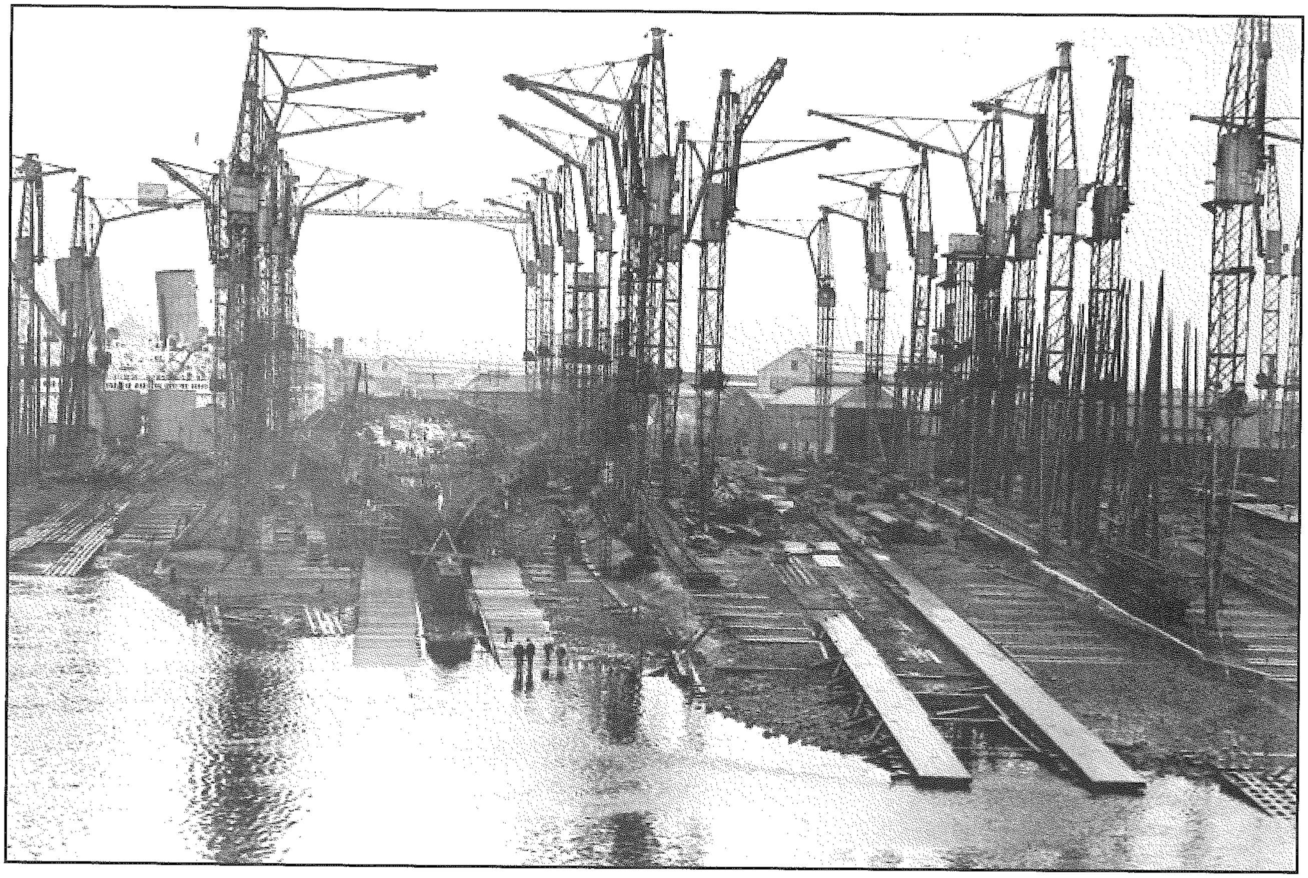
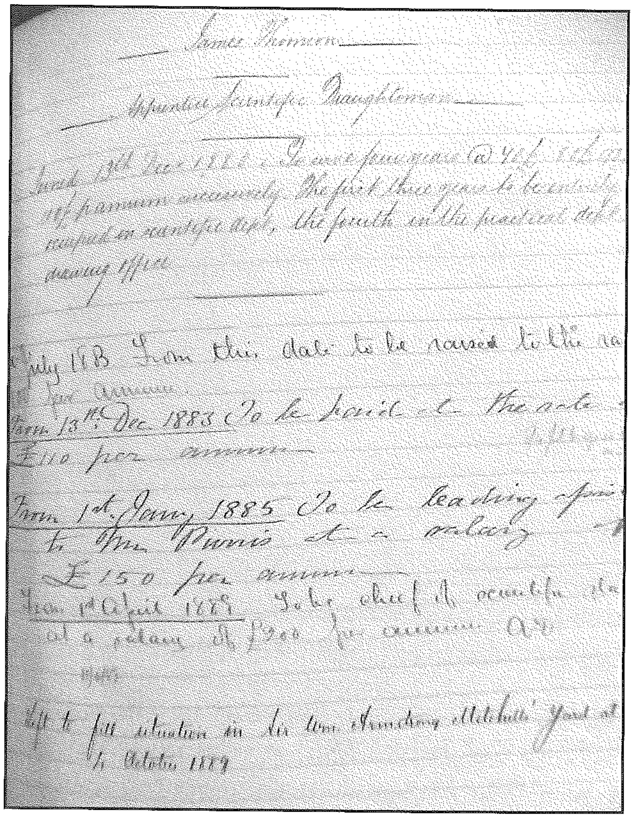


Figure 12. The Thomson yard in 1914. Courtesy of the Scottish Maritime Museum.



James Thomson

Apprentice Scientific Draughtsman

Bound 13th Dec 1880 [illegible] five years @ [illegible] per annum [illegible] the first three years to be [illegible] occupied in scientific dept, the fourth in the practical [illegible] drawing office

July 1883 From this date to be raised to the [illegible] per annum

From 13th Dec 1883 To be paid at the rate [illegible] £110 per annum

From 1st Jany 1885 To be leading [illegible] to Mr Purvis at a salary [illegible] £150 per annum

From 1st April 1888 To be chief of scientific [illegible] at a salary of £200 per annum [illegible]

Left to fill situation in Sir Wm Armstrong Mitchell's Yard at [illegible] October 1889

Figure 13: J & G Thomson wage book, 1880 (Thomson Archives). Courtesy of the University of Glasgow.

ny's wage books from 1880 to 1891, which provide a fascinating insight into the structure of the company. The first wage book (Figure 13) in 1880 showed a business with highly specialised divisions: foreman, drawing office, and girls (presumably to do tracing), "counting office" and other intermediate roles. The wage book for 19 March 1881 (Figures 14 and 15) mentions a new Science Department, followed a week later by a company restructure from one to two drawings offices. (Figure 16) This restructuring is then referred to as drawing office A & B (Figure 17) consistently until August 1883 when the wage book reverts back to a single drawing office. As with Denny's, the emergence of a separate Science Department indicates a growing specialization and vertical integration within the front offices, and a transition from "rule of thumb" principles, to a systematic, scientific approach towards marine design. At the same time, the

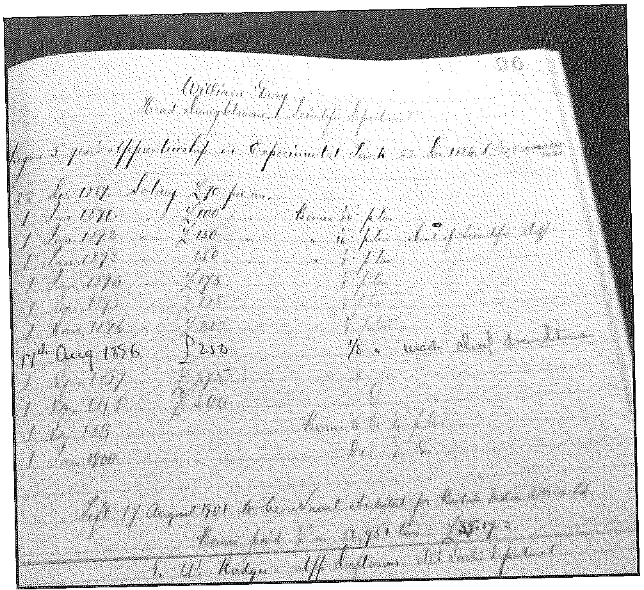
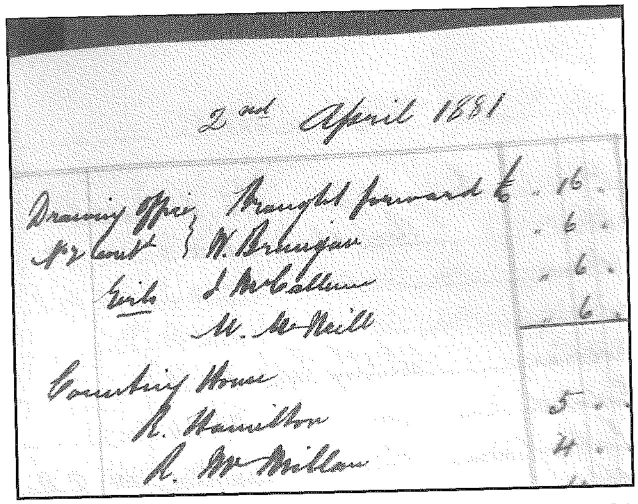


Figure 14: J & G Thomson wage book, 19 March 1881 (Thomson Archives). Courtesy of the University of Glasgow.



2nd April 1881

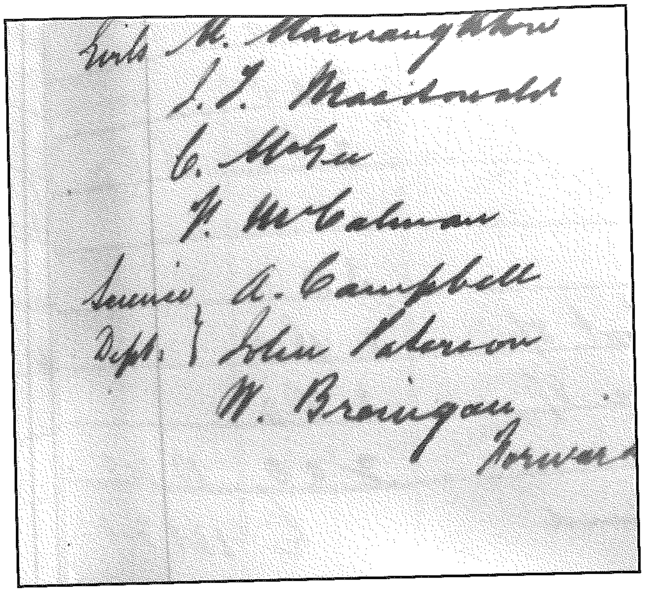
Drawing Office Brought forward £ . 16 .
No 2 cont } W. Branigan . 6 .
[illegible] J McCallum . 6 .
M. McNeill . 6 .

Counting House
R. Hamilton 5 .
R. McMillan 4 .

Figure 16: Drawing office No.2 wage book, 2 April 1881 (Thomson Archives). Courtesy of the University of Glasgow.

Thomson shipyard was also rationalising and concentrating its production, creating a set of specialised, vertically-integrated facilities (boilerworks, engine works and fitting-out basin) into a single site. (Johnston 2000, 53-87) (Figure 18)

Some useful insights may be garnered by following a particular career. As with William Gray of Denny's, William David Archer was one of the highest paid members of the shipyard, which suggests that not only had he been there a long time but his position within the company was one of high levels of authority and responsibility. Archer first appears in the wage book for 29 July 1885, presumably when he was first engaged in the drawing office and worked under John Biles. Archer was admitted to the INA in 1888, during their



[illegible] M. Macnaughton
J. T. Macdonald
C. McGee
J. McCalman
Scienc. A. Campbell
Dept. } John Paterson
W. Branigan
Forward

Figure 15: Scientific Department wage book, 19 March 1881 (Thomson Archives). Courtesy of the University of Glasgow.

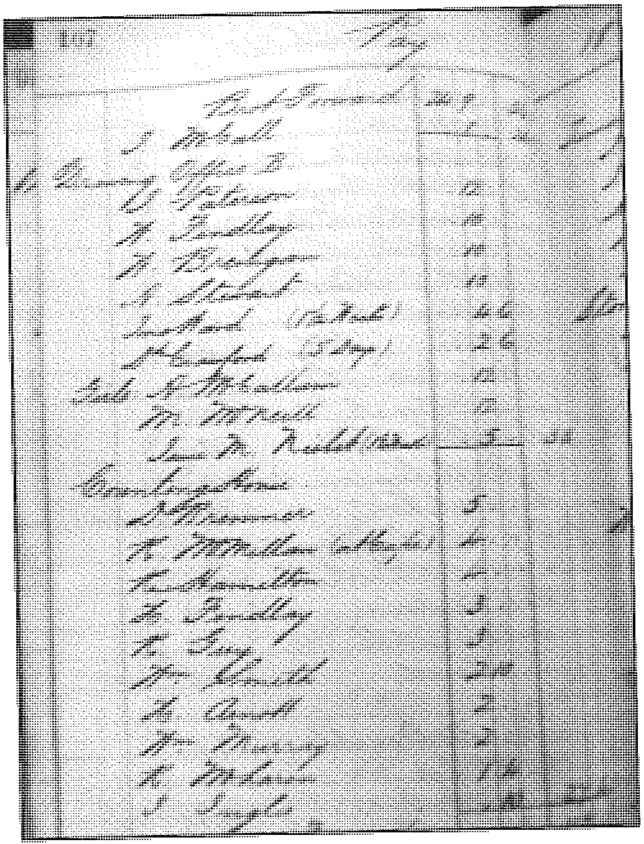
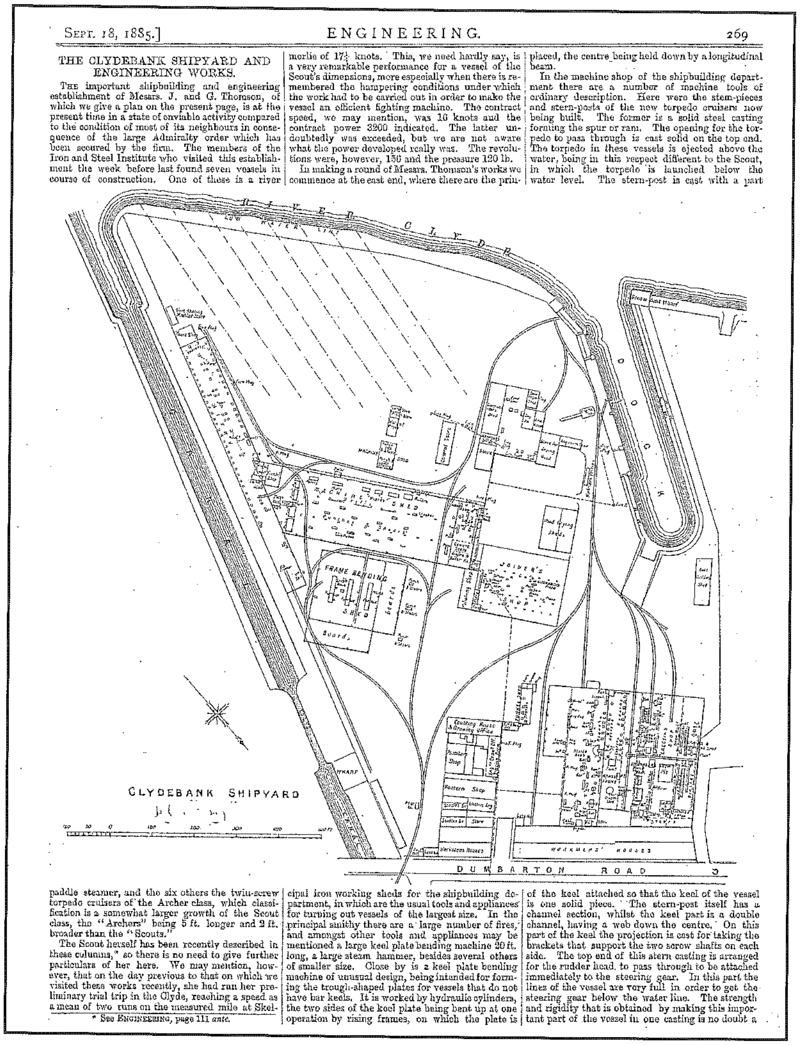


Figure 17: Drawing office A & B wage book, 1882 (Thomson Archives). Courtesy of the University of Glasgow.



Sept. 18, 1885.] ENGINEERING. 269

THE CLYDEBANK SHIPYARD AND ENGINEERING WORKS.

The important shipbuilding and engineering establishment of Messrs. J. and G. Thomson, of which we give a plan on the present page, is at the present time in a state of enviable activity compared to the condition of most of its neighbours in consequence of the large Admiralty order which has been secured by the firm. The members of the Iron and Steel Institute who visited this establishment the week before last found seven vessels in course of construction. One of these is a river paddle steamer, and the six others the twin-screw torpedo cruisers of the Archer class, which classification is a somewhat larger growth of the Scout class, the "Archers" being 5 ft. longer and 2 ft. broader than the "Scouts."

The Scout herself has been recently described in these columns,* so there is no need to give further particulars of her here. We may mention, however, that on the day previous to that on which we visited these works recently, she had run her preliminary trial trip in the Clyde, reaching a speed as a mean of two runs on the measured mile at Skelmorlie of 17½ knots. This, we need hardly say, is a very remarkable performance for a vessel of the Scout's dimensions, more especially when there is remembered the hampering conditions under which the work had to be carried out in order to make the vessel an efficient fighting machine. The contract speed, we may mention, was 16 knots and the contract power 3200 indicated. The latter undoubtedly was exceeded, but we are not aware what the power developed really was. The revolutions were, however, 156 and the pressure 120 lb.

In making a round of Messrs. Thomson's works we commence at the east end, where there are the principal iron working sheds for the shipbuilding department, in which are the usual tools and appliances for turning out vessels of the largest size. In the principal smithy there are a large number of fires, and amongst other tools and appliances may be mentioned a large keel plate bending machine 20 ft. long, a large steam hammer, besides several others of smaller size. Close by is a keel plate bending machine of unusual design, being intended for forming the trough-shaped plates for vessels that do not have bar keels. It is worked by hydraulic cylinders, the two sides of the keel plate being bent up at one operation by rising frames, on which the plate is placed, the centre being held down by a longitudinal beam.

In the machine shop of the shipbuilding department there are a number of machine tools of ordinary description. Here were the stem-pieces and stern-posts of the new torpedo cruisers now being built. The former is a solid steel casting forming the spur or ram. The opening for the torpedo to pass through is cast solid on the top end. The torpedo in these vessels is ejected above the water, being in this respect different to the Scout, in which the torpedo is launched below the water level. The stern-post is cast with a part of the keel attached so that the keel of the vessel is one solid piece. The stern-post itself has a channel section, whilst the keel part is a double channel, having a web down the centre. On this part of the keel the projection is cast for taking the brackets that support the two screw shafts on each side. The top end of this stern casting is arranged for the rudder head to pass through to be attached immediately to the steering gear. In this part the lines of the vessel are very full in order to get the steering gear below the water line. The strength and rigidity that is obtained by making this important part of the vessel in one casting is no doubt a

* See Engineering, page 111 *ante*.

Figure 18. Plan of the Thomson yard in 1885. Courtesy of the Scottish Maritime Museum.

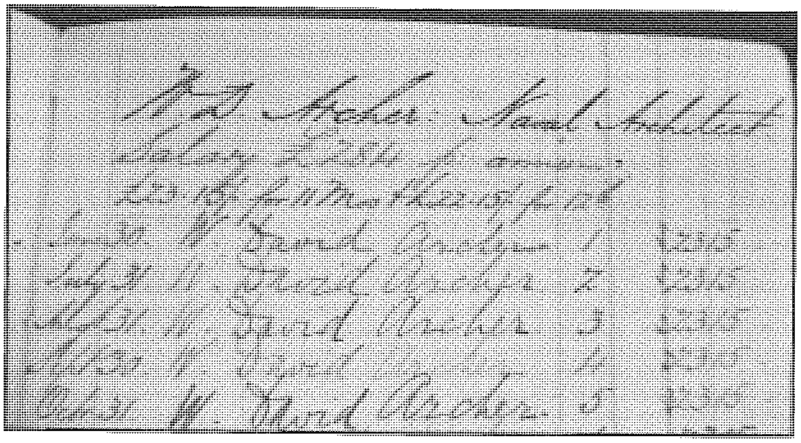


Figure 19: Salary records for William David Archer (Thomson Archives). Courtesy of the University of Glasgow.

annual meeting held in Glasgow on the occasion of the International Exhibitions of Science, Art & Industry. (*TINA* 1888, 143) After Biles's departure from Thomson in 1891, Archer was elevated to the position of naval architect. (Figure 19) This use of the term 'naval architect' here, in conjunction with the information relating to the scientific departments, is another indication of the transformation of marine design to what we see and recognise in ship design offices worldwide today.

Further information from the archives provides a unique insight into the scientific and technical complexity of the organisation and their created designs. Prior to 1880, little technical information was included in ships' plans or notebooks. Starting in 1880, coinciding with John Biles's arrival, the general calculation notebooks (1880-1890) begin exhibiting specifications and calculations that demonstrate a sophisticated degree of scientific naval architecture:

- General calculations for the passenger ship *Servia* (1881), which include longitudinal BM, moment of buoyancy, metacenter, volume, added weight and an inclining experiment. (Figure 20) Additionally, launching drafts are discussed, compared and calculated, referring to previously built vessels *Arab* (1879) and *Trojan* (1880).
- Launching calculations for the passenger ship *America* (1883), showing stability parameters such as the draft and trim, freeboard, load lines, centre of gravity and the metacentric height.
- Resistance and thrust calculations for paddlewheels and propellers, for example, for *Trojan*, 1880.

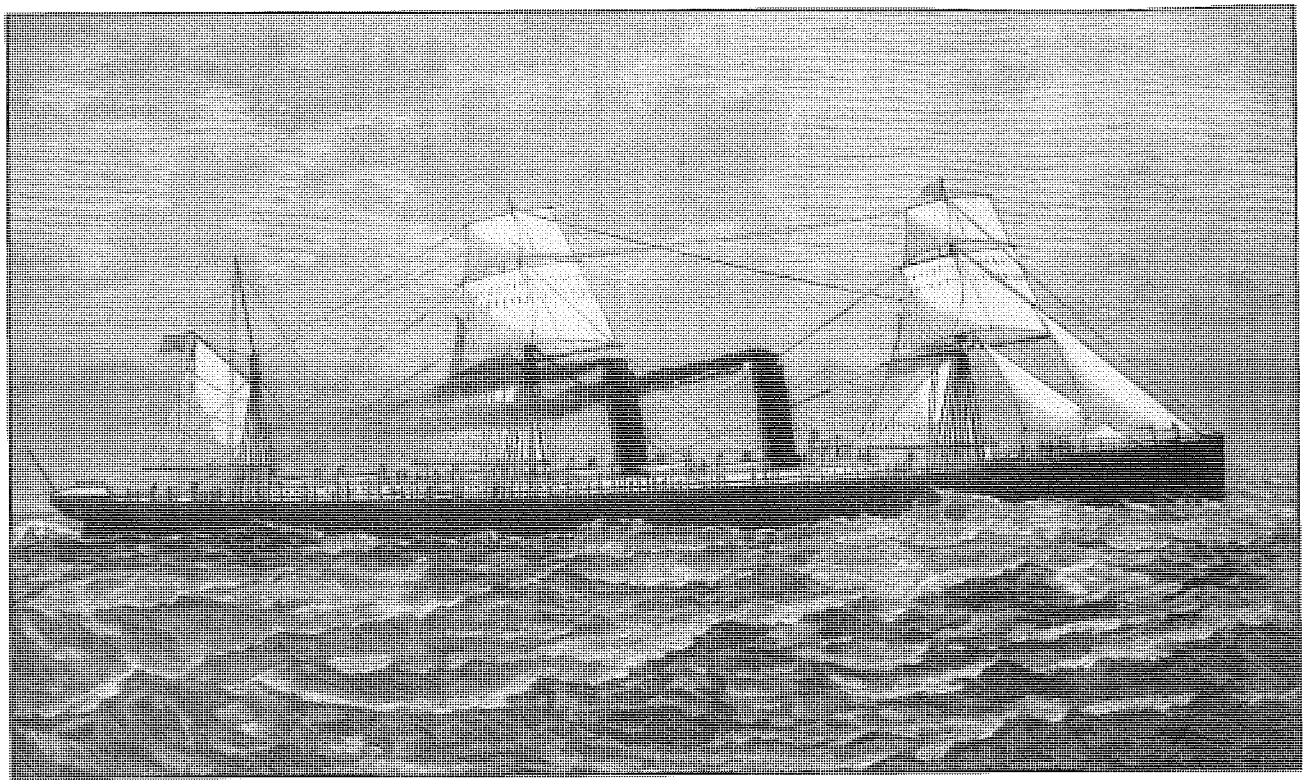


Figure 20. The steamship *Servia*, 1880. *Illustrated London News.*

Robert Napier & Sons

Although titled as Robert Napier's shipyard, the firm was actually run by his sons, James R. and John Napier. The extant business records do not include details of the shipyard organisation. They do, however, show that the shipyard, under the influence of the scientifically-minded partner James R. Napier, was quite advanced in using scientific naval architecture. As early as the 1860s, he was carrying out longitudinal and transverse strength calculations for iron paddlewheel steamers. By the 1870s, he was making increasingly sophisticated calculations for ship launch (including the vertical and longitudinal travel of the centre of gravity). From 1872 to 1876, James R. Napier was corresponding with William Froude on the subject of ship's rolling, which had been a topic of pressing concern for the new steamships that did not have the stabilizing influence of masts and sails.

Transforming the Shipyard on the American Clyde

The American industrial revolution lagged several decades behind that of Britain, in particular in the development of the iron and coal industries. Britain, due to its shortage of wood, had developed these industries quite early; for example, by the 1830s iron had become the favored material for British railroad bridges, whereas in the United States, with abundant stands of timber throughout the vast countryside, wood was used in quite substantial bridge structures until the turn of the twentieth century. (Kranakis 1996)

The transition from wood to iron was especially slow in American shipbuilding, where the abundant wood supply and federal protection of shipbuilding from outside competition (called the "free ship" policy) meant that many American shipbuilders were still working in wood well after the Civil War. The majority of

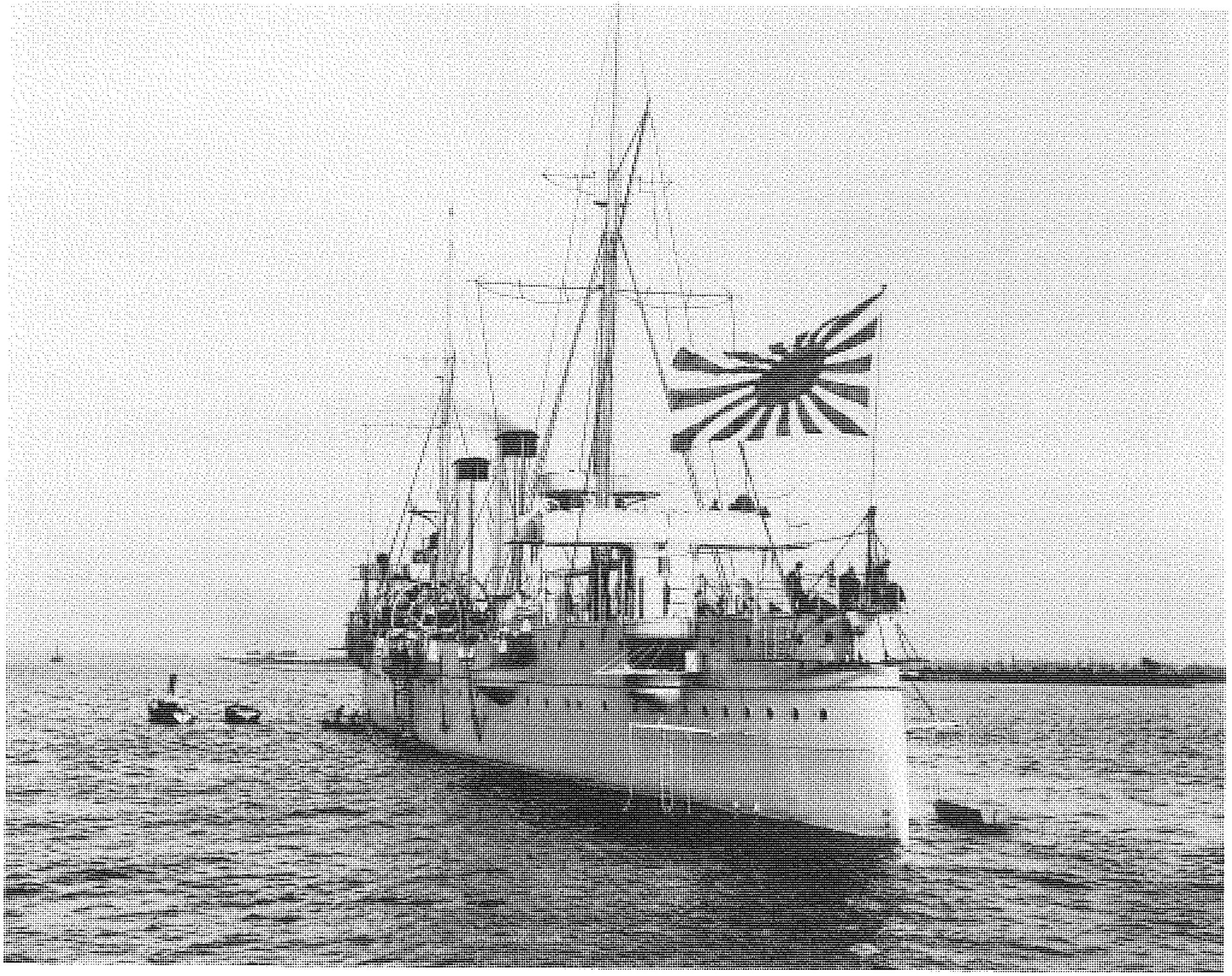


Figure 21. The Imperial Japanese Navy protected cruiser *Kasagi* in 1898. Naval History and Heritage Command image.

shipyards building these wooden vessels—both steam and sail-powered—were small family-owned firms. (Fassett 1948 vol. 1, 34-37) The facilities were generally quite simple; a slipway on a river or protected bay and small woodworking shops sometimes fitted with steam-driven saws. A foreman oversaw the small crew (generally between eight and twenty-five men), consisting of carpenters, caulkers, joiners, riggers and ropemakers, to construct a medium-sized vessel. The introduction of iron hulls into American shipbuilding during the 1840s and 1850s did not automatically result in a restructuring of the shipyards. In many cases iron shipbuilders remained small in size and followed the same procedures as wooden shipbuilders. (Bames 1878; Fassett 1948 vol. 1, 38)

The changeover from small-scale shipyards to large-scale, vertically-integrated shipbuilding firms began in the 1870s and was in full swing a decade later. By the 1880s, the shipbuilding business had become concentred on the Delaware River, in Philadelphia and the surrounding cities of Chester and Wilmington. This was already a major hub of locomotive building, and the availability of materials, infrastructure, skilled labour and management gave rise to the most important metal-and-steam shipbuilding center in the nation, which became nicknamed "The American Clyde." Three shipyards soon became the most important: William Cramp & Sons, John Roach & Sons, and Harlan &

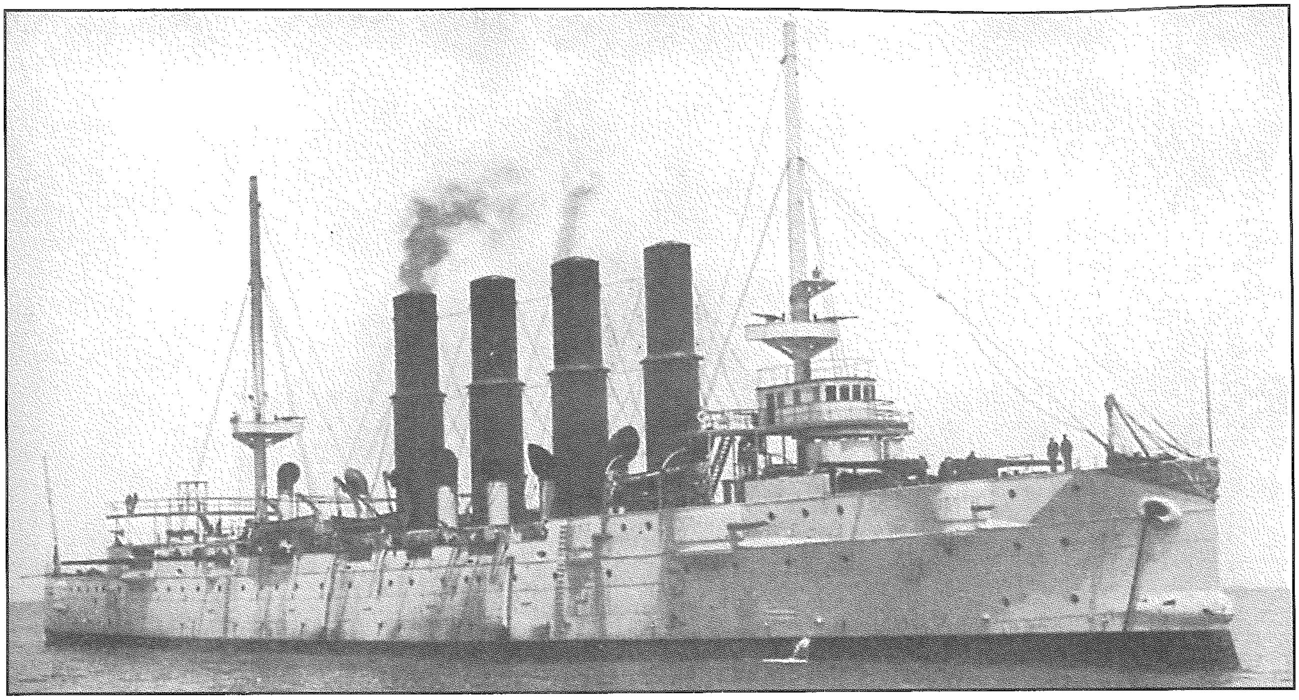


Figure 22. The Imperial Russian Navy protected cruiser *Variag*. Naval History and Heritage Command image.

Hollingsworth. (Tyler 1958; Heinrich 1997; Thiesen 2006)

To identify the scope and breadth of the changes in these shipyards, we employed the archives of the Hagley Museum Library in Wilmington, Delaware and the Independence Seaport Museum in Philadelphia, Pennsylvania. Unlike the shipyard records in Glasgow, most of these records were quite sparse and had little in the way of business records; in particular, the papers of John Roach & Sons were destroyed in a fire in 1887. The Harlan & Hollingsworth collections at the Hagley Museum Library consist of a handful of ship specifications, corporate minutes and account sheets. The Cramp & Sons' collection of archived drawings and plans at the Independence Seaport Museum, Philadelphia are by far the most complete. (Farr and Bostwick 1991) The plans consulted included: *Pennsylvania* (Hull 180, 1872); *Columbus* (Hull 184, 1873); *Zabiaka* (Hull 203, 1878); *Cetus* (Hull 219, 1881); *Terror* (Hull 195, 1883); *Venezuela* (Hull 263, 1889); *Pittsburgh* (Hull 289, 1896); *Kasagi* (Hull 291, 1898); *Variag* (Hull 301, 1899); *Pontoon* (Hull 307, 1901); and *Kroonland* (Hull 311, 1902). See Figures 21 and 22.

William Cramp & Sons

(Figure 23)

As with many industries during the period, this development was highly influenced by the railroad industry. This was no accident, as many railroad magnates extended their domains into shipping, and vice versa. Cornelius Vanderbilt, nicknamed "The Commodore" for his vast merchant fleet, also created a great rail empire, thus pioneering the intermodal railroad/shipping industry. This concept was extended by the Pennsylvania Railroad, which funded a fleet of iron and steam ships, starting with SS *Pennsylvania*, to transport passengers cross-country and then transatlantic. (Roland et al. 2008, 201-204)

Pennsylvania (Figure 24) was built at the William Cramp & Sons Shipbuilding Company in Philadelphia, and this was no accident, either. Cramp had begun as ship-

Figure 23. Cramp's shipyard in Philadelphia. From the editor's collection.

builder in 1825, but, unusually for most builders of wooden vessels, his company was able to transition to iron and steam during the Civil War. Most other shipbuilders had begun as machine shops, boilermakers and iron foundries. (Thiesen 2006, 80-112) The yard was able to make this transition by creating an integrated system similar to that found in locomotive builders. It also sent its chief engineers to Scottish shipyards and engine manufacturers to study the newly-developed compound steam engines.

William Cramp noted, "the growth of complexity in modern ships have entailed upon the naval architect and constructor demands and difficulties never dreamed of in earlier days…the staff required to design and construct [a modern ship], and the complexity of its organisation, has augmented almost infinitely." (Buell 1906, 111-117, 196-197) In order to improve efficiency, Cramp initiated a systematic design and production schema so that "the form of every plate must be sketched before it is ordered." Thus, by 1880, draftsmen had moved beyond simply drawing hull lines to creating highly complex shell expansion plans, which define a precise two-dimensional shape for a plate that will be bent and curved to fit a three-dimensional hull. (Figure 25) By 1883, simple curves of form for displacement were becoming commonplace. (Figure 26) By 1890, full stability curves including metacentric height were being developed, launching calculations began appearing in 1898, and by 1901 hull stress curves were being developed. (Buell 1906, 108)

John Roach & Sons

The technology, equipment and expertise to create these large, integrated industrial plants did not exist in the United States, so shipbuilders went abroad to obtain them, primarily to Britain. John Roach made an extensive tour of the Clyde

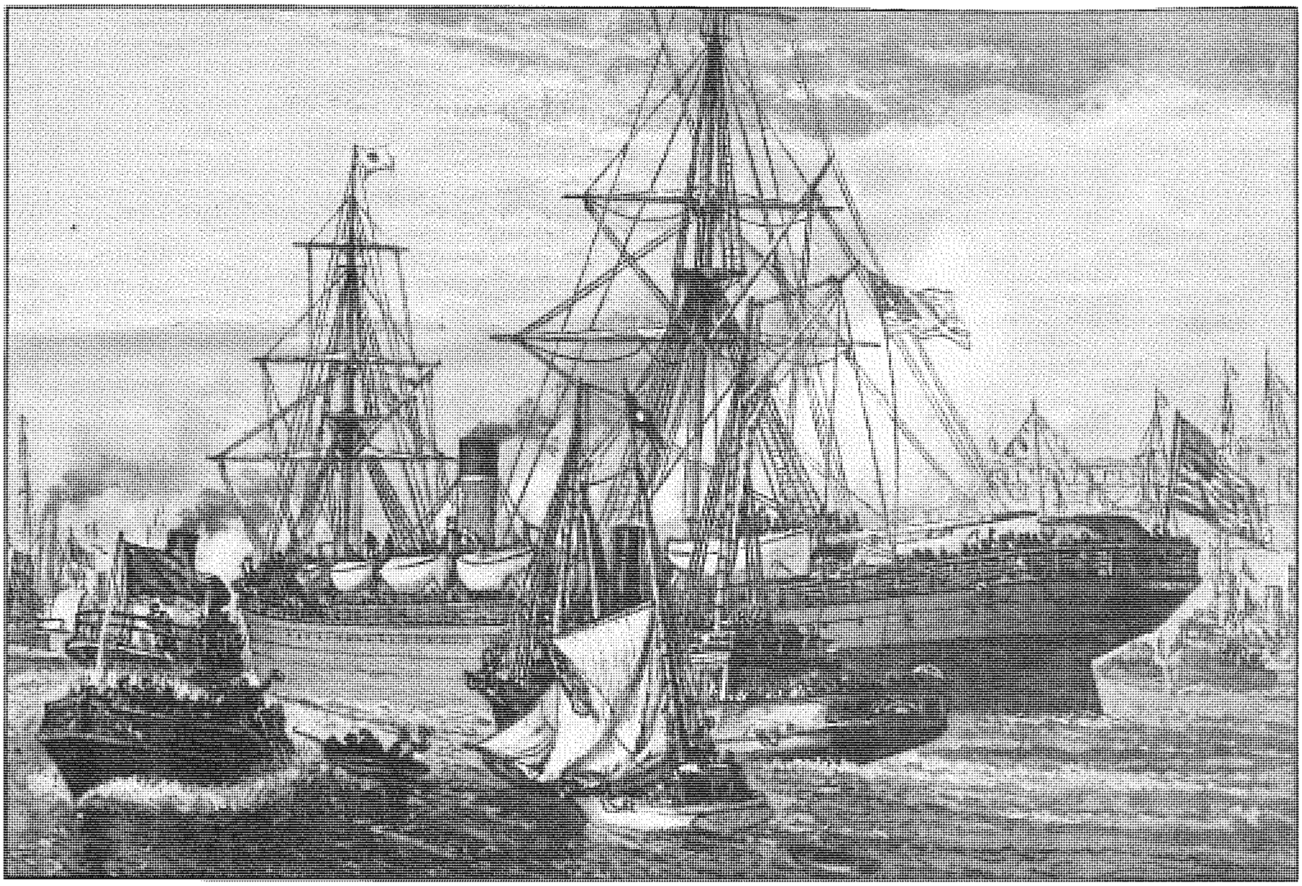


Figure 24. SS *Pennsylvania* departing for trials, 1872. From Edward Strahan (ed.), *A Century After: Picturesque Glimpses of Philadelphia and Pennsylvania* (1875).

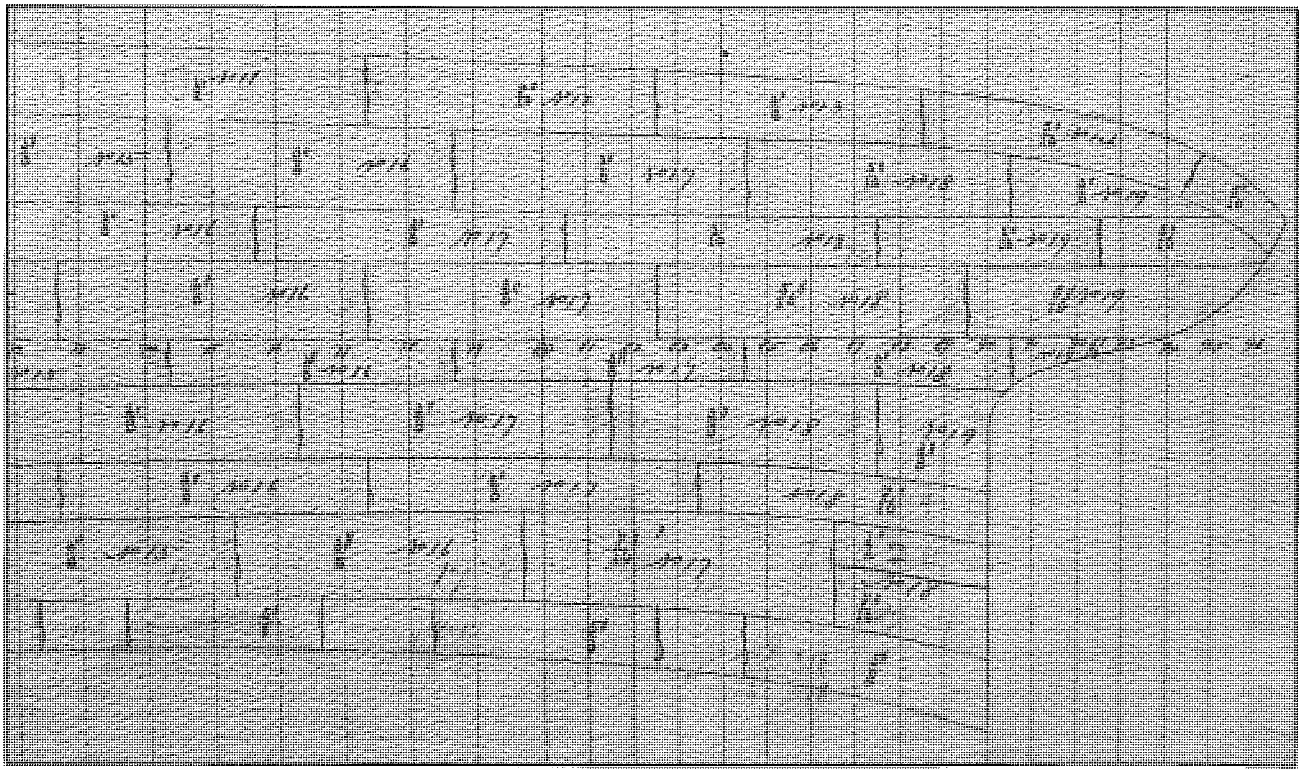


Figure 25. Cruiser *Zabiaka* plate expansion, 1878. Courtesy Independence Seaport Museum, Philadelphia.

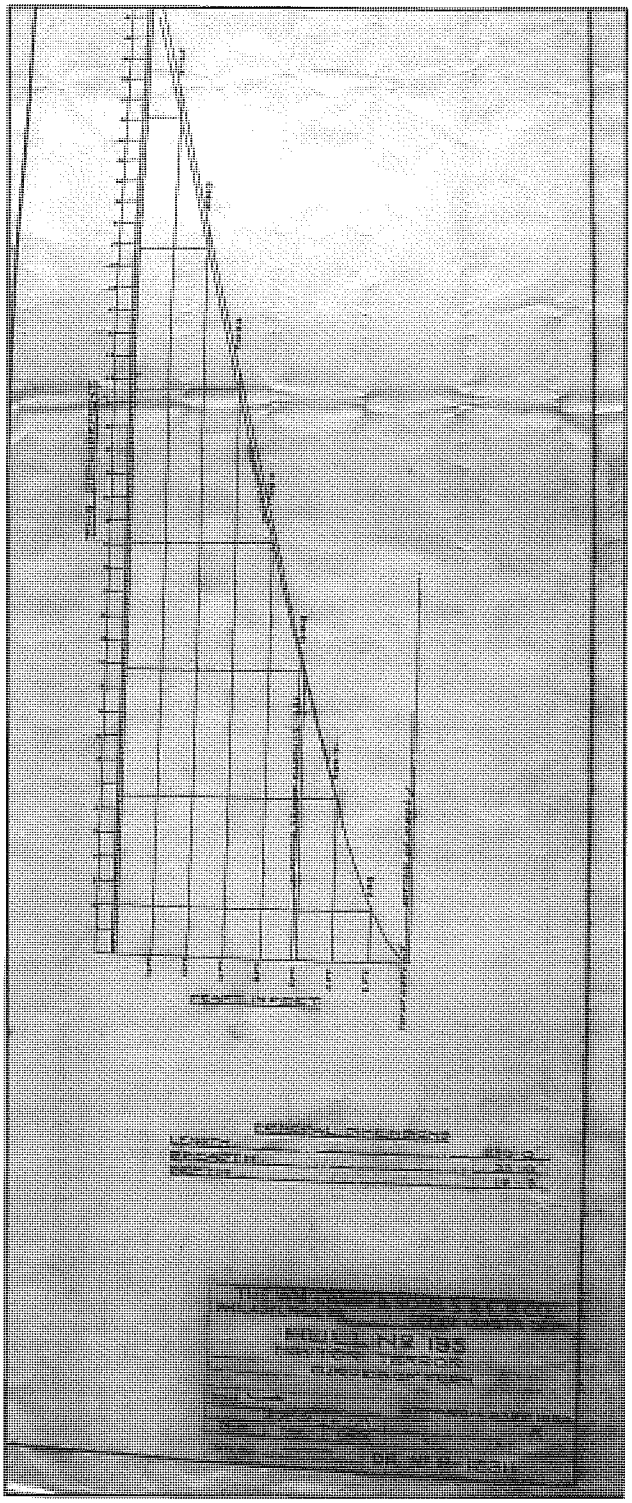


Figure 26. Monitor *Terror* curves of form, 1883. Courtesy Independence Seaport Museum, Philadelphia.

River shipyards to understand their techniques and organisation. In particular, the United States Navy facilitated the transfer of British technology by purchasing thousands of plans and drawings for armored cruisers and compound steam engines, which formed the basis for the "ABCD ships" (*Atlanta*, *Boston*, *Chicago* and *Dolphin*) begun in 1883, which signalled the birth of America's new steel navy. (Cooling 1979; Swann 1965, 50-51; Thiesen 1999) (Figures 27-30)

As the Delaware River shipyards expanded in scale and scope, their management structure changed as well. John Roach, upon returning from an overseas tour to the British Clyde in the 1870s, used what he had learned to create a vertically integrated plant "in which I could build ships from the ore up," including the production of plate, frames, boilers and piping. During the 1880s, he enlarged his workforce by fifty percent to over 1,500 men, consolidated functions into specific departments under direct control of supervisors, eliminated outmoded craft specialities like blacksmiths and greatly increased the skilled trades like boilermakers. He also created a strong middle management team of specialists in finance, labour management and engineering, including a department of twelve naval architecture draughtsmen to prepare ships' plans. These were considered valuable employees, with their daily wage of $3.19 being twice that of a ship's carpenter. (Swann 1965, 54-65)

Harlan & Hollingsworth

The engineering and naval architecture capabilities of the shipyards grew in step with the increasing complexity of the company and the ships it built. (Figures 31 and 32) Harlan & Hollingsworth's drafting department (the forerunner of the naval architecture department), which had been previously staffed by company-trained draughtsmen, was by 1880 employing university-educated engineers. (Harlan & Hollingsworth 1898)

It is instructive to note the difference in education and training of a father

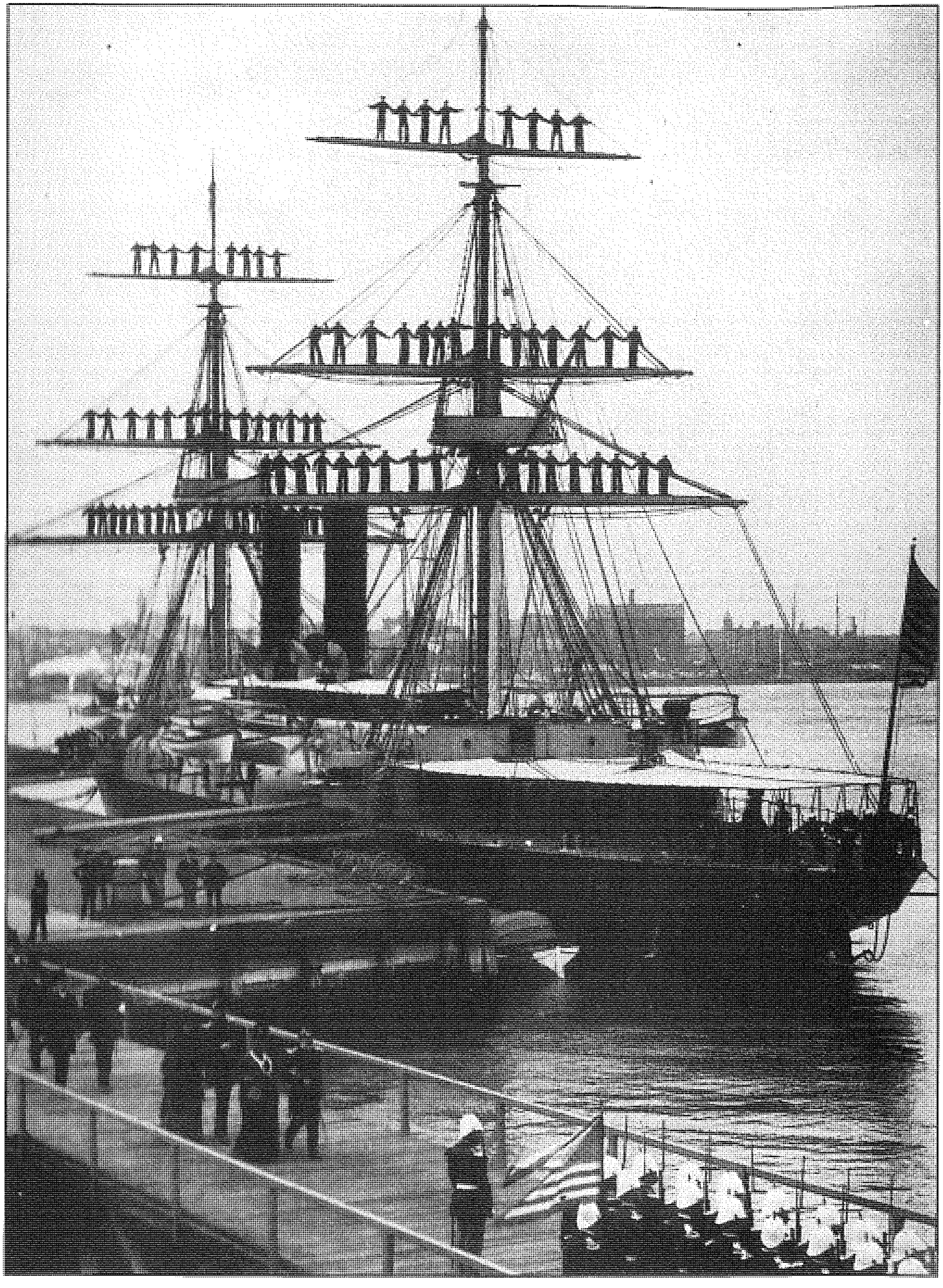


Figure 27. Cruiser *Atlanta*. Library of Congress image.

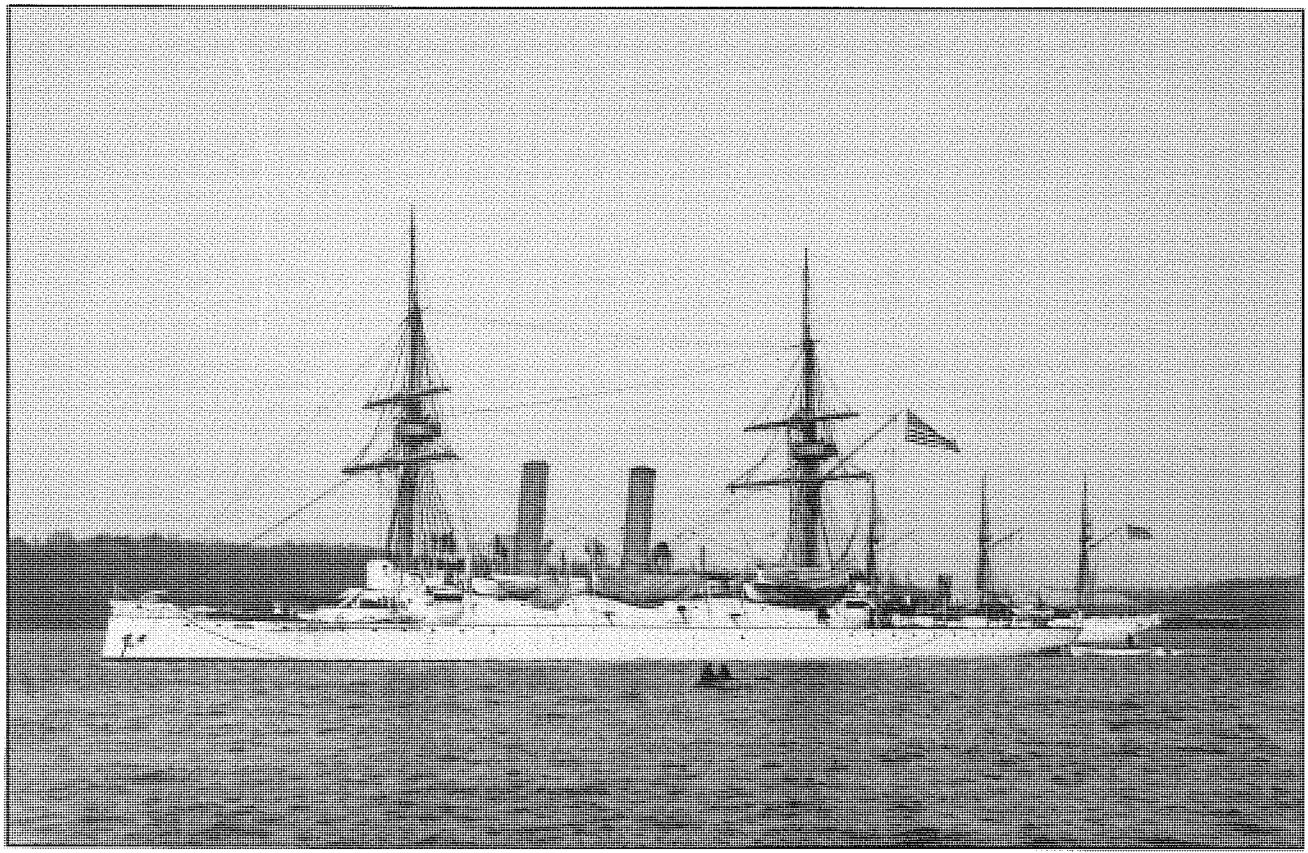


Figure 28. Cruiser *Boston*. Library of Congress image.

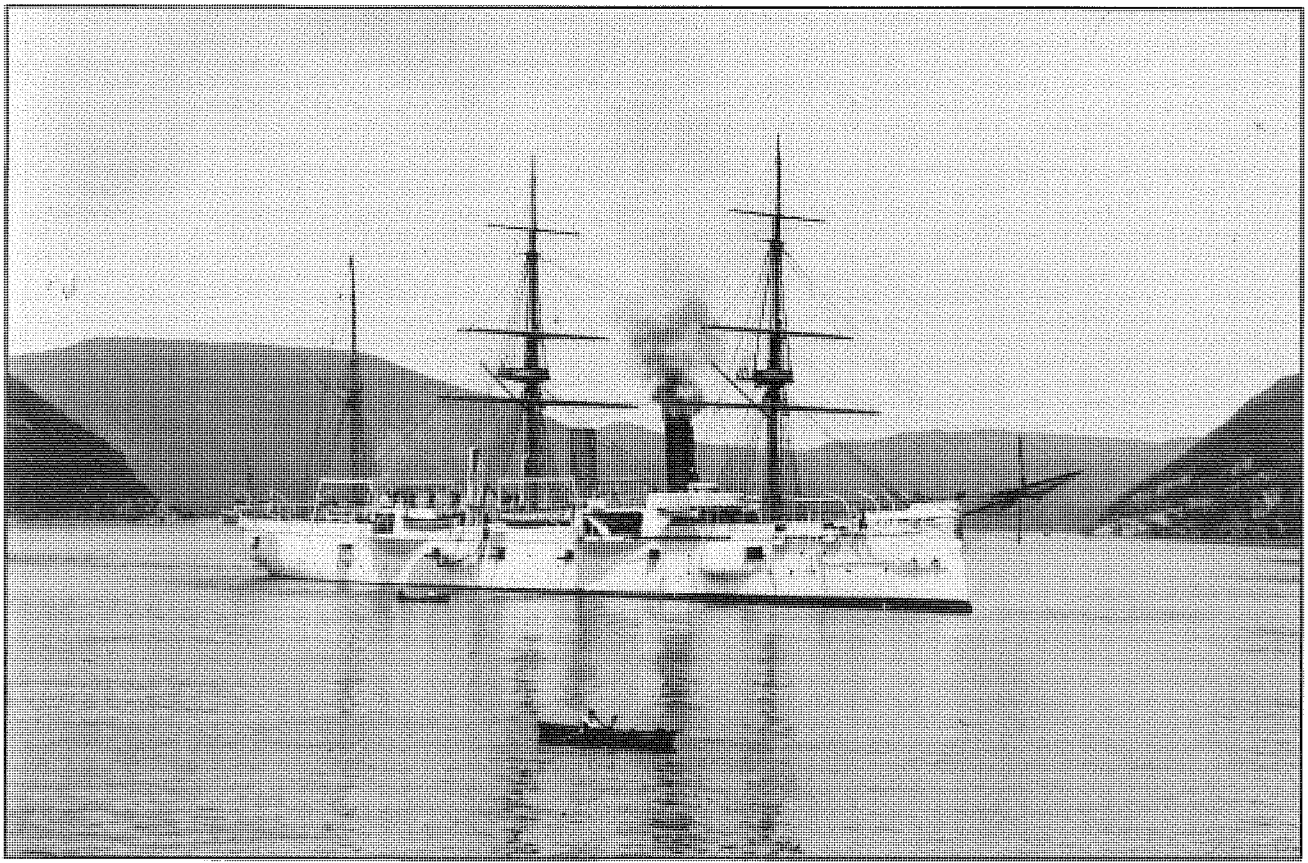


Figure 29. Cruiser *Chicago*. Library of Congress image.

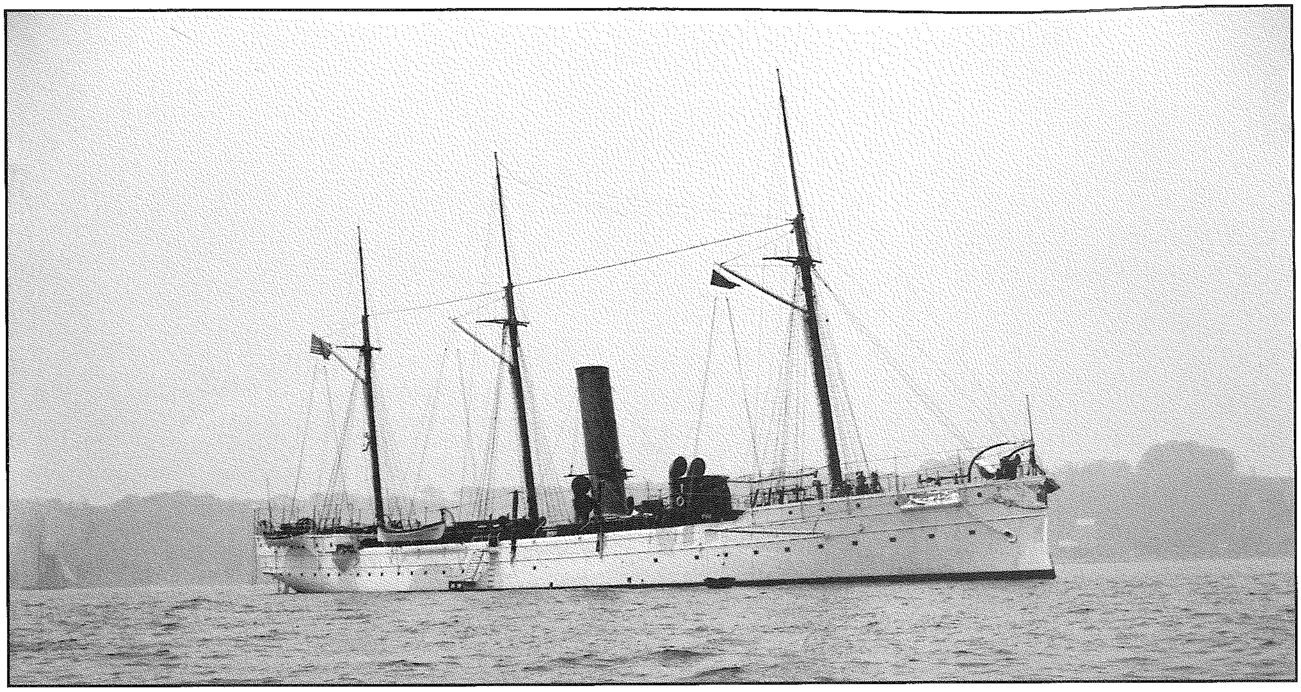


Figure 30. Despatch vessel *Dolphin*. Library of Congress image.

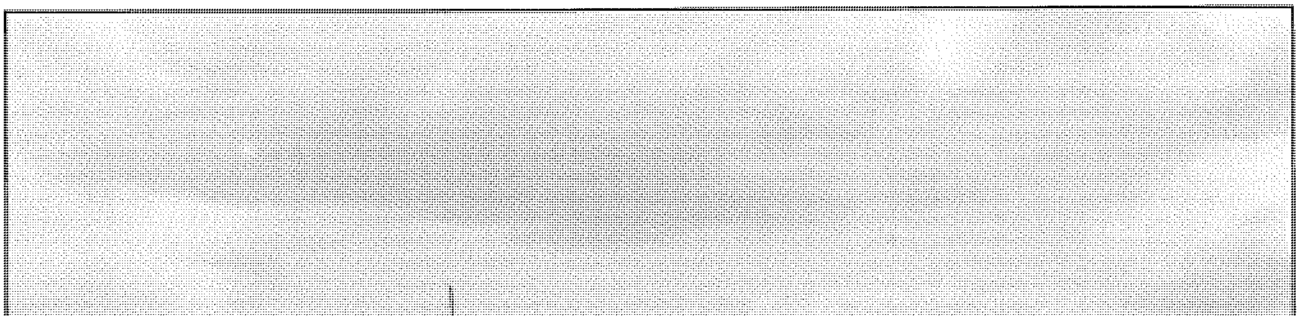


Figure 31. Monitor *Amphitrite*. Library of Congress image.

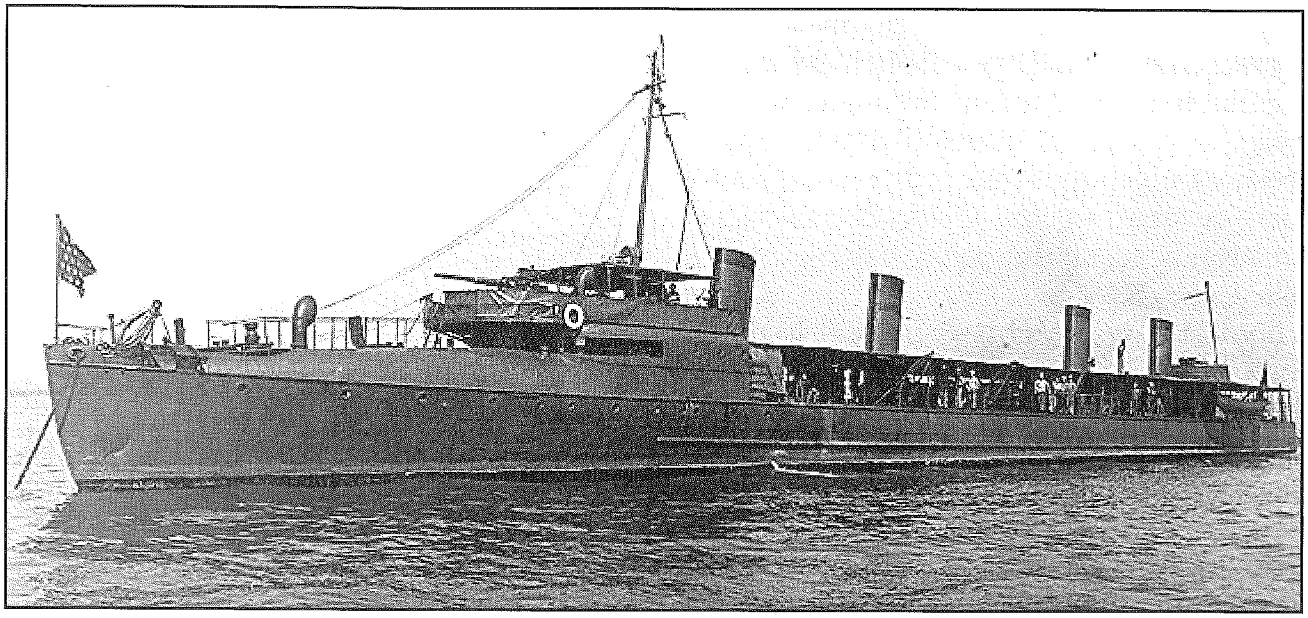


Figure 32. Destroyer *Hopkins*. Naval History and Heritage Command image.

and son employed at Harlan. Thomas Jackson came to Harlan in 1843 as a machinist, having been previously apprenticed in a wool mill. He rose up through the company during the transition from wood to iron shipbuilding, and, in 1856, became head of the Draughting Department, where he became "an authority upon many branches of marine architecture" by dint of his experience. His son Edward Jackson, by contrast, went to Cornell University and received a Bachelor of Science degree in 1875 before coming to the firm as a draftsman. This development coincided with increasingly prescriptive shipbuilding contracts and specifications (including calling for specific plate and frame sizes, hull speed, and so on) that had to be informed by theoretical developments in ship science, and individuals capable of carrying out those calculations. (Harlan & Hollingsworth collections; Harlan & Hollingsworth 1886, 291-292, 301-302, 366)

Conclusions

The institutionalisation of naval architecture from 1870 to 1910, as part of ship design and industrial management on the Two Clydes, is shown in Table 1. The initial steps in this process began in the 1870s with industry leaders like William Denny and John Roach, and quickly spread among major shipbuilders who sought to rationalize their operations in order to create the large, complex ships demanded by an increasingly globalized shipping industry

	1870s	1880s	1890s	1900s
Denny (UK)	Draughtsmen	Chief Designer Scientific Draughtsmen Experiment Tank	Scientific Department	
Thomson (UK)		Naval architect Stability calculations		
Napier (UK)	Strength calculations Launch calculations Froude letters			
Cramp (USA)		Curves of form Shell expansion	Stability calculations Launch calculations	Hull stress calculations
Roach (USA)	Draughtsmen	Naval architecture draughtsmen	---	---
Harlan (USA)	Draughtsmen	Engineering-trained draughtsmen Detailed specifications		

Table 1: Milestones in development of naval architecture on the two Clydes.

The need for more highly-trained naval architects to carry out such extensive engineering and project oversight was a major factor in the development of engineering universities and professional societies devoted to the field. Britain was already ahead of the pack, having established the INA in 1860, and the Royal School of Naval Architecture and Marine Engineering in 1864. In 1881, the University of Glasgow became Britain's second university to teach naval architecture and marine engineering, and within two years was endowed with a chair in memory of John Elder. Many Glasgow shipyard apprentices followed this course, evenings or in winter months. (*TINA* 1889, 65-89)

At the time, no American schools had programs in naval architecture, so the United States Navy took the first steps towards remedying this problem by sending a select few Naval Academy graduates to receive their naval architecture education in Britain and elsewhere. By 1900, naval architecture courses were being offered at universities such as Cornell, Webb, MIT and Michigan, whose programs were generally modeled on the British system. At the same time, an American Society of Naval Architects and Marine Engineers (SNAME) was also created, emulating the INA. (Thiesen 2006, 160-168)

By the end of the nineteenth century, therefore, a twenty-year transformation had changed the face of the shipbuilding industry, from a collection of small craft shops led by self-taught artisans, to a few industrialized, vertically-integrated plants managed by scientifically-educated engineers, who used the latest theoretical developments to design and build the complex ships that became the hallmark of the twentieth century.

Acknowledgements

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