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The Unpredictable Course of Naval Innovation – The Guns of HMS Thunderer

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On 2 January 1879, a squadron of Britain's Mediterranean Fleet was anchored near the entrance to the Gulf of Ismit in the Sea of Marmora. That morning, it conducted target practice. One of the battleships involved was HMS *Thunderer*, commissioned in 1877. Armed with two 38-ton (12.5 inch) muzzle-loading guns in its forward turret and two 35-ton (12 inch) guns in the aft turret, she was one of the most powerful and modern warships afloat. During the exercise that day, a broadside was fired at a target at a distance of 400 yards. After that, the guns were re-loaded and aimed at a target 1,000 yards distant. Firing independently, the right gun in the forward turret fired. Two or three minutes later, the left gun was fired and disaster struck. The gun's barrel exploded, the lid of the turret was destroyed, and all but one man in the gun crew were killed, with 34 other members of the ship's company injured.[2] A parliamentary committee convened in Malta only three weeks later. It concluded, after considering

[1] The author is grateful for comments and suggestions on earlier drafts provided by Capt. (N) Matthew Coates (RCN), Cdr. William Reive (RCN), LCdr. Robert Bedard (RCN), Maj. Bill Ansell (RCAF), and Dr. Roy Rempel.

[2] "Disaster in Naval Gunnery," *The Illustrated London News*, 18 January 1879: pp. 4-6.

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several hypotheses and the testing of the undamaged 38-ton gun ("that burst like its former companion"[3]), that the barrel had exploded after being double loaded.[4]

Although largely forgotten today, the accident on *Thunderer* has been described as the impetus for the Royal Navy switching from muzzle loading to breech-loading guns – a decision that would eventually change the way naval engagements would be fought.[5] That the gun in question was a muzzle-loader might seem to us antiquated ordnance but, at the time, it was considered to be the most advanced armament available. Together with an innovative loading mechanism, they are examples of how a premier military force wrestled with the challenges posed by an era of technological change.

Invention and Innovation

To avoid confusion in any discussion of technological change, innovation has to be distinguished from invention. While there will always be some overlap, ideas having many parents, the two processes are quite different. Invention refers to the creation of new technologies and radically newer capabilities that can be channeled into creating an edge over putative adversaries. Defence-related publications are filled with articles describing the advantages that will inevitably follow from the introduction of unmanned systems and sensors based on new technologies, directed-energy weapons, rail guns, hypersonic missiles, artificial intelligence, and quantum computing. Invention also applies to warship design. Recently, for example, a consortium of naval architects and engineers tasked by Britain's Royal Navy offered a design for a prototype future warship – Dreadnought 2050 – with a hull made of composite acrylic and powered by a fusion reactor.[6]

[3] Captain H. Garbett (RN), *Naval Gunnery; A Description and History of the Fighting Equipment of a Man-of-War* (London: George Bell and Sons, 1897), p. 85.
[4] United Kingdom Parliament, *Report of the Committee appointed to inquire into the Cause of the Bursting of one of the 38-ton Guns in the Turret of H.M.S. "Thunderer"* (London, February 1879: p. 14, para. 38.
[5] Stanley Sandler, *The Emergence of the Modern Capital Ship* (Newark: University of Delaware Press, 1979), pp. 109-110.
[6] Alan Tovey, "Dreadnought 2050: Here's what the Navy of the future could be sailing," *The Daily Telegraph*, 31 August 2015.

The risks to military organization of adopting untried technologies are nevertheless extremely high. In many cases, they are associated with the newness of the technology itself. For instance, the US Army's Sgt. York air defence gun was cancelled in 1985 because the new technology it depended on was "not adequately effective in protecting friendly forces", and that decision followed upon the investment of nearly US$2 billion in developmental costs.[7] But perhaps the best example is the DDG-1000 or Zumwalt-class destroyer. Designed for the US Navy (USN) in the 2000s, it incorporated, as one author has recently written, "every next generation technology then conceivable."[8] In doing so, however, the cost spiraled out of control (to over US$4.5 billion per ship), the projected number of the class was subsequently reduced from 32 to three ships, and the cost of the ammunition for the advanced gun system was so exorbitant (at US$800,000 a round) that it was cancelled with the result that the gun has been rendered useless. International developments have also played a role. The rise of China as a major naval Power, which was not a consideration when the ship was being designed, has meant that its intended role (supporting littoral operations) is no longer the priority.[9]

In other cases, the risk associated with new military technology comes from inevitable uncertainty - the fact that in the testing that precedes its adoption wartime conditions can only ever be approximated. Tactical and operational capabilities can be examined under laboratory conditions, but how new technologies will perform when confronted by adversarial behaviour or capabilities can never be accurately predicted.[10] This type of risk – what can be called strategic risk - is particularly relevant when, as the

[7] Rudy Abramson, "Weinberger Kills Anti-Aircraft Gun: After $1.8 Billion, He Says Sgt. York Is Ineffective, Not Worth Further Cost," *Los Angeles Times*, 28 August 1985.

[8] Sebastian Roblin, "The Navy's Stealthy Zumwalt-Class Destroyer has One Big Problem," *The National Interest* (The Buzz Blog), 22 December 2018 [available at https://nationalinterest.org/blog/buzz/navys-stealthy-zumwalt-class-destoryer-has-1-big-problem-39572].

[9] Congressional Research Service, *Navy DDG-51 and DDG-1000 Destroyer Programs: Background and Issues for Congress* (Washington, D.C.: 21 July 2020), p. 23.

[10] See Harry Winton, "Introduction – On Military Change," in *The Challenge of Change; Military Institutions and New Realities, 1918-1941* , ed. Harold R. Winton and David R. Mets (Lincoln: University of Nebraska Press, 2000), p. xiii.

current Chief of Naval Operations has recently stated, the modern era's competitive strategic environment is in part defined by technological advances.[11]

Innovation, by contrast, is the adaptation of existing ideas and/or technologies. Consequently, the level of risk is generally lower relative to what inevitably accompanies invention. As with invention, armed forces have sometimes been resistant to innovation because it requires them to abandon proven equipment, organizations, and methods in favor of untested alternatives. Since innovation can be presented as a type of adaptation of something familiar, the level of risk is often assessed as acceptable. It is, however, never eliminated.

For many, military innovation is viewed unambiguously: "[i]ts parameters and its implications are clear to anyone with eyes unblinded by whatever scales are fashionable to denounce… ."[12] Yet questions still arise. Is an innovation considered successful because it is successfully incorporated into an organization or because it accomplishes what it is intended to do – but over what span of time? In an age of rapid technological change how do we know when to abandon a pattern of incremental adaptations of existing systems for a newer and untried technology? None of these questions have easy answers. Historians believe that it took nearly 150 years for the sternpost rudder to become a basic feature of sailing ships despite what to us is its obvious advantages over the steering oars it would eventually supersede.[13] Others during that century and a half must have thought otherwise and that is noteworthy.

Armed forces innovate in peacetime to prepare for war in an uncertain future, against an opponent that is not always clearly identified, and in conditions that are not yet predictable.[14] It is readily apparent that several factors – invention and adaptation, the interplay of government budgets and personalities, and, frequently, international developments – also exercise an influence. As a result, the outcome is never foreordained.

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[11] United States, Chief of Naval Operations, *A Design for Maintaining Maritime Superiority – Version 2.0* (Washington, D.C., December 2018), p. 4.

[12] Dennis Showalter, "Military Innovation and the Whig Perspective of History," in *The Challenge of Change*, eds. Winton and Mets p. 220.

[13] Carla Rahn Philips, *Six Galleons for the King of Spain* (Baltimore: Johns Hopkins University Press, 1968), p. 35.

[14] Williamson Murray, "Innovation Past and Future," *Joint Force Quarterly* (Summer 1996): pp. 51-60.

Innovation and the Royal Navy

Historian Dennis Showalter has written, "(m)ilitary innovation in peacetime is a complex process whose interfacing variables defy easy categorization."[15] We can see this in the way that the Royal Navy (RN) confronted the technological revolution that characterized the mid- to late-Nineteenth Century. The RN was a gigantic institution in terms of ships, manpower and infrastructure, and it was the principal means by which Britain contributed to the balance of power and defended its vast empire. As one author has written, "knowledge by the opposition, and by the British themselves, of the Royal Navy's fighting prowess doubtless made it more likely that a dispute would be settled once a cruiser had appeared over the horizon."[16] That was a reputation that successive governments wanted to uphold, in part by ensuring that their warships were the most modern in design, propulsion and armament. It was an enormous undertaking, and the RN has been described as "one of the most historically significant, and yet singularly neglected institutions in the history of technology and war."[17]

The RN nonetheless wrestled with the consequences that accompanied the arrival of the machine age, particularly "the phenomenon of continuous technological change."[18] The stakes involved were very high, and errors in judgement had to be avoided for both fiscal and strategic reasons.[19] As always, however, the actions of other Powers had a way of intruding upon force planning. The Russian Fleet's destruction of an Ottoman naval squadron at the Battle of Sinope (November 1853) convincingly revealed that ships-of-the-line could not resist modern shellfire. That, and its own experience in the Crimean War (1853-1856), persuaded France to begin building a fleet of ironclads, posing a threat to the cross-Channel naval balance. While the RN responded by building HMS *Warrior*, its first ironclad and commissioned in 1861, the fleet remained a mixture of old and new approaches to warship design. The tipping

[15] Showalter, "Military Innovation and the Whig Perspective of History," p. 252.
[16] C.I. Hamilton, *The Making of the Modern Admiralty; British Naval Policy-Making, 1805-1927* (Cambridge University Press, 2011), p. 306.
[17] Don Leggett, *Shaping the Royal Navy; Technology, Authority and Naval Architecture, 1830-1906* (Manchester: University of Manchester Press, 2015), p. 271.
[18] John Beeler, "Maintaining Naval Hegemony in the Industrial Age: Britain, 1850-1889," in *The Sea in History; The Modern World* (Woodbridge, Suffolk, edited by N.A.M. Rodger (The Boydell Press, 2017), pp. 138-139.
[19] James Phinney Baxter, *The Introduction of the Ironclad Warship* (Harvard University Press, 1933), p. 116.

point came with the engagements at Hampton Roads (8 and 9 March 1862), that led to the ramming and sinking of two Union warships by the CSS *Virginia*, a Confederate ironclad, and that ship's duel the next day with the USS *Monitor*. Those engagements confirmed what some already thought: the onset of the industrial era heralded the end of wooden ships-of-the-line. Accordingly, in April 1862, the Admiralty took the momentous decision to cease construction on all wooden ships.[20]

Making the transition to ironclad warships was daunting. The pace of change that the RN underwent was nothing short of extraordinary. A sailor in Sir Francis Drake's *Golden Hind* would have easily adjusted to duties aboard HMS *Queen*, Britain's last purely sailing ship-of-the-line that was launched in 1839. Three decades later, he would have felt completely out of place on HMS *Devastation*, its first ocean-going turreted and mast-less ironclad that was commissioned in 1871. When *Thunderer*, the only other of that class, followed four years later, several other similarly designed ships were already under construction. "The progress of improvement," the Duke of Somerset, a former First Lord of the Admiralty, observed, "was rapid, and ships were hardly completed before they were superseded by better designs."[21] As the succession of warship classes suggests, the process was probably never fully comprehended by those who were engaged by it.

For the RN, the approaches to ship design that *Warrior*, *Thunderer* and others represented were both unsettling and expensive, the latter not only in terms of its purchase. Naval infrastructure also had to adapt. Steam-power freed ships from the wind, but it increased their dependence on docks, depots, repair facilities and an educated workforce.[22] Technological innovation meant that the Navy became more costly to build and maintain, and more challenging to keep afloat and ready.[23] Consequently, innovation was often viewed less as an opportunity to preserve British naval supremacy and instead as a new source of risk.

How, therefore, did the RN confront this quandary? When to invest in new technology? When not to? In a June 1858 report to the Admiralty, Sir Baldwin Wake

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[20] Jesse A. Heitz, "British Reaction to American Civil War Ironclads," *Vulcan* 1, No. 1 (2013): p. 62.
[21] Edward Adolphus Seymour, *The Naval Expenditure from 1860-66 and its Results* (London, 1867), p. 37.
[22] Leggett, *Shaping the Royal Navy*, p. 93.
[23] See Beeler, "Maintaining Naval Hegemony in the Industrial Age: Britain, 1850-1889."

Walker, the Surveyor of the Navy, spoke to this problem: "any important change in the construction of ships of war which might have the effect of rendering necessary the introduction of a new class of very costly vessels until such a cause is forced upon us" by the loss of strategic advantage over putative adversaries ought to be avoided. "It then becomes", Walker argued, "a matter not only of expediency, but of absolute necessity."[24] It was this perspective that led him to be a strong advocate of large, heavily armoured ships, such as *Warrior*, that were revolutionary in their design – but only after French ironclads were already being built.

For the most powerful navy, Walker's approach is easily defensible. Weaker Powers might be prepared to absorb a higher level of risk because they see radical technological change as a way to compensate for their comparative deficiencies. It is for that reason that France spearheaded the development of ironclads. For a leading naval Power such as Great Britain, however, that approach might offer vast improvements in platform or weapons performance, but at a very high cost: it threatened immediate obsolescence of its entire fleet.[25]

For the RN, that calculation was the issue. The era 1840-1880 was characterized by the challenge of radical change regarding naval propulsion (steam or sail) and construction (wood or iron), how guns were to be mounted on ships (broadside or turrets), as well as new types of guns (muzzle- or breech-loaders). As the testimony before several parliamentary committees investigating warship design indicates, there was a lively debate about each of these questions. "A perfect ship of war," the report issued by the Designs Committee (1872) stated, "is a desideratum which has never yet been attained and is now further than ever removed from our reach."[26]

[24] Baxter, *The Introduction of the Ironclad Warship*, p. 117.
[25] Jimme A. Keizer and Johannes I.M. Halman, "Risks in major innovation projects, a multiple case study within a world's leading company in the fast moving consumer goods [sic]," *International Journal of Technology Management* 48, No. 4 (2009): pp. 500-501.
[26] United Kingdom Parliament, *Report of the Committee Appointed by the Lords Commissioners of the Admiralty to Examine the Designs Upon Which Ships of War Have Recently Been Constructed* (London, 1872), p. viii. (Hereafter referred to as the Report of the Designs Committee.)

The Guns of H.M.S. *Thunderer*

As the second and last ship of the *Devastation*-class, *Thunderer*'s design was very advanced for the time. Even so, the class was not entirely trusted to have the necessary sea-keeping qualities a warship required. During *Devastation*'s sea trials in 1875, the First Sea Lord was so concerned about its stability that he assigned a safety ship to accompany her. The concern was understandable. HMS *Captain*, a radically innovative but flawed warship, foundered with nearly all hands in 1870. It was a measure of the anxiety that disaster fostered that a signboard once fixed to a post before *Devastation*'s gangway advised naval personnel that letters to *Captain* could be posted aboard the ship.[27] And, indeed, senior Admiralty officials referred to both Devastation-class ships as experimental for some years.[28] It did not help matters that *Thunderer* was, as one author has termed her, an "unlucky ship".[29] A newly designed boiler exploded during its sea trials in 1876 killing the captain and 40 crew. An inquiry revealed that the problem was poor safety standards and, even more interesting, unfamiliarity of the engineers with new boiler technology.[30]

Three years later, British newspapers reported with considerable detail on yet another tragedy that struck the ship when its 38-ton muzzle-loader exploded. As Andrew Lambert has succinctly stated, "[t]he purpose of a warship is to carry and, if necessary, use an armament."[31] From our vantage, 140 years after its gun exploded, the question that presents itself is not so much why the gun exploded, but rather why *Thunderer*, one of the RN's most modern warships, was originally armed with muzzle-loading cannon and equipped with a ram at her bow? Breech-loading technology was already available, was widely used in the British Army, and was being pursued by other navies. We also know that breech-loaders would eventually come to dominate naval ordnance for decades to come. Seventy-four years after Trafalgar, the presence of

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[27] Peter Padfield, *The Battleship Era* (London: Rupert Hart-Davis, 1972), p. 77.

[28] Sandler, *The Emergence of the Modern Capital Ship*, p. 242.

[29] David K. Brown, *Warrior to Dreadnaught – Warship Development, 1860-1905* (Annapolis: Naval Institute Press, 2011), p. 61.

[30] "HMS Thunderer – Boiler Exploded 14 July 1876 – Forty-five Men Killed and Thirty Wounded," *The Nautical Magazine* 45 (1876): pp. 870-876 [available at https://books.google.ca/].

[31] Andrew Lambert, *HMS Warrior 1860 – Victoria's Ironclad Deterrent* (Annapolis: Naval Institute Press, 2010), p. 102.

a ram seems equally anachronistic. Why, then, would Britain choose to hold fast to older technology when so much else was changing?

Innovation is not, however, a linear process. What we see today as an obvious improvement on existing technology or approaches, was not necessarily equally apparent to the people of the time. Neither capability - guns nor ram - had been thoughtlessly incorporated in *Thunderer*'s design. Speaking in the House of Lords, a month after the parliamentary investigation into the gun accident had concluded, the Duke of Somerset stated that "great sums of money – I may say millions" had been expended on gun development, including experiments in rifling, projectiles and powder. The end result was the 38-ton gun that he considered among, if not the, most advanced weapon of its type.[32] Additionally, the ship's designers had developed an ingenious mechanism (using hydraulics for the first time on a warship) to load these enormous guns. As each gun was too long (16 feet six inches) to be loaded in the turret, Somerset explained how that problem was overcome:

> …arrangements were made to draw in the guns from their position and lower or depress the muzzle, so that they be loaded from the battery deck. In addition to this, there was an arrangement to wash out, as well as load, the guns by hydraulic power; and there was also a contrivance that when the rammer which, made like a telescope in two joints, had reached the breach of the gun, it should indicate that the washing was completed, so that it might be known to the crew if the gun was not properly washed out. There was also an ingenious contrivance by which the head of the rammer admitted water into the gun, so as to allow it to be thoroughly washed out.[33]

The loading procedure was so complicated that mistakes were probably inevitable. "If these failures happen when the men were quietly at practice, without any excitement, without any enemy,", Somerset noted after the accident, "what must be expected amidst the hurry, noise and confusion of an action at sea?" Nevertheless, this cumbersome procedure had been developed for both Devastation-class warships because, as he went on to say, "for the last twenty years or so – in fact, ever since armoured ships have been built – the great difficulty has been to manufacture guns

[32] United Kingdom, House of Lords, *Hansard*, 17 March 1879, vol. 244, col.1000.
[33] Ibid., col. 999.

sufficiently heavy to arm them."[34] The incremental changes made to muzzle-loading ordnance required new loading systems. As First Lord, Somerset had a reputation for being cautious, but Britain needed a fleet that could successfully rival that of France, its principal threat, and that meant risks had to be taken.[35] As his statement reveals, *Thunderer*'s state-of-the-art 38-ton muzzle-loaders relied upon a novel, if potentially flawed, loading mechanism.

Although the vast majority of senior officers would have trained on and relied upon muzzle-loaders for most of their careers, the explanation for the guns' retention cannot be entirely attributed to dogmatism. In fact, breech-loaders had not been ignored by the RN. Such guns, designed by Sir William Armstrong, and adopted by the British Army, had been deployed on RN ships in the early-1860s, including *Warrior*. It was quickly revealed, however, that this new type of ordnance was less effective as an armour-piercing weapon than the muzzle-loaders they were replacing. Armstrong guns had been used during the naval bombardment of two Japanese forts in the Straits of Simonosaki in 1864, and there were problems.[36] According to the squadron commander, Admiral Augustus L. Kuper, the smaller breech-loading guns (40-pounder or 4.75 inch) had performed very well, but the 110-pounder (7 inch) guns were "too easily put out of order to render the guns perfectly efficient as a naval weapon."[37] The 21 guns mounted in his ships suffered 28 accidents after firing only 365 rounds, and their accuracy was reportedly erratic. A captain serving under Kuper wrote that "I should extremely regret being again dependent on such a gun in action."[38]

For the RN, the breech mechanism had proven faulty, with the vent piece either jamming and preventing the gun from being reloaded, blowing out from the force of the firing, or failing to make a tight seal to ensure muzzle velocity. Arguments by Armstrong that the problem with the large guns was due to untrained crews and cost-

[34] Ibid., col. 1000.
[35] Leggett, *Shaping the Royal Navy*, p. 102.
[36] Lambert, *HMS Warrior 1860*, p. 104.
[37] United Kingdom, "A Copy of the Report of Admiral Kuper in reference to the Armstrong Guns in the Action of Simonosaki," *Parliamentary Papers* 32 (May 1865): p. 309.
[38] Ibid., p. 316.

saving modifications imposed by the government's arms foundry at Woolwich were largely ignored.[39]

The discovery that the largest caliber breech-loaders were unreliable, occurred at the same time as the invention of a method to transform smooth-bored into rifled muzzle-loaders, thereby increasing their accuracy and range. These two developments led the Ordnance Board, responsible for purchasing naval guns, to abandon Armstrong breech-loaders. When the issue came up again for discussion later in the decade, the Director-General of Naval Ordnance, Rear Admiral Cooper Key, argued in a September 1868 report (or around the time that *Devastation* and *Thunderer* were being designed) that it was too soon to change over to breech-loaders when the navy had not yet mastered the many problems associated with "rifled, muzzle-loading ordnance."[40] Key's report argued that retrofitting the entire fleet would be extremely expensive, an important consideration in any era. Also, he judged doing so to be premature given that there were too few studies available upon which to base a decision to change the guns. As historian Oscar Parkes has written, "[t]oday such an ultra-conservative outlook would suggest something akin to a conspiracy of obstruction, but it must be remembered that the Admiralty was just out of wood after the Armstrong fiasco and the subsequent confusion with regard to ordnance."[41] Muzzle-loading technology made more sense and therefore warranted the large-scale investment in its continued development mentioned by Somerset.

Perhaps just as important, the risks associated with new technology were just not worth it: there was no pressing strategic requirement for breech-loaders. The assumption of many naval thinkers at the time was that engagements would be close range during which the "simplicity and ruggedness" of muzzle-loaded guns and rams would be sufficient.[42] The Designs Committee observed that as "it is very improbable that the fleet of any nation will ever consist of armour-clad ships alone", the need to penetrate armour at a distance was not the "only work that may be required from the

[39] Marshall J. Bastable, *Arms and the State; Sir William Armstrong and the Remaking of British Naval Power, 1854-1914* (Aldershot: Ashgate, 2004), pp. 96-97.
[40] Oscar Parkes, *British Battleships* (London: Seeley Service & Co., 1970), p. 187.
[41] Ibid.
[42] Sandler, *The Emergence of the Modern Capital Ship*, pp. 108-109.

guns of a ship of war."[43] Both the initial battle at Hampton Roads (1862) and the Austrian fleet's successful use of ramming at the Battle of Lissa (1866) against a larger Italian force suggested that rams, rather than guns, would play the decisive role in future battles at sea. In his testimony before the committee, Rear Admiral Spencer Robinson, the Controller of the Navy, stated that, in his opinion, "all engagements of ironclads will take place by direct fire ahead, either in closing with the enemy or ramming which I believe will decide most actions."[44]

Today we know that Key's assessment regarding the future of naval guns and Robinson's view of future naval engagements were completely wrong. Nevertheless, at the time, both were informed by strategic-level considerations and were evidence-based. They were likely also informed by the desultory performance of the French Navy's own breech-loaders.[45] Indeed, two years after Key's report was issued, further support came from the questionable performance of Krupp breech-loaders several of which had burst during Prussia's war with France in 1870.[46] According to Parkes, the advanced muzzle-loading technology the RN adopted had proven itself so successful that, without the accident on *Thunderer*, the RN's conversion to breech loading would probably have been postponed.[47] The continuing utility of the 38-ton muzzle-loader was even reaffirmed by the commission that had investigated the explosion on *Thunderer*. Its report concluded that the problem had been due to the gun crew, not any inherent flaw in the gun.

Although Key's report was not seriously challenged from within RN circles, in less than a decade it was completely overturned. How, then, did the explosion on *Thunderer* lead to the adoption of breech-loaders? The answer lies in the arrival of innovations that made possible the replacement of muzzle-loaders. Around the time of the accident, Armstrong's engineers had improved the seal of the breechblock and had developed slow-burning powder that reduced the pressure at the base of the gun – the weak spot of any breech-loader. The slow-burning powder meant that, when the gun was fired, a projectile left the barrel with greater velocity, and, as a result, would be

[43] *Report of the Designs Committee*, p. xix.
[44] Ibid., p. 73.
[45] See Ernest Sagaret, "Les Flottes militaires," *Revue Moderne* 49 (décembre 1868): pp. 625-651.
[46] Bastable, *Arms and the State*, p. 135.
[47] Parkes, *British Battleships*, p. 187 & 198.

more effective at piercing the armour of the strongest ship. This changed the way that battles could be fought and rendered the ram of little relevance. To take advantage of these developments, however, required that the length of the barrel of a muzzle-loading gun would need to be extended. Deploying such weapons in the turret of a warship was assessed as impracticable because of the difficulties that a gun crew would face during loading. In other words, the accident on *Thunderer* coincided with the rectification of the faults associated with earlier breech-loading naval guns and, in the face of increased ships' armour, convinced those in charge that that type of ordnance would be more effective.

By 1881, two years after the accident, the manufacture of steel breech-loading guns (as opposed to iron muzzle-loaders) for Britain's warships commenced. As a near-contemporary observed, "[t]he immense strides that have been made in the method of construction of the guns, no less than in their greater power, their increased rapidity of fire, and the efficiency of the mountings, are striking testimonies to the mechanical and engineering genius of the present day."[48] Perhaps just as important, adoption of breech-loading guns meant that an accident such as had occurred on *Thunderer* could not happen again. Adopting the new guns provided the means of reasserting RN dominance in naval armaments (i.e., reducing strategic risk) which was an essential consideration for Britain's political leadership. At the same time, reducing the physical risk associated with the increasingly powerful explosive force needed for naval guns would have been psychologically reassuring to RN planners and crews.

It is important to be aware, as was earlier noted, that innovation is never a panacea, for it never eliminates all types of risk. The ongoing development of guns and armour would continue to demand new investment. In 1886, the chase of a 43-ton breech-loader blew up on HMS *Collingwood*. An investigation concluded that the gun had been made of steel that had not been hardened properly and was not of a uniform character. And 27 years after the accident on *Thunderer*, preserving the RN's command of the seas required implementing a further change to warship design - the introduction of the all-big gun battleship, HMS *Dreadnaught*. Other navies soon did likewise testifying to the fact that successful innovation solves a problem, but success is never final.

[48] Garbett, *Naval Gunnery*, p. 83.

Concluding Thoughts

Technological change creates enormous challenges; but, while it must be a consideration in force planning, predicting its implications is never conclusive. Decisions taken for very good reasons could prove very wrong. At the time that *Thunderer* was built, breech-loading naval guns were assessed as having failed in the most important of circumstances, namely combat. Adaptations made to existing muzzle-loading ordnance meant that they were superior. Admiralty officials could not have predicted that incremental changes that would overturn that relationship. Moreover, with the advent of ironclads and increasing thickness of armour, it was believed that in future sea battles, where the ram would be favoured, slow-firing but massive ordnance was all that was necessary. That prediction seems ludicrous to us, but we know how history played out.

The story of *Thunderer's* guns reminds us that not all innovation pays dividends. The British invested heavily in the development of the large muzzle-loaders that the ship carried. In the end, that investment was wasted as the technological changes it sponsored proved to be a dead end. Taken together, slow-burning powder and improvements in the design of breech-loading guns offered a better way forward than muzzle-loaders. The RN could not predict these advances when *Thunderer* was commissioned, but the Admiralty readily accepted their utility in the aftermath of the accident.

Another important takeaway from the explosion of the gun on *Thunderer* is the impact of unintended consequences. The loading mechanism for the 38-ton guns was the first time that hydraulics had been used for that purpose on a warship. It was certainly an innovative application of hydraulic technology. However, as one author has written, "[t]he more complex the system an innovation enters, the more likely and severe those consequences are." [49] Arguably, that was the case, for it was the cumbersome loading procedure that led to the accident that ultimately doomed the guns themselves. Its vulnerability to similar mishaps undoubtedly helped sway the opinion of the Admiralty in favour of the new generation of breech-loaders.

[49] "Innovation Risk: How to Make Smarter Decisions," *Harvard Business Review* (April 2013) [available at https://hbr.org/2013/04/innovation-risk-how-to-make-smarter-decisions].

How is any of this relevant today? The challenges associated with incorporating technological change today are much the same as those confronted in the 19th Century – building and maintaining modern armed forces while identifying and mitigating accompanying risks. Innovation is unavoidable but how to know when or when not to do so, and how to calibrate and mitigate the risk that follows from such decisions? For example, the Duke of Somerset's inferred warning that wartime conditions ought to determine the utility of military innovation is as valid today as it was back then.

There are many examples in modern navies that highlight a commitment to innovation and/or innovative design. For example, one could point to, the US Navy's Littoral Combat Ship (LCS) and the Zumwalt-class destroyers, the digitization of shipboard systems, as well as the adoption of modularity. However, will these prove in time to have been good decisions? So far, for the latter two the jury is out. Modularity retains capabilities, but has it not become, in many instances, little more than a means by which governments justify reductions in fleet size, which is in itself an important strategic consideration? Digitization undoubtedly improves a platform's performance, but what impact will it have on a ship's resiliency in combat? After all, it is not merely what new or cutting-edge capabilities one side brings to a fight, but the extent to which they create new vulnerabilities that might be successfully exploited by an adversary.

Sometimes, the mistakes regarding innovation are all too apparent long before combat situations. Perhaps this is nowhere more evident than in new classes of ships that incorporate considerable change into their design. A navy that aims to be combat capable must keep pace with technological development if it is to prevail in a conflict with a peer competitor. However, recent efforts by some navies to "produce innovative, affordable ships in the quantity and of the quality needed to configure a larger, redesigned fleet" has encountered significant failures.[50] The LCS's original design was flawed for what it was intended to do (littoral operations), as recent 'fixes', including new weapons and armour, in addition to a larger crew size, testify. Even with these changes, however, many observers doubt that these ships would survive in a combat environment. Because of this concern, as well as serious cost overruns, the original plan for 55 LCS in two variants has since been curtailed at 32 and they are to be

[50] James A. Russell, "Twenty-First-Century Innovation Pathways for the U.S. Navy in the Age of Competition", *Naval War College Review*, 73 (Summer 2020): p. 60.

decommissioned far sooner than had originally been planned. In seeking to reduce the risk of a repeat failure, and at the urging of a US Congress now very skeptical of naval shipbuilding plans, an existing design adapted from a proven Italian programme (the FREMM) has been selected for the USN's future frigate (the FFG(X)), as the replacement for the LCS.

Whether the initial decisions regarding innovation were good is not the sole issue, given the inevitability of errors. After all, one can assume that well-intentioned officials who advocate such changes in ship capabilities or design do so after a careful review of their probable impact. The issue is not so much that failures happen, but what is their cost in terms of resources and strategic effect, and can those consequences be mitigated. The Zumwalt-class destroyers discussed above are a very good example of this. It will likely now be rearmed with advanced armaments, including hypersonic weapons, to replace each ship's very advanced but unusable gun system.[51] The initial purpose for which this class was built (naval fire support for forces ashore) has been replaced by a focus on surface warfare.[52] Nevertheless, even with the enormous resources that the USN can call upon to effect that change, the Zumwalt-class, with all its "technical problems, schedule delays and cost overruns", has been described as "nothing short of disastrous."[53]

As the case of *Thunderer* demonstrates, being able to deal with such inevitable challenges in an era of technological change relies upon a mindset that acknowledges that the very nature of innovation means that occasional, even frequent, failure is to be expected and ought to be planned for. In this context, therefore, it is necessary to take account of the words of historian Michael Howard who, in an essay written in the 1970s, cautioned military planners about their ability to understand and prepare for the future. While not specifically about innovation, his words are nonetheless applicable to that subject. "I am (…) tempted to declare," he wrote, "that it does not matter that they got it wrong. What does matter is their capacity to get it right quickly when the moment

[51] Megan Eckstein, "House Defense Bill Pushes Hypersonic Weapons for Zumwalt Destroyers, Slows LUSV Procurement", *USNI News*, 22 June 2020 [available at https://news.usni.org/2020/06/22/house-defense-bill-pushes-hypersonic-weapons-for-zumwalt-destroyers-slows-lusv-procurement].

[52] Congressional Research Service, *Navy DDG-51 and DDG-1000 Destroyer Programs: Background and Issues for Congress*, p. 21.

[53] Russell, "Twenty-First-Century Innovation Pathways for the U.S. Navy in the Age of Competition", p. 61.

arrives."[54] The accident on HMS *Thunderer* highlights the uncertainties that are attached to innovation. In some cases, errors in judgement flow directly, as they did in that case, from an assessment of risk that was eventually revealed to be flawed. Luckily, the Admiralty was able to compensate for an earlier error in judgement due to the availability of an alternate type of ordnance. For the purpose of this paper, however, Howard's admonition suggests that while we should be open-minded regarding the durability of older and modified, and the potential of newer but untried, technologies, we ought also to be modest in our ability to assess the implications of both.

[54] Michael Howard, "Military Science in the Age of Peace," *RUSI Journal* 119, No. 1 (1974): p. 7.

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