# The Strength of the Wolf is the Pack: U-boat Tactics in the Battle of the Atlantic

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*In winter 1942–43 unique circumstances gave Germany's U-boats the possibility of temporary victory in the North Atlantic. At the same time, Royal Navy operational research considered the possible German adoption of developed stand-off salvo tactics ("browning"), better suited to attacking large, dense convoys than Germany's existing "ace" tactics of individual commanders infiltrating convoys. We test and verify the RN studies with a simulation, confirming that such tactics would have greatly increased U-boat success. While not denying ultimate Allied victory, "browning" would have increased sinkings, threatened the viability of large convoys, and possibly averted the May 1943 rout, at a critical juncture for Allied strategic decision-making. German lack of OR, Nazi heroic culture, and Dönitz's methods all contributed to the absence of the feared tactical evolution.*

*Au cours de l'hiver de 1942–1943, des circonstances exceptionnelles ont fait en sorte que les sous-marins allemands ont pu envisager la possibilité d'une victoire temporaire dans l'Atlantique Nord. Parallèlement, le service de recherche opérationnelle de la Marine royale envisageait l'adoption par l'Allemagne de tactiques de salve à distance de sécurité, mieux adaptées à l'attaque de convois importants et denses que les tactiques allemandes « d'élite » composées de l'infiltration des convois par des commandants individuels. Ici, nous mettons à l'essai et vérifions les études de la Marine royale*

***The Northern Mariner / Le marin du nord*** **35, no. 1 (Spring 2025), 29-56**

*à l'aide d'une simulation qui confirme que de telles tactiques auraient considérablement accru les succès des sous-marins. Sans réfuter la victoire finale des Alliés, lancer une salve de torpilles aurait accru les naufrages, menacé la viabilité des grands convois et peut-être évité la déroute de mai 1943, à un moment critique de la prise de décisions stratégiques par les Alliés. Le manque de recherche opérationnelle de l'Allemagne, la culture héroïque nazie et les méthodes de Dönitz ont tous contribué à l'absence de l'évolution tactique redoutée.*

## Introduction

The 1939–45 Battle of the Atlantic was not a pitched battle but rather a campaign that lasted the duration of the Second World War, a *guerre de course* intended by Nazi Germany to starve Great Britain of food and fuel and, after the entry of the United States into the war, prevent its resources from being carried across the Atlantic. It is canonical that the battle had a "turning point," most narrowly defined as the spring of 1943, on which "the prospect of invading the continent would depend absolutely."[1]

The pivotal moment of the allied British, Canadian, and American victory was the month of May 1943, during which 42 German submarines were sunk. U-boats were then temporarily withdrawn, the attack never to be renewed with the same intensity. But this should not be considered a finely balanced climax which determined the ultimate victor. Rather the Allied success was the culmination of long incremental development – of increased escort numbers, of their weapons and sensors, of training and tactics, of air cover. While the Germans also continued to develop U-boat technology – acoustic homing torpedoes promised much but were defeated while true submarines rather than mere submersibles arrived too late to change the course of the campaign – by 1943–44 they could not compete with Allied resources and the continually improving effectiveness of their use. In this view, Allied success in 1943 was assured, even if the victory need not have been so unambiguous or sharply defined.[2]

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1 R.K. Dickson, "The Battle of the Atlantic: A Retrospect of Six Heroic Years," BBC radio broadcast of 15 July 1945, in *Naval Broadcasts* (Allen & Unwin, 1946).

2 There are many general histories of the Battle of the Atlantic. We pick out John Terraine, *Business in Great Waters: The U-boat Wars 1916–1945* (Leo Cooper, 1989); Marc Milner, *Battle*

Nevertheless the battle was highly contingent, and most subtly so on the organizational and cultural disparities between the antagonists. The Germans were not simply overcome by better equipped, more organised, and more systematic opponents. The view that amateurs talk tactics whereas professionals study logistics can lead to deprecation of study of the former.[3] But during the Atlantic campaign, professionals in the Royal Navy studied tactics too. Famously, the campaign against the U-boat forged the discipline of Operational Research (OR) in the United Kingdom, while the Western Approaches Tactical Unit (WATU) used wargames to create highly effective escort tactics and train crews in their implementation.[4] In neither of these did the Germans match the Allies, and the deficit was crucial.[5]

On the German side, the "wolf packs," which enabled concentration of U-boats on Allied convoys, are justly famous.[6] However, the mere name of the *Rudeltaktik* obscures the fact that, once in the presence of a convoy

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*of the Atlantic* (Tempus, 2005) restores appropriate credit to Canada; D. Syrett, *The Defeat of the German U-boats* (University of South Carolina Press, 1994) covers 1943 onwards; J.M. Waters, *Bloody Winter* (Naval Institute Press, 1984) is an account of the crucial winter of 1942–43 by a first-hand witness.

3 In this form the quote appears to be due to US Marine Corps General Robert H. Barrow in 1979, although earlier General Omar Bradley made a similar point.

4 For OR see Patrick M.S. Blackett, "Operational Research – Recollections of Problems Studied, 1940–45," *Operations Research* 5 (1954): 131; and C.H. Waddington, *O.R. in World War 2: Operational Research Against the U-boat* (Elek, 1973). Its history is treated by J.F. McCloskey, "The Beginnings of Operations Research: 1934–1941," *Operations Research* 35, no.1 (1987): 143–52; and "British Operational Research in World War II," *Operations Research* 35, no. 3 (1987): 143–52; see also Stephen Budiansky, *Blackett's War* (Vintage, 2013). The classic study of WATU is Mark Williams, *Captain Gilbert Roberts RN and the Anti-U-boat School* (Weidenfeld & Nicolson, 1979); see also Simon Parkin, *A Game of Birds and Wolves: The Secret Game that Won the War* (Hodder & Stoughton, 2019); and P.E. Strong, "Wargaming the Atlantic War: Captain Gilbert Roberts and the Wrens of the Western Approaches Tactical Unit," paper for Validity and Utility of Wargaming: MORS special meeting, October 2017, https://www.professionalwargaming.co.uk/171210WATU-MORS.pdf.

5 Cajus Bekker, *Hitler's Naval War*, trans. and ed. Frank Ziegler (Doubleday, 1974); K. Assmann, "Why U-boat Warfare Failed," *Foreign Affairs* 28 (1950): 659–70; E. Wilson and R. Schapiro, "German Perspectives on the U-boat War, 1939–41," *Journal of Military History* 85 (2021): 369–98; US Office of Naval Intelligence, Diary of German Naval Staff (Operations Division) Part A, 1939–1944 [typescript translations of war diary captured in 1945], RG-08-Series III, US Naval War College Archives (hereafter USNWCA), www.usnwcarchives.org/repositories/2/archival_objects/34404. A recent comparative study of British and German operational research is Dennis Haslop, *Britain, Germany and the Battle of the Atlantic* (Bloomsbury, 2013), chaps. 9–10.

6 Karl Dönitz, *Memoirs: Ten Years and Twenty Days* (Greenhill, 1990); Bernard Edwards, *Dönitz and the Wolf Packs* (Cassell, 1996).

and in contrast to the behaviour of wolves, the U-boats were expected to make independent attacks, without communication, cooperation, or overall command.[7] U-boat aces, highly successful individual commanders, prided themselves on their ability to penetrate the convoy's escort screen and make multiple kills, expending several torpedoes on a single ship if necessary to assure a kill.[8] Meanwhile, as attrition of these aces mounted, an increasing proportion of U-boat commanders were novices who lacked the expertise to sink ships in this way.[9]

In this article we reconsider German tactics in the unique set of circumstances that applied through 1942 and until the spring of 1943. The famous loss of Enigma decrypts, the failure of the Allies to close the "air gap," and a weak escort force whose radar could not reliably detect surfaced U-boats up to the range of their torpedoes coincided with the availability of large numbers of U-boats and crews to give the Germans a window of opportunity to greatly increase sinkings and disrupt the flow of oil, food, and war materiel to Great Britain, at a critical juncture for Allied strategic decision-making for the war in Europe.

A fundamental aim of OR on any topic is to improve practice. In this case, apparently perversely but naturally anticipating potential threats, two Royal Navy OR studies suggested ways to improve *enemy* tactics.[10] We argue on the basis of this British analysis, verified with a computer simulation incorporating evidence not then available, that the Royal Navy studies were soundly based and greater German success could have been achieved if the pack had stood off the convoy, in flotillas on its flanks and under a single commander, using long-range steam-powered torpedoes in a salvo or, in contemporary parlance, "browning" attack aimed at the whole convoy.[11] Such an attack supersedes the standard OR arguments for large convoys, and results in much greater numbers of torpedoes fired at, and ships hit in, such convoys, with no diminution of

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7 Bob Carruthers, ed., *The Official U-boat Commander's Handbook* (Pen & Sword, 2013), 149.

8 For the purposes of this article, ace without quotation marks refers to individuals, while "ace" refers to tactics used by these individuals.

9 Malcolm Llewellyn-Jones, "The Royal Navy on the Threshold of Modern Anti-submarine Warfare, 1944–1949" (PhD diss., Kings College, London, 2004), 53; and W.S. Chalmers, *Max Horton and the Western Approaches: A Biography of Admiral Sir Max Kennedy Horton* (Hodder & Stoughton, 1954), 179.

10 The two wartime studies, discussed in detail below, are held in ADM 219/55, The National Archives of the UK, Kew (hereafter TNA), and MFQ 1/583/15, TNA.

11 "Browning" here is "firing into the brown," firing indiscriminately into a mass of targets without singling out an individual. The term was standard British usage (*Oxford English Dictionary*, 4th ed., 1951) in both game shooting and warfare.

individual torpedo hit probabilities. Whilst it might naively appear wasteful of resources, "browning" achieves much better concentration of fire in large convoy battles and could, we contend, have brought the U-boats a temporary victory through 1942 and much of 1943.

To gain an enhanced perspective on the Royal Navy studies we construct a simple computer convoy simulation, written in Visual Basic, to test, explore, and extend them. The model is calibrated to the events of two convoys of winter 1942–43, SC107 and TM1, and used to validate the original studies and thus confirm the potential effectiveness of "browning."[12] The question is then why these were not considered or introduced by the U-boat force. As we shall see, the answer is complex and at least three-fold, combining lack of German OR, Grand Admiral Karl Dönitz's personal command style, and the way that Nazi culture lauded and incentivized the U-boat ace as the ideal and exemplary warrior, just as it did tank and air aces.

## U-boat tactics and Royal Naval operational research

In 1917, when the *Kaiserreich* first used unrestricted U-boat warfare against the United Kingdom during the First World War, it came close to starving the islands of food and supplies. The introduction of convoys, against Admiralty resistance, played a critical role in saving the situation. In the vastness of the ocean, a convoy is little easier to find than an individual ship – yet there are far fewer convoys, and an entire convoy will not be sunk by any individual U-boat

[12] To our knowledge there has been no comparable modern quantitative study of a convoy battle, perhaps the closest being B. McCue, "Applying Hughes's 'Salvo Equations' to Engagements Between U-Boats and Convoy Escorts," *Military Operations Research* 19, no.4 (2014): 41–50. Search problems and the Bay of Biscay campaign are studied in B. McCue, *U-boats in the Bay of Biscay: An Essay in Operations Analysis* (National Defense University Press, 1990); R.R. Hill, L.E. Champagne, and J.C. Price, "Using Agent-based Simulation and Game Theory to Examine the WWII Bay of Biscay U-boat Campaign," *The Journal of Defense Modeling and Simulation* 1, no.2 (2004): 99–109; R.B. Duffey and J. Gallehawk, "Quantifying Countermeasure and Detection Effectiveness to Threats Using U-boat Data from the Second World War," *Journal for Maritime Research* 20, nos. 1–2 (2018): 67–91. McCue has performed a range of related further studies ("An Exploration of Zigzagging," *Phalanx: The Bulletin of Military Operations Research* 37, no.2 (2004): 14–15, 28–9; "A Chessboard Model of the U-boat War in the Atlantic with Applications to Signals Intelligence," *Naval Research Logistics* 52, no.2 (2005): 107–36; and "Using Simulated Annealing to Solve a Problem of 'Ecological Inference,'" *Phalanx: The Bulletin of Military Operations Research* 47, no.2 (2014): 32–39). Submarine warfare is more widely considered by R.E. Kuenne, *The Attack Submarine: A Study in Strategy* (Yale University Press, 1966); and K. Lautenschläger, "The Submarine in Naval Warfare, 1901–2001," *International Security* 11, no.3 (1987): 94–140; and its literature catalogued by M.L. Huygen, *Submarine Warfare in the 20th & 21st Centuries: A Bibliography* (United States Naval Postgraduate School, 2009).

which does happen to find it. A ship is safer in a convoy.

The U-boats' response was developed in the mind of Karl Dönitz, a U-boat captain in the First World War, a committed Nazi, and the commander of the U-boat force in the Second World War. The essence of his "wolf pack" idea, or *Rudeltaktik*, was to have a patrol line of U-boats perpendicular to the likely path of a convoy. When one boat sighted a convoy, it would signal the others to converge. Thus one tactic addressed the twin problems of finding a convoy and concentrating force upon it.[13]

This simple argument says nothing, however, about the best tactics once in the vicinity of a convoy. Submarines had hitherto been very much lone actors, their commanders focussed on approaching individual ships undetected and sinking them, and this remained so in most theatres. Early attempts at wolf packs failed, and the tactic was only fully adopted after successes in late 1940. By that time the most daring and successful commanders were firmly established by propaganda as aces, most famously after Guenther Prien's October 1939 sinking of the battleship HMS *Royal Oak* in the supposedly impenetrable anchorage of Scapa Flow. The most effective tactic was found to be a surface attack at night, for this negated the British ASDIC (undersea echo-location) system, in which too much confidence had been placed. U-boats were faster on the surface and were not limited in their endurance there. One problem with wolf packs was the large volume of radio traffic in bringing about convergence, using the high frequencies and short wavelengths which achieved long range by reflecting off the ionosphere. The Allies, unknown to the Germans, used HF/DF (high-frequency direction-finding) to locate these communications.[14] Much of the traffic was needless; another ace, Otto Kretschmer, found it possible to remain mostly silent. Above all, aces emphasized close-range attacks, and these required penetration of the escort screen and attacks from inside the convoy. Aces' preferred weapon was the G7e electric torpedo, which had a short range but left no trail of bubbles, unlike the otherwise-similar but much longer-range steam-powered G7a. Kretschmer's maxim was "one torpedo, one ship," but there are many instances of aces using multiple torpedoes to sink a single ship in order to make certain the "kill" which would help assure their ace status.[15]

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[13] Dönitz, *Memoirs*, chap. 3; Edwards, *Dönitz and the Wolf Packs*, 22; G. Williamson, *U-boat Tactics in World War II* (Osprey, 2010); J.A. Howe, "Wolfpack: Measure and Counter," *US Naval War College Review* 23, no.8 (1971): 61–5.

[14] Dönitz, *Memoirs*: early experiments in tactics, 19; need for radio communications, 20; pre-war tactical refinement, 21; surface attacks at night, 22; sinking of *Royal Oak*, 69; speed of U-boat on surface, 127; HF/DF, 495.

[15] Lawrence Paterson, *Otto Kretschmer: The Life of the Third Reich's Highest Scoring U-boat*

Attacked by U-boats using such "ace" tactics, large convoys enjoyed a further advantage over small convoys beyond there being fewer to find, in a classic scaling argument of early OR.[16] Imagine two alternative methods of convoying a given number of merchant ships and available escorts as one large or four small convoys. An "ace" U-boat attacking the convoy must first get close to or inside it, penetrating the escort screen, after which the number of ships the U-boat sinks is independent of convoy size. The probability of this is inversely proportional to the escort screen's linear density, the number divided by the perimeter. But a convoy larger by a factor of four, with four times the ships and area, has a perimeter that is only doubled, so that the large convoy, with four times the escorts distributed over double the perimeter, has an escort density that is twice that of the smaller convoys. Thus any individual ship inside the screen is twice as safe.

Further, the Allies were developing effective counter-tactics of their own. In January 1942 they had set up a Tactical Unit (WATU) at Western Approaches command in Liverpool which proved very effective at thinking-through U-boat tactics from both sides and finding simple counters to aces' stratagems. For example, some aces, once inside a convoy, would allow it to pass beyond them and emerge from its rear; WATU's "Raspberry" tactic directed escorts to converge upon the U-boat. WATU's wargaming not only created such tactics but was also very effective at training crews in them.[17]

Nevertheless, the wolf packs achieved great success, which was at its peak through the winter of 1942–43. Concentration of U-boats and the re-routing of convoys to evade them were subject to the ebb and flow of codebreaking throughout the war, which was at its most asymmetric during this period when the German navy had added a fourth rotor to its naval Enigma machines, thus denying Bletchley Park's famous Ultra decryptions while the Germans were breaking the British naval cipher.[18] While it remained the case that many convoys crossed the ocean unmolested, the ability of wolf packs to concentrate

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*Commander* (Greenhill, 2018), 132; Dönitz, *Memoirs*, 172.

16 See, for example, John Winton, *Convoy: The Defence of Sea Trade 1890–1990* (Michael Joseph, 1983), 240; N. Falconer, "On the Size of Convoys: An Example of the Methodology of Leading Wartime OR Scientists," *Operational Research Quarterly* 27 (1976): 315–27.

17 This is a classic advantage of naval wargaming, since crews rarely had the opportunity to train in coordinated tactics at sea during wartime. Williams, *Roberts and the Anti-U-boat School*; Parkin, *A Game of Birds and Wolves.*

18 Patrick Beesly, Jürgen Rohwer, and Kenneth Knowles, "Ultra and the Battle of the Atlantic," *Cryptologic Spectrum* 8, no. 1 (Winter 1978): 5–16, https://media.defense.gov/2021/Jun/30/2002752888/-1/-1/0/ULTRA.pdf. This work was revised and published in *Changing Interpretations and New Sources in Naval History: Papers from the Third United States Naval Academy History Symposium*, ed. R.W. Love (Garland, 1980), 413–49.

on convoys was never greater.

The result was the since-disputed "crisis" of March 1943. The official history regards it as such and is worth quoting at length: "Nor can one yet look back on that month without feeling something approaching horror over the losses we suffered … More than half a million tons of shipping was sunk in those 20 days; and what made the losses so much more serious … was that nearly two thirds of the ships were in convoy." The official historian, Stephen Roskill, further claims that the Admiralty considered abandoning the convoy system at this point, although there appears to be no contemporary evidence of this.[19] Certainly the minutes of the Cabinet Anti U-boat Warfare Committee (CAUBWC) between November 1942 and May 1943 betray none.[20] However it may have been perceived, the crisis soon passed. Convoys were retained and improved Allied measures against U-boats paid off, contributing to the sinking of 42 U-boats in May 1943. The onslaught was never to be renewed with the same intensity.

**A troubling possibility identified**

In parallel to WATU, the British Admiralty had created a Directorate of Operational Research (ADOR) under OR pioneer Patrick Blackett in December 1941. This produced many reports on convoys and wolf packs, including the famous scaling arguments for convoys and escorts mentioned above, which assumed the German employment of "ace" tactics. Early wartime OR on both sides of the Atlantic naturally concentrated on search and attack problems.[21]

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[19] S.W. Roskill, *The War at Sea 1939–45*, vol. 2 (Her Majesty's Stationery Office, 1956), 367. The "crisis" is disputed by D. Redford, "The March crisis in the Battle of the Atlantic: myth and reality," *History* 92 (2007): 64–83. Roskill cites the December 1943 Monthly Anti-Submarine Report (ADM 199/2060, 3, TNA): "it appeared possible [in March 1943] that we should not be able to continue convoy as an effective system … against the enemy's pack attacks." Further evidence came from the memoirs of Neville Lake, a staff captain at Western Approaches, who reported that Henry Hall, financial secretary to the Admiralty, visited Liverpool around 20 March and said that "the Naval Staff had stated in a paper that unless the situation improved, it might be necessary to abandon the convoy system" (Miscellaneous papers of Captain H.N. Lake, GBR/0014/MISC 7, Churchill Archives Centre, Cambridge [hereafter CAC]). We have been unable to trace this paper.

[20] CAB 86/2, TNA.

[21] In the USA the Anti-Submarine Warfare Operations Research Group, established in 1942, considered problems of search, attack, and equipment capabilities but does not seem to have studied tactics at the operational level. Philip M. Morse, "The beginnings of operations research in the United States," *Operations Research* 34, no. 1 (1986): 10–17; K.R. Tidman, *The Operations Evaluation Group: A History of Naval Operations Analysis* (Naval Institute Press, 1984).

However, it is the essence of imaginative OR also to consider enemy options, and the Admiralty scientists understood various tactics that, they considered, could have brought the U-boats still greater success. We discuss two such documents in detail.

The first, "How U-boats can greatly intensify their attack on shipping,"[22] primarily concerns how to achieve concentration by putting the wolf pack under local unified command. The commander can then choose "to make his attacks on selected points … with overwhelming force," "improve his convoy reconnaissance," and "so organize matters that operations are controlled on the spot by [the] most resolute U-boat captain in such a way that all others who shirk decisive action can be detected and replaced." This last point is crucial, and is reinforced: "the laggards will tend to conform to the standards of the best" and will be monitored when "definite orders are given to carry through attacks in a certain way." The report is unequivocal: "probably the only way in which U-boats can make a simultaneous and concentrated attack at a given point is by operating in flotillas. This form of attack should be much more damaging than the haphazard attacks now practiced." The unnamed author clearly understood a crucial outcome of prolonged use of the perilous "ace" tactic – that, as losses mounted, increasingly most U-boat captains were not aces and did not have the experience or expertise to carry through a successful "ace" attack, and those that did so found themselves disproportionately among the losses. Acting under a local commander might have increased their chances both of kills and of survival – certainly they would have been guaranteed to fire some torpedoes, which in reality often went unused.[23]

Could such command and concentration have been achieved? The wolf pack's convergence led naturally to the formation of flotillas of U-boats on the convoy's flanks, but these had no commander, with Dönitz retaining command from ashore.[24] Yet we have noted already the excessive radio traffic that accompanied a wolf pack's convergence and which continued during the multiple independent attacks. Local command could have been effected with much less use of radio. Above all, whereas shore command necessitated the HF radio transmissions which were detectable by shipborne HF/DF, local command could have used short-range medium-frequency homing beacons.

The flotilla tactic proposed by this ADOR paper was a "Saturation Night Attack" from ahead of the convoy, passing through and finishing astern of it. Thus, it retains from "ace" the feature that the U-boats must pass through the

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22 ADM 219/55, TNA.
23 ADM 219/55, 3, point 4(6), TNA.
24 Dönitz, *Memoirs*, 20.

escort screen – here defeating it by overwhelming it at a single point. There is then a natural Allied response to repeated use of this tactic: place most of the escorts ahead of the convoy. This is not considered in the paper, the intention of which was that the flotilla attack from ahead be just one of various possibilities.

A viable alternative mode of attack is considered in a second, earlier report by the Admiralty's Anti-Submarine Warfare Division in September 1940 (and thus predating the formal ADOR), "Possibilities of U-boat browning a

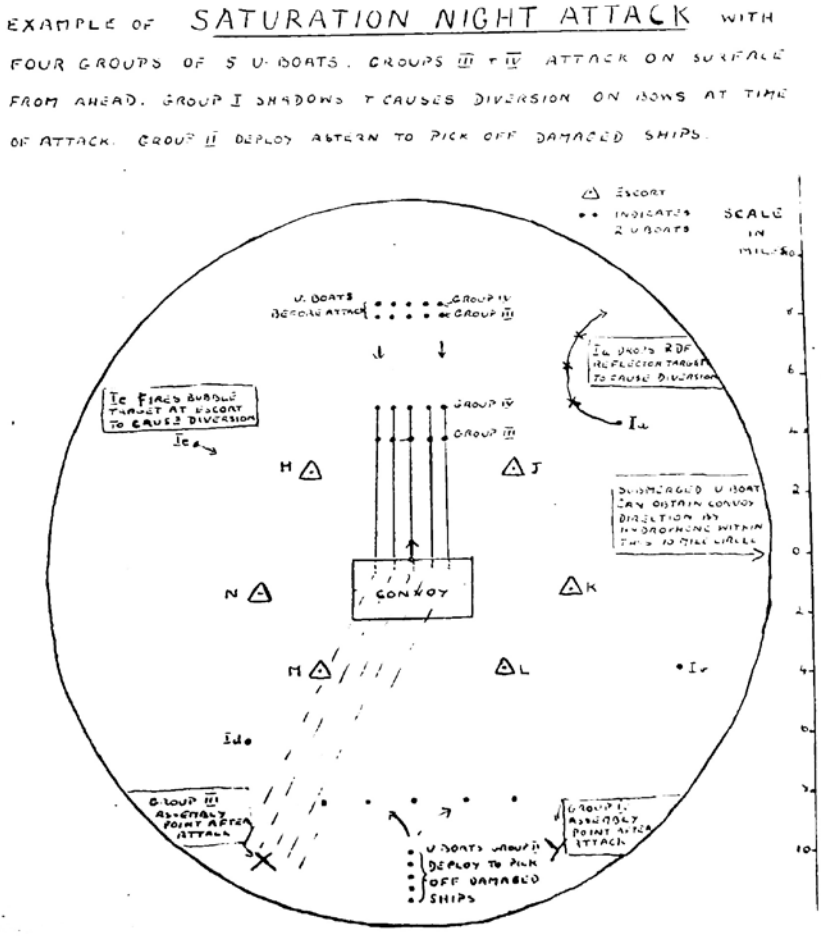


Figure 1. Illustration of "Saturation Night Attack." (ADM 219/55, TNA)

convoy."[25] Here "browning," in the sense of salvo, "firing into the brown," means that the U-boat stands off the convoy, about 8,000 yards from its centre, and fires at the whole convoy – which it is almost certain to hit – rather than at an individual ship. The probability of a hit is then the proportion of the convoy's profile that is occupied by the profiles of ships, as viewed by the U-boat commander through his periscope.[26] The percentage of hits for the paper's example 45-ship convoy ranges from 70 per cent to a near certain 95 per cent for attacks from just ahead of the beam. Notice that 8,000 yards is

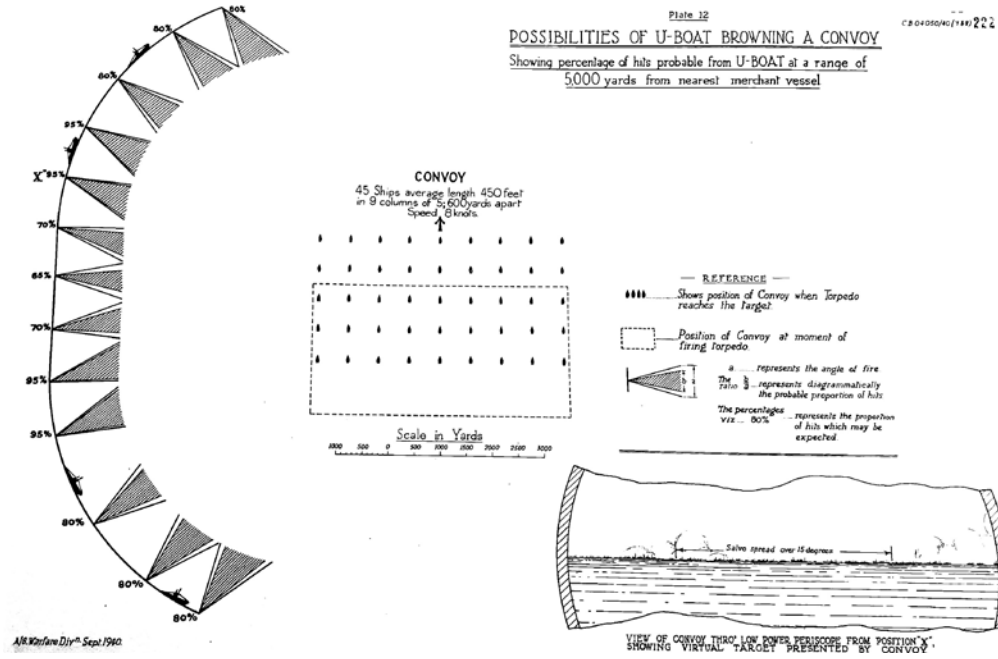


Figure 2: "Possibilities of U-boat browning a convoy." (MFQ 1/583/15, TNA)

[25] MFQ 1/583/15, from "Anti-submarine Monthly Reports, Vol. 1, 1939–1940," ADM 199/2057, folios 222 and 223, TNA.

[26] Throughout, we use the word "profile" to mean the linear cross-section (as viewed on the horizon). The "proportion" is really the "weighted proportion": weighted by both the denser centre of the convoy and the approximately Gaussian bell-curve of the torpedo tracking error.

beyond the 5,500 yards range (at 30 knots) of the aces' weapon of choice, the G7e electric torpedo. In contrast the otherwise-similar steam-powered G7a was more stable and reliable and had (at 30 knots) a range of 13,000 yards, ample to reach the whole convoy.

"Browning" and "ace" diverge only after the wolf pack is in contact with a convoy, and are thus identical in matters of search and convergence – in particular, in the argument that ships in large convoys are less likely to be found initially in searches by U-boats. However, the remainder of the scaling argument for large convoys under "browning" attack is inverted relative to "ace." A convoy four times as large now appears twice as deep, with twice the density on the horizon and thus twice the probability of a torpedo hit.[27] Thus a ship in a four-times-larger convoy, half as vulnerable under "ace," is twice as vulnerable under "browning." One should expect that, when a large convoy was intercepted, coordinated flotillas using "browning" attacks would have sunk many more ships, an argument which we test more rigorously with our computer battle model in the next section.

**Simulation of a salvo attack**

To calibrate "ace" and test "browning" against it we constructed a computer simulation, written in Visual Basic, of two eastbound convoy battles of the period, the slow convoy SC107 of October–November 1942 and the fuel tanker convoy TM1 of January 1943.[28] The central idea is to reproduce the actual U-boat manoeuvres under "ace," calibrate the parameters to reproduce the real outcomes, and then use these parameters in multiple reruns of the convoy under "browning." Note that, in terms of U-boat movement, "ace" is complex but "browning" is simple: there is no need for U-boat agency within the model, since we reproduce their actual behaviour under "ace," while under "browning" they have no autonomy.

In our model for "browning," the wolf pack assembles into two flotillas of surfaced U-boats, each under single command.[29] The U-boats in each flotilla

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[27] Further, there is now no role for the escort screen in the argument. Far from presenting a barrier to U-boat penetration, the screen now adds more initial targets for a surprise "browning" attack.

[28] Full details may be found in Peter G. Lloyd, "Tactics and Operational Research in the Battle of the Atlantic in WWII" (MSc thesis, University of York, 2021), https://etheses.whiterose.ac.uk/30541/. For SC107, see for example W.A.B. Douglas and J. Rohwer, "'The Most Thankless Task' Revisited: Convoys, Escorts, and Radio Intelligence in the Western Atlantic, 1941–43," in *RCN in Retrospect 1910–1968*, ed. James A. Boutilier (University of British Columbia Press, 1982), 187–234.

[29] This authority of the flotilla commander might be exercised via VHF radio when operating

are in line abreast and separated by a few hundred metres, depending on the sea state, and the two flotillas work in a synchronised attack on either flank of the convoy. Most importantly, the individual U-boat commanders are trained to fire their torpedoes in salvos aimed at the centre of the convoy and not at any individual merchant ship. Neither the U-boat separation nor the synchronisation are parameters to which the results are sensitive.

Our model uses actual ship numbers, lengths, and spacings and is calibrated to reproduce the actual outcome of the convoy battle under the "ace" tactics used in reality.[30] The known identities of the U-boats, their location, and the time of firing of each torpedo or salvo of torpedoes, together with the identity of the targeted merchant ship, are used as input.[31] For "browning," in contrast, the U-boats are placed in appropriate flotilla locations on either side of the convoy. In both "ace" and "browning" the track followed by the torpedo includes a random Gaussian error based on post-war analysis of actual German torpedo accuracy at various ranges and in the real weather and sea states of the North Atlantic, a typical standard deviation at 10,000 yards being around 2,000 yards.[32] The ships' locations and their resilience to torpedoes – that is, how many torpedoes it takes to sink that ship given the cargo it is carrying – are inserted manually.

The role of escorts in the model is limited. Convoy SC107, which consisted of 42 merchant ships routed from New York to Halifax and then on to the UK, was protected by one warship of the Royal Navy and five warships of the Royal Canadian Navy for the attacks of 1–2 November,[33] although the number of escorts varied greatly during its voyage. TM1, a small convoy of nine oil and fuel tankers from the Caribbean to Gibraltar, was protected by four warships.[34]

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at safe distances from the convoy and by shielded light signals and simple code words via VHF when close to the convoy. ADM 223/3, folio 271, TNA. We used eight U-boats in each of the two flotillas, but this number is immaterial – we shall use the number of ships sunk per U-boat present as our final measure of tactical success.

30 The attacks by the U-boats were taken from Jürgen Rohwer, *Axis Submarine Successes of World War Two* (Naval Institute Press and Greenhill, 1999), 132–34. The identities and positions of the ships sunk were taken from "Convoy: SC 107. Report of Proceedings by Commodore of Convoy," 18 November 1942, ADM 199/716/45, folios 463–77, TNA.

31 Waters, *Bloody Winter*, 15–91; ADM 199/716/45, folios 463–471, TNA; Rohwer, *Axis Submarine Successes*. For SC107 the data are limited and their reliability and accuracy less than perfect, as is the case in most convoy engagements of the period. For TM1 the data is more readily available and is in "Report of Board of Inquiry on Convoy TM1," January 1943, ADM 199/719/76, TNA.

32 "German Torpedo Attacks 1939–45," November 1947, figure 8b, ADM 213/745, TNA.

33 HMC Ships *Algoma*, *Amherst*, *Arvida*, *Moose Jaw*, and *Restigouche*, and HMS *Celandine*.

34 HM Ships *Havelock*, *Pimpernel*, *Godetia*, and *Saxifrage*.

A great deal of escort effort was devoted to chasing U-boats at some distance from the convoy but with no U-boats sunk or damaged. When the individual U-boats did attack SC107, the escorts were ineffectual, mostly because they lacked functional radars to detect the surfaced U-boats at night and so were effectively blind to the U-boats' presence.[35] Thus in the "browning" attack it is reasonable to assume that the escorts are unaware of the attacking flotillas at their stand-off ranges and are incapable of reacting fast enough to prevent the launch of the initial salvo of torpedoes.[36] Indeed, they would have been likely to remain unaware of the attack until the first hits on merchant ships.

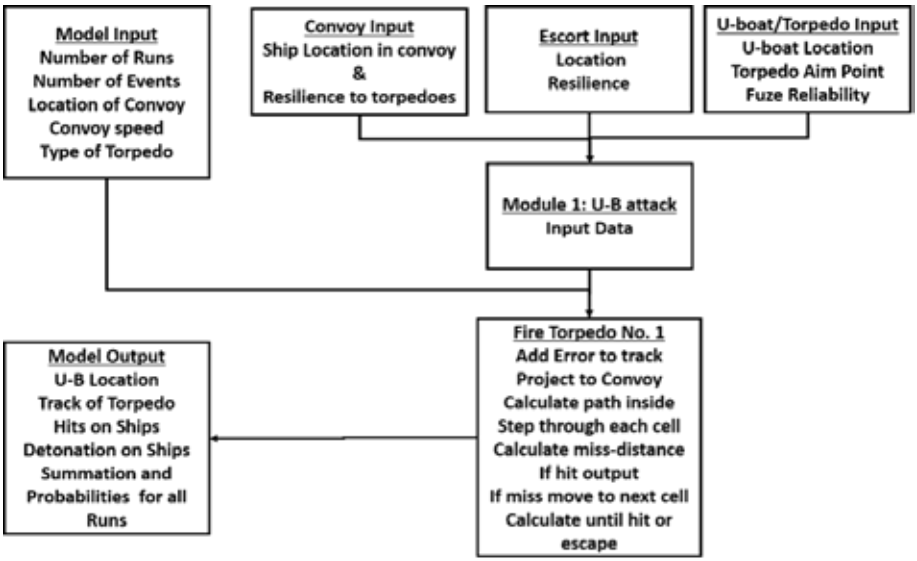


Figure 3. Architecture of the battle model.

The battle model then executes code that simulates an attack by U-boats on a convoy using torpedoes, with an architecture represented by the flow chart in figure 3. The four boxes shown at the top of the diagram cover the inputs – essentially, parameters and the "script" for the engagement between U-boats and convoy. Any changes to these are input manually. The model is then set running, the U-boats are positioned, and torpedoes fired in the scripted sequence. As a measure of tactical success, whether of "ace" or "browning,"

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35 "Operational Use of 271P Radar in A/S Warfare," ADM 219/29, TNA.

36 Every U-boat could have launched its four torpedoes, from the four bow tubes, within minutes.

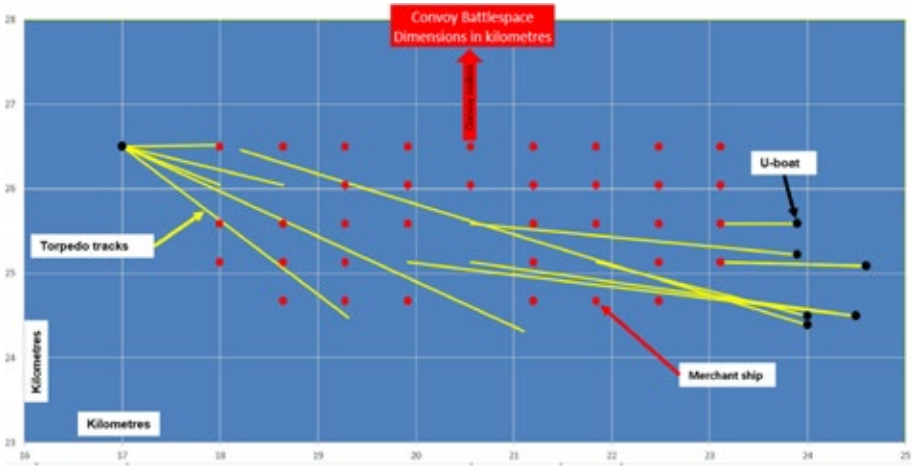


Figure 4. The attack on SC107 by individual U-boats using “ace” tactics for the day night cycle 1–2 November 1942. Note that U-boats, merchant ships, and torpedo track widths are not to scale.

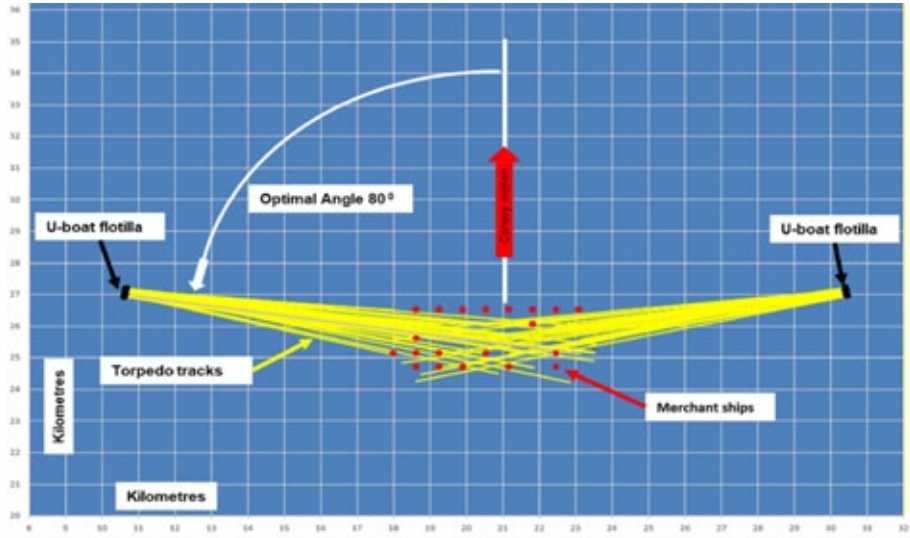


Figure 5. A counterfactual “browning” attack on SC107 using two flotillas of U-boats.

**Baseline Configuration of SC107 Cargo ratings**

| ROWS \ COLUMNS | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 2 | 2 | 2 | 3 | 1 | 2 | 2 | 4 | 0 | 0 | 0 |
| 2 | 1 | 1 | 2 | 2 | 4 | 3 | 1 | 3 | 2 | 0 | 0 | 0 |
| 3 | 1 | 2 | 1 | 2 | 2 | 4 | 3 | 1 | 1 | 0 | 0 | 0 |
| 4 | 2 | 3 | 2 | 1 | 4 | 2 | 2 | 2 | 2 | 0 | 0 | 0 |
| 5 | 0 | 2 | 2 | 1 | 0 | 1 | 2 | 2 | 0 | 0 | 0 | 0 |

**Active Configuration of SC107**

| ROWS \ COLUMNS | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 2 | 2 | 2 | 3 | 1 | 2 | 2 | 4 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 1 | 3 | 1 | 0 | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| 5 | 0 | 2 | 1 | 1 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 |

RED ORANGE GREEN BLUE

Figure 6. The chart on the top shows the layout of SC107 before the “browning” attack and on the bottom its immediate aftermath. Each ship (green) is labelled by the number of torpedoes required to sink it, which depends on its cargo. Ships sunk immediately have been removed (blue), while those hit but still afloat are shaded red or orange depending on their remaining resilience to attack.

| | Percentage of Total Torpedoes to score hits on Ships in that Location | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Column | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| Row | | | | | | | | | | Sum In Row |
| 1 | 1.53 | 0.91 | 0.58 | 0.66 | 0.61 | 0.44 | 0.72 | 0.83 | 2.23 | 8.50 |
| 2 | 1.55 | 1.50 | 2.61 | 2.42 | 4.80 | 3.64 | 1.03 | 4.08 | 2.95 | 24.58 |
| 3 | 1.36 | 2.75 | 1.55 | 2.91 | 3.00 | 5.41 | 3.88 | 1.17 | 1.34 | 23.36 |
| 4 | 1.38 | 1.42 | 1.75 | 1.20 | 3.22 | 2.11 | 2.50 | 1.56 | 1.50 | 16.64 |
| 5 | 0.00 | 0.55 | 0.88 | 0.45 | 0.00 | 0.39 | 1.06 | 0.55 | 0.00 | 3.88 |
| Sum In Column | 5.81 | 7.13 | 7.36 | 7.64 | 11.63 | 11.98 | 9.19 | 8.19 | 8.03 | 76.95 |

Table 1. Accumulated hits on each location in SC107 under “browning” expressed as a percentage of the 64 torpedoes fired over 100 runs of the battle model at 80 degrees from the convoy axis.

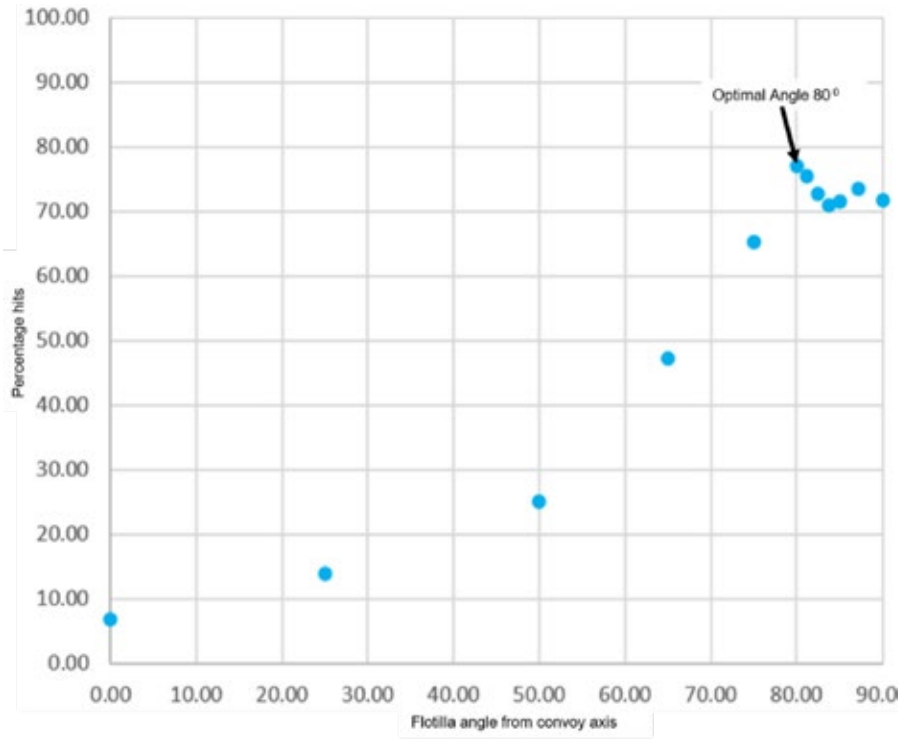


Figure 7. Percentage hits against angle of attack measured from the convoy direction of travel for 100 runs of SC107.

we use the number of merchant ships sunk per U-boat present in the wolf pack. Note that under "browning" every U-boat present has the opportunity to fire at least one salvo of four torpedoes, whereas under "ace" not all U-boats present actually fired any torpedoes, as occurred with many wolf pack attacks.[37]

A pictorial example of the output of the model is shown in figure 4. This represents the "ace" attacks that took place on the day/night cycle of 1–2 November 1942. The actual number of ships sunk on that day was nine; a further six were sunk during the next two days, but these were not modelled.

A pictorial output of the model for "browning" is shown in figure 5. This again represents just one day/night cycle and a single simultaneous attack by eight U-boats in each of two flotillas firing a total of 64 torpedoes in around a minute.

The results of the attack are shown in figure 6. On the top is the disposition of merchant ships in SC107 on the first night of attacks. The green shaded cells are the locations of the merchant ship while the blue shaded cells are empty – open sea. The numbers in the filled cells are the resiliencies of the ships to torpedo attack and depend on the nature of the cargo – a dense cargo such as steel or iron ore, which caused a ship to sink in a few tens of seconds after a single hit, typically gives a resilience of one, while a ship with a cargo of less dense material such as lumber or oil might absorb multiple torpedo hits without sinking and consequently has a resilience as high as four.[38] In the case of "ace," these numbers are all set to one because it was typical that a ship hit by even one torpedo would come to a stop, drift backwards through the convoy, and be left behind (and subsequently lost), usually within an hour and before the next U-boat attack. Each time a torpedo hits a ship in the model the resilience is reduced by one until it reaches zero, at which point the ship is sunk and its cell now allows subsequent torpedoes to pass through unhindered. This is a crucial effect to incorporate into modelling "browning" to avoid overestimating kills: such masking of targets by others is the most important modifier of the calculation of convoy density on the horizon. Table 1 shows the "browning" model output for each cell expressed as accumulated percentages of the 64 torpedoes fired in 100 runs.

The results in table 1 are for the 80-degree angle of attack, which is optimal for the SC107 configuration of nine columns by five rows including the three empty cells in the fifth row. The scores in the fifth, sixth, and seventh

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[37] Wolf pack *Veilchen* had 15 U-boats when formed. One was sunk by the Royal Canadian Air Force before the attack, leaving 14, but only 11 fired torpedoes at SC107. Waters, *Bloody Winter*, 25.

[38] Budiansky, *Blackett's War*, 150.

columns are the highest, as is to be expected – these are at the centre of the convoy, where the torpedoes converge, and where the high-resilience tankers are placed for safety. The tankers absorb torpedoes readily before they are sunk and thus accumulate higher scores in a "browning" attack.

The model was run multiple times for a range of angles relative to the axis of travel of the convoy and the accumulated percentage scores are shown in figure 7. The chart shows clearly that the convoy is more porous to torpedoes at low angles relative to the axis of travel but has correspondingly higher percentage hits for larger angles, in an enfilading effect. This is because a ship seen bow-on has a smaller profile than when seen beam-on, and the depth of the convoy is less than its breadth – there are more columns than rows – so that there are fewer ships, with smaller profiles, when viewed at low angles. The variation is not monotonic, however; notice that the optimal angle is 80 degrees, before a drop-off as it approaches 90 degrees. This is due to "crystallographic" effects: when the torpedoes are almost parallel to the rows, gaps appear in the convoy profile as the remainder of each row is masked by the near-most ship. In reality, and especially in bad weather, this would have been affected by the typically poor station-keeping of the merchant ships, smoothing the interpolating curve and reducing masking effects.

It is quite clear that "browning" is a more effective tactic against SC107 than "ace." In terms of our final summary statistic, of ships sunk per U-boat which sights the convoy, the actual "ace" tactics saw 14 boats present, 32 torpedoes fired, and 15 ships sunk (over four days), while the counterfactual "browning" tactic gave, with our posited 16 U-boats, 64 torpedoes fired (in a single attack within a period of minutes) and 29 ships sunk (in that one attack). Thus the ships sunk per U-boat present were 1.07 in the factual "ace" attack and 1.81 in the counterfactual "browning." The number of ships sunk per torpedo fired was approximately the same. Note that SC107 was chosen to model precisely because it was one of the largest convoy battles, in which "ace" attacks were highly successful. Thus it provides the strongest possible challenge to the "browning" tactic – which nevertheless nearly doubles sinkings. Further, each U-boat carries 14 torpedoes (12 for the bow tubes, two for the stern). It would be reasonable to expect that most U-boats could and would fire an effective second salvo, while still retaining torpedoes for future use.

Recall that the theoretical advantage of "browning" is principally for larger convoys. For the much smaller TM1 the simulation outcome was simple. Typically the barrage of torpedoes sank most or all of the tankers as well as escorts that were close to the convoy, just as in reality under "ace" seven tankers were sunk. Compared to SC107 a smaller percentage of the torpedoes

found a target, but "browning" was nevertheless as effective as "ace" even without so dense a profile as SC107.

The targeting advantage of "browning" is best thought of in terms of simple probabilities. Under "ace," a very close attack has to be made in order for the target profile to occupy most of the probability mass of the bell curve of torpedo tracking uncertainty – that is, for a hit to be highly likely. Under "browning," a torpedo is almost certain to pass through the convoy, and the hit probability is then the horizon ship density encountered – and, especially for large convoys, this is typically higher than the hit probability of all but the closest "ace" attack.

We should not be overly precise about the overall effect of adopting "browning" as a standard tactic. Our simulation suggests a 70 per cent increase in hits over one of the most successful instances of "ace." The original ADOR study found, at a shorter range of 5,000 yards, a higher hit probability at non-optimal angles than in ours, which would be likely if there were any imperfections in station-keeping, bearings, or zig-zagging, such as typically occurred. Supplementing the initial with a further salvo, or (at the expense of forgoing the defensive advantages of "browning") with subsequent "ace" tactics, would have increased sinkings greatly. "Browning" certainly suggests as a reasonable, restrained counterfactual possibility that sinkings of merchant ships could have been increased at least by some tens of percentage points. Minimally, it demonstrates the falsehood of the sense pervasive in contemporary German sources, memoirs, and secondary literature that the U-boats had no tactical alternatives.[39]

**"Browning": analysis, implementation, and response**

"Browning" offers advantages both offensive and defensive. Offensively, its apparent profligacy with torpedoes is spurious because the hit probability remains high, and "browning" ensures that all U-boats engage and that all target opportunities with high hit probabilities are taken up. As aces were lost and replaced by novices who rarely tried such tactics and survived, "browning" would have offered a disciplined, controlled means to maximize the U-boat's principal combat objective of torpedoing merchant ships.

In contrast, "ace" appears superficially to optimize the use of resources – Kretschmer's "one ship, one torpedo."[40] Of course this is not so if it

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[39] For example, Dönitz, *Memoirs*; Syrett, *Defeat of the German U-boats*; Haslop, *Britain, Germany and the Battle of the Atlantic*; Diary of German Naval Staff, 1939–1944, RG-08-Series III, USNWCA.

[40] M. Magnozzi, "'One Torpedo, One Ship': An appraisal of Otto Kretschmer's U-boat Tactics,

disproportionately sends U-boats and crew, materiel and men, to the bottom or indeed if it merely sends large numbers of torpedoes to a distant combat zone and then returns them to base. The true waste was that many U-boats, even those that encountered convoys, brought their torpedoes back home. For example, if we look at the 10 U-boats U223 to U232, their 17 patrols during the period from November 1942 to June 1943, and thus the 238 torpedoes they took to sea, only 12 per cent were fired. Of the others, 41 per cent were never in the presence of a target – but 47 per cent were present, unused, in wolf packs which *did* attack convoys.[41] "Browning" would certainly have required plentiful G7a torpedoes, but since the Reich produced around 70,000 torpedoes of which only around 10,000 were fired, this is not a critical constraint.[42]

Defensively, too, "browning" is crucial, for it places U-boats in much less peril than "ace": they attack at maximal distance from the convoy and its escorts, whose radar fits of the time would rarely have detected them;[43] then, once the salvo is released, they can scatter before the escorts can respond, with 10 of their 14 torpedoes in hand. Above all, their need to submerge is minimized. A crucial Allied advantage was the slowness of the type VII underwater: "Thus it became the tactical objective of the Allied escorts to intercept U-boats as they approached a convoy, [and] force [them] to submerge."[44] Of the 56 U-boats sunk in April and May 1943, 36 were in the vicinity of convoys.[45]

One obvious objection to the viability of "browning" is that convoys routinely zigzagged, using secret Admiralty patterns designed to appear unpredictable.[46] However, this defensive tactic which is so effective for individual ships is less so for large convoys. Even if we set aside the inconsistency of implementation and allow a six-knot slow convoy a 35-degree turn, the largest of Admiralty pattern no. 30 ("For use in specially dangerous waters"), immediately after the salvo is launched, the transverse location of the

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1939–1941," *The Mariner's Mirror* 107, no.2 (2021): 202–15.

41 The percentages and number of torpedoes were computed as summary statistics using information on the many individual U-boat cruises which took place during this period, found on the website developed by Gudmundur Helgson, https://uboat.net/about/foreword.htm; J. Rohwer, *Axis Submarine Successes, 1939–1945* (Naval Institute Press, 1983). Rohwer's book is an updated English translation of *Die U-boot Erfolge Der Achsenmächte, 1939–1945* (J.F. Lehmann, 1968).

42 John Campbell, *Naval Weapons of World War Two* (Conway Maritime Press, 1985), 260.

43 ADM 219/29, TNA.

44 Syrett, *Defeat of the German U-boats*, 261.

45 Stephen W. Roskill, "CAPROS not Convoy: Counterattack and Destroy!," *Proceedings of the United States Naval Institute* 82 (1956): 644.

46 *Zig-zag Diagrams for Single Ships and Convoys* (Admiralty, Signal Department, 1940), https://www.commsmuseum.co.uk/publications/br248.pdf.

convoy's centre on the horizon is shifted by at most 300 yards when viewed by a U-boat abeam, reducing the probability of hitting a convoy covering 6,000 by 4,000 yards by only about 1 per cent.

Would "browning" really have been implementable by the U-boat force, and how would the Allies have countered it? Certainly the Royal Navy considered it, and no aspect of its implementation at sea was difficult. Training crews and commanders would have been straightforward – it is much simpler than "ace." It had been a standard British destroyer tactic since the First World War.[47] More importantly, it was also a German destroyer tactic in the Second World War, used for example by flotilla commander Alfred Schulze-Hinrichs in action against arctic convoy PQ11 in 1942.[48] However, Dönitz had in 1939 rejected local command of U-boat flotillas. His *U-boat Commander's Handbook* introduces the possibility of a local commander – but to be appointed only by Dönitz and solely for the purpose of finding a convoy again when contact was lost.[49] He rejected local tactical command on the grounds that a flotilla commander must either to be too far from the convoy to gain useful information or so close that he must take the same defensive precautions as any other commander. Instead Dönitz asserted his own desire that "control of operations could and should be exercised exclusively from a shore base."[50] This may be so for complex operations, but local command of "browning" could have been minimal. The tactic is simple even in the fog of war: place yourself abeam of the convoy, on its flank, within your G7a torpedoes' range of its furthest ships; then, as soon as possible after the command, fire a salvo of torpedoes at the centre of the convoy. Further, the tactic remains effective even when imperfectly implemented: variations in the U-boats' positions and times of attack reduce its effectiveness only slightly. The most obvious barrier to the adoption of "browning" is Dönitz's command style – "I could myself quite easily direct the *whole* tactical operation against a convoy" – which he clearly enjoyed.[51]

There was, perhaps, an even greater barrier to the conception of "browning." A thorough recent study by Haslop aims to counter the near-universal view in the Anglophone literature that Germany lacked OR, but

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47 The term "browning" was applied to torpedoes in the RN's 1916 *Handbook of Torpedo Control*, ADM 186/381, TNA, cited in John Brooks, "British Destroyers at Jutland: Torpedo Tactics in Theory and Action," *British Military History* 3 (2017): 30–52.

48 Bekker, *Hitler's Naval War*, 268.

49 Carruthers, *U-boat Commander's Handbook*.

50 Dönitz, *Memoirs,* 22.

51 Dönitz, *Memoirs*, 62–3. Emphasis in the original.

succeeds only in part.[52] Haslop convincingly demonstrates that Germany had effective empirically based scientific development of physical equipment and its usage, such as torpedoes, decoys, and camouflage. However, he finds no evidence of any combat modelling of the kind done by the Admiralty – no analysis of tactics at the scale of convoys and wolf packs – and it is precisely this that is needed to rebut the superficial impression that "browning" would waste torpedoes. Above all, training was of individual U-boats, with tactical training taking place at sea in the Baltic – there was no analogue of WATU, no tactical wargaming of collective action or its possibilities.

Another barrier is cultural context. Among the many reasons the Allies won the war, one seldom emphasized is the counterproductivity of the Axis powers' privileging of the heroic in military culture, its emphasis on individual heroism and bravery, which, while it produced excellent short-term results in battle, failed to preserve such individuals' hard-won skills and transfer them to novices. The *völkisch* ideal of Nazism as a mass movement was always in conflict with the *Führerprinzip*'s emphasis on Darwinist demonstration of superiority through the individual's struggle for supremacy. In the *Wehrmacht* the latter principle dominated. Thus Germany produced higher-scoring air aces, by far, than the Allies – but the Allies rotated their combat-proven pilots into training roles to help develop the same skills in new pilots, so that in the Battle of Britain "Germany's score-chasing hunter-killers were beaten by the team-players."[53] Later in the war, German pilot aces were increasingly partnered by undertrained wingmen whose combat life expectancy was very short, creating a vicious cycle in which new aces rarely emerged – and when the old ones got unlucky, there was no cadre of experts left on which to build. As Jay Baird notes, "the German cult of heroism was tied more to death than to life."[54] The propaganda value of the exemplary heroism of aces, whether in aircraft, tanks, or submarines, was both cause and effect of this culture, which naturally emerged from the atavism of the warrior-patriarchal states. Among the Allies, by contrast, and even in the totalitarian but collectivist Union of Soviet Socialist Republics, collective effort for the common good was emphasized – and in the liberal democracies this naturally combined with rotation out of the front line, so that citizen-soldiers with a future to live for could see a route to that future, for their survival was valued.

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52 Haslop, *Britain, Germany and the Battle of the Atlantic.*

53 Stephen Bungay, *The Most Dangerous Enemy: A History of the Battle of Britain* (Aurum, 2000), 395.

54 Jay W. Baird, *To Die for Germany: Heroes in the Nazi Pantheon* (Indiana University Press, 1990).

In the U-boat service we can see clearly how the cult of the individual ace – "the propaganda image of the German submariner as legendary hero"[55] – was counterproductive. The "ace" tactic imperilled the U-boat force's greatest experts, and in technological warfare expertise is much costlier and less replaceable than the manufactured equipment the expert uses. "Ace" tactics failed to make effective use of novices or to enable them to develop into experts. Further, in the Nazis' culture of heroism, the "browning" tactic would have appeared pusillanimous, its clear advantages in self-preservation and in torpedoes fired at enemy ships appearing to be mere cowardly neglect to press home the attack. Whatever its potential merits, even though the British Admiralty was able to see them, the seeds of "browning" would not have found fertile soil in Nazi Germany.

The obvious Allied response to "browning" would have been to abandon the large convoys against which it is most effective and whose advantages it vitiates. We have already seen that the Admiralty may have been considering this during the March 1943 "crisis." Reverting to small convoys and independently routed ships would inevitably have led to much worse total losses than in reality. If large convoys were instead retained, a natural immediate response would have been for the escorts to concentrate on the pack's firing position, but as we have seen and as the Admiralty's "Possibilities" paper observes,[56] effective attacks from a broad range of flank positions are possible, and the tactic does not require that the U-boats be grouped together – the initial concentration of torpedoes is, in the sense of the classic study by Lanchester, concentration of long-range fire and thereby of effect, not of mass.[57] If the U-boats are grouped, then their principal tactic must be to fire their torpedoes and then disperse, taking advantage of their distance from the escort screen.

The British had already been considering the introduction of Support Groups (SGs), dedicated groups of sloops or destroyers (the larger, faster, and better-equipped escorts) already at sea which could concentrate quickly against attacked convoys. "Lake's Folly," a simulation by Captain Neville Lake at Western Approaches command, tested the viability of such groups not in WATU's tactical gaming but rather by the deployment of imaginary SGs among the real events of March 1943. Lake showed that they could indeed traverse the ocean with sufficient fuel and in good time to ensure that

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55 Michael L. Hadley, *Count Not the Dead: The Popular Image of the German Submarine* (McGill-Queen's University Press, 1995), 4.

56 MFQ 1/583/15, TNA; see note 25.

57 F.W. Lanchester, *Aircraft in Warfare: The Dawn of the Fourth Arm* (Constable, 1916), following a series of articles in *Engineering* magazine, 1913–14.

every convoy attacked could receive help from an SG. Western Approaches commander Admiral Max Horton attended CAUBWC on 17 March 1943 with the details of Lake's game, made the case for SGs, and they were created. But in reality, the attacks on convoys often went on for several days, giving time for the SGs to act. If instead the U-boats had fired their torpedoes immediately upon being in a position to do so and then dispersed, the SGs might well have arrived too late.[58]

Groups of U-boats would also have been better able to repel air attacks. This was understood in "How U-boats can greatly intensify,"[59] which noted that "by operating in flotillas on the surface the U-boats will render [air] attacks … both dangerous and ineffective."[60] This is perhaps an overstatement, but the flotillas would have concentrated on the surface principally at night, and the effective denial of the surface by day to the U-boats by both carrier- and shore-based aircraft would have been both contested and delayed.

**Implications**

It is not our contention that by adopting "browning" the U-boat force could have "won" the Battle of the Atlantic. As we noted at the outset, Allied improvement in every dimension was continual. Escorts, air cover, sensor and weapons fits were all likely to ensure Allied denial of successful U-boat operations in the Atlantic by late 1943. We do contend, however, that "browning," had it been adopted by the U-boat arm before the "bloody winter" of 1942–43, would have offered advantages both offensive – in increased sinkings before spring 1943 and continued sinkings thereafter – and defensive, through placing U-boats in less danger while making their attacks. In this light, the sudden Allied victory of May 1943, coming so soon after the "crisis" of March, should appear much more contingent. "Browning" would have deepened and delayed the lowest ebb of the battle – sufficient, among other things, to create a specific Allied crisis in the supply of oil and fuels reaching the UK in the critical year of 1943.

The availability of fuel in England was crucial to both the Normandy landings and the strategic air offensive,[61] and the continually declining number

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58 Lake's account is in GBR/0014/MISC 7, CAC, cited previously, and informs Martin Middlebrook, *Convoy SC122 and HX229: Climax of the Battle of the Atlantic, March 1943* (Allen Lane, 1976).

59 ADM 219/55, TNA.

60 A limited attempt to do precisely this during Biscay transits is recorded in Waddington, *O.R. in World War 2*, 240: [from June 1943] "the U-boats adopted the policy of sailing in groups of three in V formation, the idea being that the flak of all three would dissuade aircraft from making an immediate attack."

61 For our figures we rely on the definitive study by Derek J. Payton-Smith, *Oil: A Study of*

of tankers was a hard constraint until mid-1943, after which the enormous increase in US shipbuilding reversed the position. "Browning" would have deepened the problem in early 1943, with the fuel reserve in Great Britain likely to reach its minimum in late 1943 and the net flow turning positive only in 1944. The crucial link between tactics and strategy was made quite explicit by Dönitz at the time: "Tonnage is the decisive factor in any plan which envisages the use of Britain as a base for operations in Europe. If I go for … oil supplies, I am getting to the root of the evil."[62]

In such circumstances the potential consequences for Allied arms were substantial, not least because the aspiration to prepare and launch the invasion of northern France was predicated on substantial progress in the Battle of the Atlantic. The early months of 1943 are pivotal in this regard, as was well understood when in January 1943 Anglo-American military leaders gathered for the SYMBOL conference at Casablanca to settle grand strategy for the coming year.

SYMBOL's outcome was a compromise, an agreement to prosecute a united Mediterranean campaign in 1943 including the invasion of Sicily at the expense of an invasion of northern France, instead scheduled definitively for May 1944.[63] This compromise reflected the fact that Allied ability to prosecute the latter invasion was not guaranteed. A paper prepared for SYMBOL by the Combined Chiefs of Staff[64] acknowledged "the serious tanker position in the UK," and that "the movement of an additional 100–200 ships a month in the latter half of the year" would be required. No tonnage figure was given, and it was not clear where the required shipping would ever come from, but it was suggested that a 25 per cent reduction in sinkings might suffice. In the aftermath of the actual Allied victory in the U-boat war, the position became vastly better, but a deeper, later trough would have made it much worse and made these conditions impossible to satisfy in 1943.[65]

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*War-time Policy and Administration* (Her Majesty's Stationery Office, 1971).

62 Diary of German Naval Staff (Operations Division), 15 April 1942, reported in Dönitz, *Memoirs*, 228.

63 T. Ben-Moshe, "Winston Churchill and the Second Front: A Reappraisal," *Journal of Modern History* 62 (1990): 503–37, provides a historiographical summary.

64 Combined Chiefs of Staff, Combined Staff Planners, "Minimum escort requirements to maintain the sea communications of the United Nations," 19 January 1943, C.C.S. 160 in *Casablanca Conference, January 1943: Papers and Minutes of Meetings* (Office of the Combined Chiefs of Staff, 1943), 45, https://permanent.access.gpo.gov/gpo93767/casablanca-9780160938948.pdf.

65 Payton-Smith, *Oil*, 399, table 35.

The contingent nature of the decision making at Casablanca, including the bleak but tacit projection for the U-boat war, was therefore evident in the agreed program of the western Allies for 1943, which placed defeat of the U-boat first priority but showed a marked reluctance to discuss the issue frankly. The assembly and preparation of the Normandy invasion force in England was a hugely protracted undertaking and immensely costly in all resources, particularly shipping; only allied superabundance, and its largely free transatlantic passage from mid-1943, made a 1944 invasion possible. The massive and unexpected victory over the U-boats in May 1943 has skewed later perceptions of strategic realities, and the possibility of "browning" offers a clear argument against its inevitability.

**Conclusion**

Our argument is that Germany's Atlantic U-boat campaign, had it been subject to OR-based tactical analysis, conducted within a less hero-orientated military culture, and commanded in a less centralised manner, could have been more successful through 1942 and continued this success further into 1943 and that this was well understood in the British Admiralty. The necessary "browning" tactics were studied in British wartime operational research, which we tested and validated with a computer simulation. The history of early OR – conducted mostly by untrained individuals, under pressure, with pen and paper – has tended to be limited to memoir and qualitative study, but its value and significance can be much better appreciated when it is reproduced, tested, extended, and placed within a broader historical analysis.

Finally, the strategic implications of the 1942–43 crisis in the Battle of the Atlantic have not yet been fully explored. In retrospect the 1944 invasion of France from England may appear inevitable but, until a year earlier, given that the Allied front ran through the USSR, the Middle East and Africa, it could appear an outlying adventure. Even limited support for alternative progressions of the tactical and attritional balance of the Atlantic campaign serves an important purpose in facilitating a dispassionate analysis of the strategic consequences. It removes from the enquiry the effects of hindsight, which are particularly overbearing in this field; it forces a fuller concentration on the actual strategic circumstances facing the Allies in the winter of 1942–43; and perhaps most importantly it exposes assumptions which have long remained unchallenged. We plan to address this in future work.

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