Tactics and Operational Research
in the
Battle of the Atlantic in WWII

Peter G. Lloyd

Master of Science by Research

University of York

Mathematics

November 2021

ABSTRACT

This study concerns the naval campaign in the 1939-1945 conflict between the Allied and Axis forces known as the ‘Battle of the Atlantic’. To facilitate the understanding of this battle a computer-based battle model of a typical engagement between the opposing forces was created. The key naval assets in this conflict were the Allied merchant ships carrying vital supplies that were organised into convoys and were escorted for their protection by warships. On the Axis side were submarines (U-boats) including their organisation into Wolf Packs. The Axis goal for the U-boats was the cutting off of the supply of vital war materials, especially oil and fuel, that were carried in the Allied convoys to Britain and the Allied forces in the UK, Mediterranean theatre and on the Russian front. Allied air power played a key role eventually, as did radio signal detection and interception. The focus of the modelling work was on the battles over the convoys SC107 and TM1, which represented serious Allied failure and Axis tactical, but not strategic, victory. The model created was a convoy centric kinematic one and was not a dynamic model of forces and accelerations. During this study, it was found that the U-boat commanders were not using their U-boats and torpedoes to the full efficiency that they could have achieved. The reason lay in the direct orders to attack individually and not simultaneously. A counterfactual aspect was created in the model to explore the effects of simultaneous formation attacks by all the members of a Wolf Pack. A profound increase in sinking of convoy ships per U-boat was obtained and reductions in U-boat losses identified. If used this could have led to a temporary Axis victory in the Atlantic in 1942-1943, and might even have delayed Allied victory and impacted post war Europe.

DECLARATION

I declare that this thesis is a presentation of original work and I am the sole author. This work has not previously been presented for an award at this, or any other, University. All sources are acknowledged as References.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

I would like to thank Professor Niall MacKay of the Department of Mathematics at the University of York for taking me on as a research student for this MSc study and suggesting the Battle of the Atlantic as the topic area to investigate for my thesis. I would also like to thank him for his photographing of the 'Lake papers' in the Churchill Archive at Churchill College Cambridge, as well as his tireless patience, great enthusiasm for the application of mathematics to the study of historic events and processes, his sense of humour and extensive knowledge that he has shared with me.

I would also like to thank, Dr. Christopher Price of the York St. John University for providing his advice and support on the historic credibility of the subject matter of my thesis, Dr. Ian Horwood of the Department of History at the University of York St. John for providing details of numerous games about the Battle of the Atlantic.

Additionally, I would like to thank Dr. Marcus Naraidoo of Cyber Vector Limited for allowing me to use his company's computer facilities and CST electromagnetic modelling tool to calculate the radar cross section of a surfaced and a trimmed down U-boat. Similarly, I would like to thank Sally Davis of DSTL for the interesting and insightful briefing on the workings of the Western Approaches Tactical Unit and the splendid re-enactment of a WATU on-floor war game.

Finally, I would like to thank all the members of the York Historic Warfare Analysis Group for their company, humour and great knowledge that they share at our regular 'Coffee club'. I would particularly like to thank Dr. Brennen Fagan for providing a URL to the historic weather charts at the UK Met-Office that had eluded my best efforts to find them myself.

DEDICATION

I dedicate this work to my late parents, Frank and Phillis, who dodged bullets, bombs and suffered great hardship in the British Army and war factories respectively during the six years of the Second World War and then went on to raise my siblings and I in a stable and loving family home.

ACRONYMS

ADM	Admiralty
AoB	Angle on the Bow
ASDIC	Anti-Submarine Detection supersonIC
A/S	Anti-Submarine
BdU	Befelshaber der U-Boots (U-Boat High Command)
BM	Battle Model
C in C	Commander-in-Chief
CST	Computer Science and Technology (Software for electromagnetic Modelling)
DNI	Division of Naval Intelligence
DSTL	Defence Science and Technology Laboratory
EM	Electromagnetics
GHz	Giga Hertz
HF	High Frequency
HF/DF	High Frequency Direction Finder
HitDets	Hit and Detonation
HitDud	Hit and failure to Detonate
MF	Medium Frequency
HMCS	His Majesty's Canadian Ship
HMS	His Majesty's Ship
IJN	Imperial Japanese Navy
NAK	National Archives Kew
NDRC	National Defense Research Committee
NOAA	National Oceanographic and Atmospheric Administration
OR	Operational Research
POWE	Power and technology subcommittee Cabinet Office
RAF	Royal Air Force
RCN	Royal Canadian Navy
RCS	Radar Cross Section
RDF	Radio Direction Finding
RN	Royal Navy

SC Slow Convoy (Can also be Sidney to UK)

SOE Senior Officer Escorts

U-boat Undersea Boat

UK United Kingdom

URL Uniform Resource Locators (Web address)

USA United States of America

USS United States of America

VBA Visual Basic Applications

VHF Very High Frequency

WAAF Women's Auxiliary Air Force

WAC Western Approaches Command

WATU Western Approaches Tactical Unit

WRNS Women's Royal Naval Service

WS Worksheet (Excel)

WWII World War Two

Chapter 1 INTRODUCTION

1.1 THE OBJECTIVE OF THIS RESEARCH PROJECT

This research project creates a mathematical battle model of a critical moment in the life of a convoy of Allied merchant ships crossing the North Atlantic Ocean in WWII. The purpose of the convoy system was to bring war supplies from North America to the UK. However, on the way the convoys were attacked by German U-boats. A Battle Model (BM) has been created mathematically and represents the ships, U-boats and weapons employed in a kinematic set of equations. The purpose of the model is to explore a credible counterfactual to the U-boat tactics that might have gained an advantage to the German efforts to disrupt the supply of war materials, particularly that of oil. The counterfactual chosen explores the improvements to the number of ships sunk in a convoy per U-boat present in the Wolf Pack attacking if they had been used in mass synchronised formations while stood off from a convoy in the 'Browning' method of attack[1]. The historic tactic was dominated by the lone 'Ace' attacking independently despite the presence of multiple other U-boats who were doing little to contribute to the attack.

1.2 BACKGROUND

1.2.1 A Key Moment in the Battle of the Atlantic

There have been many studies, documentaries and commentaries covering the long campaign known as 'Battle of the Atlantic' of the second world war[2]. In this research the focus is on a point in the campaign when Admiral Doenitz, the commander of the German U-boat Force, had three important factors on his side in late 1942 and early 1943, these factors were;

a) 235 operational U-boats in service in April 1943 and increasing numbers of U-boats coming into service each month[3].
b) The existence of a large gap in the protection of the Allied convoys provided by airpower in the central North Atlantic where the convoys had to cross the ocean[4]
c) The Allied navies loss of vital intelligence in the form of the decrypted radio messages that in the UK carried the code name ULTRA. These messages were sent from and to the U-boats using Enigma encoding machines. When the Enigma machines were upgraded in the U-boats in early 1942 the Allies lost this vital source of information[5]

The growing number and effectiveness of the U-boats had serious impacts upon the supply of materials to the UK in this period. These took the form of the following negative impacts;

1 MFQ 1/583/15, Diagram showing the technique known as 'Browning' of a convoy where a submarine stands off at long range (8,000 yards) from a convoy to fire its torpedoes at the mass of ships rather than target an individual ship from close range. See also Brooks, John "British Destroyers at Jutland and the reference there to the Royal Navy Handbook of Torpedoes 1916.
2 Blair The Hunters, page 244
3 Grove, Defeat of Allied Trade, page 15
4 Milner, Battle of the Atlantic, page 56
5 Terraine, Business in Great Waters, page 424

a) Losses of tankers were becoming significant and this was because Doenitz chose to attack the oil supplies as a priority for his U-boat commanders[6]
b) A combination of reduced supplies of oil and fuel products reaching the UK and the transfer of stocks of oil and fuel to the North African and Mediterranean operations, were rapidly depleting oil and fuel stocks in the UK to dangerous levels
c) A serious shortage of escort vessels to protect the convoys under the increasing threat from the U-boats.
d) In March of 1943, U.S. Navy Commander Admiral Ernest King delivered a shock development to the British and Canadian forces in the form of his decision to withdraw U.S. Navy escort vessels from the North Atlantic for duties elsewhere. This left a huge deficit in the number of escorts expected to be available to those required to meet the planned expansion of the convoys leading up to the invasion of Northern Europe.

Doenitz focussed his U-boat Force on the North Western Atlantic where convoys carrying war supplies concentrated near the Canadian coast, particularly to the east of Newfoundland. The stage was set when he perfected the concentration of his U-boats into what was named Wolf Packs. These Wolf Packs were formed so that they could carry out mass attacks that would overwhelm the escorts of the convoy and sink the merchant ships. The result that Doenitz wanted was a devastating blow to the oil supply to the UK that would put the British war effort and the much-anticipated Allied invasion of Europe back indefinitely[7].

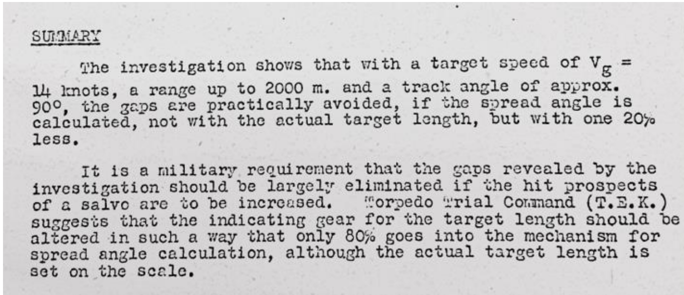
The German Navy did, in a limited way, analyse how they might improve the efficiency of the U-boats[8][9]. In the UK the application of scientific methods and free thinking about tactics became the norm and groups of scientists and service personnel were formed for these purposes. The role of such groups included analysis of operational tactics, evaluation and development of new tactics and the simulation of such engagements. Once these new tactics had been developed and approved then training of the commanders of the vessels in the combat force would be carried out. This training was delivered in the classroom using battle models and exercises. They would then go on to training at sea in the warships in which the commanders served and they would be against friendly vessels simulating the opponents for this training. For the Allies these great assets were the Directorate of Operation Research and the Western Approaches Tactical Unit (WATU), the latter being based in Liverpool, England and was located alongside the Western Approaches Command at Derby House[10].
The UK senior commanders of the armed forces were at first somewhat reluctant to be told how to do their jobs: however, with Prime Minister Winston Churchill in office the reluctance was overcome and the value of the scientific approach to warfare was soon recognised and adopted wholeheartedly [11]

In the example of a German operational research project cited above, it is possible that such a group might have had the ability to propose and evaluate the type of tactical improvement proposed in the counterfactual of this thesis. This particular German research activity cited resulted in the summary

---

[6] Doenitz "Memoirs", page 228.
[7] Doenitz, Memoirs, page 228, Doenitz wrote in his U-boat Command War Diary of April 15th 1942 "If, therefore, I go for the hub, and particularly the oil supplies, I am getting to the root of the evil." See also chapter 3 on U-boat tactics.
[8] ADM 292/209 Tactical Use of Torpedoes; This is an English translation of a German document that appears to have been written during the war. There are mixed opinions concerning such a capabilities existence but the ADM 292 series cover numerous such documents concerning torpedoes in German service during WWII.
[9] Haslop, Britain and Germany, page 183, Chapter 12 discusses German operational research.
[10] Williams, Captain Roberts, page 85
[11] Jones R.V. Most Secret War, page 106

statement shown in Figure 1. It is a very concise summary and does not do justice to the mathematical modelling carried out in this highly detailed study. The research report does show they were thinking about how improve U-boat use of torpedoes.



SUMMARY

The investigation shows that with a target speed of V_g = 14 knots, a range up to 2000 m. and a track angle of approx. 90°, the gaps are practically avoided, if the spread angle is calculated, not with the actual target length, but with one 20% less.

It is a military requirement that the gaps revealed by the investigation should be largely eliminated if the hit prospects of a salvo are to be increased. Torpedo Trial Command (T.E.K.) suggests that the indicating gear for the target length should be altered in such a way that only 80% goes into the mechanism for spread angle calculation, although the actual target length is set on the scale.

Figure 1 German wartime operational research on torpedo hit performance

The battle model developed in this research project investigates how Doenitz might have achieved a temporary victory in the Atlantic with potentially strategic consequences and the possible reasons why he did not do so. In the longer-term, factors such as the availability of very long-range aircraft equipped with radar to detect U-boats on the surface and attack them would turn the tide in favour of an Allied victory in the Atlantic. A counterfactual variation of the U-boat tactics in the battle model has been developed and exercised to evaluate its effectiveness against a typical convoy of 1942/43.

1.2.2 The USA joins the War

The Allied effort to defeat the Nazi threat to civilisation was boosted when Hitler declared war on the USA following the Japanese attack on the US fleet at Pearl Harbor on December 7th 1941. The USA had up to that point provided support to the UK by supplying arms, oil and even committing limited but helpful naval escorts to the convoys crossing the Atlantic. However, the politics within the US establishment and the leadership of her armed forces were producing a bias towards the Pacific war against Japan rather than the Atlantic and the war against Germany. A key figure in this division of opinion in the US Navy was Fleet Admiral Ernest King. One of the greatest impacts that King had on the Battle of the Atlantic came when at the Atlantic Convoy Conference in Washington DC in March of 1943 he proclaimed that he was opposed to mixed forces operating together in the context of Anti-U-boat operations[12]. This resulted in the US Navy's withdrawal from the general convoy system in the North Atlantic and to concentrate its efforts in the Atlantic on supporting the Allied Operation Torch in defeating the Axis forces in North Africa. This came as a shock to the British Admiralty as their planners had expected a further increase of 65 US escort vessels in the North Atlantic escort force[13]. These additional US escorts were to be used in support of the North Atlantic convoys in order to cope with the increasing number of supplies needed for the British and American forces in the UK. It also impacted on the fuel crisis in the UK where tanker losses due to U-boat attacks on convoys had left a deficit in the numbers of tankers that could not be made up by the new tankers projected to be built at that time. The resulting 'Escort and oil' crisis has been the subject of many commentaries as to its nature and even its existence. This study has examined the evidence for these crises in the official records and the conclusions are reported in this thesis.

In Nazi Germany there were many talented scientists and engineers engaged in the development of technologies, devices and systems for the German forces. Scientific 'Operational Research' as practiced by the UK and adopted by the USA on its entry into the war is not generally identified as being practiced

[12] ADM 199/1148, Washington Convoy Conference Minutes 1st March page 3

[13] ADM 1/14793, A/S Warfare, page 8 item (d)

by the German forces in WWII although Haslop has identified examples of German naval research activities that can be interpreted as being examples of such operational research[14].

In 1932 a Torpedo Officer serving on a destroyer in the Imperial Japanese Navy (IJN) was puzzled by the lower than expected hits he was getting during the repeated training firings that he was responsible for. He was competent at mathematics and set about studying the kinematics of torpedoes fired from moving platforms at moving targets. He realised that the trajectory of the launch platform as used in the standard IJN tactics was not optimum. He used "algebra, geometry and trigonometry" to study how a greater hit probability could be achieved[15]. Hara calculated an optimum hyperbolic track for the destroyer to follow and torpedo release points using his formulae and wrote a thesis on his work that revolutionised the IJN doctrine and operational procedures. He was carrying out operational research a decade before the RN did so under Blackett. However, Hara points out that the senior officers of the IJN were incompetent and accepted no advice on how to improve their strategy and tactics, other than Hara's revolutionary torpedo tactics research more than a decade before they went to war with the USA[16].

Torpedoes were used by a wide variety of naval vessels and aircraft besides submarines before during and after WWII. As such it is important to note that the tactics employed in firing torpedoes differed depending on the nation and type of launch vessel involved. Various nations and branches of their navies, including the German Navy's surface fleet, had mass attack tactics that were designed so as to sink more ships per torpedo.

1.2.3 Combat Efficiency

The battles fought in the campaign that is known as the 'Battle of the Atlantic' were many and deadly for the participants. 22,858 merchant seamen lost their lives in allied convoys due to U-boat attacks and 648 frontline U-boats were sunk in action, this being 75% of U-boats, each with 42 crewmen on average resulting in 27,000 U-boat crewmen being killed[17][18].The fortunes of the rival forces in this long-lasting campaign in the Atlantic ebbed and flowed as new inventions were introduced and then countered. There was also a race to outproduce each other for numbers of ships and U-boats by the Allies and the Germans. However, ships, aircraft, weapons and technology can only be exploited to the full if the personnel who are to use them in battle are trained in the technical operation of them as well as the tactics needed for their most efficient use in combat. Within the eb and flow of the fortunes of Admiral Doenitz plan to stop the flow of supplies to the UK there came a confluence of multiple factors that provided Doenitz with a period where he could have achieved much greater damage with his U-boats than he actually did. The counterfactual in this thesis explores how he might have taken this step and possibly extended the war in Europe before the inevitable defeat befell his and Adolf Hitler's plans for world domination.

1.2.4 Admiral Doenitz and his role in Allied Victory

Behind all these factors are the controlling minds of the national leaders and their military and naval commanders on both sides of the conflict. In the research carried out for this thesis it has become clear that the Allied victory in the 'Battle of the Atlantic' owes greatly to the mindset and determination to exert his will of one man in particular. That man is Admiral Doenitz. This remarkable conclusion is evident when the reader studies the orders given by Doenitz to his U-boat commanders concerning how they should conduct themselves at the very moment they actually pressed home their attack on the

---

14 Haslop, British and German Operational Research, page 3.
15 Hara, Japanese Destroyer Captain, page 27
16 Ibid, pages 257 and 262.
17 Hague, Convoy System, page 107
18 Niestle, U-boat Losses, page 4

convoys of merchant ships crossing the Atlantic[19]. The issue here is that Doenitz correctly gathered his U-boats together into Wolf Packs that outnumbered the escorts in the convoys. This usually happened during the part of their passage where the convoys had minimum support. But instead of concentrating this firepower in a synchronised attack he instead insisted a piecemeal attack by individual U-boat commanders separated by location and time. This diluted the attack and threw away the opportunity to deliver maximum damage on each convoy attacked. It also gave the advantage to the escorts protecting the convoys because they only had to deal with single or very low numbers of U-boats attacking at any given time. This latter fact made the U-boats more vulnerable to counterattack and possibly suffer higher losses than might have been.

The ethos of the Nazi regime was centred on the racial superiority of the German people and this was expressed most vividly by the ‘Conquering Hero’ adulation that was fixed upon by Doenitz and exemplified by the accolades he and Nazi propogandist Goebel lavished on the successful U-boat commander or the U-boat ‘Ace’, men such as Prien, Schalke and Kretschmer[20]. However, in the background Doenitz himself crippled the concept of Wolf Pack of U-boats. He did this by expressly ordering the commanders not to synchronize their attacks via the written instructions in the U-boat commander’s Handbook[21]. They were instead ordered to attack as individuals as soon as was possible on their own. This one obsession of Doenitz on the individual U-boat attacking on its own had origins not only in the official handbook but had been reinforced in Doenitz mind by Kretschmer, whose success at the early stages of the war had been accomplished by him by taking his U-boat on the surface inside of the columns of merchant ships. Doenitz did the one thing that could cause the failure of the U-boat offensive in the Atlantic and that was the failure to take advantage to full effect of the numbers of U-boats in a Wolf Pack firing their torpedoes in a huge volley of fire that was synchronized in time and place.

In order to maximise the efficiency of every torpedo fired at a convoy it is necessary to harness the fact that they were not accurate when fired at a target. To do this it is essential to aim at the convoy not a single ship on the edge of it. Also, it is necessary to place the U-boat in such a position that the ships in their rows and columns of the convoy line up to close up the gaps between them. If these positions are used by a U-boat so that a torpedo is more likely to hit a ship rather than going to waste by passing through the convoy without hitting anything then a greater hit number of ships will be sunk. This study has examined the best range and angle to fire at the convoy from.

An escort moving to attack an entire flotilla of 8 U-boats in close formation would be outmatched by the 32 torpedo ready to fire in their forward torpedo tubes and the 8 main 88mm or 105mm deck guns. The danger faced by the escort would be that the flotilla would be commanded by a single commander in charge of all the other U-boat commanders in his flotilla. These commanders would be trained and drilled to stand and fight on the surface and not seek to hide underwater unless ordered to do so. This combined protection would also cover fighting on the surface if attacked by an aircraft where even a very long range four engine aircraft would be subject to the combined anti-aircraft firepower of one or perhaps the 2 flotillas, each of 8 U-boats.

1.2.5 Modelling how Doenitz might have won the Battle of the Atlantic in 1942

The concept of this extra concentrated U-boat attack is examined here by means of modelling convoy attacks in this manner for a typical convoy of 42 Merchant ships protected by four or five escort warships. Aspects of the attack were examined to find the optimum kill positions. Two examples of what was regarded as a successful attack on a convoy were chosen to further examine the conditions

19 Doenitz “Conduct of the War”, page 40
20 Paterson, Kretschmer, plate “Before the interview…..and during”
21 Carruthers, U-boat Commanders Handbook, page 148

and causes of the escorts force to fail in the engagement and compare them with the results that might have been obtained had Doenitz, see Figure 2, used the tactics of final attack. The two convoys chosen that were disasters for the Allies were SC107 in November 1942 and TM1 in January 1943.

Figure 2 Admiral Karl Doenitz [Photo: Anonymous]

1.2.6 Summary of the opportunity for a temporary U-boat victory in 1942-1943 and why Doenitz failed to deliver it.

The effectiveness of the U-boats against the Allied convoy system in the North Atlantic was growing in 1942 due to:

- Numbers of U-boats available was growing rapidly
- Allies had lost the advantage of the decrypted Enigma signals telling them about U-boat deployments
- Germany had access to Allied encrypted signals to and from the convoys and their escorts.
- Doenitz had targeted tankers carrying oil and fuel to the UK
- Lack of air cover over the middle of the North Atlantic.

The consequences of amplifying the growing U-boat success by concentrating their firepower into simultaneous and closely focused flotillas of U-boats attacking convoys could have caused an effective, albeit temporary, interruption of the convoy system. The men, machines and fuels needed to carry out the Allied plans for a combined bombing offensive against Germany and the preparations for the invasion of Northern France might have been delayed.

However, Doenitz failed to capitalise on the potential of concentrated and synchronised U-boat attacks on the Allied convoys for the following reasons;

a) The Nazi culture of the individual ‘Ace’ that could be propagandised to rally public support in Germany influenced the U-bat tactics
b) The apparent lack of any effective operational research in the U-boat force due to the Doenitz’s desire to control all aspects himself

c) The lack of strategic and tactical vision by Doenitz that prevented him optimising the use of the U-boat force and its firepower

1.3 APPROACH

1.3.1 Overview

The approach taken for this research has been along three principal directions. First, an in-depth review of the literature available was consulted with this effort split between primary sources such as the National Archives at Kew in the UK and the extensive range of secondary published works. Second, an analysis of some of the data available was undertaken in both the archival material and the secondary published works covering the shipping losses in relation to the strength of the escort provided to defend the convoys. Third, a computer-based battle model has been created to represent a convoy and its escorting warships while they are under attack by a Wolf Pack.

1.3.2 Primary Sources of Information

The primary sources accessed have included original official documents held at the following bodies and accessed as indicated in table 1.

Table 1 Primary Sources of Information accessed in support of this research

Archive	Number of Documents Accessed	Means of Access	Key Examples
UK National Archives Kew	200+	Personal access at the reading rooms and on-line	Washington Atlantic Convoy Conference minutes March 1943[22]
Library and Archives Canada	1	DVD Via Reprographics Dept.	Deck Logbook of HMCS RESTIGOUCHE Oct. and Nov. 1942[23]
US Library of Congress	2	on-line	Summary technical report of division 6, NDRC 1946 Vol.2B[24]
Churchill Library University of Cambridge UK	1	The Lake Papers collected by Prof. N. MacKay	Churchill Archive, Captain Lake RN member of WATU

1.3.3 Published Data on individual Convoy losses

Recognised concise sources of data on the merchant ship losses in the battle of the Atlantic proved most useful in providing input for some illuminating analysis, the results of which will be provided later in this thesis[25][26].

1.4 REVIEW OF THE LITERATURE ON OPERATIONAL RESEARCH OF THE BATTLE OF THE ATLANTIC

The literature on the use of operational research as it was and still is applied to the Battle of the Atlantic in WWII has been consulted by the author for this thesis. The following brief notes of review for the

[22] ADM 199/1148, Note: Washington Conference records are located in the second half of the folder.
[23] Library and Archives Deck Log of HMCS Restigouche, Canada RG24, kindly supplied by the Reprographics department 2021
[24] US Library of Congress Summary Technical Report of Division 6 NDRC: Vol. 2B, page 119.
[25] MFQ 1/587/26, single sheet 26th in folder
[26] Hague, The Allied Convoy System", Appendix 3.

main sources are the author's own views on them, these notes are presented in the following two subsections.

1.4.1 Primary Sources on Operational Research of the Battle of the Atlantic

> Sternhell and Thorndyke, Antisubmarine Warfare. This classic analysis covers the wartime history of the use of U-boats to attack individual ships and ships in convoys. This is followed by detailed analysis of the search for U-boats by aircraft and surface vessels and the ensuing combat.
>
> NDRC: Summary Technical Report of Division 6 , Vol. 2B, A Theoretical Basis for Screening, Chapter 8 Sonar screens. This highly detailed report covers the mathematical modelling of the search for U-boats and the effectiveness of the torpedoes used by the Germans. These include analysis of the performance of patten running and homing torpedoes developed in WWII.
>
> PREM_3_414_3, Blackett, Progress of analysis of the value of escort vessels and aircraft in the anti U-boat campaign. This highly important paper was prepared by Blackett himself and presented to the Admiralty antisubmarine committee before being brought to the attention of Churchill himself. It shows the effectiveness of escorts and aircraft in finding U-boats and defending convoys from them.

ADM 219 series of reports from the Directorate of Operational Research and predecessors, this series contains 733 reports and are located in the UK National Archives Kew, 4 of the 10 reports from this series that are quoted in this thesis are reviewed below,

> Blackett's, Paper on convoy size: PB 4/5/2, See ADM 219/46 and ADM 219/37 The latter paper is the only one that has been obtained for this research study and is described below.
>
> ADM 219/37 Statistical Analysis of Effect of Surface Escort of Convoys, Jan 27 1943 This is the original analysis by L. Solomon and V.V. [Thimann], that determined that the larger the size of a convoy the fewer ships would be sunk. It was not carried out by Blackett personally. This finding on convoy size is true for the case of the lone U-boat 'Ace' attack but not true for the counterfactual proposed in this thesis and will be presented in later sections. This analysis is the wartime work on 88 convoy attacks that are referred to by McCue in his papers referred to below. The analysis reported in this thesis used data from many convoys that covered the same period as the 'missing' 88 convoys and compared McCue's annealing with them favourably.
>
> ADM 219/55 How U-boats can greatly intensify their attacks on shipping 1943, this research proposed mass surface attacks by U-boats in concentrated and synchronised flotillas.
>
> ADM 219/60 Note on expected casualties due to A/A fire from U-boats 1943. This shows that attacks by a lone aircraft on a lone U-boat had a 25% chance that the aircraft might be shot down if flying at 1500 feet.
>
> ADM 219/99 Pack Attacks by Submarines. 1944. This study examined the theory behind pack attacks but dismissed the possibility that the U-boats could attack in concentrated formations.
>
> ADM 219/334 Analysis of U-boat hunts by surface craft 1944

ADM 292 series of reports are from the Admiralty Underwater Research Establishment. Contain English translations of German wartime operational research documents, an example used in this study is shown below, ADM 292/209 Tactical Use of Torpedoes: Accuracy of Torpedo Fire, date not specified but written during WWII. This mathematical analysis of hit probability of torpedoes fired from U-boats demonstrates that the German Navy did have an effective operational research capability.

1.4.2 Secondary Sources on Operational Research of the Battle of the Atlantic

The following works have been consulted in the course of the studies for this thesis, other useful works are also available[27].

Morse and Kimble, Methods of Operational Research. This insightful manual on how to conduct operational research based on experience gained in WWII. It covers examples that include anti U-boat warfare in the Bay of Biscay, US coastal waters of the Eastern seaboard and suicide aircraft attacks as employed by the Japanese. Use is made of the 88 convoys used in ADM 219/37. It also considers many pairings of platforms and weapons against each other.

McCue, U-boats in the Bay of Biscay. This classic analysis of the U-boat war in the Atlantic has detailed analyses and models to explain what happened in the war against the U-boats. The author correctly identifies that Doenitz was using the U-boat force as a strategic weapon system to defeat the UK by means of strangulation of vital supplies. He does not, however, go as far as to note that Doenitz identified the supply of oil to the UK as his key strategic target. McCue does identify Doenitz as a 'Battle Manager' which we can interpret this as a micromanager of every aspect of the U-boats at the tactical level as this thesis also has. Where McCue has not ventured is to identify that Doenitz held back the ultimate capability of the force he commanded by rigidly following the U-boat Ace tactics of individual U-boat attacks at close range. Nor was any mention made of synchronising of the attacks which this thesis does explore.

McCue, ''Using Simulated Annealing to Solve a Problem of 'Ecological' Inference,'' Phalanx, Vol47 No2, June 2014, the data from this paper has been used in this thesis to compare with the data from Hague on convoy losses.

McCue, 'Applying Hughes's "Salvo Equations" to Engagements between U-Boats and Convoy Escorts', Military Operations Research, Vol. 19, No. 4 (2014), pp. 41-50 This analysis is a comprehensive treatment of the subject but once again uses the 'missing' 88 convoy data set used in ADM 219/37.

Waddington, Operational Research Against the U-boat This a comprehensive work covering the use of aircraft to find U-boats with the intention of sinking them with bombs and depth charges dropped from the air. The historical development of the battle is provided but the emphasis is on the aircraft, the radar, night lights and weapons they carried as well as the question of aircraft serviceability. This latter key feature highlights the dominant aspect of the use of aircraft in the Battle of the Atlantic, that of the numbers of aircraft needed to find the U-

[27] Important works not specifically used are;

Falconer, N, " On the size of convoys"

https://www.tandfonline.com/doi/abs/10.1057/jors.1976.59?journalCode=tjor20

Duffy, R.B., Gallehawk, J, "Submarine warfare and Intelligence "

https://www.tandfonline.com/doi/abs/10.1080/21533369.2017.1412680 boats. This matters to the viability of the counterfactual proposed in this thesis as a flotilla of U-boats on the surface would be able to defend itself against one or two aircraft with ease. For the Allies the task of finding one flotilla in the Bay of Biscay might require the same number of airborne searches as needed to find one U-boat in the same area. Therefore, the Allies would need formations of aircraft to search for and attack a flotilla of U-boats safely if the counterfactual had been used in reality and for which they would not have the aircraft to carry out.

Beall, The development of a naval battle model and its validation using historical data Naval Postgraduate School, Monterey California, March 1980. Beall's masters thesis forms an important contribution to the debate about the representation of naval battles and helped shape the structure of the work carried out for the authors thesis. Where Beall's approach focussed on combat between peers the current work focuses on the situation in the Atlantic in 1942 and early 1943 where the U-boats were in effect unopposed in the significant number of convoy engagements. The convoys SC107 and TM1 are exemplars of this asymmetric matching of the combatants. Beall makes use of groups of combatants who fire at the same time and this is effectively as modelled in this thesis. Beall's 'Pulse fire' battle concept is exactly the effect delivered by a barrage of torpedoes against a collection of helpless targets such as is formed by a convoy of merchant ships where the escorting warships are either absent or blind to the presence of the enemy.

1.5 THE BATTLE MODEL

The research has encompassed the creation and exercise of a computer based 'Battle Model' of an attack on a typical convoy by a Wolf Pack of U-boats in the North Western Atlantic. The focus has been on the fate of Convoy SC107, which was escorted by a varying number of naval vessels during the course of its passage. Leading the escorts of convoy SC107, was a destroyer of the Royal Canadian Navy, HMCS RESTIGOUCHE[28]. RESTIGOUCHE was commanded by Lieutenant Commander D.W. Piers RCN[29]. At the time of the first attack on Convoy SC107, the night of the 1st/2nd November 1942, Piers had several other vessels of the RN and RCN to assist in the protection of the convoy, all of which were Flower class corvettes. Controversially, most of these corvettes were poorly equipped with electronic sensors and the one corvette that had an RDF271 radar had that radar fail just prior to the time of the first U-boat attack[30]. RESTIGOUCHE had a functional RDF271, ASDIC (which stands for Anti-Submarine Detection supersonIC[31] and importantly HF/DF(High Frequency Direction Finders). The very limited range of the early ASDIC and RDF sets meant that the probability that a U-boat would be detected was very low beyond 2 kilometres submerged (using ASDIC) or 6 kilometres on the surface (using RDF) before late 1943[32][33]. The performance for the ASDIC and RDF were both reduced further with worsening sea states.

1.5.1 The Computer Battle Model

The Battle Model (BM) was created on a laptop computer using an Excel workbook and implemented in Visual Basic Applications (VBA) within the Excel development environment. The BM implementation was chosen to be a 'Convoy Centred' kinematic one so as to reduce the complexity of

---

28 Waters, Bloody Winter, page 23
29 Douglas et al, No Higher Purpose, page 547
30 Ibid, page 40
31 SONAR, Wikipedia
32 Milner, Battle of the Atlantic, page 132
33 ADM 219/29, Appendix Table I

the physics and computational tasks and is a simplified and approximate model. The counterfactual was evaluated with the same BM but with some of the values of merchant ship susceptibility to sinking by torpedoes adjusted to reflect the synchronous arrival of 32 torpedoes. These would arrive from each side of the convoy in a much shorter period of time than in the typical historic engagements that had attacks by individual U-boats separated by several hours and even days[34].

1.5.2 Convoy SC107 Modelling

The BM was exercised 1000 times using the historic data for the first night of the attack on SC107 to ensure it reproduced an accurate account of the battle losses suffered by the convoy in the form of ships lost, which was 9 in total for that day/night cycle on 1st/2nd November 1942. It was found that one of the two key U-boat commanders (Schneider in U-522) had reported firing a number of torpedoes at the convoy and 2 of these had no corroborative hits and were potentially erroneous reports of the alleged targets descriptions. These two reports from Schneider describing the targets he allegedly fired at (a large burning tanker and a cargo vessel with exploding ammunition) were not supported by the actual evidence of vessels hit up to the point of his claim[35]. These two torpedoes fired by Schneider were his first to be fired in his first combat as a commander of a U-boat. As a consequence, they have been disregarded in the modelling.

1.5.3 Convoy TM-1.

A second example of a very successful attack by U-boats on an Allied convoy was chosen, convoy TM-1, the first of the tanker only convoys from the Caribbean. It was composed of 9 large fast tankers carrying oil and fuels to the North African and Mediterranean theatres of operations in January 1943. The losses of these tankers were 7 out of the 9 being sunk by the U-boats that attacked them. The attacks took place to the West of Morocco's Atlantic coast and south of the Azores from the 9th to the 11th of January 1943[36]. Convoy TM-1 was escorted by warships of the Royal Navy and led by the commander of HMS HAVELOCK. He had three Flower class corvettes under his direction[37]. Three of the four warships had RDF fitted but only two of these were functioning during the days of the attacks[38].

1.5.4 Modelling a counterfactual

The BM was then used to examine a counterfactual modification to the tactics used by the U-boat force in their actual torpedo attacks carried out on the surface at night. The standing orders imposed by Admiral Doenitz, in the form of the 'U-boat Commanders Handbook', instructed the U-boat commanders to attack on their own and not to wait to coordinate with other U-boats. This meant that the attacks actually implemented by U-boats were piecemeal and separated in time by hours and neglected one of the principles of war, i.e., to attack by concentrating in space and time. This played into the hands of the escorts who could concentrate their efforts in searching for and sinking individual U-boats one at a time. The counterfactual made use of standard operating procedures used by the Kriegsmarine surface vessels, such as destroyers to coordinate an attack on a large target such as a convoy by concentrating them in one firing area and firing their salvoes of torpedoes on command by the flotilla commander. These same tactics were standard in most Navies of World War two for surface craft. The U-boat Commander's Handbook permitted groups of U-boats to be commanded by a local commander. This tactic was rarely ever used and the handbook stated that it was only to be initiated by the explicit order of U-boat command, i.e. Doenitz himself and only for searching for targets and not for organising attacks.

[34] Rohwer, Axis Submarine Successes, page 132 timings of attacks on convoy SC107
[35] Ibid, page 132 Note 3
[36] Ministry of Defence(Navy), Volume II page 79
[37] ADM 199/2016, page 3
[38] Ibid, page 1

1.5.5 Tactical Details for the counterfactual

The modelling results of the counterfactual showed that the efficiency of torpedo use averaged over the war was raised to 70% hit probability if the firing point of the torpedoes was an approach angle of 80 degrees from the direction of travel of the convoy. The firing points were set at a range of 10 kilometres from the centroid of the convoy and the attack was effectively a 'Browning' attack by the Wolf Pack[39]. In this counterfactual a Wolf Pack of 16 U-boats was divided into two flotillas of 8 boats with each flotilla having a flotilla commander to marshal his boats on the surface at night and give the order to fire the volley of 32 torpedoes. There would be two such flotillas one from each side of the convoy at a range of 10 km.

An Admiralty study carried out in 1943 asked how many torpedoes do U-boats require to sink a ship?[40] Although the document in the NAK is incomplete the answer is given in the conclusions to the report as between 5 and 10 torpedoes expended for every ship sunk. If the BM is used to assess the counterfactual then 64 torpedoes fired resulted in 29 ships being sunk in the convoy of 42 ships, i.e. 2.2 torpedoes per ship sunk per torpedo. This would have been a vast improvement in the efficiency in the use of torpedoes compared to the Ace tactics actually underemployed by the Germans.

Figure 3 shows an image taken from the BM illustrating the attack by two flotillas of U-boats positioned on either side of the convoy so as to maximise the efficiency of the use of the torpedoes.

The metric adopted in the counterfactual is the number of ships sunk per the number of U-boats in the Wolf Pack. This takes into account the U-boats that did not attack, the wasted torpedoes of multiple hits for visual confirmation of the sinking of a ship by the 'Ace' and the wasted torpedoes of the counterfactual when multiple hits were accumulated by a ship that has greater resilience to torpedoes but would have sunk later after only one hit.

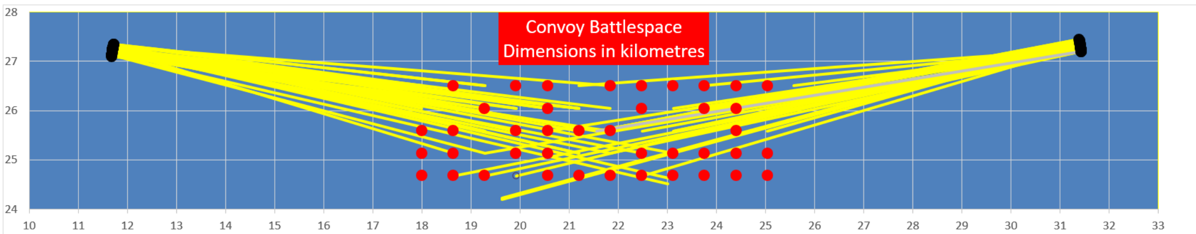


Figure 3 The Battle Model screen showing the attack by two flotillas of U-boats (black dots) against the convoy of merchant ships (Red dots) with torpedo tracks shown (Yellow lines)

1.5.6 Consequences of the counterfactual

If such a tactic as represented by the counterfactual had been implemented from mid-1942 onwards to mid-1943 then the number of Allied merchant ships sunk, including crucially tankers, could have been much higher than it was. This would have been a significant increase in losses of tanker fleet as they were often placed in the centre of a convoy[41].

---

39 Brooks, British Destroyers at Jutland, page 37

40 ADM 219/54 The number of Torpedoes, page 5 Note the document contains only 3 pages of text whereas the last page is numbered 5.

41 ADM 219/23 Relative Safety of Freighters and Tankers in Convoys, page 1 item 3 " Tankers are supposed to be placed in the centre of the convoy".

The employment of the tactic of the counterfactual might also be expected to reduce the losses of U-boats due to the effects of their collective defence while they are fighting as a coordinated force on the surface. The consequential counters to this tactic by the Allies would of course come into play in such evaluations of the merits of the counterfactual but are beyond the scope of this study.

Chapter 2 BATTLE OF THE ATLANTIC IN WWII

2.1 OVERVIEW OF THIS CHAPTER

In this chapter there are four further subsections which consider the following topics,

> 2.2 Key People: this covers the most influential figures in the Battle of the Atlantic below the national leader levels on both sides. In each case the person or group mattered to the eventual outcome and its timing. Each person has been presented by first stating their important achievement and role. This is followed by a brief biography and then further details of what they did.
>
> 2.3 The U-boat Force: here the key elements of the German machines that were used are described starting with the torpedoes, their initial unreliability and their fire control system. This is followed by a brief description of the two principal types of U-boat used.
>
> 2.4 The Allied convoy system is discussed, the merchant ships, the escorts protecting them and the organisation of the convoys. An understanding of the efficiency of the convoy in terms of the losses suffered against various parameters such as the number of escorts or the size of the convoy and other factors are reported for the actual statistical data from a run of 130 convoys in the HX series.
>
> 2.5 Fictional accounts in literature, movies, games and also documentary coverage are briefly reported to show the modest interest that is held by the general public in the Battle of the Atlantic.

2.2 KEY PEOPLE

2.2.1 Grande Admiral Doenitz

Karl Doenitz was born Grunau-Berlin on September 16th 1891[42] and served in U-boats during WWI.

In the1930s he joined the Nazi party and then joined the newly formed U-boat force after Hitler took power and began Germany's rearmament. He rose up the command structure and became the commander of the U-boat Force but this position carried little influence over how the U-boat development programme was run[43]. Doenitz grew in fame rapidly from the very start of the war due to the remarkable combat achievements of the first group of U-boat 'Aces' such as Prien, Kretschmer and Schepke with Doenitz himself being awarded the Knights Cross on the 21st April 1940 for his excellent leadership of the U-boat force[44]. Such awards put Doenitz in direct face to face contact with Adolf Hitler and his closest aides and ensured his upward progress including being appointed successor to Gross Admiral Raeder as Commander in Chief of the whole German Navy in 1943. Hitler eventually awarded him the greatest accolade any Nazi could dream of: that of Hitler's successor as Fuhrer of the Third Reich. In May of 1945 Doenitz was captured by the Allies and later was sentenced to 10 years in

---

[42] Padfield, Doenitz, Last Fuhrer, page 17
[43] Mallman. Showell, Doenitz, U-boats, page ix
[44] Dixon, U-boat Commanders, page 27

prison. He was released and lived on in West Germany, where Nazi followers still exulted him as Fuhrer during his remaining life and at his funeral in 1980[45][46][47].

2.2.2 Admiral Horton RN

The man who was recognised as Doenitz's most capable opponent was Admiral Sir Max Horton RN. In 1942 Horton wrote a paper which included the need for the RAF. to play its part in securing the sea communications of the Empire. This prophetic paper resulted in Prime Minister, Sir Winston Churchill taking steps that eventually secured more long range aircraft for RAF but most importantly appointing Horton as C-in-C Western Approaches Command (WAC) in November of that year[48]. From the time when he took over the command of WAC in November 1942 until the end of hostilities in Europe in 1945 Horton made certain that the Royal Navy and its Allied counterparts were effective in escorting the convoys. It was these convoys that were bringing the vital supplies across the North Atlantic Ocean that Doenitz's plan to cut off the UK. Horton had resources available to help him in his task including a group of men women who staffed the plotting room and a unique group that analysed enemy tactics and developed new manoeuvres and trained escort commanders in their use.

National Maritime Museum

Figure 4 Admiral Sir Max Horton

The fledgling Western Approaches Tactical Unit (WATU) was located on the top floor of the WAC headquarters at Derby House in Liverpool[49].

WATU was instrumental in being the seat of original thinking and analysis on anti-U-boat tactics and the training of escort commanders on how to use those tactics. One of the most important tools WATU had was the use of War Gaming of the ideas they generated to prove their worth and develop them.

[45] Brown, Captain Eric, Wings on my sleeve, page 252-253
[46] Padfield, Doenitz, Last Fuhrer, page 485
[47] Dixon, U-boat Commanders, page 30
[48] Ibid, page 144
[49] Ibid, page 170

At the end of March 1943 Horton went to see Churchill to discuss the disastrous three months of that year where large Wolf Packs of U-boats were taking an increasing toll of merchant ships in the Atlantic that had resulted in serious consideration in some parts of the Admiralty of the possible suspension of the convoy system itself[50]. However, backed by the battle modelling of WATU that showed that the concept of having additional escort vessels available in the form of free roaming 'Support Groups' ready to move swiftly to rescue beleaguered convoys, he persuaded Churchill to assign 15 additional warships to this new role[51]. The man who created WATU was Captain Gilbert Roberts RN and is described in Section 2.2.6.

2.2.3 Fleet Admiral King USN

The United States supported the UK in the fight against Nazi Germany from the beginning of WWII but with restraint at first because of the internal politics there. Once the USA entered the war fully following the Japanese attack on Pearl Harbor and Hitler's declaration of war on the USA the United States Navy committed itself to defeating the U-boat menace as a priority. The man in command of the US Navy throughout the majority of WWII was Fleet Admiral Ernest King. King was born in Ohio on 23rd November 1878 and entered the U.S. Naval Academy in 1897 and almost immediately saw action in 1898 during the Spanish-American as a Midshipman on the cruiser U.S.S. San Francisco[52]. During the 1930s King commanded the aircraft carrier USS Lexington. In February 1941 he was appointed Commander in Chief Atlantic Fleet and promoted to the rank of Admiral. By the 16th December of that year he had been promoted to be Commander of the US Fleet[53].

King has been described by many authors as an Anglophobe, i.e. someone who dislikes the British, this may seems curious to some as both of his parents were first generation British immigrants to the United States[54].

In March 1943 at the Atlantic Convoy Conference in Washington King shocked the British and Canadian delegations by pulling the US Navy escorts vessels out of supporting the Allied convoys in the North Atlantic just as the build-up to D-Day and the bomber offensive was beginning[55]. There was some justification for Kings decision since he was also charged with providing naval protection to the convoys of US soldiers and their supplies being sent over to North Africa and the Mediterranean theatre. However, King also stated in his address to the Washington conference that he was not in favour of mixed nationality forces, effectively segregating the US Navy from their allies[56].

2.2.4 Vice Admiral Percy Nelles RCN

The contribution made by the Canadian people, their government, industry and armed forces is significant on all counts but none more so than that of the Royal Canadian Navy (RCN) in the Battle of the Atlantic. The most senior commander of the RCN during WWII was Vice Admiral Nelles but his contribution to the war effort was tarnished by accusations that he deliberately inhibited the repair and update of the corvette vessels that played such a key role in the RCN force deployed mainly in the Western Atlantic. He was eventually sacked but post war research has shown that the fault lay higher up in the Canadian government itself[57].

---

50 Lake, The Lake Papers, page 5 "Abandon the convoy system"
51 Middlebrook, Convoy, pages 287 to 289
52 King, Fleet Admiral, page 4
53 Ibid, page 143
54 Milner, Battle of the Atlantic, page 93
55 King, Fleet Admiral, page 252
56 Roskill, War at Sea, Vol.II.page 358
57 Mayne, Betrayed, page218

Nelles was born 7th January 1892 and enlisted as a cadet in the Fisheries Protection service in 1909 on a path that would lead to him being one of first officers of the RCN. Nelles then served on various RN warships. He rose up the command structure of the RCN and was promoted to Rear Admiral rank in 1938 and appointed as Chief of Naval staff [58].

The RCN contribution to protecting the convoys crossing the Atlantic centred on the escort groups stationed on the maritime provinces of Eastern Canada and consisted of four groups of warships, C1 to C4[59].

Nelles was replaced under a cloud of complaints and accusations from his own subordinates[60]. The Canadian Liberal government of the day has since been accused of scapegoating Nelles to cover up their own lack of commitment to fund the war effort effectively and the consequential increased losses of Allied ships and seamen[61][62]. Nelles later served as the senior representative of the RCN in the preparations for the D-Day landings on June 6th 1944.

2.2.5 The 'Cult' of the U-boat Aces

In war, success and gallantry are usually followed by the awarding of medals, honours and the spoils of war to those individuals and units responsible. In Nazi Germany the situation was no different and that applied to the commanders of U-boats, however there and in the other branches of the services the Nazi culture took it to extremes.

The organised public adulation of the successful individual members of its armed forces in WWII made those individuals heroes in the eyes of the Nazi regime. This is especially true for those who built up significant victories in combat and has been used and justified by authors who have studied the self-defeating Nazi racist philosophy and its manipulation for propaganda purposes[63].

The success of Gunter Prien as commander of U47 at the very start of WWII in gaining access to the main anchorage of the Royal Navy's Home Fleet in Scapa Flow on the 14th October 1939 and sinking the battleship HMS Royal Oak set the stage for not just the exultation of Prien as a great hero. He and his crew were honoured by Hitler himself in very public ways including a cult-like parade of U-boat aces throughout the first years of the war. This had a profound influence over the thinking of Admiral Doenitz and also ultimately over the conduct of the Battle of the Atlantic[64][65].

The top three scoring U-boat Aces of WWII are[66];

	Ships Sunk	Tonnage
Kretschmer	42½	238,327
Lüth	47	229,000
Prien	32½	211,393

58 Douglas et al, page 27
59 Mid-Ocean Escort Force, Internet
60 Mayne, Betrayed, page 3
61 Ibid, page 189
62 Ibid, page 217 to 218
63 Baird, To Die for Germany, page xi
64 Martindale, Gunter Prien, page 30
65 Ibid.page 39
66 Blair, The Hunted, page 813

The award of the Knights Cross and its higher adjuncts was based on the sinking of ships not simply the firing of torpedoes and observing of hits. The ships had to be unquestionably sunk by the commander or other members of his crew. This posed problems for the aspiring ace or established ace trying to reach the top of the ships sunk ladder. This was because the number of torpedoes required to sink a ship and indeed to see it sink within a reasonable time depended on the nature of ship and its cargo[67]. The records and the reported contents of the records show that the top aces fired multiple torpedoes into ships that refused to sink swiftly after just one torpedo[68][69][70]. This resilience to torpedo attack bestowed on merchant ships by the nature of their cargo has been incorporated into the Battle Model and will be discussed further in Chapter 3.

One characteristic of the U-boat aces was a preference for the use of the electrically powered torpedo over that of the steam powered variety because the latter produced a stream of bubbles on the surface of the ocean whereas the former did not. These bubbles could be used by the targeted merchant ships and escorts to detect the attacking torpedo before it hit and therefore determine the direction of the U-boat and facilitated counterattack against the U-boat. However, the steam powered torpedo had over twice the range and 50% greater speed than the electrically powered variety.

2.2.6 Captain Roberts RN and Western Approaches Tactical Unit

Captain Roberts RN was born in October 1900 and entered the Royal Navy at the age of 12 and was educated at the Royal Naval college Osborne[71].

Roberts also attended Dartmouth to complete his education[72]. By 1937 he was promoted to Commander and placed in command of the destroyer HMS Fearless. It was while he was in command of the Fearless off the coast of Spain that Roberts fell seriously ill with tuberculosis. As a result of his illness he was invalided out of the navy.

When WWII broke out he carried out duties in volunteer civilian organisations before being called on by the admiralty to take charge of an excess of men coming out of the training schools in Portsmouth. Following this period of service he was called to the Admiralty and was sent to Liverpool to form a new unit to develop the tactics of anti-U-boat warfare within the WAC HQ at Derby House[73]. Roberts is shown in Figure 5 at his desk in WATU at Derby House.

---

[67] Budiansky, Blackett’s War, page 150
[68] Martindale, Convoy, page 120 and 121
[69] Paterson, Kretschmer, page 62 and 63
[70] Vause, U-boat Aces, page 76
[71] Williams, Captain Roberts, page 7
[72] Ibid, page 9
[73] Ibid, page 85

Figure 5 Captain Gilbert Roberts RN

Commander in Chief of Western Approaches at that time was Sir Percy Noble. He was completely underwhelmed by the arrival of Roberts, whom he saw as a retired officer with limited service in submarines and a specialist in gunnery. The fact that this new officer was to set up a 'School' of some form in his headquarters was seen as more of a nuisance than a help and Nobel dismissed him by saying "Well you can carry on with it but don't bother me, I am busy"[74]. Roberts was not put off by this rebuff, instead he went to work finding out from the escort commanders what happened when U-boats were attacking merchant ships in a convoy. He rapidly came to understand the nature of the U-boat tactics of getting inside the columns of ships in a convoy if they could and torpedoing them at point-blank range. This was something that the U-boat 'Aces' had been doing since 1940 with Otto Kretschmer the unbeaten ace. However, Kretschmer's U-boat had been depth-charged and driven to the surface by the renowned escort commander Macintyre and Kretschmer and his crew captured in 1941[75][76].

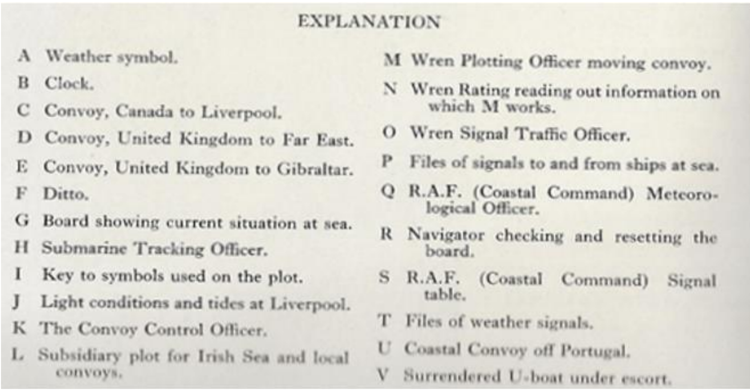
WATU grew from the start by being staffed by the women of the Women's Royal Naval Service, or Wrens as they were universally known, but this team was led by Roberts.

The plotting room at Derby House is shown in Figure 6[77] and was staffed by men and women of the Royal Navy, WRNS, RAF and WAAF but this was a separate unit to WATU at Derby House.

[74] Ibid, page 86
[75] Ibid, page 87
[76] Macintyre, U-boat Killer, page 34
[77] Chalmers, Max Horton, Plate facing page 209

Figure 6 The Plotting Room at Western Approaches Command Derby House Liverpool

The explanation of the referenced features in Figure 6 is shown in Figure 7.



EXPLANATION

A Weather symbol.
B Clock.
C Convoy, Canada to Liverpool.
D Convoy, United Kingdom to Far East.
E Convoy, United Kingdom to Gibraltar.
F Ditto.
G Board showing current situation at sea.
H Submarine Tracking Officer.
I Key to symbols used on the plot.
J Light conditions and tides at Liverpool.
K The Convoy Control Officer.
L Subsidiary plot for Irish Sea and local convoys.
M Wren Plotting Officer moving convoy.
N Wren Rating reading out information on which M works.
O Wren Signal Traffic Officer.
P Files of signals to and from ships at sea.
Q R.A.F. (Coastal Command) Meteorological Officer.
R Navigator checking and resetting the board.
S R.A.F. (Coastal Command) Signal table.
T Files of weather signals.
U Coastal Convoy off Portugal.
V Surrendered U-boat under escort.

Figure 7 Key to the plotting room photograph

An example scene from the training room in WATU is shown in Figure 8 where the escort commanders under training can be seen peering through ‘Peep holes’ that restrict their view of the marked-out floor. Simple model ships were placed on the floor while the Wrens indicate events being reported to them as if they were actually happening to the commanders as they stood on the simulated bridge (Compass platform) of their escort vessels[78].

[78] Strong, Wargaming the Atlantic War, page 8

Figure 8 Wrens teaching the escort commanders the new tactics that they will employ once they return to sea duty

One of the great problems faced by the escort commanders was the situation where a U-boat got in among the ships of the convoy and started sinking them at very close range, ~ 250 metres or less. At night it was hard for the crews of the escorts and merchant ships to distinguishing the attacks from U-boats inside the convoy from the more common situation of U-boats firing from outside the convoy[79]. Roberts and his team from the Wrens analysed the situation and realised that if a U-boat was known or was suspected to be in convoy it would be important to force it to submerge and drift towards the rear of the convoy. This then enabled the Senior Officer Escorts (SOE) to redeploy his escorts so some of them would move to a position behind the convoy at high speed and then in formation zig-zag towards the rear of the convoy they might then engage the U-boat. To do this the escorts would employ their ASDIC detection equipment and could catch the U-boat as the convoy left it behind. This manoeuvre was given the code word ‘Raspberry’ by Wren Jean Laidlaw. Her role was gathering and analysing the statistics of the tactic[80].

The WATU team went on to work out new tactics and give them code words as each new development of German torpedo technology was deployed. These included: Pineapple to defeat a suspected attack by a U-boat approaching at night from ahead of the convoy, Beta Search to deal with a U-boat that has just submerged and Step Aside to avoid an acoustic homing torpedo fired at an Escort. These manoeuvres where explained and taught to the escort commanders attending the many training courses at Derby House. During this training the use of the codewords like Raspberry were employed to trigger the manoeuvre. At sea these orders would be issued over the VHF radios. See Figure 9 and Figure 10, these show the manoeuvres diagrammatically [81].

79 Williams, Captain Roberts, page 90-91
80 Ibid, page 95
81 Ibid, pages 96 to 99

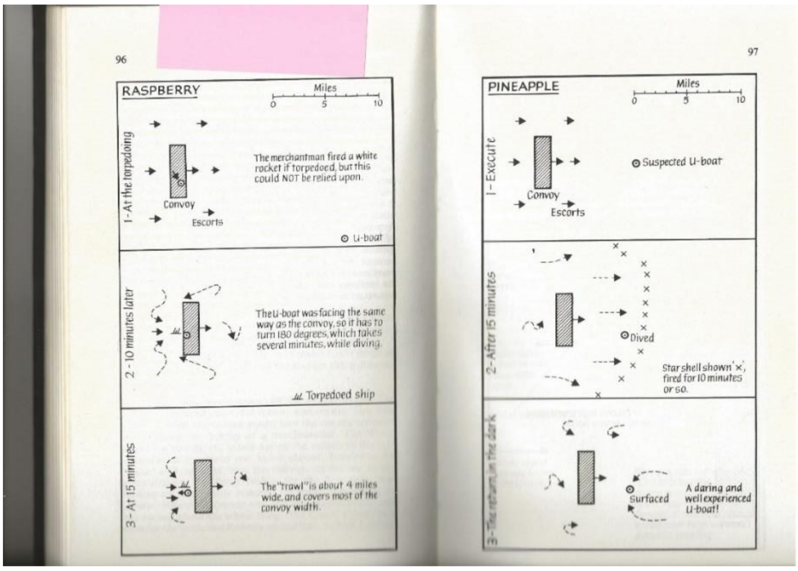


Figure 9 The Raspberry and Pineapple Manoeuvres

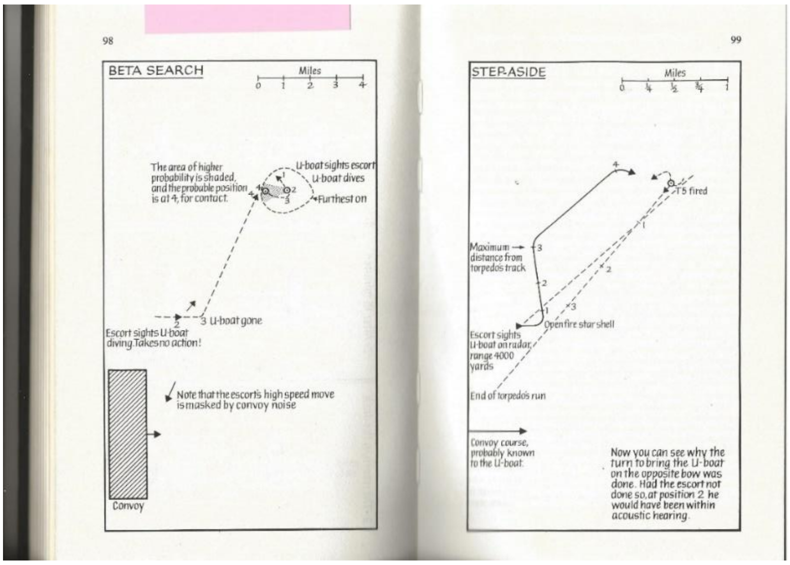
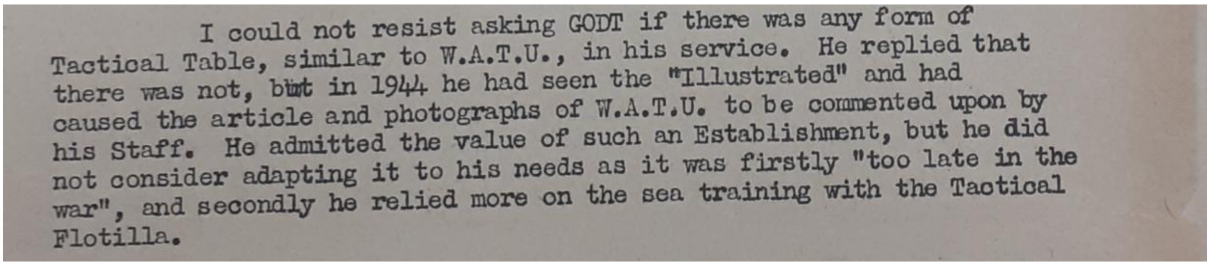


Figure 10 The Beta Search and Stepaside Manoeuvrers

At the war in Europe was drawing to a close Captain Roberts was sent to Germany to interrogate German high ranking U-boat Command officers and learn as much as possible about the U-boat tactics and technology. He interrogated Admiral Godt, Doenitz's deputy in the U-boat Force, from whom he learnt that the Germans did not have the equivalent of WATU[82], but he said they were aware of the code name 'Raspberry' but did not know what it meant[83].

Figure 11 shows a photograph taken by the author of the paragraph from Roberts report dealing with the question about German equivalent to WATU.

82 ADM 1/17561, Appendix II page 1
83 Ibid, page 2



I could not resist asking GODT if there was any form of Tactical Table, similar to W.A.T.U., in his service. He replied that there was not, but in 1944 he had seen the "Illustrated" and had caused the article and photographs of W.A.T.U. to be commented upon by his Staff. He admitted the value of such an Establishment, but he did not consider adapting it to his needs as it was firstly "too late in the war", and secondly he relied more on the sea training with the Tactical Flotilla.

Figure 11 A photograph of the paragraph by Captain Roberts RN in his report detailing his interrogation of U-boat Force Commander Admiral Godt in 1945.

2.2.7 Prof. Patrick Blackett Director of Operational Research in the Admiralty

Patrick Blackett came from a background in Physics and became famous for his research in elementary particles via his development and use of cloud chambers[84]. Later in his career he won a Nobel Prize for his pre-war discovery of the particle known as the Positron, a positively charged version of the Electron[85].

Once war had broken out, like many scientists Blackett put his mind to work as to how science could be used to identify problems, find solutions as well as capitalise on things that went well in military operations. This ‘Operational Research’ (OR) would also be used to gain a better understanding of how to use resources in winning a war.

After taking up a post in OR for RAF Coastal Command Blackett was be drawn into the Admiralty’s task of ensuring the U-boats were defeated[86].

Blackett’s work on convoy protection from U-boat attacks included some very significant contributions. His analysis of the relationship between the number of ships sunk per U-boat in a pack attacking a convoy and the number of escorts present[87] was important in showing that the greater the number of escorts the fewer the number of ships that would be sunk. Figure 12 shows the number of ships sunk in a convoy per U-boat in the pack attacking against the number of escorts present. From this it can be seen that there is a straight line fitted to the rather sparse data points plotted. The study included data from 32 convoys, including SC107, but it is noteworthy that the size of the pack in the tabulation of the data was estimated on a daily basis rather than the post-war known total pack member numbers.

The second point made by Blackett in his report was the advantage of larger convoys over smaller ones[88]. This latter point was based on the assumption that the U-boats attacked individually and at close range which was in fact largely true. The counterfactual proposed in this thesis in latter chapters will show that standing off at range and firing torpedoes aimed at the centre of the convoy reverses the advantage that Blackett found for larger convoys.

[84] Budiansky, Blackett’s War, page 46-47
[85] Ibid, page 63
[86] Ibid, page 175
[87] PREM 3/414/3, Figure 1
[88] ADM 219/37, This study was not carried out by Blackett’s but by two other scientists in Blackett’s OR group.

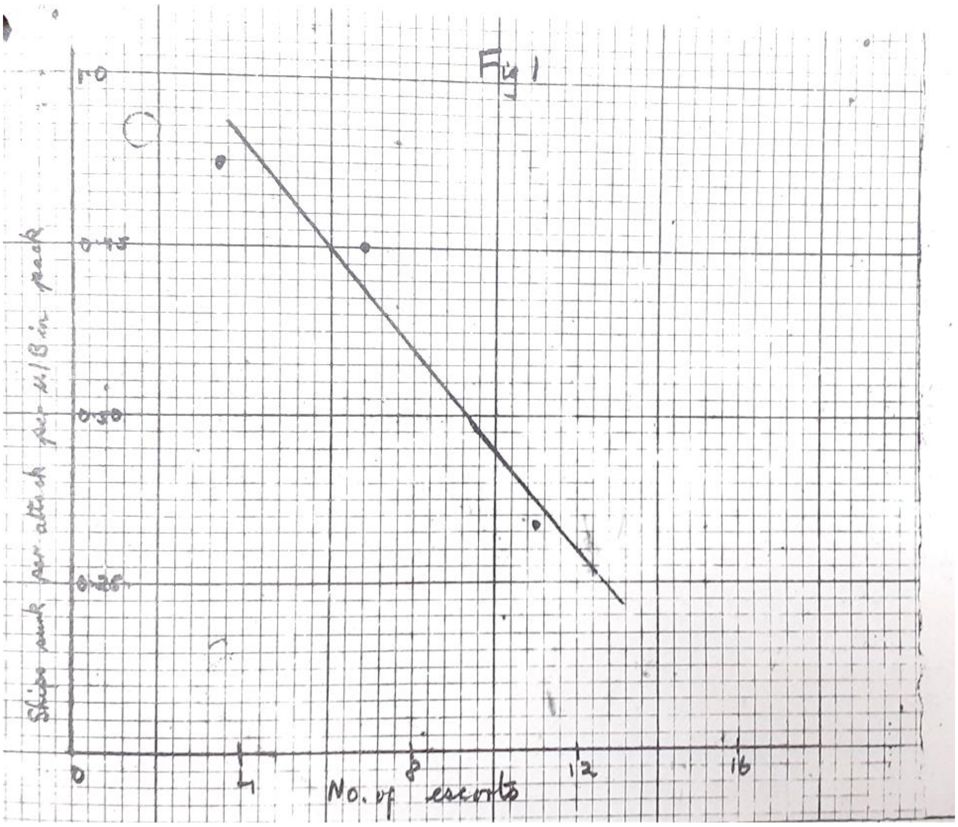


Figure 12 An extract from Blackett's paper of Feb 1943 showing ships sunk per U-boat in a pack against the number of escorts protecting a convoy.

2.3 U-BOAT FORCE

2.3.1 German Torpedoes

German torpedoes in WWII were effective weapons for the smaller craft from destroyers down and especially important to U-boats as their primary weapon. Total production of torpedoes by German industry in WWII has been stated as being approximately 70,000[89].

They came in a variety of versions based on the 21inch diameter and 7 metre length formats. Of these G7e and G7a were the most numerous types. The G7e was an electrically powered model whereas the G7a was a steam powered type. The guidance, warhead and other parts were common to both types. The differences in advantage between the two types lay in the speed and range performance as well as the detectability of the weapons [90]. The numbers of torpedoes produced each month by the Germans varied during the course of the war and is reported to be as set out in Table 2 German Monthly Torpedo Production.

[89] Campbell, Naval Weapons, page 260
[90] ADM 234/466, page 4

Table 2 German Monthly Torpedo Production

Year	Production All types
Pre-1939	70
1941	1000
1943	1700
1944	1400

The actual usage of torpedoes by the Germans is shown in Figure 13[91].

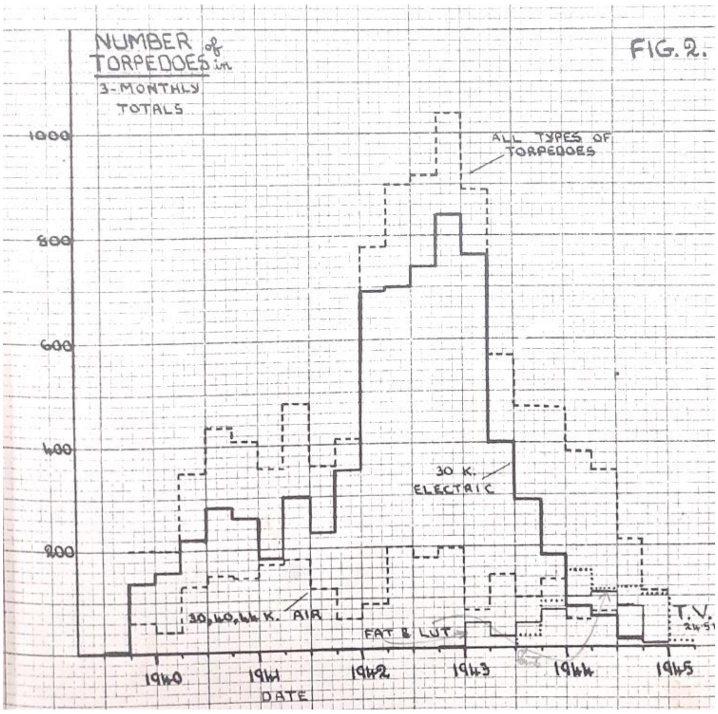


Figure 13 German torpedo usage during WWII

From this figure it can be seen that far more electric (G7e) torpedoes were fired than the steam (G7a) version.

Table 3 German torpedo characteristics for the two most commonly used types of torpedo in the German navy.

The total number of torpedoes fired by the Germans during the war was 10,499 of which 8259 were fired from U-boats, although this figure excludes torpedoes of type T.V., or acoustic homing torpedoes[92], of which only 610 were fired in total for both types combined.

At the beginning of WWII German torpedoes were notoriously unreliable with the majority of them failing to either hit the target, prematurely detonate, or detonate when they were supposed to[93]. Gunter Prien in U-47 at Scapa Flow had numerous torpedoes fail after he fired them at stationary 'sitting duck' targets. These included the first salvo he fired at HMS Royal Oak and another salvo at HMS Pegasus with all four being G7e types in October 1939. Only one of these hit and detonated on the Royal Oak

91 ADM 213/745, figure 2
92 Uboataces.com, 7es (Acoustic Homing Torpedo) http://www.uboataces.com/torpedo-tv.shtml
93 Habersham-Wright, page 45

but did so without doing significant damage. A further torpedo was fired from the stern torpedo tube but that also failed to hit or detonate. After sneaking away and reloading the tubes Prien brought his U-boat back to face the starboard side of Royal oak and fired 3 more G7e torpedoes and all 3 hit and detonated against the hull of the Royal Oak.

The following year of 1940 Prien, again in U-47, missed a spectacular success in the fjords of Norway as the British invasion force were chaotically trying to land thousands of troops at Harstad. Through poor preparation the British were unable to unload three ships carrying the British troops because the harbour at Harstad was unable to take ships of that size. Instead, the British had to round up many small fishing boats and other vessels to ferry the troops ashore over the course of two days. The U-47 was in the fjord with the British troop ships and Prien waited until the opportune moment and through the periscope he could see in the brightly lit night a wall of ships at anchor. He fired 3 G7e and 1 G7a torpedoes at the stationary targets at anchor. Three were troop ships and other was a cruiser. None of the torpedoes hit or detonated. The following morning Prien had taken U-47 to the other side of the fjord and came to periscope depth and fired another four torpedoes at the stationary targets and once again they all missed but Prien did hear a single detonation on the far side of the fjord[94]. When Prien was safely on his way back to his home port he reported the missed opportunity to knock out the British invasion force intended to take Narvik before it even got ashore.[95].

Table 3 German torpedo characteristics

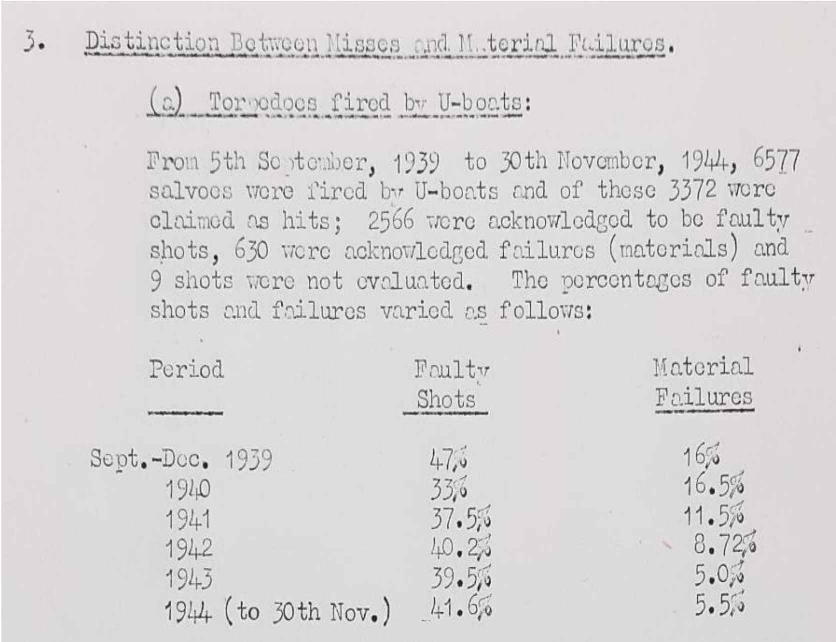
Type	Speed kts	Range m	Warhead Size kg	Guidance	Detectability	Notes
G7e	30	5000	300	Gyro	No Bubbles	Preferred by 'aces' for lack of bubble track on surface
G7a	44	5000	300	Gyro	Bubbles	Option deleted later in WWII
	40	7500	300	Gyro	Bubbles	
	30	12500	300	Gyro	Bubbles	Long range for 'browning'

The Gyro stabilised guidance system common to all these German torpedoes was used to provide greater accuracy and remove the need for the U-boat to actually point the boat at the target ship or in the direction to intercept the target when launching the torpedo. A complex electromechanical fire control computer in the U-boat was required to calculate the bearing that the torpedo needed to follow to hit the target. The data input into the computer was based on the periscope/sighting binoculars angles relative to the U-boat and the target. The output from the computer was connected to the torpedoes in their launch tubes by electrical signalling cables until launch and was then used to guide the torpedo onto the correct trajectory to intercept the target ship.

The unreliability of German torpedoes together with the aiming and the launching of them gave the U-boats much poorer scores than they might have had. As many as 50% of the torpedoes failed during the attacks[96]. During the course of the war Doenitz ordered an inquiry into the high failure rates of the torpedoes and they were then improved[97].

94 The author's father was onboard one of these troop ships, the Monarch of Bermuda
95 Martindale, pages 71 to 78
96 ADM 219/342 Directorate of Operational Research: Further Analysis on German Torpedo Attacks, 1949, page 3.

97 Doenitz, Memoirs, page 91


3. Distinction Between Misses and Material Failures.

(a) Torpedoes fired by U-boats:

From 5th September, 1939 to 30th November, 1944, 6577 salvoes were fired by U-boats and of these 3372 were claimed as hits; 2566 were acknowledged to be faulty shots, 630 were acknowledged failures (materials) and 9 shots were not evaluated. The percentages of faulty shots and failures varied as follows:

Period	Faulty Shots	Material Failures
Sept.-Dec. 1939	47%	16%
1940	33%	16.5%
1941	37.5%	11.5%
1942	40.2%	8.72%
1943	39.5%	5.0%
1944 (to 30th Nov.)	41.6%	5.5%

Figure 14 Failures of German Torpedoes 1939 – 1944

2.3.2 German Torpedo Fire Control System

The fire control system for the gyrostabilised torpedoes used in a U-boat begins with the periscope where the operator must take sightings of the target and use the its electrically connected bearing measurements to determine the angle of the target relative to the torpedo tubes at a number of times. The range to target is estimated as is the ‘Angle on the Bow’ of the target relative to the line of sight. These measurements are transferred to the electromechanical fire-control computer.

Figure 15 A U-boat commander using the attack periscope

The required estimates of angle and range are shown being made in Figure 15.

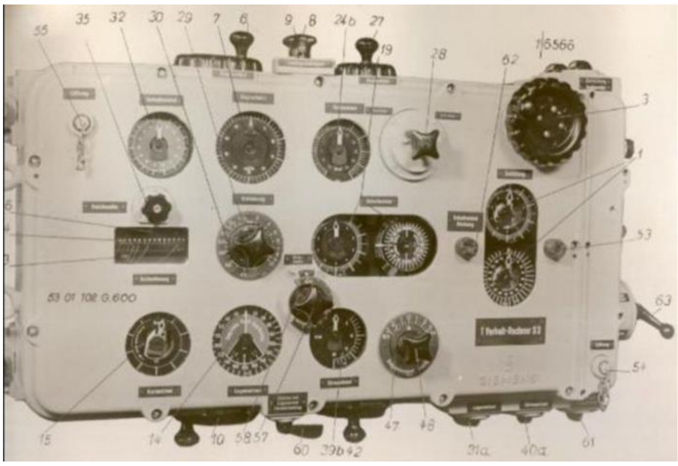


Figure 16 An example of the electro-mechanical fire-control computer used in a U-boat

Once the data on the target's bearings are input into the computer, see Figure 16, it may be used together with the data on the torpedo type, desired depth and torpedo fuze settings to calculate the solution for the torpedo. This may then be transferred electrically to the torpedo in the firing tube.

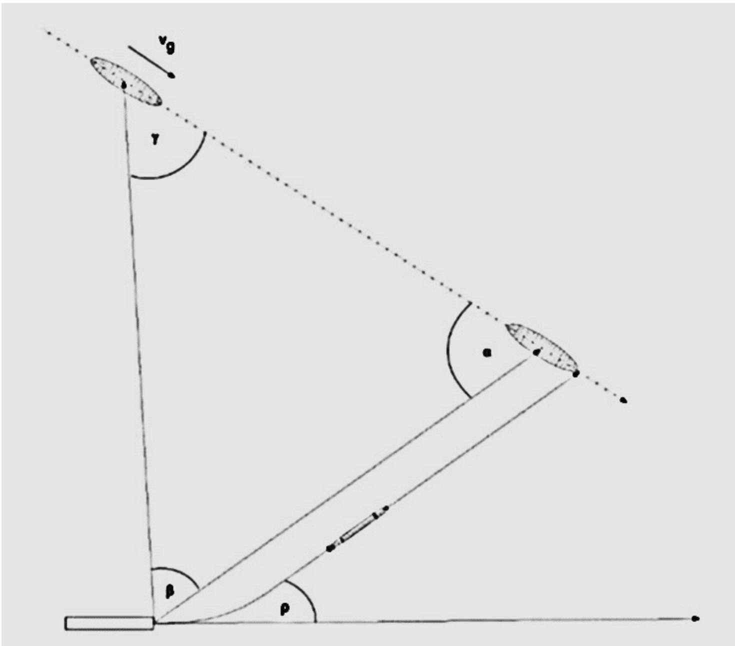


Figure 17 The torpedo turns onto the calculated bearing so that it can intercept the target on its predicted track

When the command to fire the torpedo is given verbally by the crewman using the attack periscope this is acted upon by the torpedo tube operator who will have already prepared the tube by opening the door at the outside of the U-boat hull. The periscope operator could also just press a button to launch a torpedo. Once launched the gyro control system in the torpedo turns the torpedo, see Figure 17, on to the correct bearing[98].

[98] Torpedo Vorhal Trechner Project, Internet

2.3.3 U-boat Types most common in the North Atlantic

The two most common types of U-boat in the Battle of the Atlantic were the Type VII C and the Type IX B/C.

a) The Type VIIC boats carried a crew of 42 to 45 and when fully armed carried 12 torpedoes in the forward compartment, which amounts to three loads for the four bow torpedo tubes and 2 Torpedoes for the single stern torpedo tube.
b) The Type IX C U-boat which also carried a crew of between 42 and 45 crew members but this was a larger boat was the Type VII C. The main advantage of this increase in size was that it could accommodate a great number of Torpedoes, 22 in total. It also had a significantly greater range due to its larger fuel tanks.

As will be seen later in this thesis, the attack on convoy SC107 included 10 Type VII B and C and four Type IX C U-boat from the Wolf Pack Veilchen. It should be noted that like most Wolf Packs the sinkings of ships were usually due to a relatively few U-boat commanders. In the case of SC107 15 ships sunk in the attack over 4 days. On the first night Forstner in U402 and Schneider in U522 fired 7 and 9 torpedoes respectively[99].

2.4 ALLIED CONVOY SYSTEM

2.4.1 Allied Convoys in WWII

In response to the U-boat attacks on British and Allied merchant ships as they were travelling independently and unprotected immediately after the war began the Admiralty reintroduced the convoy system. This entailed the marshalling of the merchant vessels in the main ports of departure such as New York and Halifax Nova Scotia. The ships were organised into columns of ships following each other line-a-stern. There were multiple columns travelling in parallel with a safe separation between the columns. Figure 18 shows various images of convoys, their escorts, a U-boat and a torpedoed tanker[100].

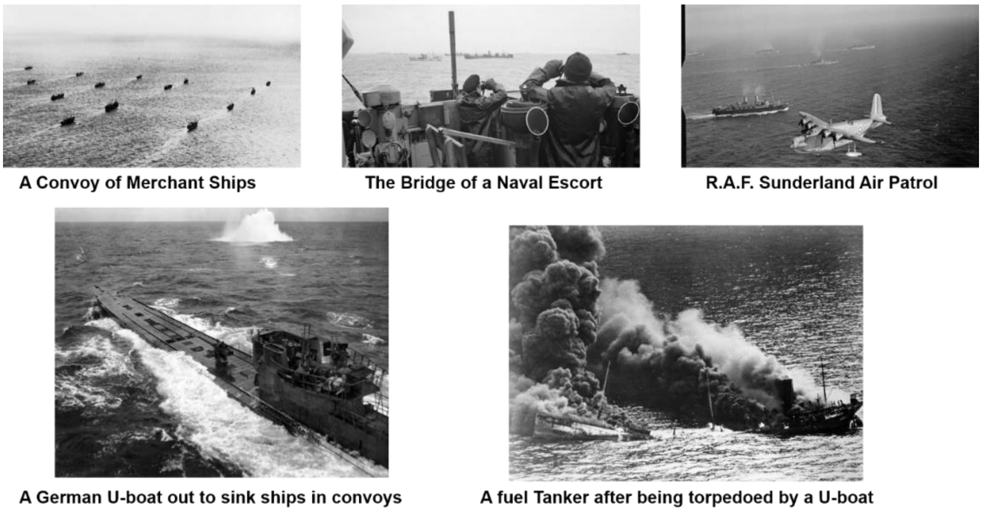


Figure 18 Photographs of scenes from convoys, their sea and air escorts and an enemy U-boat and its target

[99] Rohwer, Axis Submarine Successes, pages 132 to 135
[100] Battle of the Atlantic, Wikipedia

2.4.2 The spectrum of convoy losses in the Battle of the Atlantic

A study by the author of the data available within the recognised authority on Allied convoys of WWII provides an interesting insight into the spectrum of losses suffered by the convoys in the critical period covered by this thesis, 1942 to 1943[101].

Merchant Losses Oceanic Convoys 1939 to April 1943

Hague A The Allied Convoy System 1939 - 1945

Series	1 & 2	3 & 4	5 & 6	7 & 8	9 & 10	11 & 12	13 & 14	15 & 16	
HX	15	8	7	0	1	1	0	0	
SC	8	6	1	3	2	1	0	3	
SL/MKS	18	4	3	1	0	1	0	0	
HG	5	1	1	1	1	0	0	0	
OG	5	2	0	2	0	0	0	0	
OS	8	0	1	0	0	0	0	0	
ON	10	3	2	2	0	1	1	0	
Total	69	24	15	9	4	4	1	3	129
%	53	19	12	7	3	3	1	2	

Merchant Losses Oceanic Convoys 1941 and 1942

Hague A The Allied Convoy System 1939 - 1945

Series	1 & 2	3 & 4	5 & 6	7 & 8	9 & 10	11 & 12	13 & 14	15 & 16	
HX	4	2	3	0	0	0	0	0	
SC	6	5	1	1	2	0	0	2	
SL/MKS	9	2	3	1	0	1	0	0	
HG	4	1	1	1	1	0	0	0	
OG	0	2	0	2	0	0	0	0	
OS	8	0	1	0	0	0	0	0	
ON	8	3	1	2	0	0	1	0	
Total	39	15	10	7	3	1	1	2	78
%	50	19	13	9	4	1	1	3	

Merchant Losses Oceanic Convoys 1941 and 1942

McCue B. Using Simulated Annealing To Solve A Problem Of "Eccological Inference"

	1 & 2	3 & 4	5 & 6	7 & 8	9 & 10	11 & 12	13 & 14	15 & 16	
Total	57	12	6	9	2	2	0	0	88
%	65	14	7	10	2	2	0	0	

Figure 19 Losses for the main North Atlantic convoys 1939 to 1943

In Figure 19 Losses for the main North Atlantic convoys 1939 to 1943 are shown and contain three tables of merchant ships sunk within the convoys, these are

a. Top Left 1939 to April 1943 losses covering the U-boat campaign before the defeat of the U-boats
b. Top Right 1941 and 1942 the main period of opportunity for Nazi victory in the Atlantic.
c. A theoretical analysis to retro-determine the losses in a previous work where the details of it were lost to posterity[102].

The data within Figure 19 is presented as graphs in Figure 20. The graphs of the historic data are very close to each other from which we can conclude either the conditions for U-boat success remained the same throughout the 1939 to 1943 period or that the data is dominated by the 1941 and 1942 periods. The theoretical study showed strong correlation with the historic data but had a greater variance about the trend line despite the 'Smoothing' effects of grouping the data points into adjacent pairs of sinkings.

[101] Hague, Allied Convoy System, pages 126 to 189
[102] McCue, Simulated Annealing, Table 6

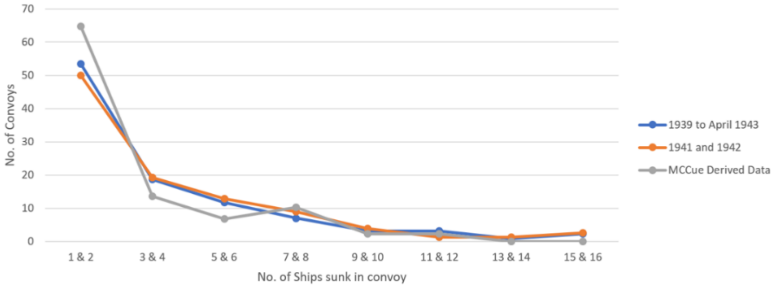


Figure 20 Number of ships sunk in a Convoy

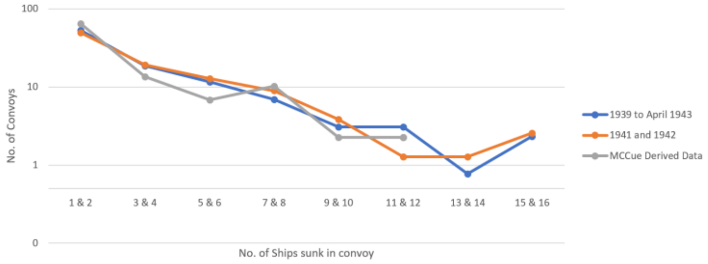


Figure 21 Logarithmic plot of the number of ships sunk in a convoy as in Figure 20

From Figure 20 it can also be seen that if a convoy is attacked it is very rare for more than 8 ships to be sunk in any convoy on its passage across the Atlantic. Convoys were typically arranged in a 9 by 5 grid meaning that 45 ships typically constituted such a convoy. Thus 8 ships sunk would be 18% of a convoy lost. A significant victory for the U-boats where more than 25% of the convoy are sunk is even rarer. An example of such a victory when 15 ships were sunk out of a total of 42 in the convoy is the case of Convoy SC107, where 36% were sunk.

The data used in Figure 20 has been replotted on a logarithmic scale in Figure 21 and this suggests that the data plotted in this represents the linear characteristics of an exponential plot in Figure 20. However, the upturn in the data plot of Figure 21 suggests that a different phenomenon may be at work for these convoys with higher numbers of ships sunk. What that phenomenon may be remains to be determined.

In the following six figures data is shown from the analysis of information contained in the most comprehensive and easily available in Hague's Allied Convoy System for convoys in the HX100 to HX230 or Halifax to Liverpool during WWII[103][104]. This sequence of convoys contains the merchant ships capable of sustaining approximately 9 knots in the 1941 to early 1943 period, whereas the SC series of convoys averaged 6.5 to 7 kts[105].

Figure 22 shows the number of merchant ships sunk in a given convoy against the size of the convoy in terms of the total number of merchant ships setting out. The most obvious feature here is that the vast majority of HX convoys suffered no losses. The immediate conclusion that can be drawn from this chart is that there is no correlation between the size of an HX convoy in 1941/42 and the number ships sunk in it.

[103] Hague, Allied Convoy System, page 127 to 129
[104] Warsailors, HX Escorts, Internet
[105] Hague, Allied Convoy System, page 25

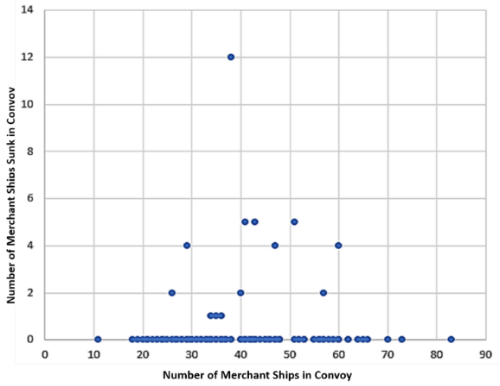


Figure 22 Plots of data HX100 to HX130: Ships Sunk Versus Number of Merchant ships in Convoy

In Figure 23 we can see that the number of escorts that spent time with a convoy during its passage shows little correlation with number of ships sunk. This has two possible explanations, firstly that the U-boats tended to attack the convoys some days after they had set out past the time when the mid-ocean escort had taken control of the convoy and had fewer escorts present. Secondly, the mid-ocean escorts on the western side of the Atlantic were usually from the less experienced and controversially less well-equipped Corvettes of the Royal Canadian Navy, although the HX convoys were supported by the Royal Navy.

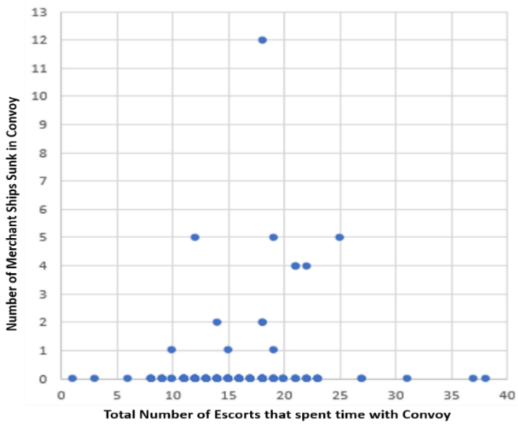


Figure 23 Plots of data HX100 to HX130: Ships Sunk versus Total Number of Escorts that spent time with convoy

The plot in Figure 24 shows the number escorts that spent time with a convoy against the size or number of merchant ships in a convoy. There is a clear correlation here, the more merchant ships the more warships escort them.

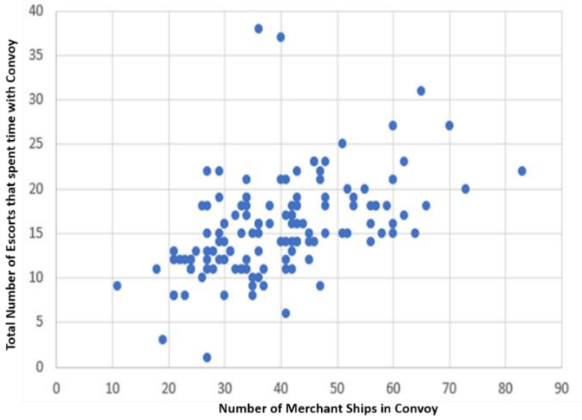


Figure 24 Plots of data HX100 to HX130: Number of Escorts that spent time with the convoy versus size of convoy

The interesting plot in Figure 25 shows the number of merchant ships in a convoy against the date of departure of the convoy. The convoys departing from the winter months of 1940/41 until the late summer of 1941 gradually rises to a peak and then reduces over the next nine months to a minimum in the early summer of 1942. The size of the convoys then get larger but with a wide range of values into the spring of 1943.

During the latter part of 1942 many escorts from the RN and RCN were diverted to support the Operation Torch invasion of North Africa and that might have influenced the size of the convoys and the number of escorts available to protect the convoys.

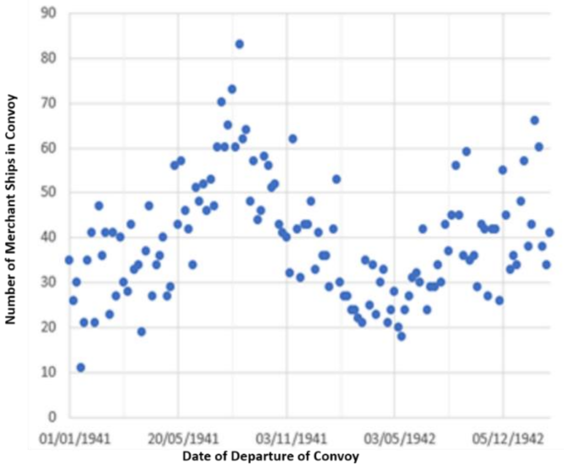


Figure 25 Plots of data HX100 to HX130: Number of merchant ships in a convoy versus the departure date

The data plotted in Figure 26 is the duration of the passage across the Atlantic against the number of ships in a convoy. From the figure it can be seen that the majority of convoys have 50 or fewer ships with a mean time of passage at 15 days. The larger convoys also have a time of passage of 15 days. The two major factors that determine the duration of a journey across the Atlantic by these convoys are the average speed of the convoy and the route allocated to them. The data represent HX convoys only so no slow convoys were involved. One factor that may add to the distance travelled and therefore the duration is the necessity for a convoy to alter course and perhaps zigzag to avoid U-boats and especially concentrated groups of U-boats in Wolf Packs.

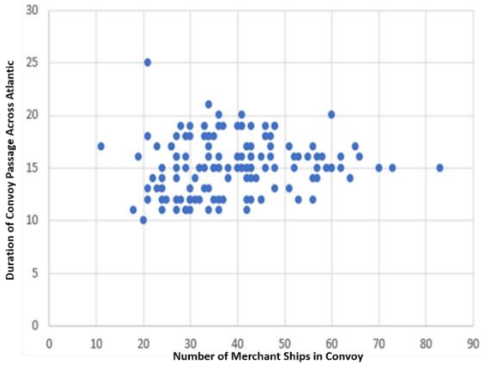


Figure 26 Plots of data HX100 to HX130: Duration of Passage across Atlantic versus Number of Merchant Ships in convoy

2.4.3 The weakest link at the most susceptible time in the Allied convoy system

In studying the narrative of the Battle of the Atlantic in WWII it becomes clear that the period from the beginning of 1942 to the end of Spring in 1943 was the closest that Doenitz's strategy of night attacks by surfaced U-boats assembled into Wolf Packs came to victory[106]. One key factor in this near success for Doenitz was the failure of the Allied leadership to provide adequate air cover for the convoys in the North Atlantic.

When there were Allied aircraft patrolling in support of a convoy they could spot the surfaced U-boats and attack them which would either lead to the U-boats diving to escape the attack, thus losing speed, and/or the U-boats being damaged or sunk so they were no longer a threat to convoys. The aircraft could either be land based, in which case they needed to be large long-range aircraft, or be small fighter bombers that were based on aircraft carriers that sailed with the convoy as an escort but at this stage of the war they were both very rare.

The second factor in the near-success for Doenitz in 1942-1943 was that in the North-Western Atlantic, at the time of the Airgap, the escort support force was much weaker than it might have been. This Escort weakness has several causes but the two most prominent ones were, the reduced numbers of escorts available for protecting the convoys that came about because they were diverted to protect the convoys to deliver the invasion force for the attack on the Axis forces in North Africa[107] and the inadequate number of escorts being produced to meet the growing need for them as the number of convoys increased. It is true that Doenitz also diverted some U-boats to the North African theatre of operations but he still continued to focus on his main task, stopping the flow of supplies reaching the UK whatever their ultimate destination was.

Thus, the stage was set for the main chance that Doenitz had of at least a temporary victory in the Battle of the Atlantic.

The first example of a convoy to study a victory for the U-boats and a defeat for the Escorts protecting a convoy was convoy SC107 as it passed through the Air Gap in the North-Western Atlantic Ocean on its way to the UK. SC stands for slow convoy to reflect the fact that the merchant vessels travelling in it were old and slow craft capable of speeds not much higher than 7 to 8 knots and for the period 1940 to 1943 speeds between 6.5 to 6.9 knots were common[108]. The Escort force protecting SC107 for the part of the journey in the mid-Atlantic were all from the Royal Canadian Navy (RCN). This force was

---

106 Roskill, War at Sea, Vol. II, page 367 and 368.
107 Ibid, pages 315 and 316
108 Hague, Allied convoy system, page 25

very new, inexperienced and as it turned out manning vessels that were not equipped with the most capable electronic sensors nor were they provided with adequate servicing of these ships and equipment. The latter point of poor provision of ships and equipment for the undoubtably courageous Canadian naval servicemen turned into a scandal that was dealt with in secrecy later in 1943 long after the battle had been won by the Allies. But this was only because Doenitz missed the opportunity to win a temporary victory in 1942.

The second convoy to be studied was the U-boat victory over convoy TM-1. This small and specialised convoy was the first of the 'Fast Tanker' convoys that had been specifically requested by Churchill in a communication to Roosevelt in December 1942. It sailed that year from the Caribbean oil fields and was intended for passage to Gibraltar. TM-1 was intercepted in the warm waters near the Azores with devastating effect. The Royal Navy escort vessels for TM-1 had similar problems to the RCN ones in SC107 and lost the battle for that convoy.

These two convoys then had the hallmarks of what might have happened to many more convoys and then delivered victory to Doenitz and his U-boat force. The fact that this did not happen possibly lies in Doenitz's pandering to his U-boat aces instead of following the principles of war, particularly 'The Concentration of Force in Space', i.e. to concentrate the U-boats in simultaneous mass attack[109]**.** The thesis of this research has been to examine the improved killing power of a Wolf Pack if it was organised to carry out such an attack instead of leaving to the individual U-boat commanders to decide where and when he fired his torpedoes at a convoy.

2.4.4 The Slow Convoys carrying vital supplies to the UK

The 'Slow Convoys' or SC series of Allied convoys between North America and the UK were easy pickings for the U-boats and the relatively inexperienced escort commanders and crews[110]. These convoys included vessels that were starting out their journeys from the Gulf of Mexico, the Caribbean, the Eastern seaboard cities including New York City and from Halifax Nova Scotia and other Canadian cities via the St. Lawrence River and associated canals.

A total of 177 convoys under the SC series of convoys sailed between 1940 and 1945[111].

2.4.5 Allied Escorts

The Royal Navy provided the majority of escorts and their crews during this period and were followed by the Royal Canadian Navy in second place. It must be said that the Royal Navy also transferred a significant number of vessels to the Canadian and US fleets during these early years of the Battle of the Atlantic. This was because those of the other nations from the British Empire and the USA that were participating in the United Nations efforts to defeat German U-boats had no great peacetime fleets with suitable ships for escort duties.

A wide range of ships were used as escorts by the Royal Navy in WWII with vessels from WWI vintage as well as from the interwar years taking part alongside newbuild vessels. Some were merchant ships pressed into service as armed merchant cruisers and there were trawlers, tugs and yachts[112]. The mainstay of the escorts in 1942 and 1943 were the Flower class corvettes which were based on a design for whalers[113].

---

109 Clausewitz, On War, page 147
110 Hague Allied Convoy System, page 25
111 Ibid, page 116
112 Ibid, pages 55 to 64
113 Terrain, Great Waters, pages 250 to 253

Figure 27 shows a variety of the escort types used by the British and Canadian Navies in WWII.

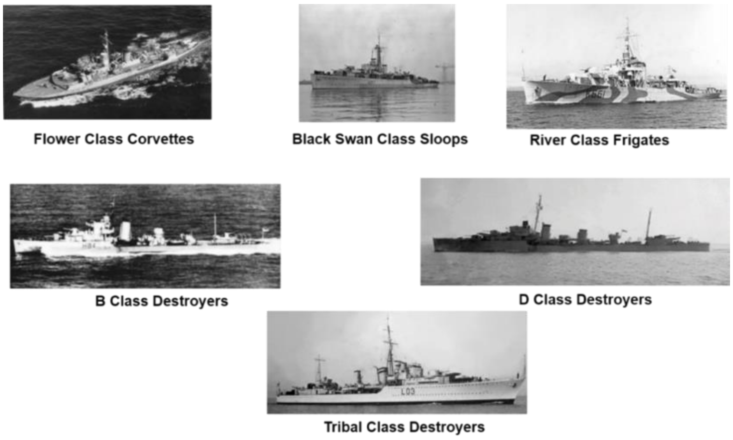


Figure 27 Types of Escort Vessel used in the Battle of the Atlantic

The Flower class corvettes were numerous with 293 having been constructed during WWII. They could match a U-boat on the surface for speed but were not a very comfortable platform for the crew in the North Atlantic storms that raged during the winter months of 1941 to 1945. When equipped with the RDF 271, Asdic 144 and HF/DF sensors and depth charges they were an adequate deterrent against U-boat attacks. Unfortunately, they seldom had all these sensors fitted and in working order when confronting attacks by Wolf Packs as will be discussed in the cases of convoys SC107 and TM-1 later.

Figure 28 shows the most common weapons deployed on the escort vessels of WWII. These included the depth charge, the Hedgehog ahead throwing mortars for submerged targets and the deck gun which was usually a 4 inch calibre weapon for surface targets. There were also lower calibre auto cannons and heavy machine guns for anti-aircraft fire which are not shown in the figure.

The depth charge was the most effective weapon for damaging or destroying a submerged U-boat but still only attained less than 10% chance of doing that for each spread of 10 charges dropped by an Escort in the early years of WWII but by 1944 the Hedgehog had a better than 40% chance with each salvo at roughly the same cost as the depth charges[114][115][116][117].

114 ADM 219/250, page 2
115 Depth Charges, Wikipedia
116 Hedgehog, Wikipedia
117 QF 4-inch naval gun, Wikipedia

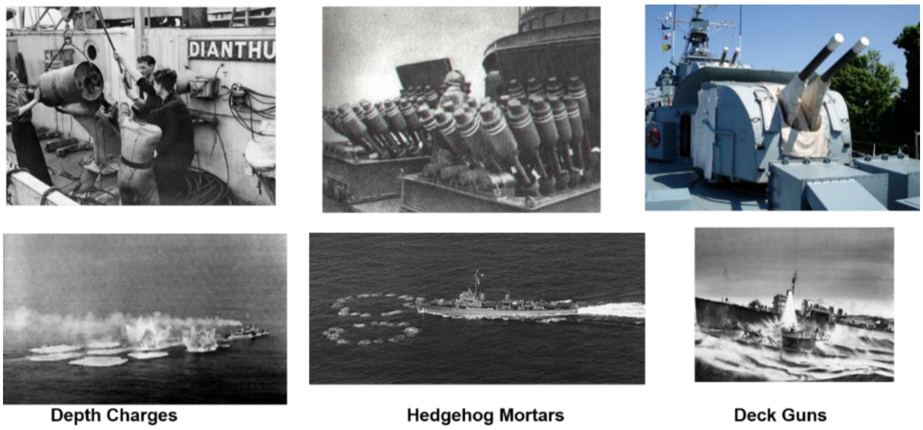


Figure 28 Some of the weapons employed on the escorts

2.5 DOENITZ'S NEAR VICTORY IN 1942 - 1943

2.5.1 The Command and Control of the U-boats

The command of the U-boat Force by Admiral Doenitz was one where his desire to closely control every U-boat at sea was very obvious to both Allied antisubmarine forces and the U-boat commanders themselves[118]. This manifested itself in that the U-boat commanders were required to report to the U-boat headquarters via long range High Frequency (HF) radio transmissions at every stage of their deployment. For example, they had to report their position, sightings of enemy ships, convoys, when they were about to attack, after they attacked they had report what happened, their status, the weather conditions and to let U-boat command know they were still alive and functioning ready to receive orders or listen to other U-boats.

The U-boat commanders were obliged to listen for orders from Doenitz or his deputies regarding their next immediate tasking or requesting information from the U-boats and acknowledge that they had received the orders. Such transmissions gave away the location of the U-boats to the Allied on-shore tracking organisation and also directly to the convoy Escort Commanders via the High Frequency Direction Finders (HF/DF), colloquially known to the Allied service personnel involved Huff-Duff[119]. Doenitz did order an investigation of the both the ability of the Allies to locate the transmission source and therefore the U-boat. He also recognised that there was the possibility that the Allies could intercept and decrypt the actual messages that were being sent to and from the U-boats[120].

The German forces used the Enigma encryption and decryption device in the majority of their land, naval and air forces communications[121]. The experts in the German navy reported back to Doenitz that the accuracy of location using shore-based monitoring stations were not good enough to be useful tactically and that there was no prospect for anyone being able to decipher the Enigma coded messages[122], see Figure 29. Neither of these assertions were true and the Allies did accurately locate the U-boats using both the shore-based monitoring stations for tasking radar equipped aircraft to search for U-boats and the sea-based HF/DF to re-route convoys away from the U-boats. Also, the escort

[118] Doenitz, Memoirs, Chapter 3 U-boat Tactics
[119] ADM 219/311, Handbook of theory and practice of DF plotting
[120] Milner, Battle of the Atlantic, page 44
[121] National Maritime Museum, Enigma
[122] Doenitz, Memoirs, Introduction by Jurgen Rohwer page XV.

vessels were able to follow the HF/DF bearings relative to the convoy and chase down the U-boats and attack them.

Figure 29 A German Enigma machine used to encrypt their telegraphy signals

Despites these Allied responses to the U-boat transmissions and their decrypted messages there came a time in late 1942 and early 1943 when the strategy and tactics of Doenitz's plan to stifle the UK by blocking its trade routes began to look as though it could succeed.

During 1942 the German navy introduced a modification to their Enigma devices to make it more secure against the possible interception and decryption of the content of the messages, so clearly there were those in the German Navy who were concerned about that possibility. The UKs intelligence service had to increase the number of machines (Bombes) that could help decrypt the messages encrypted by Enigma machines with some manual help by clues carelessly put into the messages by the German operators[123]. This work was based at the Bletchley Park School of Cyphers and Codes. The decrypted messages were distributed under the Code Name Ultra to the Allied Commanders to make use of as they saw fit. The Naval distribution of Ultra intelligence was sent to a secure group in the Admiralty in London. This was the submarine tracking room in the Admiralty[124]. From there they were sent the locations to the Western Approaches headquarters at Derby House in Liverpool. It was in Derby House where the RN and RAF personnel placed them on the big wall mounted plotting charts alongside the symbols indicating convoys and escort groups. Once a fourth encryption wheel was introduced into the U-boat Enigma machines the big plot on the wall at Derby House was a lot less informative about U-boat locations. It followed that the ability of the Admiralty to know what Doenitz was ordering his U-boats to do and what the U-boat commanders were doing was greatly impeded. It took the majority of 1942 and into 1943 before the experts at Bletchley Park cracked the U-boat codes but this was possible only after the Royal Navy had capture a U-boat and retrieved its Enigma machine and codes books. It was in this window of opportunity that Doenitz had a chance to win a significant victory in the Battle of the Atlantic.

Doenitz devoted time and resources at the beginning of the war to improve the tactics used by the U-boats and this included local commanders[125]. The conclusions of these trials was that close co-

123 Erskine, Code Breakers, page 171
124 Syrett, Battle of the Atlantic Signals Intelligence, page xviii.
125 Doenitz, Memoires, page 18 to 24.

operation involving U-boats on the surface was possible but that command was best exercised by a shore based commander. This was a missed opportunity to synchronise and concentrate surfaced U-boats in the same manner that destroyers and torpedo boats function in the navies of the world as will be shown in Chapter 3.

Figure 30 shows a page of decrypts from U-boat U522, this was commanded by Schneider during a period from his first sortie into the Atlantic as a commander of a U-boat. The decrypts were from Enigma coded messages sent in September 1942 but decoded later, this was during the period when Bletchley Park were unable to decrypt the messages because of the introduction of the fourth wheel by the German Navy and the new code book for weather reports that was used prior to Enigma encoding[126].

U-522 and its commander, Schneider took part in the battle for convoy SC107 that will be described in detail later in the victory over the convoy escorts. It should be noted that Schneider mentions Tankers in 3 of the 5 decrypts shown on this page from the Bletchley Park ledger, this is in line with Doenitz' focus on cutting off the oil supplies to the UK[127].

Ultra was the British code word for intelligence gained from the decrypted signal sent between German units via their Enigma encryption/decryption devices. From before and early in WWII the British had enjoyed the collaboration of Polish experts in the German enigma machines that led the way to the Bletchley Park School of Cyphers and Cryptography, or Station X as it was officially referred to, being able to read German communications[128].

The German naval encryption methods were also based on Enigma machines used in conjunction with various forms of code books. The U-boat Force was particularly vulnerable to having their transmissions both detected by direction finding sets on escorts and support groups but also by long range detection, interception and decryption by Bletchley Park. Doenitz knew the risks that his decision to 'micromanage' the U-boats from shore and its requirement that U-boats surface and transmit multiple times each day during a convoy battle. He requested reassurance from the German intelligence organisation that enigma's coded messages were unbreakable. In 1941 German Naval Enigma machines were converted to having 4 rotor wheels to provide extra security. By February 1942 the U-boat force was introducing the 4 rotor wheel Enigma machines widely.

Further complications to this situation were the capture of part and a whole 4 wheel enigma machine was obtained by the Royal Navy in early 1942 and the introduction of the Trident/Shark code book by the Germans that went with the 4 wheel Enigma[129]. The time line for these events were:

1942 1st February: Trident introduced

U-boats have great success in sinking Allied shipping with relatively few U-boats being sunk in comparison with the equivalent figures for 1941.

1942 13th December: Trident was broken for the first time, but this was achieved too infrequently and with too long a delay from intercept of the signal to decoded message delivered to the Admiralty Submarine Tracking Room and then to operational orders to the escorts and the RAF Coastal Command units.

---

126 Erskin, Code Breakers, page 169

127 HW 18/343, entries for U525 dispersed within document

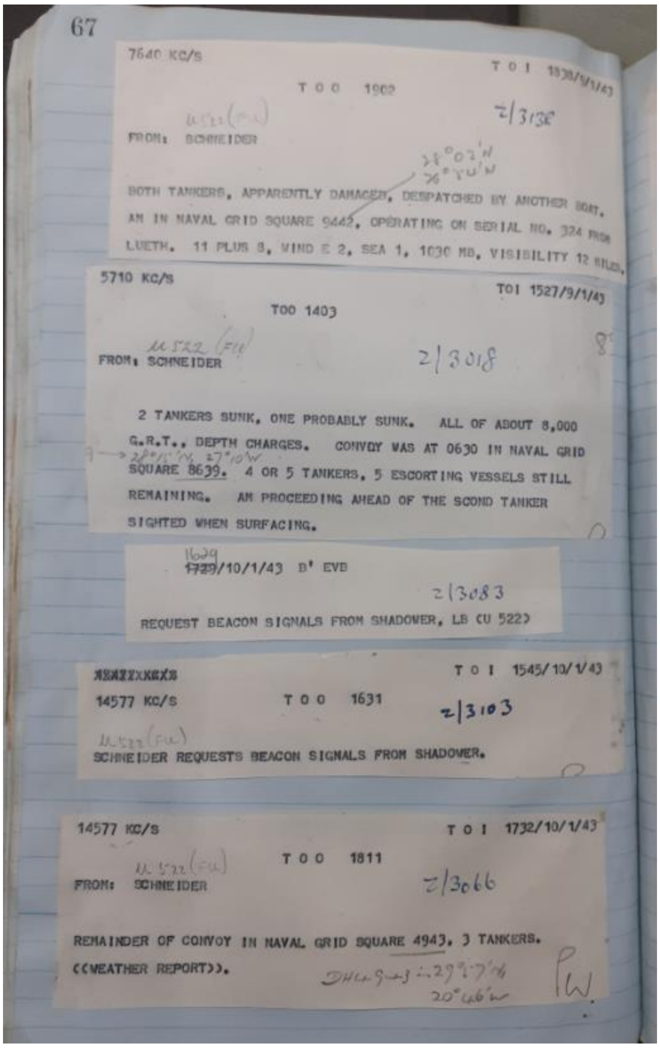
128 Doenitz, Memoirs, page 497 to 507 This is Jurgen Rowher's postscript on the cracking of Enigma and its impact on the Battle of the Atlantic

129 Erskine, Codebreakers….page 171

1943 January to March : Trident was being decrypted but it took 24 to 72 hours to decrypt each message.

1943 March 8th: Extended Trident was introduced and causes setback to decryption.

1943 Late March: Trident was regularly decrypted in short times suitable for interception and destruction of the U-boats again[130].


67

7640 KC/S
T O I 1930/9/1/43
T O O 1902
Z/3138
FROM: SCHNEIDER

BOTH TANKERS, APPARENTLY DAMAGED, DESPATCHED BY ANOTHER BOAT. AM IN NAVAL GRID SQUARE 9442, OPERATING ON SERIAL NO. 324 FROM LUETH. 11 PLUS 8, WIND E 2, SEA 1, 1030 MB, VISIBILITY 12 MILES.

5710 KC/S
TOI 1527/9/1/43
TOO 1403
U 522 (FU)
FROM: SCHNEIDER
2/3018

2 TANKERS SUNK, ONE PROBABLY SUNK. ALL OF ABOUT 8,000 G.R.T., DEPTH CHARGES. CONVOY WAS AT 0630 IN NAVAL GRID SQUARE 8639. 4 OR 5 TANKERS, 5 ESCORTING VESSELS STILL REMAINING. AM PROCEEDING AHEAD OF THE SCOND TANKER SIGHTED WHEN SURFACING.

~~1729~~ 1629/10/1/43 B' EVD
Z/3083

REQUEST BEACON SIGNALS FROM SHADOWER, LB (U 522)

14577 KC/S
T O I 1545/10/1/43
T O O 1631
Z/3103

SCHNEIDER REQUESTS BEACON SIGNALS FROM SHADOWER.

14577 KC/S
T O I 1732/10/1/43
T O O 1811
FROM: SCHNEIDER
Z/3066

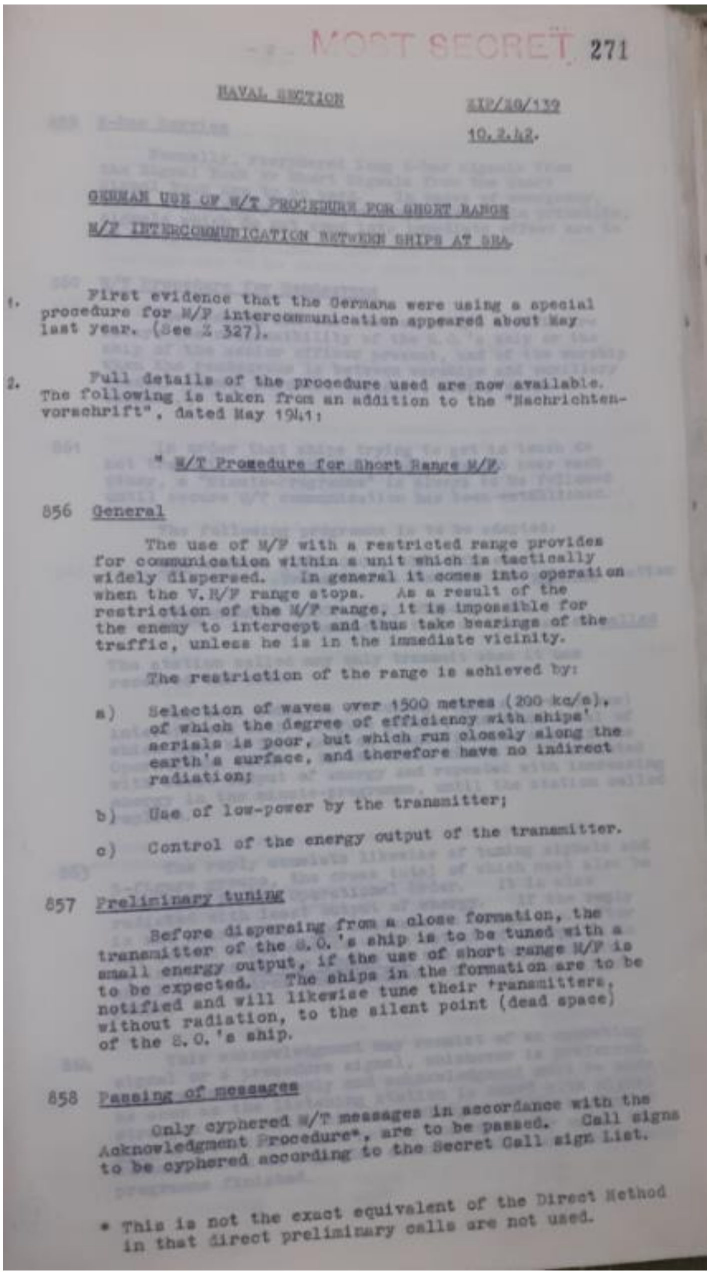
REMAINDER OF CONVOY IN NAVAL GRID SQUARE 4943. 3 TANKERS. ((WEATHER REPORT)).

Figure 30 Decrypted transmissions from U-522 September 1942

Note also in Figure 30, the request for a Beacon Signal from the shadower, as such technology operating at frequencies outside the long range HF band were integral to the U-boats standard equipment fit. Homing on the medium wavelength and Very High Frequency (VHF) allowed U-boats to come together to form Wolf Packs and for convoys to be shadowed by a U-boat and following behind the it. Intercepted

130 Ministry of Defence (Navy) The U-Boat War, Volume III, page142 and 143

signals monitoring these exchanges also appear in the documentation of the Admiralty's Department of Naval Intelligence (DNI), Figure 31 and Figure 32 show examples from one such document[131].


MOST SECRET 271

NAVAL SECTION XIP/20/139

10.2.42.

GERMAN USE OF W/T PROCEDURE FOR SHORT RANGE M/F INTERCOMMUNICATION BETWEEN SHIPS AT SEA.

1. First evidence that the Germans were using a special procedure for M/F intercommunication appeared about May last year. (See Z 327).

2. Full details of the procedure used are now available. The following is taken from an addition to the "Nachrichtenvorschrift", dated May 1941:

" W/T Procedure for Short Range M/F.

856 General

The use of M/F with a restricted range provides for communication within a unit which is tactically widely dispersed. In general it comes into operation when the V.H/F range stops. As a result of the restriction of the M/F range, it is impossible for the enemy to intercept and thus take bearings of the traffic, unless he is in the immediate vicinity.

The restriction of the range is achieved by:

a) Selection of waves over 1500 metres (200 kc/s), of which the degree of efficiency with ships' aerials is poor, but which run closely along the earth's surface, and therefore have no indirect radiation;

b) Use of low-power by the transmitter;

c) Control of the energy output of the transmitter.

857 Preliminary tuning

Before dispersing from a close formation, the transmitter of the S.O.'s ship is to be tuned with a small energy output, if the use of short range M/F is to be expected. The ships in the formation are to be notified and will likewise tune their transmitters, without radiation, to the silent point (dead space) of the S.O.'s ship.

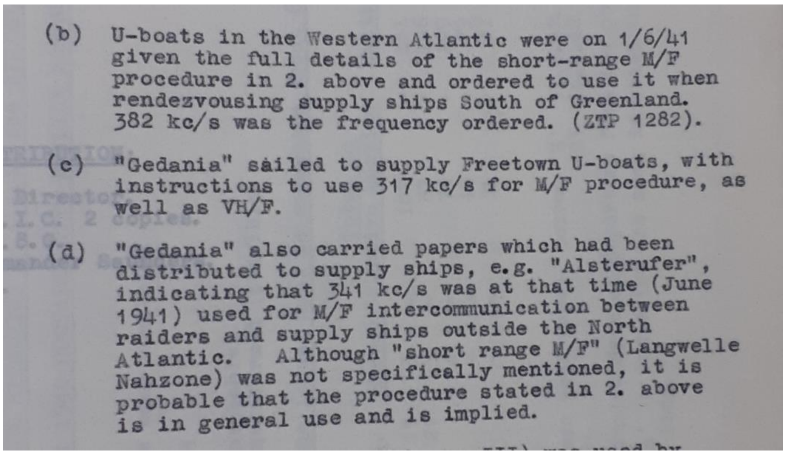
858 Passing of messages

Only cyphered W/T messages in accordance with the Acknowledgment Procedure*, are to be passed. Call signs to be cyphered according to the Secret Call sign List.

* This is not the exact equivalent of the Direct Method in that direct preliminary calls are not used.

Figure 31 Intelligence on German Navy Beacons using MF and VHF bands

[131] ADM 223/3, folio 271 and 274



(b) U-boats in the Western Atlantic were on 1/6/41 given the full details of the short-range M/F procedure in 2. above and ordered to use it when rendezvousing supply ships South of Greenland. 382 kc/s was the frequency ordered. (ZTP 1282).

(c) "Gedania" sailed to supply Freetown U-boats, with instructions to use 317 kc/s for M/F procedure, as well as VH/F.

(d) "Gedania" also carried papers which had been distributed to supply ships, e.g. "Alsterufer", indicating that 341 kc/s was at that time (June 1941) used for M/F intercommunication between raiders and supply ships outside the North Atlantic. Although "short range M/F" (Langwelle Nahzone) was not specifically mentioned, it is probable that the procedure stated in 2. above is in general use and is implied.

Figure 32 Intelligence on Inter U-boat Beacons and Communications using M/F

2.5.2 The Tanker, Oil and Escort Crises in early 1943

There have been many authors who have stated that there was a crisis of one sort or another associated with the Battle of the Atlantic and particularly at the end of March 1943. Others have argued that there was no crisis and that the rate of sinkings of merchant ships in general was very low in comparison to the number of ships in convoys that transited the North Atlantic unscathed[132]. As will be seen in the following paragraphs there are primary documents that show clear evidence for a series of crises arising from Doenitz's strategy of attacking oil tankers in the Atlantic. The combination of the following, the lack of intelligence from the Ultra decrypts of enigma signals concerning U-boats, the unilateral action by US Fleet Commander Admiral King in withdrawing US Navy escorts from the North Atlantic convoy protection task, the withdrawal of British escorts to support the convoys taking the invasion force of Operation Torch and the ever growing number of U-boats in 1942 and 1943 resulted in March of 1943 for the Admiralty to consider ending the convoy system in a crisis of profound consequences if left to Doenitz to complete his goal.

The U-boat commanders were incentivised to prioritise the sinking of tankers in their attacks on Allied convoys because denying the UK supplies of Oil and fuel products such as 100 octane aviation fuel was seen by Doenitz as the most direct means of defeating the UK and Allied war efforts in Europe and the Mediterranean theatres[133][134]. The attacks on the tankers in the convoys during 1942 took a heavy toll on the fuel supplies heading to the UK and this resulted in a crisis in the levels of stocks in the strategic fuel reserves. This was compounded by the declining number of tankers available to supply the growing war effort in the UK. These 'crises' will be described and primary sources cited for them to justify use of the word in the following two pages.

Also impacting the oil situation for the Allies was the invasion of North Africa in November 1942 by Allied forces, taking part in Operation Torch. It diverted much needed oil and fuel from the UK as well as escort vessels from the North Atlantic[135]. The shipping losses experienced during 1942 and first

132 Redford, Crisis, what Crisis, page 64
133 Paterson, Kretschmer, page 101
134 Doenitz "Memoirs", page 228
135 Milner, Battle of the Atlantic, page 130.

quarter of 1943 which in themselves could be viewed as a matter of deep concern can be seen in Figure 33[136].

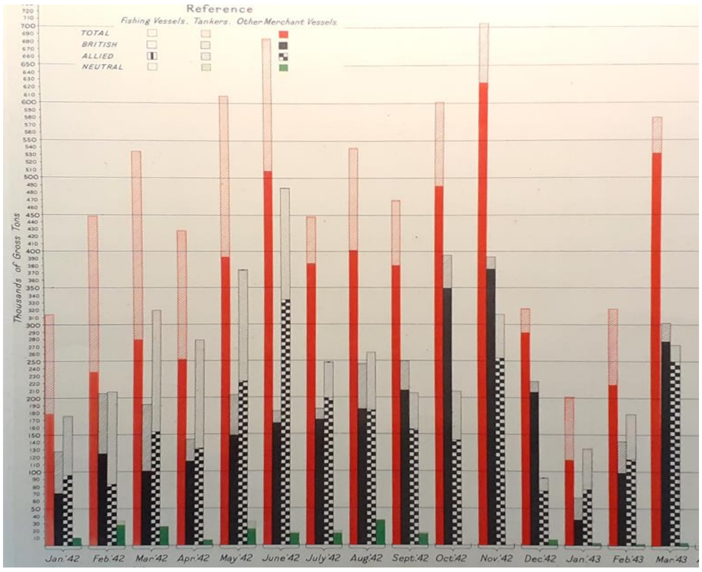


Figure 33 Admiralty data on shipping sunk 1942

The information within Figure 33 on the tanker loses was extracted by the author and is shown in derived form in Figure 34.

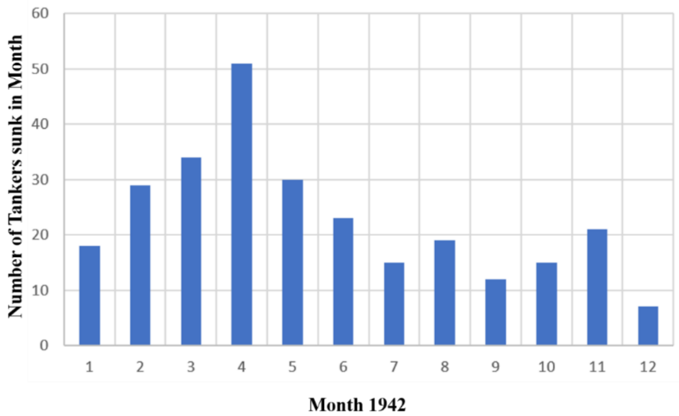


Figure 34 Number of tankers sunk per month: data derived from Figure 33

The tanker tonnage in Figure 33 was converted into the number of tankers by averaging the displacement of the five tankers in convoy SC107 and using that value, 7,430 tons displacement, to obtain the monthly figures for tankers sunk[137]. Even at the beginning of 1942 the losses prompted Churchill to write to Harry Hopkins, Roosevelt's emissary to the British Prime Minister, saying how worried he was at the number of tankers lost in the first two months of that year in the Caribbean alone (60 tankers)[138]. The total number of tankers sunk in 1942 represented in Figure 5 may be determined by dividing the total tonnage of the tankers by an average tanker's tonnage. These figures are 2.029

136 MFQ 1/587/26, 26th sheet in the folder
137 Lloyd, Personal Excel Workbook 1
138 FO-954-31B-327. page 1 paragraph 1

million tons lost in total and 7,430 tons per tanker. This gives the number of tankers lost in 1942 as 273[139}.

In December of 1942 Churchill wrote to Harry Hopkins to point out the dire state of oil supplies in the UK at that time which was being made worse by the demands of Operation Torch[140].

In January 1943 the UK government body, the Ministry of Fuel and Power, Petroleum Division, held its regular monthly meeting on Oil and Tanker requirements[141]. The issues of the loss of tankers delivering fuel to the UK that took place in 1942 and the loss of fuels that were not delivered was a subject of great concern. The fact that the fuels needed for operation Torch were being drawn from the reserves in the UK meant that the losses of tankers and their fuel were beginning to seriously stress the system of supplying the UK and US forces already in the UK[142]. The threat that diminishing fuel stocks would potentially impact the UK war industry and the demands of the convoy effort itself which required fuel for the merchant ships, the escort vessels and the Coastal Command aircraft supporting the convoys was much on the minds of the governments department responsible[143].

In the meetings held in January 1943 the POWE petroleum executives voiced the following views;

a) There will be an average deficiency of 79 tankers if the 1943 United Nations war effort centred on the UK was to be delivered.
b) The UK oil reserves will fall by 700,000 tons below the seriously low opening level for the year.
c) Fast tanker only convoys are being undertaken including those from the West Indies direct [in fact the first of these, TM-1, was underway at the time of the meeting on the 5th January and would prove to have a disastrous outcome].
d) It was unlikely that any new additional US tankers could be allocated for British service and this meant that the UK could run out of oil for anything but its most vital needs[144].

The growing unease in the government was matched by the concerns expressed in the War Cabinet Chiefs of Staff committee at their meeting on the 15th of February. The three forces expressed concerns that the reserves were being depleted and the original reserve level which had sufficient for 6 months of currently planned operations [this had the assumption that the flow of oil in the tankers bringing oil to the UK would meet the needs and would not fall] was predicted to be reduced to just 17 weeks of current operations and that no emergencies would require additional operations[145].

At this meeting Sir Henry Moore on behalf of the Admiralty said that "Any further reductions in the Admiralty's reserves would take them below the danger level". Also, he pointed out "that unless additional tankers were made available any increase in reserves for the Services would need to be taken from those for the use of the civil uses, which already had to be supplemented from the Naval stock".

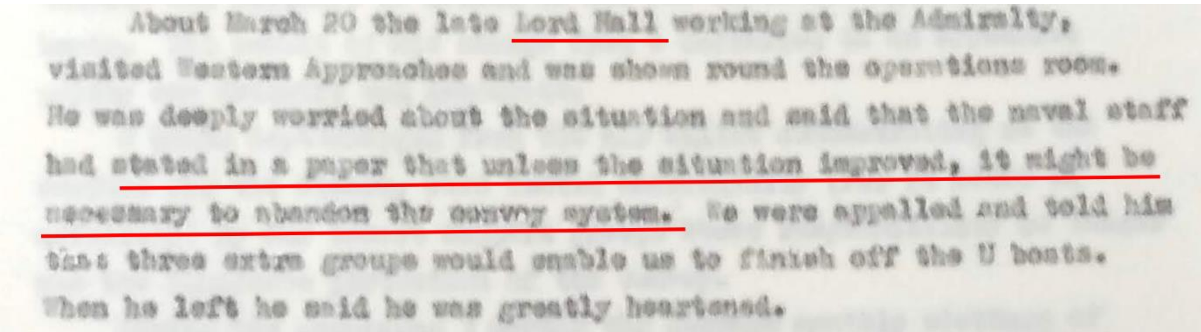
---

139 Lloyd Excel, Cell E16
140 FO-954-31B- 543, page 1 'in little over two months….60 tankers have been lost'
141 POWE-34_24, page 1 War Cabinet, Executive Committee of the Oil Control Board, 5th January 1943 section 1
142 CAB-79-59-20, War Cabinet, Chiefs of Staff Committee, 14th February 1943, page 2 Reserves being drawn down and need for more tankers
143 POWE-34_24, War Cabinet, Executive Committee of the Oil Control Board, 5th January 1943, page 2 items (i), (ii) and (iii).
144 Ibid, page 2 item (v)
145 CAB-79-59-20, War Cabinet, Chiefs of Staff Committee, 14th February 1943, page 2
Page 2

Thus, it can be seen that the losses of tankers in 1942 and those that were actually happening in the first quarter of 1943 were producing the perception that there was a tanker and consequential oil and fuel crisis in the UK. This sense of crisis would be heightened in March of 1943 with the unprecedented Wolf Pack attacks on convoy SC122 and HX 229 and the stunning announcements by the US Navy that the US escorts operating in the North Atlantic would be withdrawn, taking the Admiralty and the RCN delegates at the Washington Convoy Conference completely by surprise**[146]**.

The Admiralty had in fact planned for an increase in US escorts of 65 over and above those required to move US personnel across the Atlantic in Operation Bolero during the 1943 operational planning period and not see them decrease**[147]**. In January of 1943 Churchill wrote a memo to the Foreign Secretary, First Lord and First Sea Lord where he pointed out the loss of 6 out of nine great tankers and their oil had been lost (this being the Convoy TM-1 where 7 out of 9 tankers were sunk) and then stated that the Admiralty had told him that "If the Americans cannot lend us more destroyers- nothing can go after February" this referring to convoys to Russia**[148]**. This set the scene for the major crisis that landed on Churchill's desk where a combination of tanker, oil and convoy escort crises turned into one major crisis that threatened the UK with the loss of the Battle of the Atlantic, if at least temporarily. The Admiralty's official history of the 'War at Sea' records that there was the possibility of the abandonment of the convoy system and a return to the passage of merchant ships on solitary journeys across the Atlantic**[149]**.

Captain Lake RN of WATU, describes the set of crises that the primary sources cited above support in his papers describing the atmosphere in the Admiralty and the anti-submarine community in the UK and the conclusion that can be drawn is that the participants thought that the U-boats were causing a real crisis by March of 1943**[150]**. Figure 35 shows an extract from Lakes paper that clearly describes the growing sense of crisis at the Admiralty.

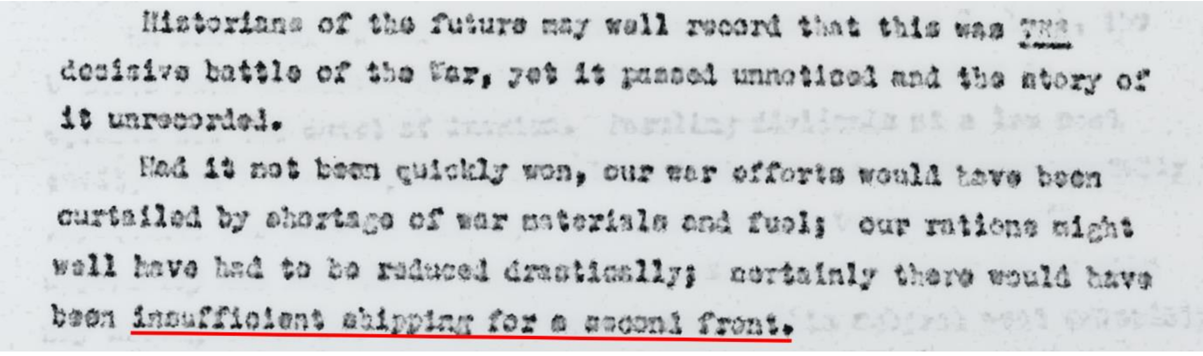


About March 20 the late Lord Hall working at the Admiralty, visited Western Approaches and was shown round the operations room. He was deeply worried about the situation and said that the naval staff had stated in a paper that unless the situation improved, it might be necessary to abandon the convoy system. We were appalled and told him that three extra groups would enable us to finish off the U boats. When he left he said he was greatly heartened.

Figure 35 Extract from Capt. Lake's paper on situation at the Admiralty in late March 1943.

Lake also pointed out that the multiple crises could lead to setbacks to the Allied second front, see Figure 36**[151]**.

[146] ADM 199/1148, A.C.C.1 3/9.43 Appendix "A" Command Relations Control. Page 1.
[147] ADM 1/14793, folio 8 paragraph (d).
[148] Churchill, Second World War, Vol. IV, pages 825 and 826
[149] Roskill, War at Sea, Vol II, page 367.
[150] Lake Papers, Churchill Archives Centre, page 5.
[151] Ibid page 1.



Historians of the future may well record that this was THE decisive battle of the War, yet it passed unnoticed and the story of it unrecorded.

Had it not been quickly won, our war efforts would have been curtailed by shortage of war materials and fuel; our rations might well have had to be reduced drastically; certainly there would have been insufficient shipping for a second front.

Figure 36 An extract from Lake's paper indicating the threat posed by the U-boat threat in 1943

2.6 THE BATTLE OF THE ATLANTIC IN DOCUMENTARIES, FICTION AND GAMES

The most significant battles, events and individual figures from WWII have been the subject of documentaries, books, film and movies and to some extent still are. To go along with this interest in the period, games and fictional stories about the U-boat war abound. The Battle of the Atlantic was and still is a subject that captures the minds of the public and the industries that attempts to satisfy that interest. The items listed here are not exhaustive but represent a sample of the most widely known and available representatives of their class.

2.6.1 Documentaries

These documentary series deserve additional comments besides just referencing them.

The World at War: Episode 10 https://en.wikipedia.org/wiki/The_World_at_War Accessed 7th October 2021, This episode includes post-war interviews with Doenitz himself, plus key members of the U-boat force such as Kretschmer and British participants in the Atlantic campaign.

Hell Under the Sea https://www.natgeotv.com/me/ww2-hell-under-the-sea 2021 Several episodes of this series cover the Battle of the Atlantic including actions involving convoys HX121, SC122 and HX229.

NOAA sanctuary off the East coast of the USA described in a National Oceanographic documentary, link is in the website. The wrecks of merchant ships, escorts, U-boats and this part of the Battle of the Atlantic are described in this excellent documentary series.
https://sanctuaries.noaa.gov/news/feb14/hitler_secret_attack_on_america.html

2.6.2 Fiction, Books

Forester, C.S. "The Good Shepherd" Penguin Books, 2021

Reeman, Douglass "Winged Escort", Arrow Books, 1984

2.6.3 Computer Games

Wolf Pack https://store.steampowered.com/app/490920/Wolfpack/

Atlantic Fleet https://store.steampowered.com/app/420440/Atlantic_Fleet/

U-boat https://www.g2a.com/en-gb/uboat-steam-gift-global-i10000187431002?aid=12711672&___currency=GBP&er=1b1ef1f4344a6fb6e9d04fbdf3c5a96e&___language=en&adid=GA-GB_PB_DIGI_PLA_SSC_AllProducts_CSS_V3_&id=14&gclid=CjwKCAjwtfqKBhBoEiwAZuesiBZW9vcMZCHhguxmH_9TlaXjTCXKKD_IlF5IHGpgqh9jh6Zv7mFOGhoCPrEQAvD_BwE&gclsrc=aw.ds

2.6.4 Board Games

U Boat Leader https://boardgamegeek.com/boardgame/85108/u-boat-leader

Steel Wolves https://boardgamegeek.com/boardgame/22359/steel-wolves-german-submarine-campaign-against-all

Run Silent, Run Deep https://boardgamegeek.com/boardgame/4740/run-silent-run-deep

Loups Gris en Atlantique https://boardgamegeek.com/boardgame/66372/loups-gris-en-atlantique

Up Scope https://boardgamegeek.com/boardgame/8024/scope-tactical-submarine-warfare-20th-century

Torpedo https://boardgamegeek.com/boardgame/2457/torpedo-run

The Hunters https://boardgamegeek.com/boardgame/113873/hunters-german-u-boats-war-1939-43

2.6.5 Motion Pictures

The cruel sea https://en.wikipedia.org/wiki/The_Cruel_Sea_(1953_film

In which we serve https://en.wikipedia.org/wiki/In_Which_We_Serve

Corvette K-225 https://en.wikipedia.org/wiki/Corvette_K-225

Sink the Bismarck https://en.wikipedia.org/wiki/Sink_the_Bismarck!

Battle of the River Plate https://en.wikipedia.org/wiki/Battle_of_the_River_Plate

Action in the North Atlantic https://en.wikipedia.org/wiki/Action_in_the_North_Atlantic

The Enemy Below https://en.wikipedia.org/wiki/The_Enemy_Below

Das Boot https://en.wikipedia.org/wiki/Das_Boot

Greyhound https://www.imdb.com/title/tt6048922/

U-571 https://en.wikipedia.org/wiki/U-571_(film)

Enigma https://en.wikipedia.org/wiki/Enigma_(2001_film)

49th Parallel https://en.wikipedia.org/wiki/49th_Parallel_(film)

Lifeboat https://en.wikipedia.org/wiki/Lifeboat_(1944_film)

2.6.6 Cartoons

“Spinach fer Britain” (Popeye the sailor) 1943 https://www.dailymotion.com/video/x2mzynh

Chapter 3 THE TWO CONVOYS TO BE MODELLED

3.1 OVERVIEW OF THIS CHAPTER

This chapter examines the background to the two convoys, SC107 and TM1, that have been modelled in this study.

The subsections contain the following aspects;

(3.2) This covers a brief overview of the modelling of battles in general and the nature of modelling a sea battle. This is accompanied by a brief consideration of a model centred on a convoy.

(3.3) This section examines the two convoy battles that are used in the modelling in later chapters. The serious failure of the escort forces deployed with these convoys are examined and why it happened. The Wolf Packs of U-boats that attacked these convoys are also described. Extensive use is made of archival records in this section in describing the sequence of events that led to the heavy losses of merchant ships and many of their crew members.

3.2 THE MODELLING OF BATTLES

3.2.1 A short history of modelling of battles

The simulation and modelling of warfare and military formations is probably as old as warfare itself. Certainly military weapons, armour and the formations of warriors acting in unison came about with the Greek Hoplite being an early example in which this happened and was accompanied by the development of tactics and manoeuvres in disciplined formation[152]. The Greek game of 'petteia' is a board game from the 5th century BC and can be played today that mimics battle between soldiers using pieces on a board[153][154].

The serious use of games and models to represent the actions of military units, formations, battles and campaigns has extensive coverage in the literature but can best be summed up succinctly in the phrase: 'A model is an abstraction of reality'[155].

3.2.2 The characteristics of battles fought on, under and above a sea or ocean

The most significant natural phenomenon in the Battle of the Atlantic was the weather in the form of the severe North Atlantic storms that raged in the critical winter of 1942-1943. Analysis in 1943 by the Admiralty's Directorate of Naval Operational Studies of the effects of the sea state and wind on the hunt by surface craft for U-boats concluded that the advantage was with the U-boats not with the escorts[156].

The convoys of merchant ships were organised into columns and rows, most typically 9 by 5 respectively, with the columns being aligned with the direction of travel and the rows being arranged at right angles to the rows, see Figure 58, the sizes of convoys varied from as few as a 9 to as large as eighty, but 9x5 was typical[157].

---

152 Connolly, Greece and Rome at War, page43
153 Samsin, Pawns and Pieces, page 1.
154 BoardGamingGeek, petteia https://boardgamegeek.com/boardgame/21488/petteia
155 Washburn et al, Combat Modelling, page 1
156 ADM 219/74, page 5
157 MFQ 1/583/15, 15th chart in the folder.

Figure 37 A convoy of ships travelling in columns

3.2.3 Kinematic representations of the motions of entities in sea battles

A kinematic representation of U-boats firing torpedoes at ships on the surface of the ocean has been implemented. This takes the launch point and the aim point that have been created by manual input in the table of events and then determines the equation of the trajectory. This equation is then used to determine the interception point coordinates of the trajectory with the outer edges of the convoy as the first step in discovering if the simulated torpedo hits a ship in the convoy. Once at the outer edge of the convoy, each torpedo is modelled as a point moving in time steps in the same direction it travelled to reach the convoy edge. At each increment of time the model calculates the closest point of the torpedo to the nearest ship. If the track passes within the rectangular outline of the nearest ship's horizontal profile it counts as a hit.

The track of each torpedo was made more realistic by including an error away from the aim point so that a salvo of four torpedoes fired in quick succession would most likely see them as a fan of four diverging tracks, see Figure 38, where two groups of 8 U-boats have each fired 4 torpedoes at the convoy. The divergence of the torpedoes from the aimed direction has been created so as to match the historic records and analysis of German torpedo and U-boat fire-control system performance.

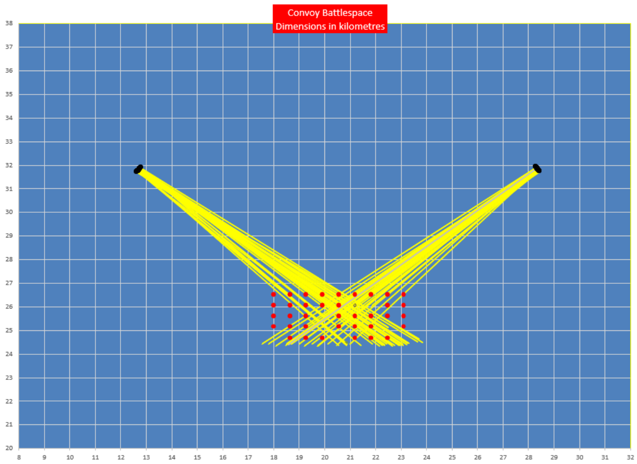


Figure 38 Torpedoes aimed at the centre of the convoy spread out due to errors in the aiming and firing system. The red dots are the ships the black dots the U-boats and the yellow lines are the torpedo tracks

3.2.4 Use of a 'Convoy-centric' frame of reference in the battle model

In this study, the frame of reference for the calculations was chosen to be 'Convoy Centric' with this meaning that the convoy entity does not move in this frame of reference. The main advantages of this approach is that it facilitates a hierarchical approach to modelling and reduces the computational load.

In the convoy entity the merchant ships are held rigidly in place in a form reminiscent of atoms in a crystalline structure.

There are many plots of where U-boats were first detected relative to a convoy they were attacking or following and these were shown in convoy centric diagrams produced by the Admiralty during and after WWII. A useful example of such a plot is shown in Figure 39. On this plot the locations of where the U-boat was first detected are shown as symbols. Each symbol is coded by shape and shade as indicated in the top left corner of the plot. It should be noted that the distribution of these first sightings cluster in both angle relative to the convoy direction of travel, taken to be towards the top of the plot, and in range. The convoys from which these data were derived are listed in the lower right-hand corner of the figure. It should be noted that the range of dates from the records for the sailings and arrivals of these convoys at their destinations is at odds with the date shown on the original plot[158]. The convoy dates range from July of 1942 to January 1943, whereas the official diagram gives the date range incorrectly as July 1st to December 31st 1943[159].

Prior to the advent of the widespread fitting of 10cm RDF radar on escort vessels the analysis of U-boat attacks on convoys is usually hampered by the lack of information on the U-boat's actual position and track but some useful information has been extracted by Admiralty analysts including many charts of where the U-boats were when they attacked[160].

158 Hague, Allied Cnvy System, pages 126 to 185
159 MFQ 1/587/19 [Note: the dates on this original diagram in the NA Kew are incorrect, it should read July 1942 to January 1943 to match the actual convoys sampled]
160 ADM 199/2495, pages 1 and 3

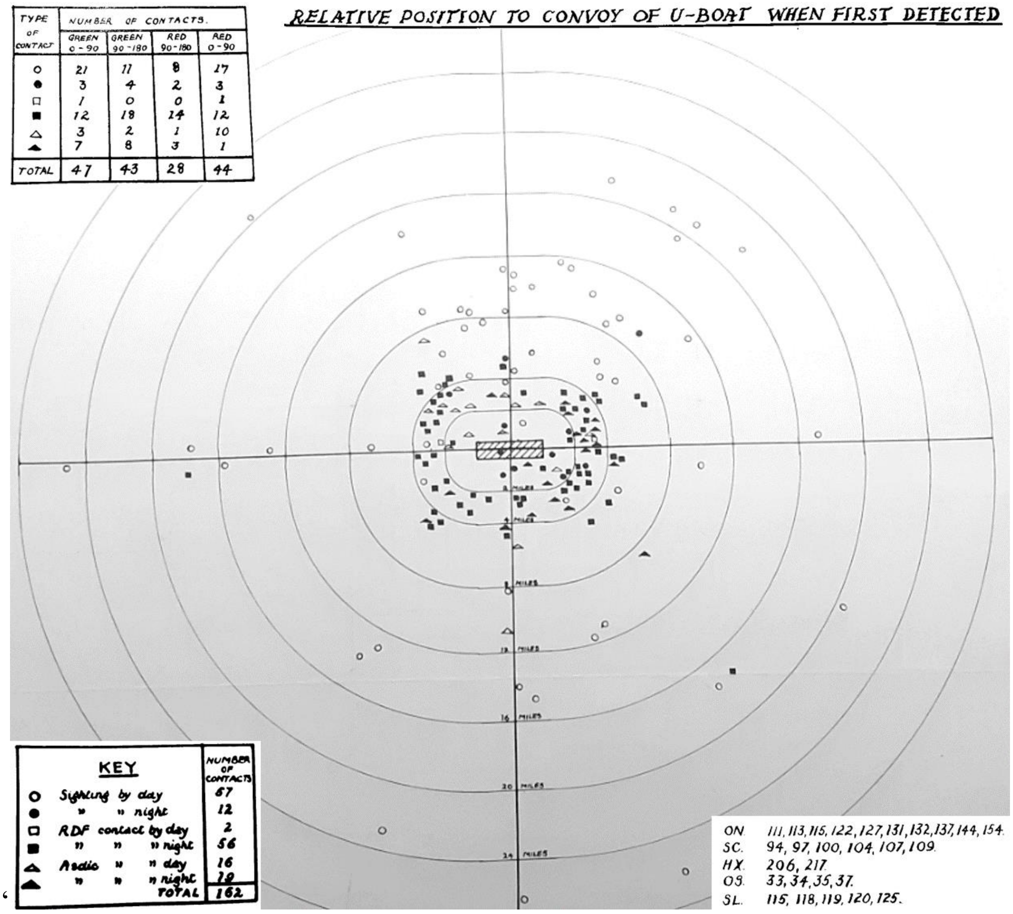


Figure 39 Plot of U-boats when first detected around a convoy

3.3 SELECTING TWO EXAMPLES OF CONVOY/WOLFPACK BATTLES FROM 1942-43: CONVOYS SC107 and TM1

3.3.1 The Factors for Selecting Two Convoys to Study

The first example chosen for this study was of a convoy that was a clear victory for the U-boats and a defeat for the escorts protecting it, was convoy SC107. This convoy was attacked initially before it entered the Air Gap in the North-Western Atlantic Ocean on its way to the UK. The prefix of SC stands for slow convoy to reflect the fact that the merchant vessels travelling in it were old and slow craft capable of speeds not much higher than 7 to 8 knots. The escort force protecting SC107 for the part of journey where they were attacked were 4 from the RCN and 1 from the RN and this force was relatively new, inexperienced and as it turned out manning vessels that were not equipped with the most capable electron sensors nor were they provided with adequate servicing of these ships and equipment. The latter point of poor provision of ships and equipment for the undoubtably courageous Canadian naval servicemen turned into a scandal that was dealt with in secrecy later in 1943. This was long after the battle had been won by the Allies. Doenitz missed the opportunity to win in 1942, see Section 2.2.4.

The second convoy to be studied was the U-boat victory over convoy TM-1. This small and specialised convoy was the first of the fast tanker only convoys that had been specifically requested by Churchill in a communication to Roosevelt in December 1942. It sailed that year from the Caribbean oil fields and was intended for passage to Gibraltar. TM-1 was intercepted in the warm waters near the Azores with devastating effect. The Royal Navy escorts vessels for TM-1 had similar problems to the RCN ones in SC107 and lost the battle for that convoy.

These two convoys then had the hallmarks of what might have happened to many more convoys and delivered victory to Doenitz and his U-boat force. The fact that this did not happen lies squarely on Doenitz's shoulders and may be simply because he pandered to his U-boat aces instead of following his instincts in how to concentrate the U-boats in mass synchronised attacks.

3.3.2 The Slow Convoys carrying vital supplies to the UK

The SC series of Allied convoys operated between North America and the UK[161]. These convoys included vessels that were starting out their journeys from the Gulf of Mexico, the Caribbean, the Eastern seaboard cities including New York City and from Halifax Nova Scotia and other Canadian cities via the St. Lawrence River and associated canals.

A total of 177 convoys under the SC series of convoys sailed between 1940 and 1945[162].

3.3.3 The Story of the SC107 convoy

The story of convoy SC107 has been discussed in many of the major works published since the end of WWII but one in particular has the most extensive records of what happened to this convoy. The book in question was written by a unique witness to the events that unfolded because he was not only an officer in the US Coastguard but he was actually an eye witness to the events as he was travelling on USS Gemini. This was one of the two US Navy troopships in convoy SC107 and were bound for Iceland. There were hundreds of US troops and US Coast Guard personnel travelling on them when the convoy was attacked by U-boats. The author of the book in question was Captain John M. Waters, Jr. US Coast Guard and he has given a detailed account of what happened to SC107 based on his own experiences, on his post war research of the log books, merchant ships, escorts and the U-boats involved and their commanding officers[163].

Elements of SC107 were formed up in New York and sailed up the East Coast of USA and into Canadian waters with some ships parting company with the convoy for Canadian ports before the convoy moving off into the North Atlantic. Some of the ships in the convoy were bound for Iceland and the Allied bases there. Most of the ships in the convoy were bound for the UK however. Convoys were commanded by a retired senior naval officer in the role of commodore of the convoy. In the case of SC107 this was Vice Admiral B.C. Watson C.B. D.S.O. RN (Ret.) and he travelled in the merchant ship S.S. Jeypore. This ship was unfortunately one of the vessels that was torpedoed and sunk, Commodore Watson survived the sinking and was rescued by one of the escort vessels. The Commodore's log book for the convoy did not survive the sinking and so the details of what happened that were recorded in it were lost. During the Royal Navy's board of investigation that took place in the weeks following the arrival of the surviving ships of the convoy, the board heard from the Commodore Watson and his Vice Commodore; R.H.R Mackay RNR, the latter travelled on the MV Geisha, as regards to what happened as best the two participants could recall[164]. The layout of convoy SC107 on the first night of the attacks is available in the Commodore's Log. This layout is shown in the photograph of Figure 40.

From the figure it can be seen that the identities of the vessels that were believed to have been sunk on the first night of the battle (1st / 2nd November 1942) are listed in bottom right hand corner of the sheet.

---

[161] Hague, Convoy System, page 25
[162] Ibid, page 116
[163] Waters, Bloody Winter, Forward by Rear Admiral Otto Kretschmer West German Navy (1967)
[164] ADM 199/716/45 folios 463 – 477.

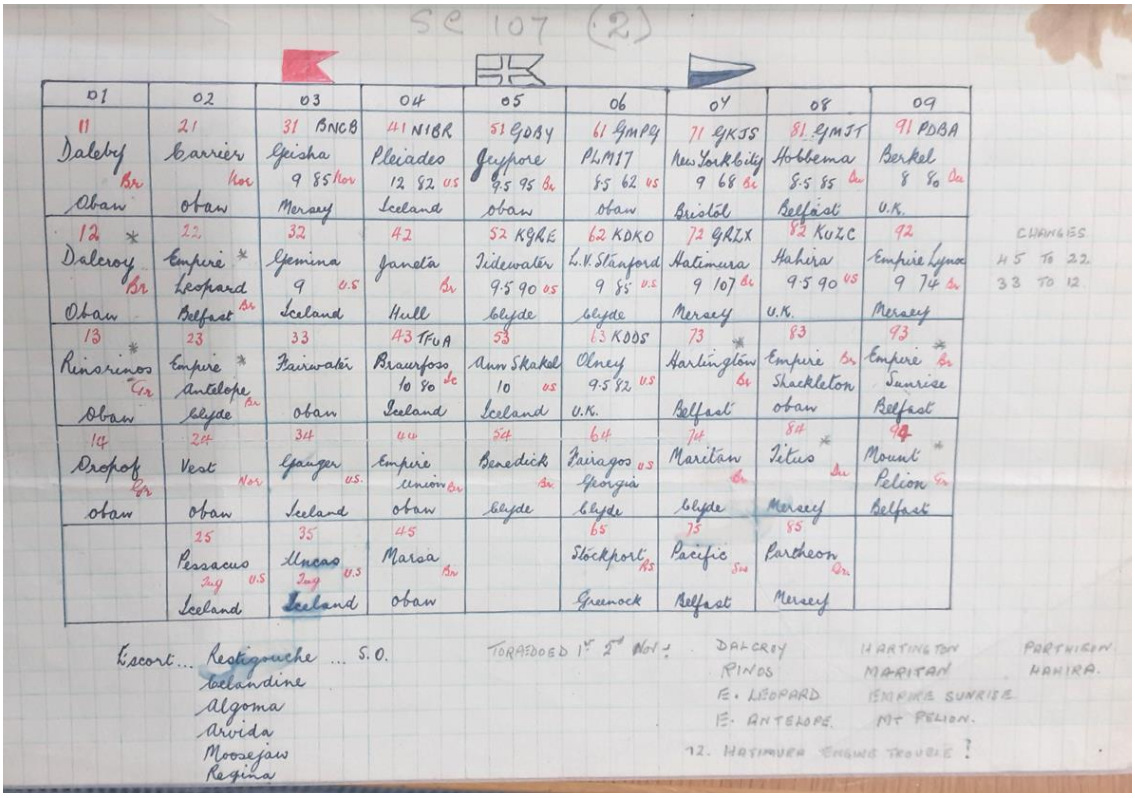


Figure 40 SC107 convoy formation on the 1st & 2nd of Nov. 1942 page from the Commodores report

SC107 was attacked by U-boats of Wolf Pack Veilchen (Violet) from the 1st November until the 4th of November during which 15 merchant ships were torpedoed and sunk. Figure 41 shows the dispositions of the ships in the convoy at the outset of the attack on the night of 1st/2nd of November 1942. The ships sunk on the first night of the attack are indicated by the red background in the figure.

		SC 107 Layout of Ships, ship type, positions and events (ADM 199/716/45) 1st & 2nd November 1942								
		COLUMNS								
ROWS	not used	1	2	3	4	5	6	7	8	9
	1	1,1 Daleby(Br)	2,1 Carrier(Nor)	3,1 Geisha(Nor)	4,1 USS Pleiadies	5,1 Jeypore(Br)	6,1 P.L.M.T. 17(Br)	7,1 New York City	8,1 Hobbema(Du)	9,1 Berkel (Du)
	2	1,2 Dalcroy(Br)	2,2 Empire Leopard	3,2 Gemini	4,2 Janeta	5,2 Tide Water	6,2 L.V.Stanford	7,2 Hatimura(Br)	8,2 Hahira(US)	9,2 Empire Lynx(Br)
	3	1,3 Rinos(Gr)	2,3 Empire Antellope	3,3 Fairwater	4,3 Braufossa	5,3 Ann Skakel	6,3 Olney(US)	7,3 Hartington(Br)	8,3 Empire Shackleton	9,3 Empire Sunrise
	4	1,4 Oropos(Gk)	2,4 Vest	3,4 Guager?	4,4 Empire Union	5,4 Benedick	6,4 Agios Georgios	7,4 Maritima(Br)	8,4 Titus(Du)	9,4 Mount Pelion
	5	1,5	2.5 Pegasus	3,5 Uncass?	4,5 Maroa	5,5	6,5 Stockport	7,5 Pacific	8,5 Partheon	9,5

Legend	Tanker Not Sunk	Sunk 1 & 2 Nov.	Sunk after 2 Nov.	Tanker Sunk after 2 Nov.	Not Sunk	Position Empty

Figure 41 The dispositions of merchant ships in Convoy SC107 the night of 1st/2nd November 1942.

The Escort vessels that protected SC107 came and went on various dates during the passage of the convoy in accordance with the deployment arrays of the ocean agreed between the Allies at that period of the conflict. Figure 42 shows the identities of the escorts for SC107 and dates of them joining and departing from the convoy.

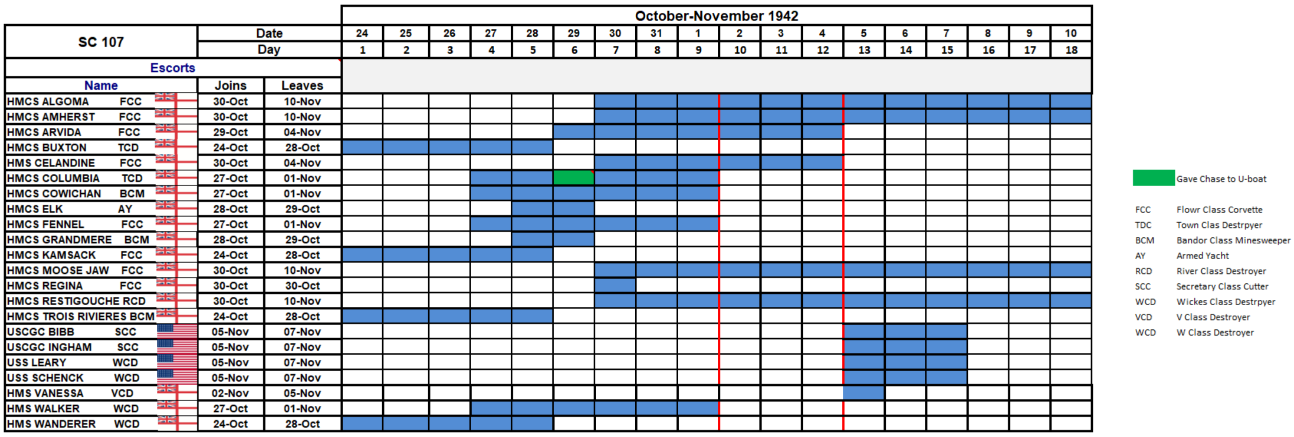


Figure 42 The deployment of escort warships for convoy SC107, note the red column lines denotes the time period of the attack by U-boats. The blue bars represent escort present.

The track chart showing the course followed by SC107 is shown in Figure 43**[165]**. From this track chart it may be observed that convoy SC107 has started out from New York city on the 24th of October and travelled in a North Easterly direction up the coast of the USA and into Canadian waters. When it reaches Halifax in Nova Scotia some ships leave the convoy and others join it there while other vessels leave the convoy. As the convoy reaches Newfoundland a similar process takes place with some ships leaving but this time the four original Escort ships leave and are replaced by RCN escort group 4 which is led by the destroyer HMCS RESTIGOUCHE, commanded by Lt. Commander Piers. At various stage of the voyage RESTIGOUCHE was also accompanied by RN destroyer HMS WALKER, RN corvette CELANDINE and a further 3 Canadian Flower Class corvettes, ALGOMA, ARIVDA and AMHERST. The RCN corvette MOOSE JAW would join them later on the 2nd November. HMS WALKER left the convoy midday on the 1st November and moved westwards back to Nova Scotian waters.

In the days before the attack numerous radio signals were detected by RESTIGOUCHE and another member of the convoy, the Rescue Ship Stockport, this being achieved by the HF/DF radio sets on these two ships. The signals were from surfaced members of the Veilchen as they radioed their reports required by Doenitz. Other detection and locations of these U-boat transmissions were made by the Allied land-based HF/DF systems in the US, Canada, Azores, Iceland and the UK. An RCAF aircraft attacked and sank one of the U-boats when it was on the surface the morning of 31st of November**[166]**.

As the growing threat that had gathered behind the convoy became obvious, RESTIGOUCHE and Stockport located a transmission from a U-boat just 5 miles astern of the convoy on the evening of the 31st of October. By the Morning of the 1st November, RESTIGOUCHE had re-joined the convoy and spent the morning and afternoon zigzagging behind the convoy looking for submerged U-boats with its ASDIC. In the evening another HF /DF contact was located 8 miles to the rear of the convoy and Piers decided to take the RESTIGOUCHE to investigate it.

---

165 Douglas, No Higher Purpose, page 545
166 Ibid, page 545

By the time that the convoy reached the point where it is actually attacked by the Wolf Pack Veilchen on the night of 1st/2nd November only 3 escorts remain with the convoy because Piers had ordered CELANDINE to chase down an HF/DF signal from a U-boat 8 miles to port of the convoy and Piers had taken RESTIGOUCHE ten or more miles to the south of the convoy. This effectively left the remaining escort force without a functioning radar set as the radar (RDF) had failed on both the CELANDINE and ARIVDA about that time which meant that fast moving (17kts) U-boats were unlikely to be detected until they were seen by eye in the dark and the effective range of that is low[167].

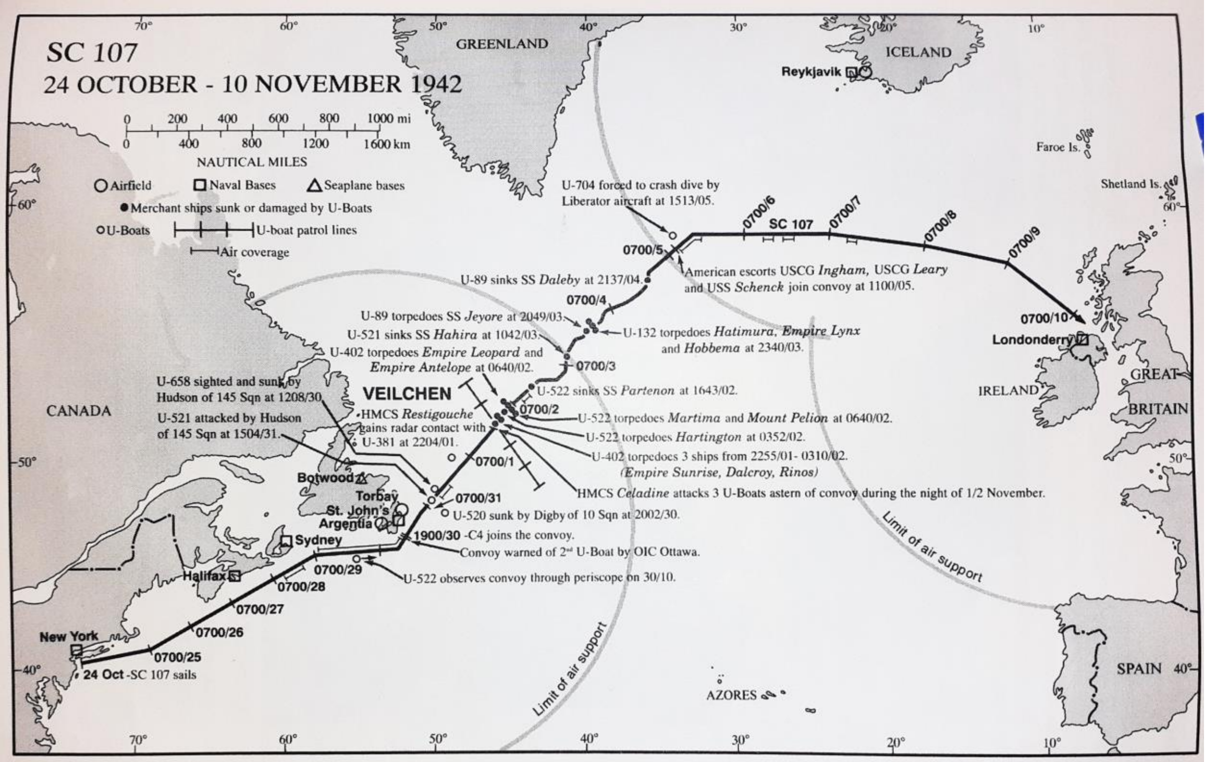


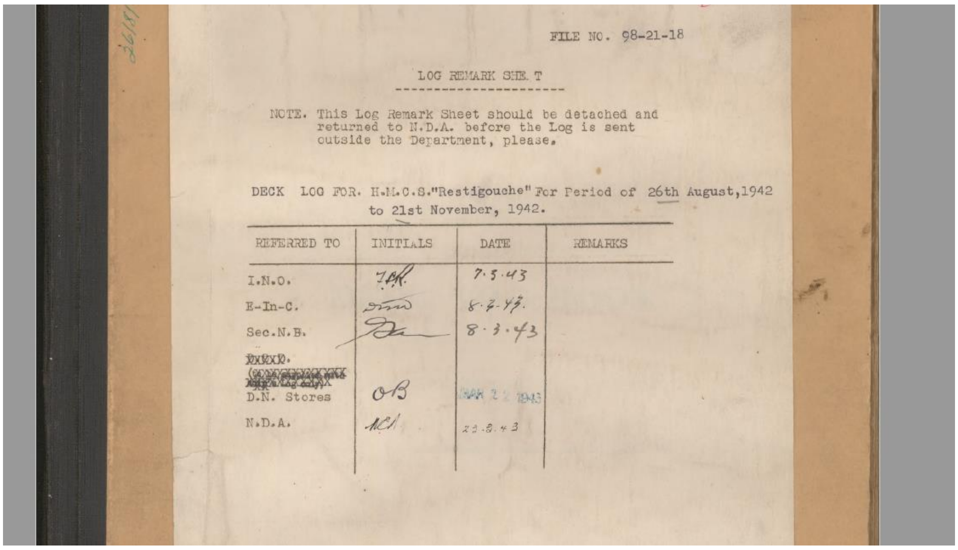
Figure 43 The Track Chart for SC107

In order to understand what happened to convoy SC107 when it was first attacked by U-boats the night of 1st / 2nd of November it is informative to look at the sequence of events from the perspective of what happened on the RESTIGOUCHE. To facilitate this understanding access was obtained by the author to the Deck Log of HMCS RESTIGOUCHE via the reprographic department of the Library and Archives Canada. The following photographs show in the next 3 figures extracts from the pages of the that Deck Log from RESTIGOUCHE for the period in question.

The author has transcribed some of the critical hours on the 31st to the 2nd of November which is the period of the first attack on SC107 and the subject of the Battle Modelling reported here. The records are hand written and are not always easily legible as this could be caused by the fact they are periods intense activity for the ships commander and his first lieutenant especially once 'ACTION STATIONS' have been called and the RESTIGOUCHE was involved in combat with the U-boats. The tables that follow the photographs of the pages are transcriptions by the author.

Figure 44 shows the first page of the Deck Log and confirms that they are from RESTIGOUCHE and cover the period of the battle of SC107 in November 1942.

[167] Ibid, page 546



FILE NO. 98-21-18

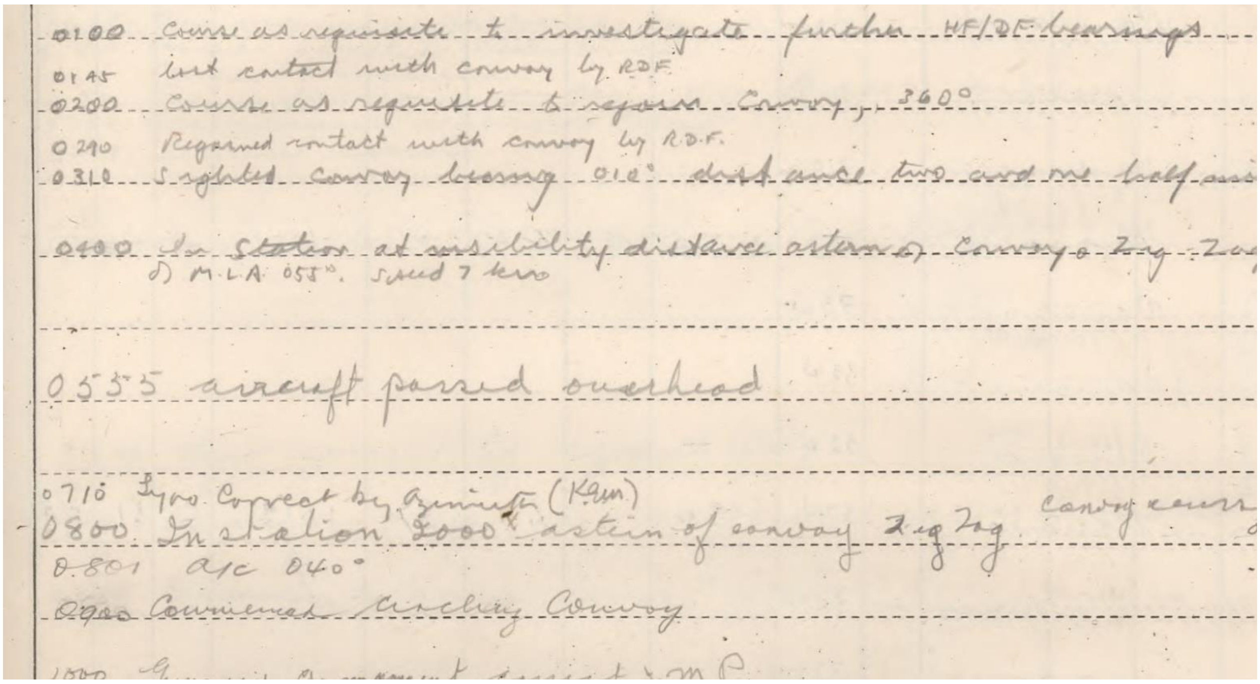
LOG REMARK SHEET

NOTE. This Log Remark Sheet should be detached and returned to N.D.A. before the Log is sent outside the Department, please.

DECK LOG FOR. H.M.C.S."Restigouche" For Period of 26th August,1942 to 21st November, 1942.

REFERRED TO	INITIALS	DATE	REMARKS
I.N.O.	[illegible]	7.5.43	
E-In-C.	[illegible]	8.4.43	
Sec.N.B.	[illegible]	8.3.43	
D.N. Stores	OB	MAR 2 [illegible] 1943	
N.D.A.	[illegible]	22.5.43	

Figure 44 The first page of the Deck Log of H.M.C.S. RESTIGOUCHE 16 Aug to 21 Nov 1942



0100 Course as requisite to investigate further HF/DF bearings
0145 lost contact with convoy by RDF
0200 Course as requisite to rejoin Convoy, 360°
0240 Regained contact with convoy by R.D.F.
0310 Sighted convoy bearing 010° distance two and one half mi[illegible]
0400 In station at visibility distance astern of Convoy. Zig Zag [illegible] of M.L.A. 055°. Speed 7 kts
0555 aircraft passed overhead
0710 Gyro Correct by Azimuth ([illegible])
0800 In station 2000 astern of convoy Zig Zag. Convoy course [illegible]
0801 a/c 040°
0900 Commenced circling Convoy

Figure 45 Log entries for the battle for SC107 for HMCS RESTIGOUCHE 1st Nov. 1942 (First Entry 01:00 and last entry 8:01)

Looking at the Deck Log in Figure 45 and Table 4 it can be seen that RESTIGOUCHE had been to the south of the convoy and had gone far enough to lose RDF contact with the convoy. In fact RESTIGOUCHE had been investigating HF/DF locations from its own and Stockport's detections of U-boat transmissions since late on the 31st October. The entry at 01:45 indicates when RDF had already been lost. At 04:00 on the 1st November, RESTIGOUCHE had returned to the Convoy and was zigzagging within sight of the convoy and was astern of it and remained there during daylight hours.

At 19:35 on the 1st November RESTIGOUCHE picked up an ASDIC contact and turned away from the convoy on bearing 110 degrees while the convoy's heading was 050 degrees by 60 degrees. At 20:24 the RDF on RESTIGOUCHE picked up a contact on bearing 325 (to the North West of RESTIGOUCHE's location) at a range of 3000 yards. RESTIGOUCHE then turned on that bearing and headed towards the contact at speed. At 20:35 what was believed to be a wake (bio phosphorescent presumably because it was after dark) of a U-boat but the boat itself was not sighted. RESTIGOUCHE then attacked the suspected U-boat with ten depth charge spread. In doing so the blast from the depth charges damaged RESTIGOUCHE’s steering gear. Repairs to the steering gear were made and within 2 minutes the steering was restored and contact regained followed by another depth charge attack on the U-boat at approximately 21:00. This was an hour and twenty minutes since RESTIGOUCHE left the convoy and the other escorts to steam away from their original speed of 7.5kts without any RDF functioning on the remaining escorts still with the convoy to detect surfaced U-boats near the it. At 21:40 star-shells were seen by RESTIGOUCHE from the direction of the convoy and a message was received by RESTIGOUCHE informing her that the convoy had been attacked and that the merchant ship Empire Sunrise had been torpedoed. This was carried out by Forstner in U-402 whilst on the surface and from a range of only 400 yards on the starboard side of the convoy where he had fired 3 torpedoes, the first of which failed to launch from the tube then the two further torpedoes were launched successfully. The next torpedo did fire and left the U-boat but it was seen to miss. However, the third torpedo launched, hit and detonated.

Table 4 The transcribed entries for H.M.C.S. RESTIGOUCHE for 1st Nov. 1942

Date	1st November 1942	Distance Run		Wind							
Time	Log Entry	Miles	Tenths	Dirct.true	Force	Weath/vis	Sea/Swell	Press/bar	Temp Dry(F)	Lat. Degs Mins	Long. Degs Mins
01:00:00	Course as requisate to investigate further HF/DF bearings	12	5	-	-	-	-	-	-	-	-
01:45:00	Lost contact with convoy by RDF	12	5	-	-	-	-	-	-	-	-
02:00:00	Course as requisate to regain contact with convoy, 360°	11	0	-	-	-	-	-	-	-	-
02:40:00	Regained contact with convoy by RDF	11	0	-	-	-	-	-	-	-	-
03:10:00	Sighted convoy bearing 010° distance two and one half miles	11	0	-	-	-	-	-	-	-	-
04:00:00	In station at visibility distance astern of convoy. Zig Zagging either side of M.L.A. 055°, speed 7 kts	11	0	WSW	3 - 4	bc 6	31	1006	48	-	-
05:56:00	Aircraft passed overhead	11	5	-	-	-	-	-	-	-	-
07:10:00	Gyro correct by azimuth	11	5	-	-	-	-	-	-	-	-
08:00:00	In station 2000^{Y} astern of convoy Zig Zag Convoy course and speed 050° 7 1/2 kts	11	5	-	-	-	-	-	-	50 27 N	47 46 W
08:01:00	a/c 040°	11	5	-	-	-	-	-	-	-	-
12:00:00	In station astern in stn' 5 Co 040° 7.5 kts	11	5	WxN	4	b 7	23	1011	52	50 53 N	47 10 W
17:00:00	In station Zig Zagging astern of convoy at 2000^{Y} course ad speed of convoy 040° 7.5 kts	11	5	NWxW	3	0c 7	33	1015	54	-	-
17:30:00	Convoy a/c to 015°	11	5	-	-	-	-	-	-	-	-
18:00:00	Convoy course and speed 015° 7 1/2 kts. In station 5000^{Y} astern of convoy Zig Zagging	11	5	NWxW	3	oc 6	31	1017	51	-	-
19:35:00	Picked up doubtful contact bg 110	11	5	-	-	-	-	-	-	-	-
19:40:00	Sounded of Action Stations	11	5	NWxW	3	oc 6	31	1017	51	-	-
20:00:00	Course and speed as requisite to investigate contact	11	5	NWxW	3	oc 5	33	1018	50	51 43 N	46 20 W
20:24:00	ADF obtained bearing 325° 3000 yards altered course towards	11	5	-	-	-	-	-	-	-	-
20:36:00	Sighted wake of what believed to be U-boat on surface target proceeding at same speed as ships 17 kts	11	5	-	-	-	-	-	-	-	-
20:38:00	U-boat dived 2038 1/2 10 charge pattern fired Steering (cugsash?) gone	11	5	-	-	-	-	-	-	-	-
20:44:00	Stearing Engine responds regains control	11	5	-	-	-	-	-	-	-	-
20:45:00	Fired (mix soiwas?) 3" Starshell found nothing	11	5	-	-	-	-	-	-	-	-
20:57:00	Decreases speed to 14 kts	11	5	-	-	-	-	-	-	-	-
20:59:00	Increases (iward) speeds as requisite and regains contact	11	5	-	-	-	-	-	-	-	-
20:59:00	Increases (iward) speeds as requisite and regains contact	11	5	-	-	-	-	-	-	-	-
21:00:00	Course and speed as requisite of attack again	14	0	-	-	-	-	-	-	-	-
21:40:00	Starshells sighted in numbers brg 030-050° Course and speed as requiste to close. From Commodore by R/T PT 93 (Empire Sunrise) Torpedoed. Snowflakes and starshells being fired by escorts.	14	0	-	-	-	-	-	-	-	-
23:04:00	In contact again range 1200^{Y} closed and dropped a ten-charge pattern	15	5	-	-	-	-	-	-	-	-
23:45:00	[?] Used very many rounds of 3" starshells from [firstly?] (bungled?) convoy and escorts clearly seen. Zig Zagging astern of Convoy 14 kts	15	5	-	-	-	-	-	-	-	-
24:00:00	None	13	5	NwxW	2	bc 6	33	1020	49	-	-

One of the escorts was reported by Forstner to have turned toward U-402 following the detonation of the torpedo against Empire Sunrise hull[168]. As a result Forstner dived U-402 and escaped by going under the convoy.

RESTIGOUCHE returned to the convoy at some point around midnight but the Deck Log does not record at what time.

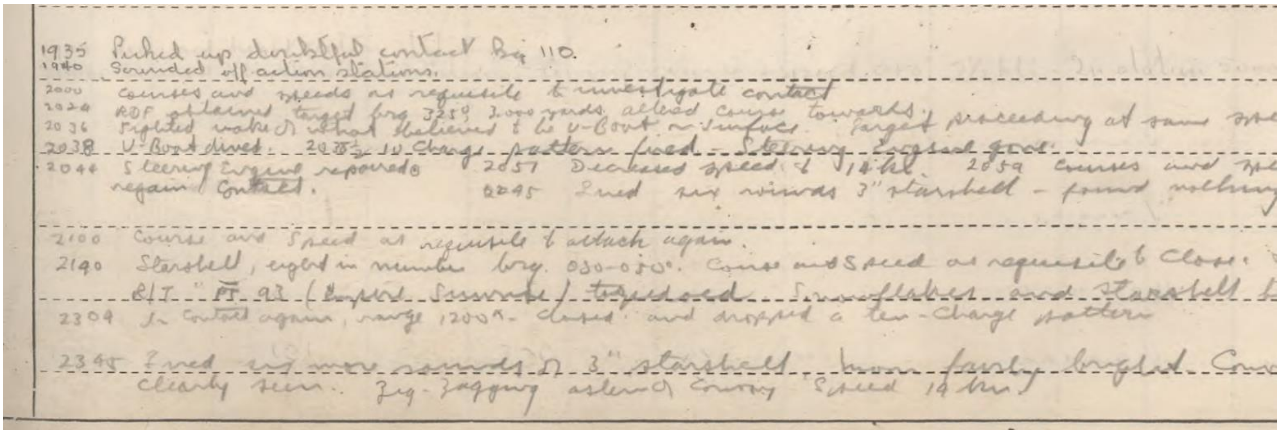

1935 Picked up doubtful contact Brg 110.
1940 Sounded off action stations.
2000 Courses and speeds as requisite to investigate contact
2024 RDF obtained target brg 325° 3,000 yards altered course towards.
2036 Sighted wake of what believed to be U-Boat on surface. Target proceeding at same
2038 U-Boat dived. 2038½ 10 Charge pattern fired - Steering Engine gone.
2044 Steering Engine repaired. 2051 Decreased speed to 14 kts. 2059 Courses and sp
regain contact. 2045 Fired six rounds 3" starshell - found nothing
2100 Course and Speed as requisite to attack again.
2140 Starshell, eight in number brg. 030-050°. Course and Speed as requisite to close.
R/T "PT 93 (Empire Sunrise) torpedoed. Snowflakes and Starshell
2304 In contact again, range 1200 x. closed and dropped a ten-charge pattern
2345 Fired six more rounds of 3" starshell. Moon fairly bright. Conv
clearly seen. Zig-zagging astern of convoy. Speed 14 kts.

Figure 46 The Log entries for H.M.C.S. RESTIGOUCHE during the evening of 1st Nov. 1942 (first entry 19:35 and last entry 23:45)

During the first half of the 2nd of November the onslaught of the U-boats built up and 7 more merchant ships were torpedoed and sunk, as may be seen in Table 5.

168 Waters, Bloody Winter, page 46

Table 5 The transcribed entries for H.M.C.S. RESTIGOUCHE for 2nd Nov. 1942

Date	2nd November 1942	Distance Run		Wind							
Time	Log Entry	Miles	Tenths	Dirct.true	Force	Weath/vis	Sea/Swell	Press/bar	Temp Dry(F)	Lat. Degs Mins	Long. Degs Mins
00:00:00	None	11	5	-	-	-	-	-	-	-	-
00:45:00	Sounded Action Stns. Ships No. 12, 73 Torpedoed	11	5	-	-	-	-	-	-	-	-
00:53:00	00:53 1/2 Two underwater explosions	11	5	-	-	-	-	-	-	-	-
01:04:00	Counter Attacked ASDIC contact	15	5	-	-	-	-	-	-	-	-
01:06:00	Convoy illuminated	15	5	-	-	-	-	-	-	-	-
01:30:00	Passed survivors in sea	15	5	-	-	-	-	-	-	-	-
01:42:00	Ship No. 74 Torpedoed	15	5	-	-	-	-	-	-	-	-
02:02:00	Two underwater explosions heard	17	0	-	-	-	-	-	-	-	-
02:19:00	Sounded Actions	17	0	-	-	-	-	-	-	-	-
04:00:00	Zig Zagging in station astern of convoy Co. 050° Speed 7.5 kts	13	0	Variable	Lt.	bc 6/7	21	1021	46	-	-
07:00:00	Gyro correct by azimuth	14	0	-	-	-	-	-	-	-	-
08:00:00	Assuming a ship of the convoy with engine trouble Co 45p of convoy 050 7.5 kts	11	0	S	1	b 7	21 (7?)	1019	50	52 30 N	44 59 W
09:00:00	Gunnery armament correct	11	5	-	-	-	-	-	-	-	-
10:35:00	Proceeding from astern to take up station in van of convoy	11	5	-	-	-	-	-	-	-	-
11:10:00	2nd station ahead of convoy 2000 yds escort assumes new screens under D.E. 6	11	5	-	-	-	-	-	-	-	-
12:00:00	Cor of convoy 050°, 7 1/2 kts In stn ahead ZZ	11	5	SxE	3	o/c 5-6	21	1015	50	52 48 N	44 24 W
14:15:00	No 84 SS Parthenon Torpedoed Loud explosion high air, no underwater explosion	11	5	-	-	-	-	-	-	-	-
14:25:00	Recalled Algonquin and Celendine	11	5	-	-	-	-	-	-	-	-
14:30:00	Proceeding to Stb quarter	11	5	-	-	-	-	-	-	-	-
14:58:00	14:58 1/2 Arrida dropped charges	11	5	-	-	-	-	-	-	-	-
15:16:00	Arivda screening 'Stockport' after Stockport rescued survivors. Set course to rejoin	13	0	-	-	-	-	-	-	-	-
15:30:00	set course to rejoin heading C0 030°	13	0	-	-	-	-	-	-	-	-
16:00:00	None	14	5	S	4	ocd 3/5	21	1011	50	-	-
18:00:00	Convoy course speed 030° - 7 1/2 kts - In station starboard quarter zig zagging	11	0	S	4	ocd 3	21	1011	45	-	-
18:25:00	Investigating HF/DF bg 234°	11	0	-	-	-	-	-	-	-	-
18:43:00	set course to rejoin convoy	11	0	-	-	-	-	-	-	-	-
18:44:00	Convoy a/c 090°	11	0	-	-	-	-	-	-	-	-
20:00:00	Convoy course speed 090° - 7 kts - In station starboard quarter zig zagging at 90 revs	11	0	S	ocd 2/3	22	-	-	-	53 19 N	43 09 W
20:20:00	Dull explosion heard	11	0	-	-	-	-	-	-	-	-
20:25:00	Another exploson heard in distance	11	0	-	-	-	-	-	-	-	-
22:39:00	steering cource 210° to investigate HF/DF contact	10	0	-	-	-	-	-	-	-	-
22:59:00	Returned to 110° investigate HF DF contact bearing 140°	10	0	-	-	-	-	-	-	-	-
23:20:00	Set course of 020° to rejoin convoy	10	0	-	-	-	-	-	-	-	-
23:50:00	signal from 'Venesa' on joining escort										
24:00:00	None										

It can be seen that RESTIGOUCHE and the other escorts were totally unsuccessful in deterring several very successful attacks on the ships of the convoy and were unable to sink any U-boats in response.

The U-boats of Wolf Pack Veilchen included 11 individual boats that attacked merchant ships of the convoy are shown in Figure 47[169].

169 Rohwer, Axis Submarine Successes, pages 132 to 134

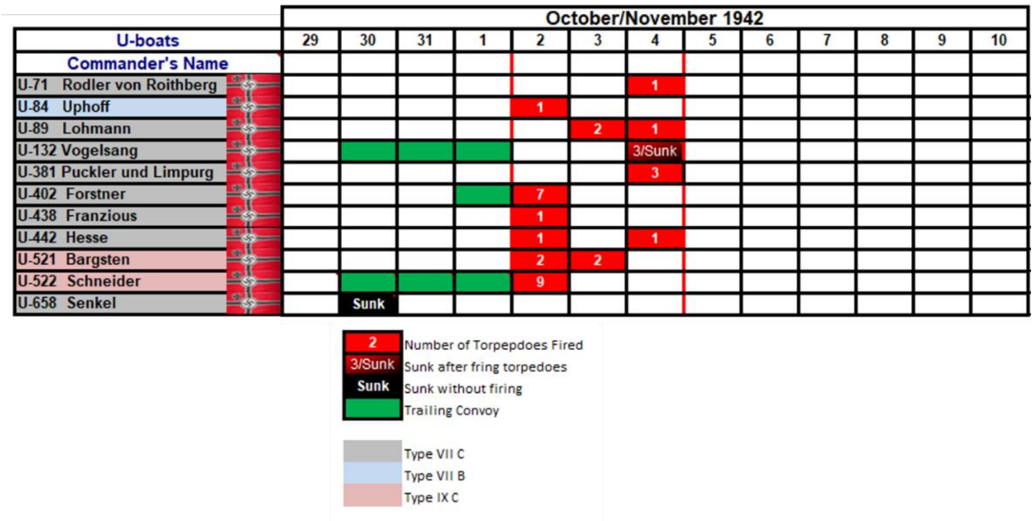
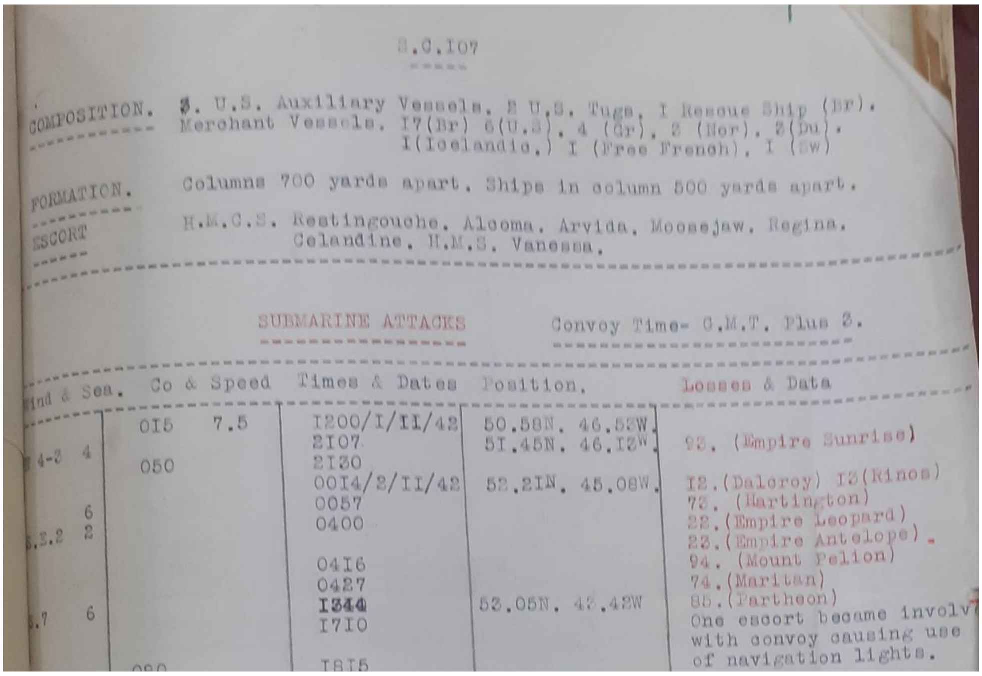


Figure 47 U-boats attacking SC107, Note the day of attack are in GMT

The attacks on SC107 continued until they were through the air gap and could be supported by aircraft from the base in Iceland. After the convoy reached the UK the Commodore and Vice Commodore reported to the Admiralty. From the records of the proceeding an official timetable was created, see Figure 48[170].



S.C.107

COMPOSITION. 3. U.S. Auxiliary Vessels. 2 U.S. Tugs. I Rescue Ship (Br). Merchant Vessels. I7(Br) 6(U.S). 4 (Gr). 2 (Nor). 2(Du). I(Icelandic.) I (Free French). I (Sw)

FORMATION. Columns 700 yards apart. Ships in column 500 yards apart.

ESCORT H.M.C.S. Restingouche. Algoma. Arvida. Moosejaw. Regina. Celandine. H.M.S. Vanessa.

SUBMARINE ATTACKS Convoy Time- G.M.T. Plus 2.

Wind & Sea.		Co & Speed		Times & Dates	Position.	Losses & Data
		0I5	7.5	I200/I/II/42	50.58N. 46.52W.	
4-3	4			2I07	5I.45N. 46.I2W.	93. (Empire Sunrise)
		050		2I30		
				00I4/2/II/42	52.2IN. 45.08W.	I2.(Dalcroy) I3(Rinos)
	6			0057		73. (Hartington)
.2.2	2			0400		22.(Empire Leopard)
						23.(Empire Antelope).
				04I6		94. (Mount Pelion)
				0427		74.(Maritan)
				I344	53.05N. 42.42W	85.(Partheon)
.7	6			I7I0		One escort became involv with convoy causing use of navigation lights.
		080		I8I5		

Figure 48 An extract of the official data for convoy SC107 in the Commodore's report.

This indicates that 8 vessels were sunk on the night of 1st/2nd November in SC107.

Examination of Figure 48 in the left hand edge close to the binding shows that weather conditions at the time of the first attack which was against Empire Sunrise were recorded as ;

170 ADM 199/716/45, Immediately following folio 472

Time 21:07 Date 1/11/42

Wind From the East, force 4 down to 3

Sea state 4

Time 00:57 Date 2/11/42

Wind [Not stated) force [Not stated]

Sea state 6

Time 04:00 Date 01/11/42

Wind from SE force 2

Sea State 2

The meteorological records, in the form of the synoptic chart, show wind from the South West which is in disagreement with the official Commodores report. There was high pressure to the south of SC107's location, see Figure 49.

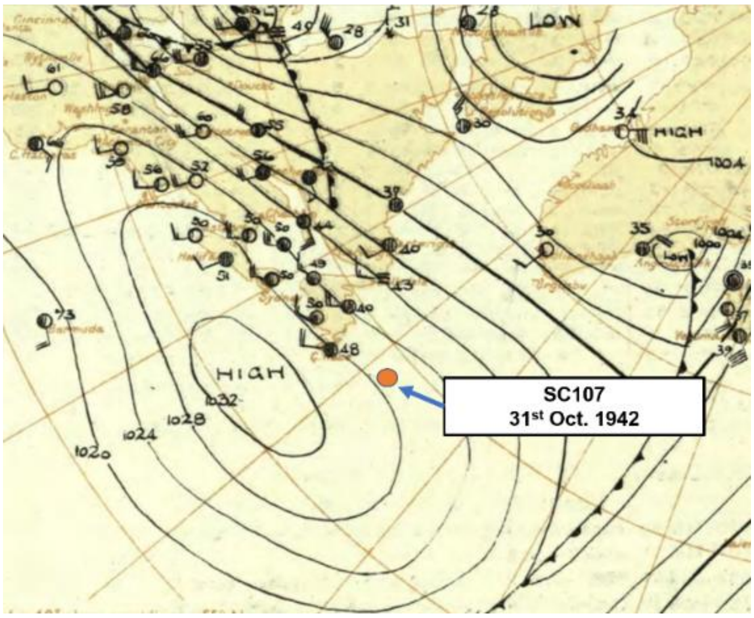


Figure 49 UK Met Office Synoptic Chart for the North West Atlantic with the approximate location of SC107 shown for 31st Oct. 1942

By the 1st November the weather had changed and developed such that a frontal system came in with winds still from the East South East. See Figure 50. This will have caused the sea state to rise possibly to the level of 6 as recorded in the official records, Figure 48.

The consequences of this would be that the conditions would have made visual sightings of U-boats difficult especially at night and as Admiralty research has shown these conditions favour the U-boat seeing a ship before the ship sees the U-boat[171].

[171] ADM 219/74, page 5

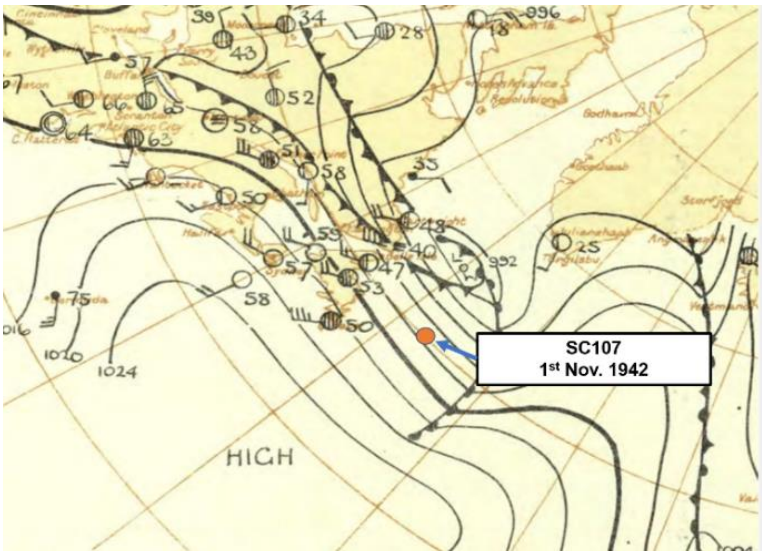


Figure 50 UK Met Office Synoptic Chart for the North West Atlantic with the approximate location of SC107 shown for 1st Nov. 1942

Once the weather front had passed the night was calm, clear sky and was illuminated by Northern Lights[172][173]. This should have favoured the visual sighting of a U-boat on the surface and also for greater detection range of the RDF 271 which only RESTIGOUCHE had a functioning set out of the 3 escorts that carried it the SC107 convoy escort that night.

When the weather had cleared and high pressure formed around the general location of SC107 on the 2nd November the conditions were favourable for the formation of fog and that is what happened during the later part of the predawn period, see Figure 51. Schneider in U522 had already torpedoed several ships during the night and early afternoon lay ahead of the convoy submerged in clear air North East of the fog bank waiting for SC1097 to emerge from it. He fired a salvo of four torpedoes and hit the Parthenon and sank it[174].

The cause of the disaster that befell SC107 and the following days was that the escorts were being scattered too thinly around the convoy for the conditions that prevailed as can be seen in the records above.

---

172 Waters, Bloody Winter, page 43
173 Ibid, page 39
174 Idid, page 57-58

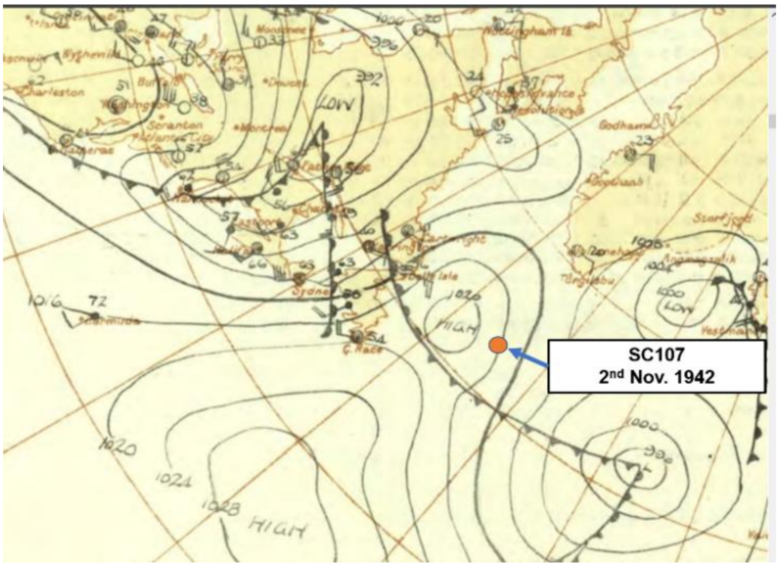


Figure 51 UK Met Office Synoptic Chart for the North West Atlantic with the approximate location of SC107 shown for 2nd Nov. 1942

3.3.4 The story of the TM-1 Convoy

In late 1942 the British government was deeply worried by the number of tankers being sunk by U-boats in the Atlantic, see section 2.5.2. As a result of this concern Prime Minister Winston Churchill sent a telegram to President Roosevelt in December of 1942 requesting that special convoys of tankers only should be formed so that they could outrun the U-boats when they were at their most deadly, on the surface and at night[175]. The first of these convoys was TM-1, where the letters stand for Trinidad to Mediterranean[176]. This first example of such a convoy turned out to be a disaster for the Allies[177]. The official Admiralty chart for convoy TM-1 is shown in Figure 52[178].

From the chart it can be seen that the main attack happened south of the Azores and half way to the Cape Verde Islands.

175 Blair, The Hunted, page 143
176 Hague, Convoy System, page 114.
177 Blair, The Hunted, page 144.
178 ADM 199/2016

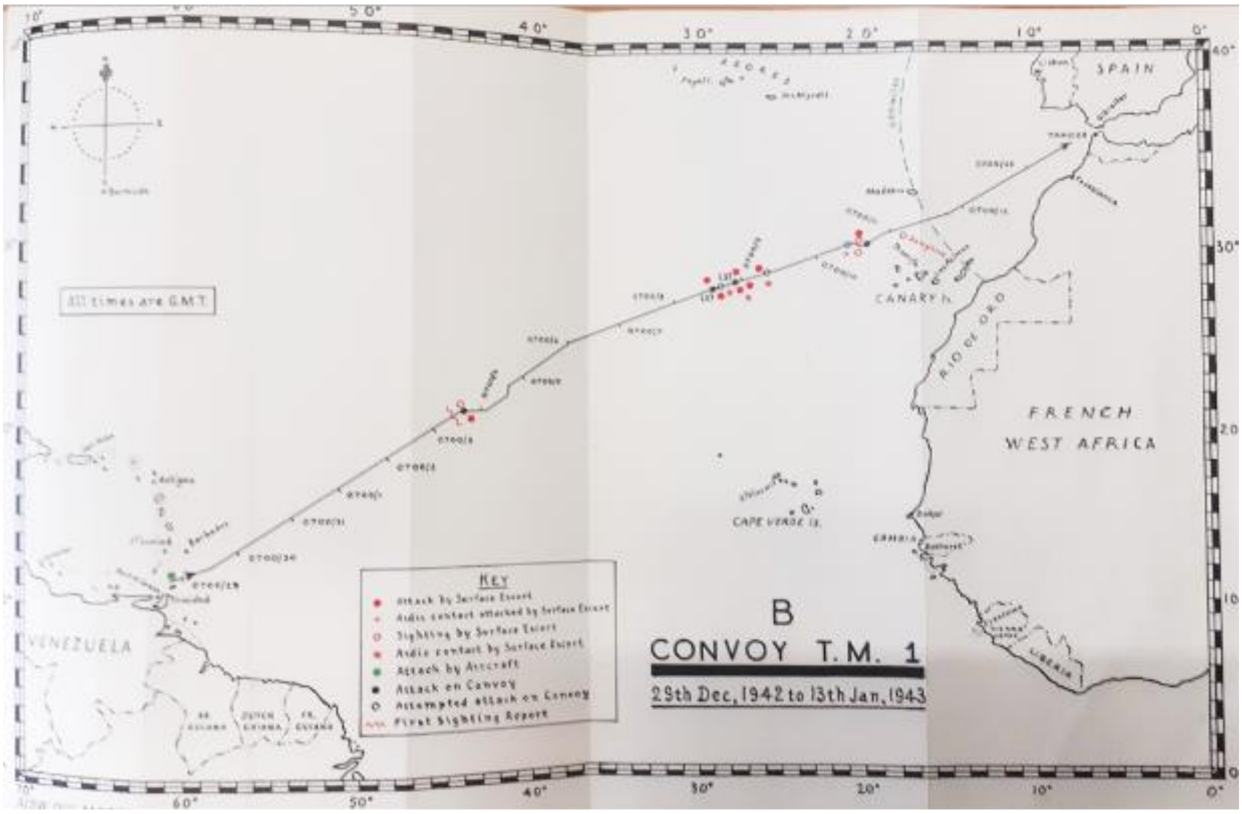
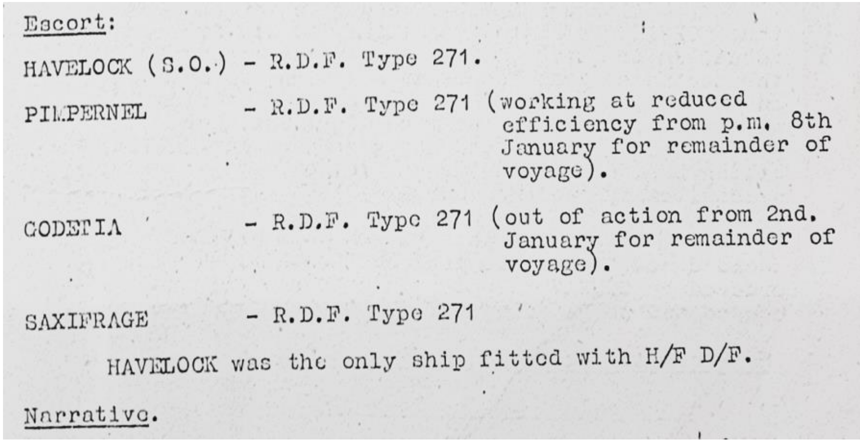


Figure 52 Official Admiralty track Chart for Convoy TM-1

TM-1 set sail from Trinidad on the 28th of December with 8 tanks formed up in the convoy and accompanied by four escort vessels of the Royal Navy, these were HAVELOCK (escort commander an H class destroyer) and PIMPERNEL, SAXIFRAGE and GODETIA (Flower class corvettes). All of these vessels were equipped with RDF 271 sets but only two of them were working. The other two escorts had RDF 271 which were not functioning at all and the other was working but with much reduced performance.

In February 1943 the Admiralty conducted an analysis of the U-boat operations in the vicinity of convoy TM-1[179]. The report from this analysis gives further details of the circumstances of the failures of the RDF 271 equipment, see Figure 53.

179 ADM 199/2016 Analysis of U-Boat Operations, page 1



Escort:

HAVELOCK (S.O.) - R.D.F. Type 271.

PIMPERNEL - R.D.F. Type 271 (working at reduced efficiency from p.m. 8th January for remainder of voyage).

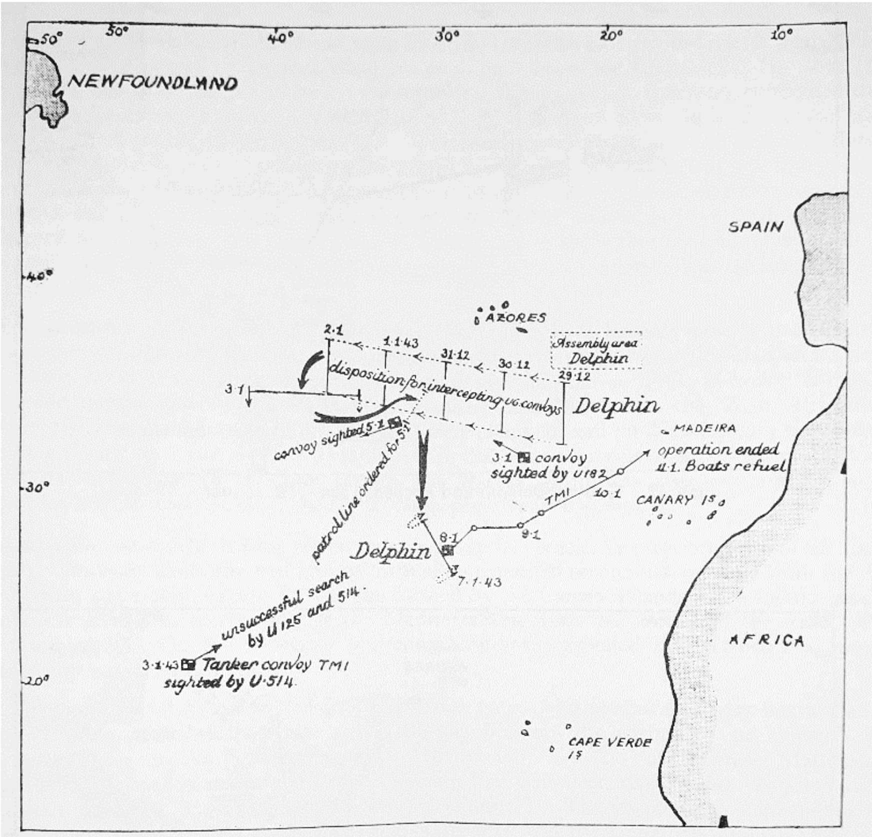
CODETIA - R.D.F. Type 271 (out of action from 2nd. January for remainder of voyage).

SAXIFRAGE - R.D.F. Type 271

HAVELOCK was the only ship fitted with H/F D/F.

Narrative.

Figure 53 Extract from the analysis of U-boat attacks showing that despite the close-range attacks by U-boats, the RDF 271 use did not prevent the disastrous results of the attack.



C

Figure 54 The attack of Wolf Pack Delphin on convoy TM-1

A board of inquiry was held once the remaining ships had reached Gibraltar. The conclusions were stark and the main reason for the heavy losses was due to the weakness of the escort force, see Figure 55.

5. COMPOSITION OF THE ESCORT. We are of the opinion that the primary cause of the heavy losses in this convoy was an escort insufficient in strength to deal with the concentration of submarines encountered. As a result, the escort commander did not feel justified in complying with Atlantic Convoy Instructions, article 113, paragraph 2, which would have been the only way of shaking off shadowers.

Figure 55 Board of Inquiry on TM-1, conclusion 5 show a weak Escort was the main cause of the disastrous outcome of the U-boat attack

The weakness in numbers of the escorts was also cited in conclusion 7 as justification for the abandonment of three of the torpedoed tankers, see Figure 56. The fact that the tankers were still afloat hours and even days later supports the adoption in this thesis of the resilience of ships that depends on their type, tanker in this case, and also on the nature of their cargo.

7. ABANDONMENT OF DAMAGED SHIPS. Owing to the lack of escorts, we consider that the escort commander was justified in abandoning the M.V's. NORVIK, MINISTER WEDEL and EMPIRE LYTTON. His decision to attempt to sink the two former by gunfire is open to question, in view of the possibility of salvage later. His reasons are given in paragraph 4 of the above quoted report and paragraphs 12 to 15 of appendix A thereto.

Figure 56 Board of Inquiry on TM-1, conclusion 7 tankers did not sink immediately.

The final points drawn from the board of enquiry was conclusion 9 which highlighted that the failure of the RDF 271 radar sets reduced the effectiveness of the escorts that were provided for the protection of TM-1. These failures was attributed by the inquiry as being partly due to the lack of spare parts for these particular escort ships in their long deployment to U.S. East Coast waters, see Figure 57.

9. FAILURE OF MATERIAL. We are of the opinion that the failure of Type 271 sets in H.M. Ships PIMPERNEL and GODETIA materially reduced the protection afforded to the convoy. This was at least partially due to the difficulty of obtaining spare parts during their ten months service in American waters.

Figure 57 Board of Inquiry on TM-1, conclusion 9, the RDF 271 failures role in the outcome.

The efforts of HAVELOCK and her companion escorts to thwart the U-boats of Wolf Pack Delphin were ineffective as can be judged by the previously stated fact that 7 out of the 9 tankers were sunk. Track chart A shown in Figure 58 shows an example of how in effective the escorts were[180]. The U-boat shown in this chart was in fact U-436 commanded by Seibike who approached on the surface after dark to within one mile of the convoy and within half a mile of HAVELOCK undetected by the RDF she had and fired two torpedoes at the convoy hitting the Albert L. Ellsworth and the Olltenia II[181]. HAVELOCK had detected U-436 and was turning to engage her at the time the torpedoes were fired and had not done anything to prevent the loss of these two tankers on the evening of the 8th of January 1943 as can be seen in Track chart A.

---

[180] Ibid, Track Chart A
[181] Rohwer, Axis Submarine Successes, page 145

HAVELOCK continued the pursuit of U-436 after the U-boat had submerged to escape by using her ASDIC and depth charges but with no success and U-436 escaped with only minor and lived on until being sunk in April of that same year[182][183].

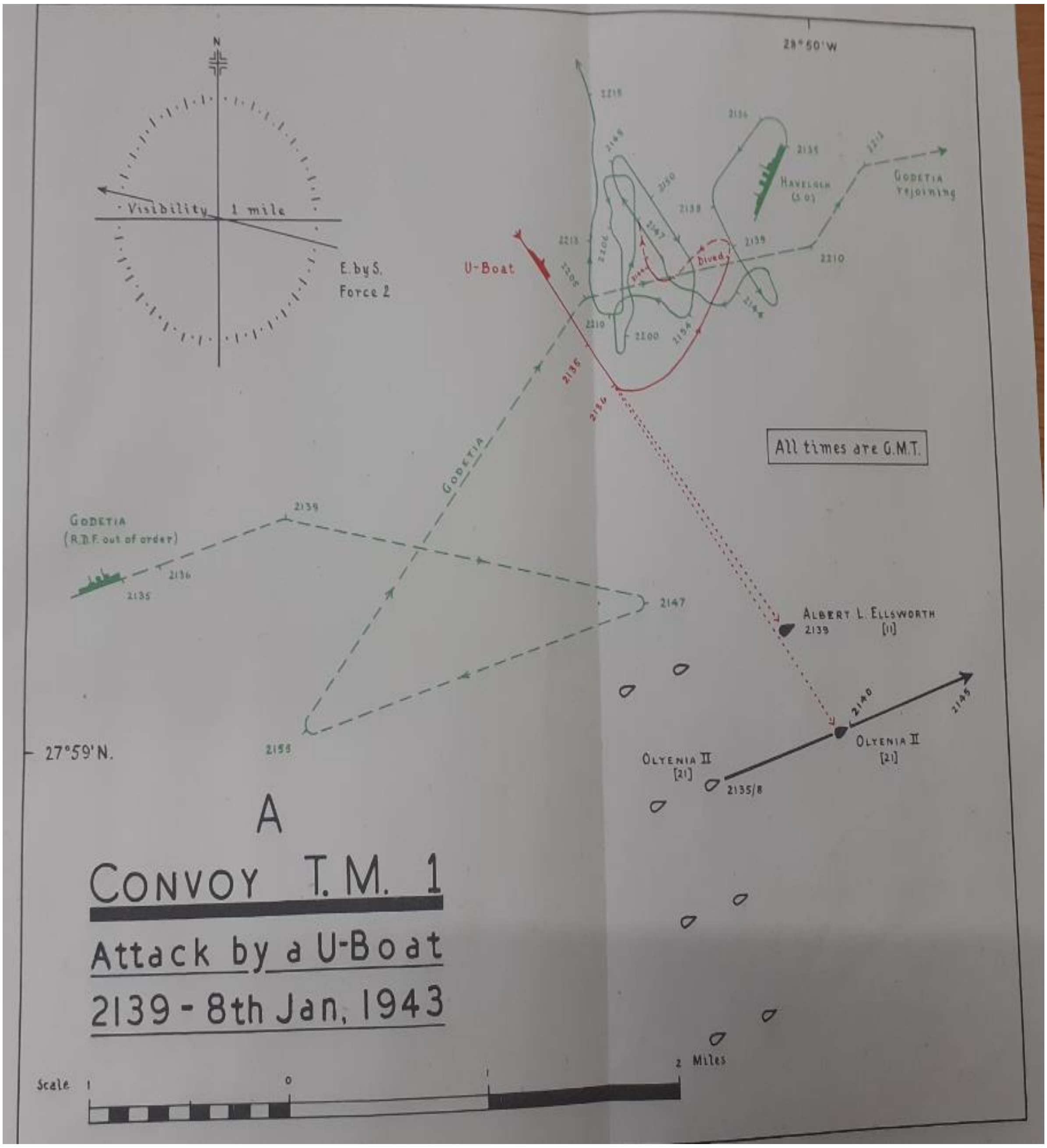


Figure 58 Track chart of an attack by escorts of TM-1 on a U-boat

From what has been stated above it can be deduced that having a functioning RDF on an escort vessel is not a guarantee of detecting a surfaced U-boat even in modest seas and at a range of only half a mile. The plots of U-boat detection shown in Figure 59 indicate where U-boats were when first detected by

182 Blair, Hunted, page 147
183 Niestle, U-boat Losses, page 64

the escorts[184]. The analysis of TM-1 reported that was well as attacks and attempted attacks there were the multiple attacks where the U-boat responsible was never detected[185].

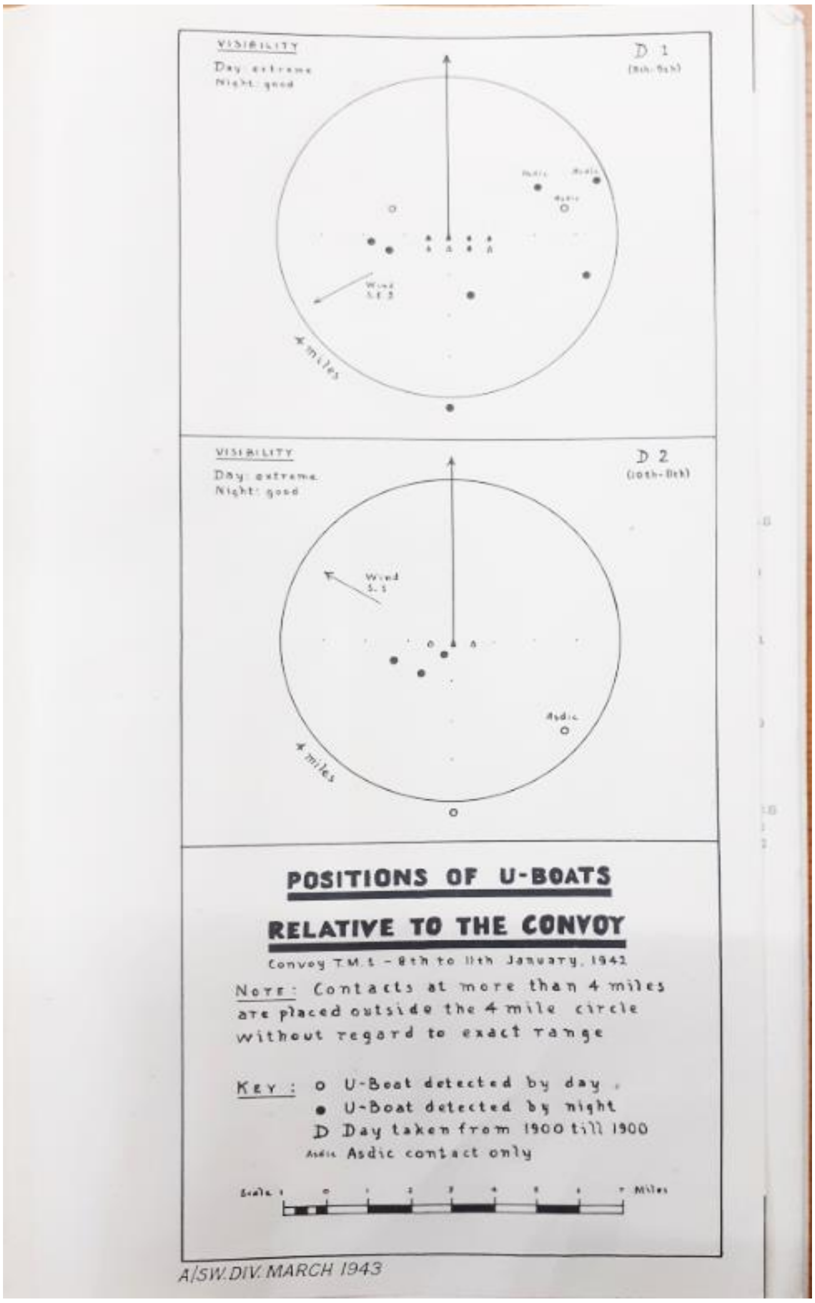


Figure 59 Plot of positions of U-boats when first detected around TM-1

Control of the U-boats attacking convoy TM-1 was done exclusively and minutely by Doenitz himself and as he reflected after the war on his success with this convoy he quotes Roskill's assessment of TM-1: 'The convoy was cut to pieces'[186].

---

184 ADM 199/2016 Analysis of U-Boat Operations, before page 12
185 Ibid, after page 11
186 Doenitz, Memoirs, page 320

Chapter 4 THE BATTLE MODEL

4.1 AN OVERVIEW OF THIS CHAPTER

(4.2) Discusses the architecture of the Battle Model (BM). Here the hierarchical nature of the computational treatment is described and its use to avoid unnecessary calculations where possible.

(4.3) Describes a convoy centric use of the BM. The design of the model is described and its convoy centric viewpoint is explained in terms of ease of plotting the torpedo tracks and understanding that an observer has in viewing them. The kinematic approach to representing the motions is discussed and the role played by the geometric arrangement of ships in the matrix of convoy columns and rows. The structure of SC107 is a 9 by 5 matrix of locations where ships may be allocated to. The rear row of the five rows has three empty locations on the night of 1st/2nd November 1942, as may be seen in Figure 41. The effects of the geometric matrix used in a convoy of 9x5 ship locations on the possible number of lines from a point outside of the convoy that intersect those ship locations is explored in Annex C. Such a study sheds light on the way that these interesting lines changes in number as the point of their origin is moved closer to the matrix centre. This geometric limitation on the number of intersections has bearing on the probability of a U-boat scoring a hit on a ship when it fires a torpedo in any given direction.

(4.4) Applying the BM to the historic data on convoy SC107. This section describes the use of the BM in simulating the main combat events that took place on the first night of U-boat attacks on convoy SC107 in which 9 of the ships in the convoy of 42 ships were sunk. A further 7 ships were sunk in the following three days of the battle against SC107.

4.2 HIERARCHICAL ARCHITECTURE OF THE MODEL

4.2.1 The architecture for the computer Battle Model (BM)

The battle model has been implemented using an Excel workbook with data logged in worksheets as well as Visual Basic Application (VBA) computer code in the form of scripts attached to worksheets and in modules within the VBA development environment of the Excel workbook. Table 6 shows the workbooks, worksheets and modules that contain the battle model, its code and modules.

Table 6 Main Excel computations for Battle Model

Location	Title	Purpose	Manual Inputs	Comments
WS5[187]	SC107 Layout	Input ship data	Cell location and resilience	Manual data input to RH layout. At start of BM data transferred to LH layout and updated as torpedoes hit ships
WS 38	SC107 2Nov Events Table	Script for BM	U-boat (location) torpedo (aim points, type), Convoy(speed) & Raspberry	Can be manually set or automatically from Torpedo Cal code

187 Excel Worksheet

WS38 (VBA[188])	Torpedo Cal	Automatic setting of U-boat flotilla locations	Flotilla x 2 (Range, spacing and angle on the bow)	Used for the counterfactual
WS27 (VBA)	Exec Control 2	Top level control of BM	Number of runs, number of items to be used from Event table in run, Torpedo, speeds, ranges, convoy speeds.	Master controller of inputs and outputs, calculates totals of hit, dets HITDETs and writes to Battlespace and SC107 Output01
Module[189] 1 (VBA)	Sub BOA SIMS	Torpedo fire, track and hit calculations	Percentage torpedo fuze failures, locations of ships in battlespace	Complex hierarchical logic and heart of BM. Output written to SC107)utput01
Module 2 (VBA}	Sub BOA_SIMS_RASP	Escort verses U-boat combat	None	If a Raspberry call has been made in the WS 38 events table the escort and U-boat initial locations, directions and speed will be input. The Rasp code then runs and the escorts charges the U-boat if on surface or submerged. The U-boat tries to manoeuvre by random turns and depth changes until U-boat is sunk or 5 attacks have been made. Multiple attacks were launched by RESTIGOUCH on suspected U-boats but with no results or evidence that U-boats were present in the vicinity of the attacks. As such Module 2 was not used in this work.
WS36	SC107Output01	Record of all runs location of hits, hitdets and hitduds	None	Main record of BM unprocessed output
WS46 (VBA)	SC107 Processed_Output01	To post process battle data generated	None	This code totalises and records on WS 46 spreadsheet the results for all the runs carried out by the Execs 2 code
WS14	Battlespace	Visualisation of last run of BM, includes torpedo tracks and remaining merchant ships	None	Also includes Diagnostic data for code development phase

188 WS Visual Basic Applications, code attached to the Excel worksheet accessed only in the VBA development environment within the Excel workbook
189 A module defined and accessed only in the VBA development environment within the Excel workbook

WS48	BattlespaceRaspberry	Visualisation of the escort verses U-boat battle	None	Includes tabulated locations of combatants and diagnostic data for code development

The BM has been implemented using an Excel workbook and Visual Basic Applications (VBA) language embedded in the workbook. There are two sequences that the BM can follow during the course of it running. First, there is the primary mode of operation where the model executes code that simulates an attack by U-boats on a convoy using torpedoes; this is represented by the flow chart in Figure 60. Data is input manually to the four boxes shown at the top of the diagram when the model is changed. Once the data has been input and the BM set running via the Executive Control 2 spreadsheet code then the U-boats are positioned and torpedoes fired in the sequence that has been input.

The ship locations and their resilience to torpedoes (how many torpedoes it takes to sink that ship with the cargo it is carrying) are inserted manually in the spreadsheet marked as convoy layout, e,g. SC107 layout. The role of the escorts in the BM are currently limited to reflect the following keys aspects;

(a) In the cases of SC107 and of TM1, a great deal of escort time and effort was devoted to chasing U-boats at some distance from the convoy with no results and no evidence that the attacks were in fact anywhere near a U-boat.
(b) When the individual U-boats did attack SC107 and TM1 the escorts were totally ineffectual and failed to prevent the attacks.
(c) In the counterfactual to be discussed in the next chapter it is assumed 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 all the torpedoes (64 in total) of the attack in the very short time need to release them (<1 minute).

The BM includes an engagement between an escort and a U-boat and this has been set up for future use. The probability of sinking the U-boat by means of depth charges in the model is 10% which is in line with the historic data referenced later in this thesis.

It should be noted that any representation of an escort is stationary in the counterfactual and act purely as targets for an undetected attack such as in the counterfactual case. Escorts have been inserted in the convoy layout in the case of Convoy TM1 but not in the case of SC107 due to the fact that only two of the Escorts to SC107 were present when the first attack began and the location of other two escorts are not accurately known.

The Executive Control code fires the torpedoes in the sequence input in the event spreadsheet if it is a representation of an historic battle. In the case of the counterfactual the code in the Executive Control selects randomly from the list of U-boat/torpedo aim points until the required number of torpedoes have been fired.

For every torpedo fired the data is transferred to Module 1 if it is non-raspberry, i.e. the U-boat is outside the convoy, and the track of the torpedo is first adjusted away from the aim point to allow for the aiming and guidance errors expected. The torpedo track is projected towards the convoy entity outside the boundary of the convoy in one step eliminating unnecessary computation of multiple steps where nothing happens. Once at the edge of the convoy the code determines which ship cell entity box it has entered and then moves on to the kinematic timed progress through multiple ship cells calculating the miss distance to the ship in that cell. If a hit is detected then the torpedo calculation is stopped and the hit is recorded and followed by a step where the status of the fuze detonation is determined by a random number generator between 0 and 1 and if under a pre-set number (0.1) it is deemed to have failed and recorded as a HitDud instead of a Hit. The code then passes those results together with the row and column numbers of the ship that has been hit. If the hit includes a detonation, it is also recorded as a HitDet.

Once the torpedo hit status has been passed back to the Executive Control it is added to the accumulator and the data is sent to the Worksheet that records that data into the array of cells for that run number, ship location. The Executive control also subtracts that hit status for the ship in question and subtracts it from the Resilience score the ship has at that point of the battle. For example, if the ship has a resilience of 3 assigned to it at the beginning of the battle and gets hit by a torpedo the status is reduced to a value of 2, meaning it can survive on the surface and be able to be hit a further two time before it has a status of 0 and thus sunk.

To understand why this is a valid thing to do for resiliencies greater than 1 it is necessary to understand the counterfactual, when the type of attack represented by the concentrated and near simultaneous attack by many U-boats firing salvoes of many torpedoes in a relatively short time period the ship will be hit by more than one torpedo before it has time to sink or drift backwards in the convoy. For a representation of the historic battle such as that of SC107 a ship that is hit by one torpedo will stop either by having its engine room disabled or by the decision to abandon ship. Either way it will be removed from the battle before the next U-boat attack which is typically hours after the previous attack as happened on the first night of SC107's ordeal. Ships in this case for the model have a representation of resilience of 1.

Once the torpedo hit data for multiple runs have been recorded these data can be processed to determine the accumulated hits in each location within the convoy as well as the percentage of the numbers of torpedoes fired that hit ships at each location using the counterfactual tactic.

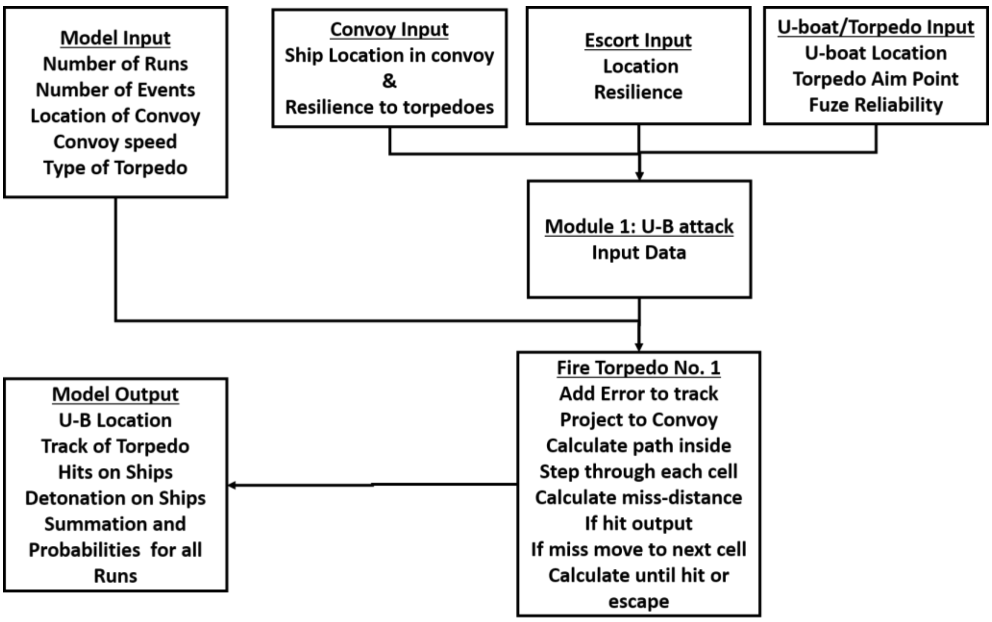


Figure 60 Top Level view of the U-boat attack on a convoy

The second mode of operation in the case where one of the events in the event table includes a Raspberry event then the Executive Control code diverts the computation for that case where a U-boat is inside the convoy and the simulation then moves to the Module 2, see Figure 61. In this module the action takes data from the spreadsheet for Escort Manoeuvres and outputs the zigzag tracks of four escorts and calculates the distance of each ship from the now submerged U-boat. If any of the escorts are within sighting or ASDIC range, which are assumed to be approximately the same, then the computation moves to the escort attack spreadsheet. In this the pre-set data for the encounter the U-boat and escort initial positions are transferred from the Raspberry output and then the behaviour of the escort is calculated as being always toward the known position of the U-boat when it is attacking. Once it has attacked it follows a typical escort run out from an attack away from the attack site and turns back until it is facing the latest position of the U-boat as it assumes at that point is detecting the U-boat by ASDIC again. During the time that the escort has been running out away from the last depth charge attack point two things are calculated, the descent of the depth charges down to the depth they are set for and the path of the U-boat in 3 dimensions which the commander of the U-boat can adjust to escape the attack by changing course and depth. These U-boat position changes are calculated using a random number generator to simulate which way the U-boat commander will decide to go after the previous attack. When the depth charge module determines it is time to detonate it is assumed that all of the depth charges detonate together at the same time and depth. The distance from the centre of the depth charge spread to the centre of the U-boat is calculated and a kill or no kill is determined.

In the event of a kill for the depth charge attack then this part of the simulation ends and the Executive Control reverts back to the torpedo attack on the convoy. For depth charge attacks that fail to kill then the simulation continues with the escort attacking repeatedly until a kill of the U-boat is achieved or 5 attacks have taken place. The figure of five attacks has been chosen as this will probably have exhausted that escort’s supply of depth charges and have taken sufficient time, the best part of an hour such that the convoy battle will have moved away by distance that will take at about a half and hour or more for the escort to reach the convoy again. It is interesting to note that this absence of key escorts chasing down distant U-boats at critical moments seems to have happened in the case of both the SC107 and TM-1 convoys and may have contributed to the heavy losses suffered by these convoys.

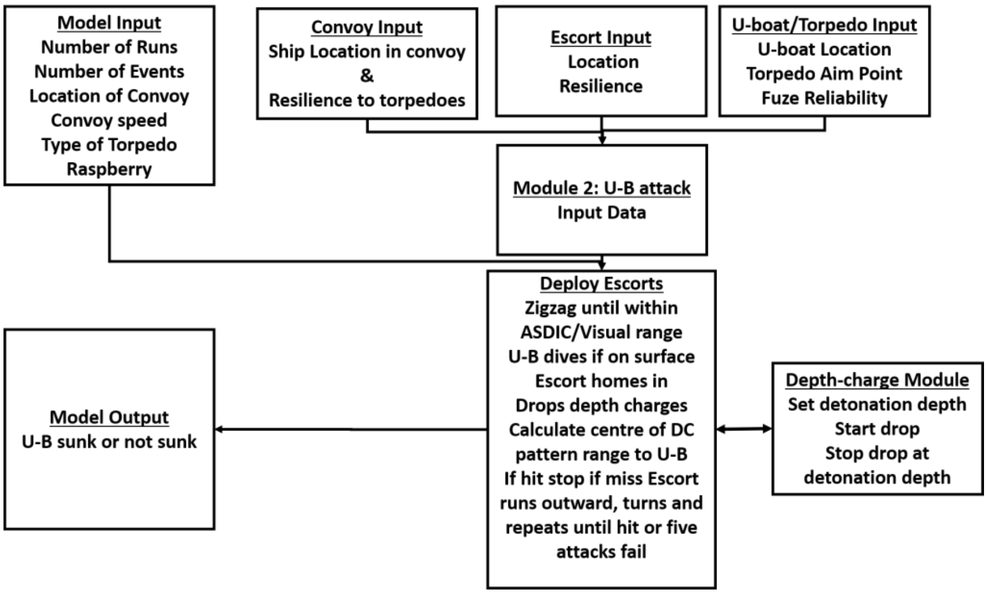


Figure 61 Top level view of the Raspberry algorithm

Examples of the VBA code are shown in Appendix D.

4.3 THE CONVOY CENTRIC AND KINEMATIC APPROACH TO MODELLING A CONVOY BATTLE

4.3.1 The Convoy Centric Frame of Reference

In this study the observer is in the frame of reference where the convoy is stationary. This method requires that a torpedo once launched has that launch point frozen relative to the convoy while the path taken by the torpedo in the convoy frame of reference will be determined by the combination of the torpedo’s velocity and that of the convoy through the ocean. This results in the track being relative to the stationary convoy.

4.3.2 The Kinematics of the BM

When the torpedo is fired with the relative velocity of U-boat, range and convoy velocity taken into account by the fire control system. From the point of view of the ocean the torpedo is aimed to pass through a point that is ahead of the target because the target/convoy is moving and the torpedo and target will come together. This complication of aiming ahead of the target is removed once the torpedo motion is combined with the convoy's motion in the equations of the BM and plotting the torpedo on a chart is a straight line from launch point to the end of the track. The speed of the torpedo will be greater in this frame of reference when the launch point is ahead of the convoy and will be reduced when the launch point is behind the convoy.

4.3.3 The Geometry of a Matrix Intercepted by Radial Tracks

Following WWII detailed analyses of anti-submarine techniques were undertaken both in the UK and the USA, The U.S. National Defence Research Committee published a set of studies covering a wide range of topics. In these the Division 6 produced Volume 2B covering anti-submarine warfare[190]. One of the diagrams from this report is reproduced in Figure 62. In this diagram a fan shaped set of lines radiating out from a firing point is indicated and represent the possible tracks that torpedoes might follow. The US analysis goes on to consider the 'Fuzy' nature of the locations of the ships in the convoy as their station keeping was not accurate and depended on the sea state, visibility and level of illumination of the scene. Such factors are not considered in the BM used here for simplicity and idealised rigid matrix used as in other studies in the U.S. series[191].

The tracks are straight lines and the target ships in a convoy are also shown in a stationary location within a crystal-like matrix. This is a kinematic model that is convoy centric, i.e., the ships and the potential torpedo tracks are relative to the convoy entity. The mathematical model created in this study follows this style of analysis. Annex A shows some examples of the US studies of torpedo fire against convoys.

---

[190] NDRC Div.6, Vol. 2B page 121

[191] Sternhell et al, US Library of Congress, Calculation of the probability of a torpedo hitting a ship after passing n columns of ships, page 103, See appendix A of this thesis for further details

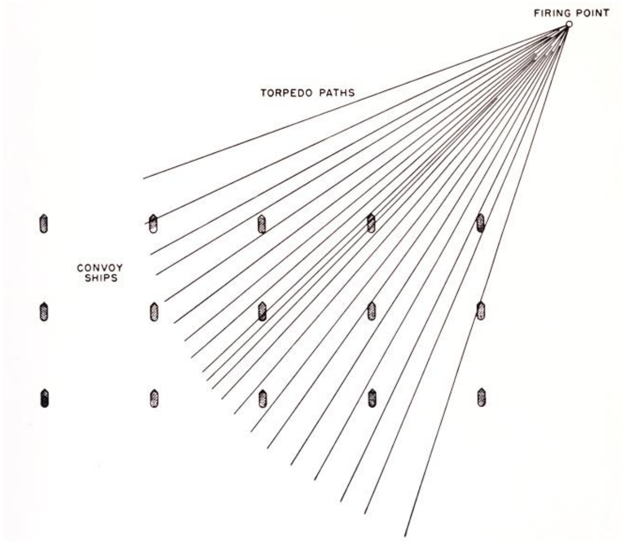


Figure 62 Geometric analysis by U.S. operational researchers looking at torpedo tracks

In this thesis the positions of the ships are locked in as if they were in a crystal matrix. The torpedo paths through this matrix provide for numerous opportunities of passing through the ship horizontal representations and the number of such intersections on any torpedo path is purely a matter of geometry dependent upon the relative location of the launch point around the convoy matrix and the size of the ship targets.

This aspects of the probability of a track passing through numerous ship locations has been explored and is reported in Appendix C. The main conclusion from this simple ray tracing exercise is that the number of opportunities a torpedo track has to intercept ships depends on the angle relative to the matrix and the range of the point from which they emanate from the convoy. It is clearly evident from Appendix C that the probability of the tracks emanating from a point that intercept ship locations has a non-monotonic curve that varies in range, see Figure 130 in Appendix C. In terms of the importance of this fact to the method it can be expected that both range and location of the U-boats relative the convoy as a whole will determine the probability of hitting any ship in the convoy and also to the overall efficiency of use of the torpedoes when fired in large numbers.

4.4 APPLYING THE BATTLE MODEL TO THE HISTORIC DATA FOR SC107

4.4.1 The Known Torpedo Attacks on SC107 on the first night of the Battle

The historic records compiled after WWII show that a total of 14 torpedoes can be reliably ascribed to having been fired at merchant ships that were inside the convoy matrix of SC107 at the time when the torpedo was fired on the night of 1st/2nd November (Noon to noon) 1942[192]. The locations of the U-boats are not recorded or reported with the exception of Forstner's first attack from U402 which from a distance of less than 1000 metres to starboard of its target the Empire Sunrise located in position column 9, row 3[193]. Table 7 shows the torpedoes and U-boasts. Also shown in the table are the locations from where torpedoes were fired and the location of their intended target[194]. An example of the exclusion from the BM of attacks of SC107 once the target ship is outside the convoy is that of the

192 Rohwer, Axis Submarine Successes…..pages 132 to 135…Note that two torpedoes fired from U522 are discounted because there is no evidence to support the commander's, Schneider, claims that they were as reported. Other claimed attacks on the escorts when they away from the convoy are also discounted.

193 Waters, Bloody Winter, page 44-45

194 Ibid, page 49

attack by U-84 on the abandoned HARTINGTON 29 minutes after U-522 had first scored a torpedo hit on it when it was undamaged and steaming inside the convoy.

Table 7 U-boat Attacks on Convoy SC107 on 1st/2nd Nov 1942

U-boat	XM	Target X	Target Name	YM	Target Y
402	23.9	23.12	Empire Sunrise	25.586	25.586
402	23.9	23.12	Empire Sunrise	25.586	25.586
402	17	18	Daleby	26.5	26.5
402	17	18	Dalcroy	26.5	26.043
402	17	18	Rinos	26.5	25.586
522	23.9	21.84	Hartington	25.22	25.586
402	17	18.64	Empire Leopard	26.5	26.043
402	17	18.64	Empire Antelope	26.5	25.586
522	24	21.84	Maritima	24.39	25.129
522	24	21.84	Maritima	24.5	25.129
522	24.6	23.12	Mount Pelion	25.09	25.129
522	24.6	23.12	Mount Pelion	25.09	25.129
422	24.5	22.48	Parthenon	24.5	24.672
522	24.5	22.48	Parthenon	24.5	24.672

The plot of one run of the BM representing SC107 and corresponding to the attacks of Table 7 is shown in Figure 63. The torpedo tracks are shown as yellow lines and the model does include a Normal Distribution of torpedo errors in the track that was actually applied in each run. This error process is incorporated in the model by calculating the miss distances in x and y coordinates based on the historic accuracy of German torpedoes extrapolated to a range of 10 km. The angular track errors for each torpedo are chosen at random from an array of numbers that contain precalculated values of a Gaussian distribution of angles from the intended aimed track angle. This Normal distribution has been given values where one standard deviation is 2km. corresponding to the known accuracy at 10km. However, the aiming accuracy of the U-boat commander has to be included in the calculation and this involves his estimation of the direction of the centre of the convoy which will vary with his perspective in the array of U-boats in the flotilla and this is taken into account in the calculations, see Appendix D for details.

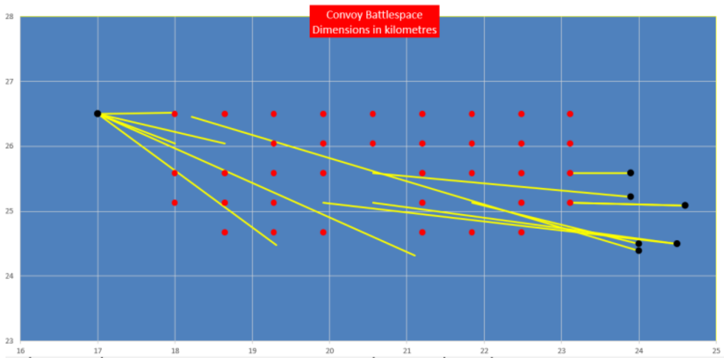


Figure 63 Example run of the Battle Model of Night of 1st & 2nd Nov. 1942

The BM was run 1000 times and the data accumulated for 14,000 torpedoes fired in total. The data on hits is shown in Figure 64. From the figure it can be seen that out of these 14,000 torpedoes 10,592 hit a ship. The resilience of the ships was set at a value of 1 meaning they would either sink immediately or effectively drift back through the convoy unless the historic recorded showed that they had been hit more than once in quick succession. The hit count on each ship location is shown for total numbers fired on the left-hand chart of the figure. The accumulated percentages for all locations in the convoy are shown in the right-hand table on the lower right of that chart as being 75.66%. This figure is of course representative for when a U-boat can get in close to the convoy and this is typically at a range of 1000 metres and mostly on the port and starboard flanks (referred to as beam in nautical terminology). The torpedoes that missed their intended target did have a modest probability of going on to hit other ships in the convoy. This effect can be seen in the ship locations that were hit but were not actually targeted. The locations coloured red are those ships that the historic records show were hit on the first night of the battle. It is notable that some locations had zero hit on them while those downstream of the flow of torpedoes from the few locations where U-Boats attacked from were hit. The locations coloured in blue represent those that were empty in SC107 according to historic records.

	Number of Hits on Ships in that Location									
Column	1	2	3	4	5	6	7	8	9	
Row										Sum In Row
1	446	56	5	0	0	0	0	0	0	507
2	448	452	117	172	24	2	9	10	23	1257
3	192	218	129	346	295	266	462	7	1972	3887
4	3	119	189	229	158	209	458	41	1870	3276
5	0	6	33	74	0	47	458	1047	0	1665
Sum In Column	1089	851	473	821	477	524	1387	1105	3865	10592

	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	3.19	0.40	0.04	0.00	0.00	0.00	0.00	0.00	0.00	3.62
2	3.20	3.23	0.84	1.23	0.17	0.01	0.06	0.07	0.16	8.98
3	1.37	1.56	0.92	2.47	2.11	1.90	3.30	0.05	14.09	27.76
4	0.02	0.85	1.35	1.64	1.13	1.49	3.27	0.29	13.36	23.40
5	0.00	0.04	0.24	0.53	0.00	0.34	3.27	7.48	0.00	11.89
Sum In Column	7.78	6.08	3.38	5.86	3.41	3.74	9.91	7.89	27.61	75.66

Figure 64 Torpedo hit statistics from 1000 runs of 1/2 Nov. 1942 model each with 14 torpedoes fired. Actual hits on left, % hit out of 14000

The BM also allowed for torpedo fuze failure and this was at a probability of 0.1. Figure 65 shows the BM results for this subset of the hits, or HitDuds.

	Number of Duds on Ships in that Location									
Column	1	2	3	4	5	6	7	8	9	
Row										Sum In Row
1	45	10	1	0	0	0	0	0	0	56
2	47	47	11	16	4	0	1	2	1	56
3	22	21	10	41	26	21	53	0	209	129
4	0	16	18	19	21	14	44	4	206	403
5	0	0	3	10	0	7	53	121	0	342
Sum In Column	114	94	43	86	51	42	151	127	416	986

	Percentage of total Torpedoes HitDuds on Ships in that Location									
Column	1	2	3	4	5	6	7	8	9	
Row										Sum In Row
1	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.40
2	0.3	0.3	0.1	0.1	0.0	0.0	0.007	0.014	0.0	0.92
3	0.2	0.2	0.1	0.3	0.2	0.2	0.4	0.0	1.5	2.88
4	0.0	0.1	0.1	0.1	0.2	0.1	0.3	0.0	1.5	2.44
5	0.0	0.0	0.0	0.1	0.0	0.1	0.4	0.9	0.0	1.39
Sum In Column	0.81	0.67	0.31	0.61	0.36	0.30	1.08	0.91	2.97	8.03

Figure 65 Torpedo Duds (no detonation) statistics from 1000 runs of 1/2 Nov. 1942 model each with 14 torpedoes fired. Actual hits on left, % hit out of 14000 on the right

The corresponding cases where the torpedoes hit and detonated are shown in Figure 66.

	Number of torpedoes hitdets on Ships in that Location									
Column	1	2	3	4	5	6	7	8	9	
Row										Sum In Row
1	401	46	4	0	0	0	0	0	0	451
2	401	405	106	156	20	2	8	8	22	1128
3	170	197	119	305	269	245	409	7	1763	3484
4	3	103	171	210	137	195	414	37	1664	2934
5	0	6	30	64	0	40	405	926	0	1471
Sum In Column	975	757	430	735	426	482	1236	978	3449	9468

	Percentage of total torpedoes hitdets on Ships in that Location									
Column	1	2	3	4	5	6	7	8	9	
Row										Sum In Row
1	2.86	0.33	0.03	0.00	0.00	0.00	0.00	0.00	0.00	3.22
2	2.86	2.89	0.76	1.11	0.14	0.01	0.06	0.06	0.16	8.06
3	1.21	1.41	0.85	2.18	1.92	1.75	2.92	0.05	12.59	24.89
4	0.02	0.74	1.22	1.50	0.98	1.39	2.96	0.26	11.89	20.96
5	0.00	0.04	0.21	0.46	0.00	0.29	2.89	6.61	0.00	10.51
Sum In Column	6.96	5.41	3.07	5.25	3.04	3.44	8.83	6.99	24.64	67.63

Figure 66 Torpedo HitDets (hit and detonation) statistics from 1000 runs of 1/2 Nov. 1942 model each with 14 torpedoes fired. Actual hits on left, % hit out of 14000

Some samples of attacks on SC107 from the BM are shown in Figure 67 with the plot of torpedo tracks on the left of each pair and the convoy layout showing the ships that survived in green and the ones that had changed to blue after being hit by a torpedo that also detonated.

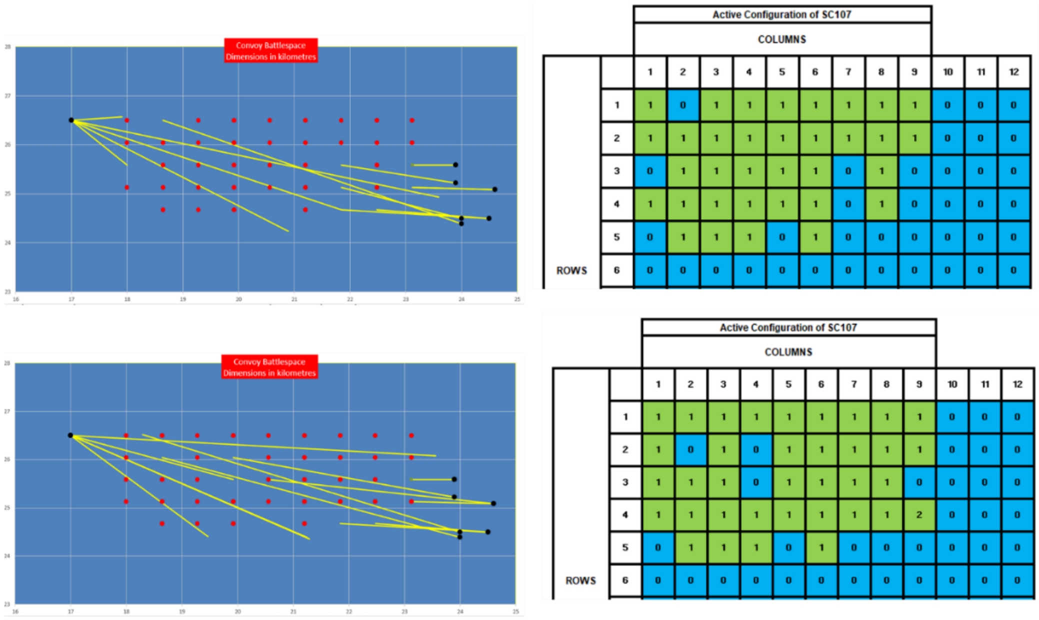


Figure 67 Two examples of the results using the Battle Model on single runs, Torpedo tracks on left with end results on ships hit or sunk on the right

Figure 68 shows two further examples of the attacks but in the second case, lower one it is showing a red coloured location. This is because the ship there was given a resilience of 2 but was only hit by one torpedo. This is location 9,3 and that represents the Empire Sunrise which was fired at by Forstner in U-522 using 2 torpedoes because the first one missed the target as was the case in this run of the BM.

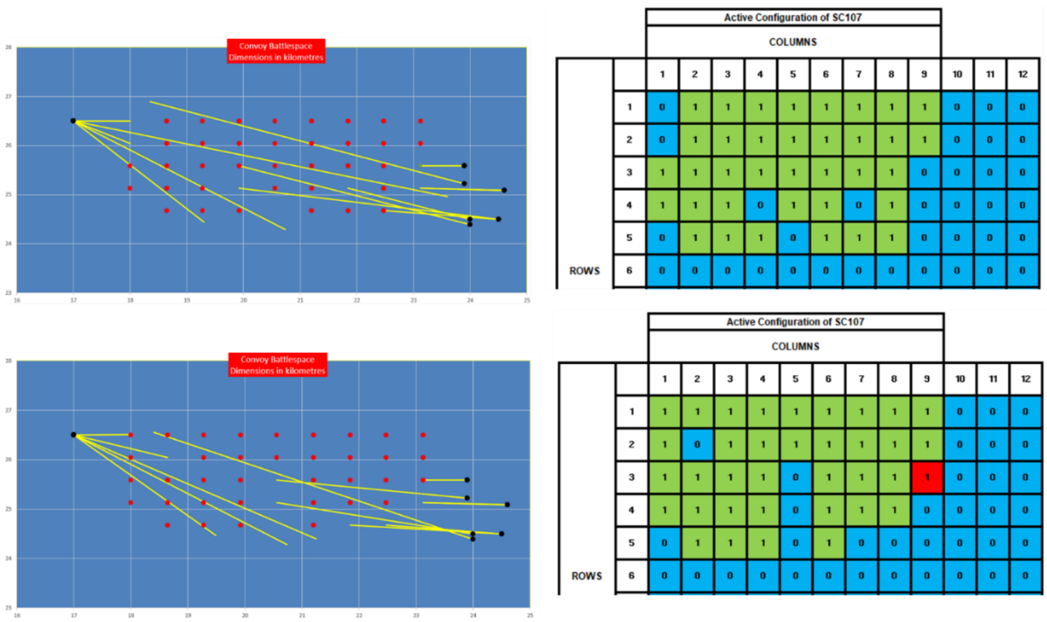


Figure 68 Two further examples of the results using the Battle Model on single runs, Torpedo tracks on left with end results on ships hit or sunk on the right

In Figure 69 the data output of the model has been collected to show the number of hits for each run of the model accumulated over the 1000 runs as a histogram. The historic values are shown by the red flag. We can therefore conclude that the BM does reproduce the typical performance of a torpedo attack on convoy SC107 and by extension can be used in the counterfactual with the expectation that the results will be representative of what could happen. We have seen already in Figure 64 that the percentage of torpedoes hitting their intended historic targets (those highlighted in red) average 5.7% probability of being hit, whereas those not historically recorded as being hit average 0.75% probability of hit. Thus the ships that were intended targets when fired at from within 1 to 2 km range were 7.6 times as likely to be victims of these attacks than those ships that were not aimed at when using 1000 runs of the BM.

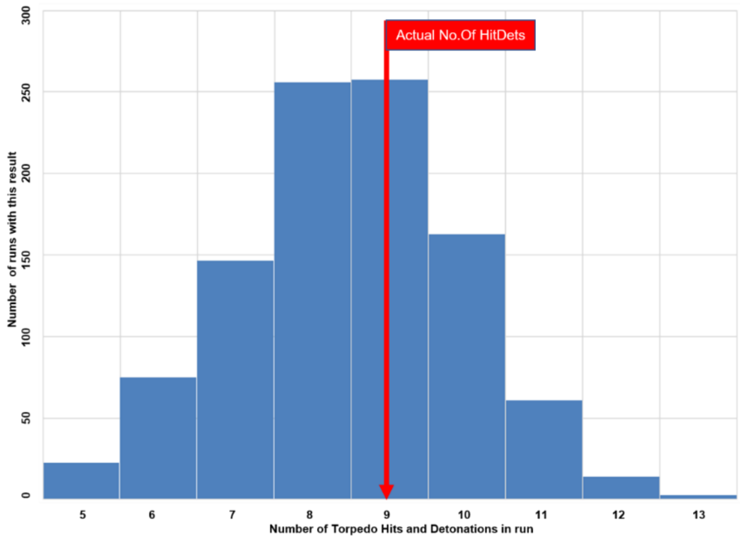


Figure 69 Statistical distributions of the results of the 1000 runs of the 1/2 Nov. showing HitDets, i.e. hit and detonation of warhead. The flag shows the historically known hits which were also detonations.

Note that the percentage of torpedoes that hit but did not detonate was set at 10% which corresponds to the historically representative value for this period of the WWII.

4.4.2 Modelling an example of the Depth Charge attack on a U-boat

There were numerous examples of the escorts of SC107 seeking out and attacking what were believed to be U-boats but which history shows us were not successful. The activities of RESTIGOUCHE on the night of the 1st/2nd November 1942, as recorded in the Deck Log reported in Chapter 2, indicate three attacks on one possible U-boat that did not sink or receive serious damage. To represent this in the BM for SC107 a single engagement was simulated using the Raspberry module. The settings used were representative of a 0.1 probability of sinking a U-boat with a depth charge spread of 10 charges dropped. Figure 70 shows one such run of an escort seeking out and attacking a U-boat.

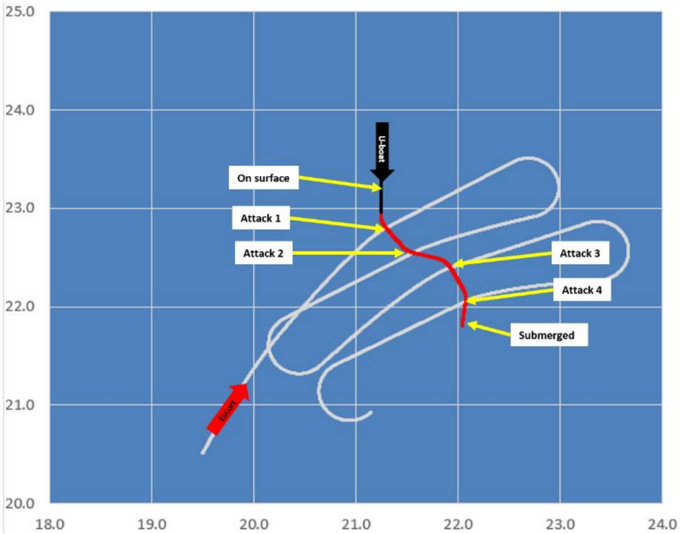


Figure 70 Modelling of a depth charge attack on a submerged U-boat

The U-boat starts out on the surface and dives when the escort is within 1.5 km of the U-boat, the figure shows a black line when the U-boat is on the surface and a red line when submerged. The escort's track is represented by a grey line. In this case four runs in to the attack are made by the escort before the simulation was stopped. On none of the four attacks were the depth charges close enough to count as a kill. The U-boat's track oscillates randomly representing the attempts by the U-boat commander to avoid the next depth charge attack. No further use of this aspect was undertaken in the study of SC107.

4.4.3 Summary of the Battle Model performance in representing SC107 and the attacks on it on night of $1^{st}/2^{nd}$ November 1942.

The model has been set up to represent a convoy by using a 'Convoy Centric' approach in which the convoy, and by extension the ships in it, are stationary and the torpedoes are the only moving elements of the model.

A separate model of an engagement between an escort and a U-boat has been created for future use. It has not been used to model each any of the failed search and attacks reported by RESTIGOUCHE on the night in question because there is no evidence to support the claims that a U-boat was in fact near to the point where the depth charges were dropped. The sounds of the charges detonating would certainly act as a deterrent for U-boats nearby but it did not deter the U-boat commanders of U402 and U522 because they were with the convoy and not where RESTIGOUCHE was.

In the use of the BM to represent the known attacks that hit and eventually led to the sinking of 9 ships on that day/night/day cycle of the $1^{st}/2^{nd}$ November the features of the model used, namely;

(a) Hierarchical representation of Convoy, ship cell, ship and torpedo
(b) Merchant ship resilience to torpedo attack has been included in the model, however, in the case of SC107 as it happened on the night of 1^{st} 2^{nd} November 1943 there were only two ships that were hit by more than one torpedo while they were actually within the convoy formation. This situation was represented by giving every ship a resilience of 1 meaning just one hit would result in the ship falling out of the convoy. However, those ships known to have been hit by two torpedoes in quick succession were given a resilience of 2
(c) Kinematic representation of the track of the torpedo in the convoy centric frame of reference including vector addition of torpedo and convoy velocities to remove actual velocities relative to the ocean to attain convoy centric values
(d) Normal Distribution of the torpedo track errors away from the aiming point
(e) Fuze malfunctions when a torpedo hits a ship (10% failures)

(f) Multi-run features to build up data base covering statistical variations of track error and fuze functioning
(g) Data recording of run results
(h) Post processing of data for examination and further analysis

All of the above features have been created, debugged and tested using the case of SC107 on its first night of battle against the U-boats of Wolf Pack Veilchen. The results of this modelling of the uncoordinated attacks by the U-boats does match the historically recorded data well, see Figure 69.

4.4.4 Use of the BM in examining the counterfactual

The proposed counterfactual is different from the situation faced by SC107 in its historically known circumstances. It is therefore reasonable to ask if the BM will be suitable for use in modelling these changed circumstances.

The counterfactual differs from a historically accurate portrayal of how Wolf Pack attack were normally conducted. To highlight these differences Table 8 has been created to show them.

Table 8 Comparing the counterfactual with the historic Wolf Pack Tactics

Aspect No.	Nature	Historic SC107	Counterfactual SC107	Comments
1	Time period between individual U-boat attacks	Hours	Seconds	The counterfactual is a synchronised attack
2	Number of Torpedoes in Salvo	1 or 2	64	All U-boats fire all four torpedo tubes in quick succession
3	Aim point of salvo	Centre of targeted ship	Centre of Convoy	The counterfactual is equivalent of Browning a convoy
4	Range to target	1 km	10 km	The Ace has to see his torpedo hit the chosen ship target to get credit for it. The counterfactual needs maximum range that the torpedoes allow and still can reach the far side of the convoy to allow spread of torpedoes at safest range
5	Angle on the bow	90 degrees	80 degrees	The analysis shown later indicates 80 degrees maximises hit

				rate against a 9x5 convoy

In creating the BM the circumstances of the counterfactual have been taken into account as well as the historically representative Wolf Pack attack. It is therefore expected that the results of the BM when applied to the counterfactual are credible within the limits of its definition.

Aspects of the counterfactual that are likely to be raised by critics might be as follows;

(a) The escorts do not detect the massive presence of the two flotillas as they approach
(b) The escorts would detect the flotillas and go forward to engage the U-boats, this despite the overwhelming firepower available to the U-boat flotillas simultaneously on either side of the convoy
(c) The chaos caused within the convoy by multiple ships being torpedoed within a time period of a few minutes would result in collisions between otherwise undamaged ships further increasing the effectiveness of the new U-boat tactic
(d) The flotillas of U-boats would be attacked and forced to scatter and submerge if attacked by an antisubmarine aircraft

The aspects mentioned above are valid points with some of them to be discussed in the following chapter. However, those aspects that involve extending the factual to cover how the Allies would have countered the counterfactual are beyond the scope of the present work but are valid and interesting.

Chapter 5 ANALYSIS OF THE COUNTERFACTUAL

5.1 OVERVIEW OF THIS CHAPTER

In this chapter the subsections deal with the following topics

> 5.2 The proposed counterfactual is described and how it amounts to a change to the tactics employed by a Wolf Pack once it has been tasked with attacking a particular handbook. This requires the U-boats of the Wolf Pack to divide into two flotillas, each with a local commander that the other U-boats formate on ready to attack the whole convoy and not individual aimed fire at lone ships. When done from a distance this was known as 'Browning' a convoy. The commanders position their flotilla to attack at the optimal angle to the convoy and both flotilla commanders simultaneously order all their U-boats to fire at the centre of the convoy. This produces a mass barrage of torpedoes hitting the convoy from both sides simultaneously. The tactic collects together all the U-boats so that they must be present in the flotillas and operate under the orders of the flotilla commander and as such even the most inexperienced and least brave U-boat commander deliver all of the four torpedoes in a devastating barrage aimed at the centre of the convoy. The tactic also conveys much improved protection for the U-boat against attack by aircraft and escorts due to the combined firepower of the U-boats using their FLAK cannons, deck guns and torpedoes therefore reducing U-boat losses.
>
> 5.3 The assumptions underlying the BM as it is applied to the counterfactual are presented. The assumptions for the U-boat force is that Doenitz has decided to exploit the new tactic of Browning the convoy in a mass attack and abandons the inefficient lone Ace attacks. This also requires that the U-boat commanders have been trained to use the tactic before they are deployed to exploit it. The assumption is that the convoy targeted is that of SC107 and has the same speeds, distances between ships. The resilience of the ships to torpedo attack is assumed to dependent on their type and the cargo they are carrying. Convoy TM1 is also modelled.
>
> 5.4 The counterfactual is 'Optimised' by modelling the flotillas at a range of positions relative to the convoy targeted. The position is defined as the 'Angle on the bow' meaning the angle made from the direction that the convoy is moving in to the line drawn from the centre of the convoy to the centre of the flotilla. The optimal angle is judged to be the one that produces the most torpedo hits on the merchant ships in the convoy.
>
> 5.5 A sensitivity analysis is then carried out to examine the robustness of the model as set up for SC107 for various parameters used, these being: torpedo spread angle, convoy speed, stand-off range, separation distances between ships and finally the number of ships in the convoy.

5.2 THE COUNTERFACTUAL: AN IMPROVED TACTICAL USE OF THE U-BOATS IN A WOLFPACK

5.2.1 Overview of the chapter

This chapter considers the counterfactual propositions that Admiral Doenitz might have won a short-term victory in the Battle of the Atlantic in the latter half of 1942. The chapter contains the following aspects

Doenitz's demand for U-boat commanders to make long range radio contact with his headquarters before, during and after very encounter with an Allied ship or convoy was his micromanaging every aspect of every of the battle. This management style prevented local command by the experienced U-boat commanders and encouraged individual attacks by U-boats.

The British Admiralty's operational research team had considered how the Germans might have changed their tactics slightly by having synchronised mass attacks of U-boat flotillas rather than the piecemeal methods advocated in the U-boat Commander's Handbook. This was thought by the Admiralty to be a more effective attack method against convoys and also facilitated greater survivability against air attack. The Admiralty also recognised that standing off from a convoy and firing torpedoes at long range without aiming at individual ships, known as 'Browning', would be safer for the submarine and more effective use of the torpedoes.

The use of synchronised mass torpedo attacks by surface craft was in widespread use in the navies of WWII including by the those of the Germany Navy and some information on these are provided.

The methods used in the modelling are reported together with the results in the case of both a convoy in the forms presented by SC107 and TM1.

5.2.2 Admiral Doenitz's methods of command

As Doenitz's plan for implementing a 300 U-boat fleet began to be implemented during 1942 the background of the U-boat commanders began to be more diverse. Non-submariners and inexperienced U-boat commanders that were brought into the service caused problems because they needed to be closely commanded by a local commander because they lacked the skill and confidence to attack on the surface at night on their own[195][196].

Throughout the war Doenitz had concentrated control of the U-boats at sea in the Submarine Command (B.d.U), i.e. himself or his immediate subordinates, and this is clearly evident in the U-boat Commanders Handbook that was required reading by all operational U-boat commanders. In one part of the handbook Doenitz introduces the concept of 'Local commanders', who may only be appointed by Submarine Command (Doenitz) but may take control of the tactical deployment of the group. However, Doenitz limited the authority of the local commander to simply relocate the enemy[197].

This concept of a local commander was never exploited during the Battle of the Atlantic despite its potential advantages when concentrated and simultaneous attack might go beyond the Wolf Pack as practised by Doenitz. However, such operational doctrine was used in the German surface fleet when mass torpedo attacks were used against enemy formations of ships[198].

5.2.3 The Admiralty predictions on concentrated U-boat attack

The capability of the British Admiralty to analyse operational results and devise new tactics, procedures and equipment was not limited to that of their own or Allied operations. Within the archives there are examples where individuals have turned their knowledge, skills and creative thoughts to asking what the enemy might do to improve German battle performance.

One such study undertaken in 1943 asked what the Germans might do to improve the effectiveness of the Wolf Pack in attacking shipping[199]. This creative paper from the Operational Research Division of the Admiralty also realises that a local commander might better discipline and control less experienced U-boat commanders if they act as a local group under a local commander, see Figure 71. This Admiralty study goes on to identify that such a concentration of U-boats on the surface would bring about improved survivability for the U-boat when attacked by anti-submarine aircraft due to the multiple anti-aircraft guns on the flotilla that could be brought to bear on the attacking aircraft[200].

---

[195] Llewellyn-Jones, Antisubmarine Warfare, page 53
[196] Chalmer, Max Horton, page 179
[197] Carruthers, U-boat Commanders Handbook, page 149
[198] Bekker, Hitler's Naval War, page 268
[199] ADM 219/55, U-boats greatly intensify their attack, page 3
[200] Ibid, page 3

(b) To make his attacks on selected points and convoys with overwhelming force and so increase the proportion of ships sunk to U-boats sunk.

(c) To so organise matters that operations are controlled on the spot by his most resolute U-boat Captains in such a way that all others who shirk decisive action can be detected and replaced.

(d) Improve his convoy reconnaissance.

Figure 71 An extract from ADM 219/55 on improving U-boat tactics

The Admiralty study goes on to consider countermeasures that the Allied forces might adopt and range of inventive concepts for devices that the U-boats employ to protect themselves.

Effect of Attacking in Flotillas.

(a) By placing the most successful U-boat Captains in charge of flotillas, the laggards will tend to conform to the standards of the best. Moreover, if, for instance, definite orders are given to carry through attacks in a certain way it should be possible for the U-boat Command to verify whether these orders have been obeyed and to subsequently weed out unprofitable officers. This should lead to increased sinkings.

(b) 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 that are now practiced.

(c) By operating in flotillas on the surface U-boats will render attacks by the few A/C that now give air cover to a convoy both dangerous and ineffective. This will lead to much greater losses of shipping.

Figure 72 A further extract from ADM 219/55 on flotilla commanders and improved survivability of U-boats

The Admiralty paper makes it clear that instilling discipline under a flotilla commander of experience and possibly timid nature, or ‘Laggards’ as the paper refers to them, see Figure 72, will improve the number of ships sunk by each Wolf Pack and its U-boats present.

An important point addressed by the study is that of the details of the tactical deployment and how such a cooperating flotilla should conduct itself during a simultaneous attack on a convoy, see Figure 73.

In the figure the flotilla of U-boats conducts their night surface attack from ahead of the convoy from the ‘Angle on the Bow’ value of 0 degrees. From this angle the merchant ships will be seen head on and have the minimum angular subtense in the U-boats periscope which would result in the ships having the minimum cross section for the torpedoes to hit them. The effects of attack angle and probability of a torpedo hitting a ship in a convoy have been examined in this study and are reported below along with the determination of the optimum angle on the bow.

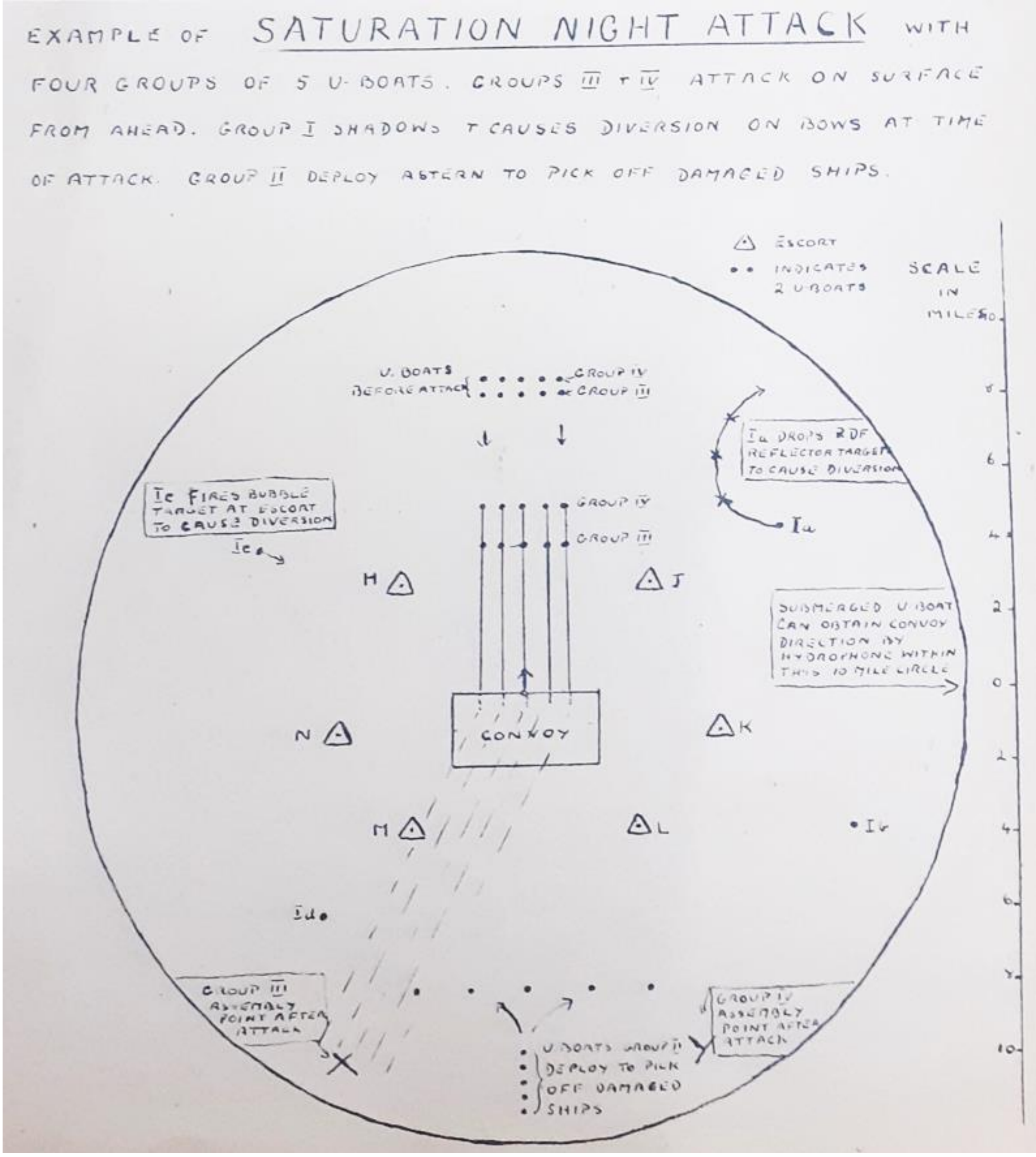


Figure 73 ADM 219/55 concept for attack created by the Admiralty OR group 1942

An earlier Admiralty study looked at the tactic for a submarine attacking a U-boat known as 'Browning' a convoy. In this tactic a submarine stands off at maximum range for the torpedoes being fired and the study in question considered the angle on the bow of the attack relative to the convoy, the torpedoes are fired in a spread of angles and are not aimed at any particular ship, see Figure 74[201]. However, from the figure it can be seen that the U-boats are expected to move through the convoy from the front and

[201] MFQ 1/583/15, A portfolio of diagrams extracted from Admiralty reports includes the Browning diagram which is the 15th one in the folder. The original use of the term 'Browning' dates back to the Royal Navy Handbook of Torpedoes in 1916 and is referenced in Brooks, John "British Destroyers at Jutland.

out of the rear of the convoy. This is unlikely to go unnoticed by the escorts who would probably attack the U-boats as would all the merchant ships that had deck guns manned by servicemen trained in their use.

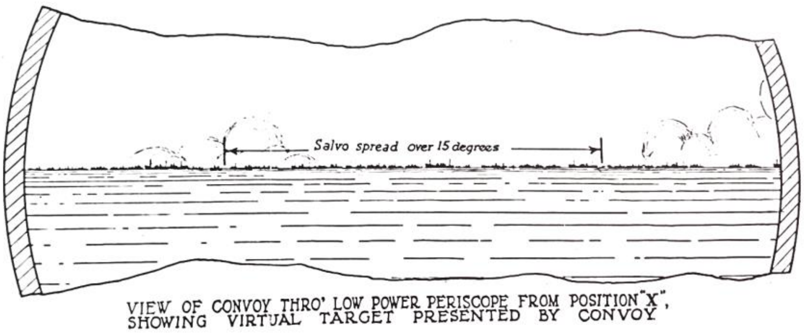


Figure 74 Extract from MFQ 1/583/15 'Browning' a Convoy periscope view

The main part of the diagram is shown in Figure 75. The two fan shaped line pairs shown emanating from each of the submarine locations shown on the arc on the left represent the two outer limits of the field of fire and the inner ones the probable angle range where hits might be achieved according to the reasoning in the legend from the diagram as shown in Figure 76.

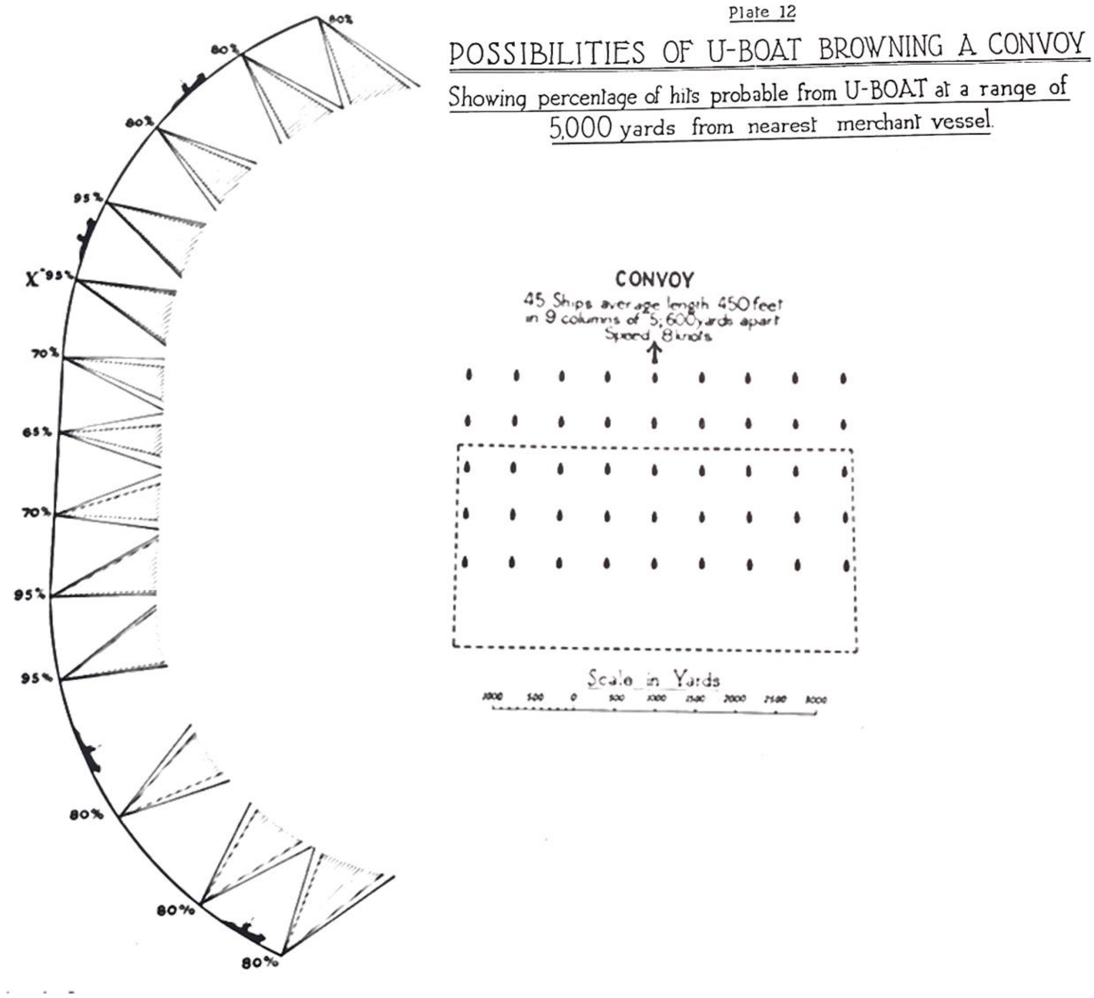


Figure 75 The main part of MFQ 1/583/15 'Browning' a Convoy

The diagram suggests that the optimum angle for firing torpedoes in a spread over the width of the convoy as seen through the periscope is at 75 degrees angle on the bow with a probable proportion of hits for these angles of 95%.

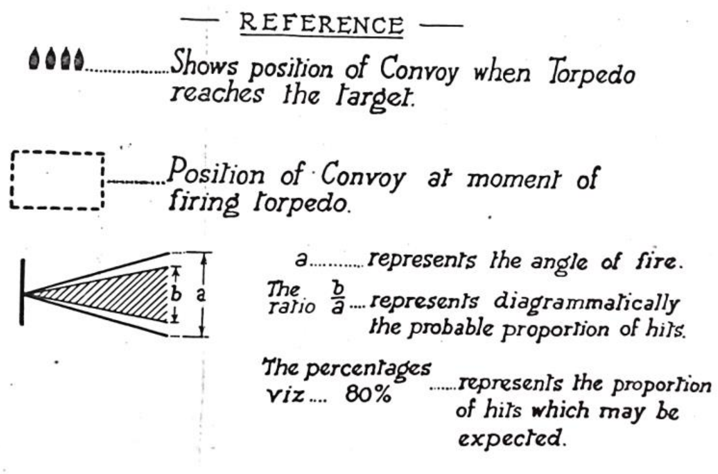


Figure 76 The legend for the Browning diagram

In the counterfactual proposed below in this thesis the equivalent performance with angle has been evaluated by the Battle Model.

5.2.4 The widespread use of synchronised and concentrated torpedo attacks in the Kriegsmarine surface forces as well as other navies of WWII

The use of mass attack by torpedoes fired from surface craft was not just limited to the German navy of WW II it was in fact the normal operating procedure for the Allied navies. As an example, the U.S. Navy had as part of their doctrine for motor torpedo boats a mass attack plan to be used against enemy convoys, as may be seen in Figure 77[202][203][204].

[202] US Navy Motor Torpedo Boats, page 42 figure 18
[203] NavWeaps, Were the best good enough, Internet group, see Bibliography
[204] Admiralty Trilogy, Surface Torpedo Tactics, internet Group, see Bibliography

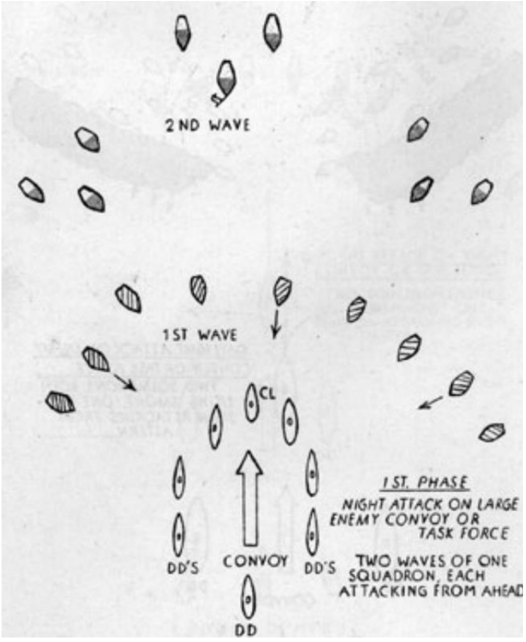


Figure 77 US Navy plan for mass torpedo attacks

The tactics shown in the figure clearly have similar thinking to that of the British Admiralty and the German navy of WWII but was not adopted by the U-boat command. The Admiralty conducted numerous studies on Wolf Pack tactics during WWII many of which mentioning concentrated and/or synchronised attacks but either ignored the tactic or dismissed it because U-boats could not locate a convoy and concentrate to attack at the same time[205].

5.3 MODELLING OF A CONCENTRATED AND SYNCHRONISED FINAL ATTACK PHASE OF A WOLF PACK ATTACK ON A CONVOY 1: THE MODEL

5.3.1 Assumptions for the U-boats in the counterfactual

The counterfactual chosen has the following principal assumptions

(1) Doenitz decides to place victory over the Allied convoy system as his first priority over all other considerations including his own control of the local tactical decisions, as he has already laid out in limited form in the U-boat commanders handbook.

(2) Trials of the new tactics including the use of existing medium wave and VHF radio beacons and single code word orders by the local commanders evaluated and further refined[206]. It should be noted that Doenitz did try local commanders in 1940 and found that it was best if he remained in total control of all aspects of the battle for every convoy[207].

5.3.2 Assumptions for the Convoy and Escort in the counterfactual

The counterfactual chosen has the following essential principal assumptions

---

[205] ADM 219/99 Pack Tactics by Submarines, page 5, This ignored the evidence that once followed by a U-boat that was reporting it was in contact with a convoy a pack could be formed in its path and then concentrate. Convoy SC107 and TM1 are examples of this. The U-boats then attacked individually and not simulataneusly.

[206] ADM 223/3 Intelligence Papers, folio 271

[207] Doenitz, Memoirs, Chapter 3 ”U-boat Tactics” pages 18 to 24.

(1) The convoy entity is treated in the same way that it was in the modelling of SC107 in Chapter 3
(2) The Merchant ships are locked into the ship entity cell as they were in Chapter 3.
(3) The resilience of the ships to torpedo impact and detonation is different to the way they were treated in Chapter 3 because in the counterfactual all the torpedoes would be fired within a matter of tens of seconds so a ship hit by one torpedo would not drop out of the convoy before the next U-boat turned up hours later for a follow up attack. As a consequence the ability of a ship to absorb multiple torpedoes before it sinks needs to be taken into account and for that an examination of the type of ship and the nature of the cargo it carries was made before assignment of the resilience took place. Ships with cargoes that float on water, like oil or lumber stay can absorb multiple torpedoes during the arrival period of the wave of torpedoes in the counterfactual so get a resilience of 4 or more. Ships with dense cargos like steel that do not take up a lot of the cargo holds volume when the load reaches maximum that is permissible for safe floatation are vulnerable to rapid sinking if the sea can flood in. Ships that have cargoes such as steel thus sink very quickly even with one torpedo hit so they only get a resilience of 1 in the BM. These findings are supported by the reports by the U-boat aces who feel obliged to see the ship sink and so fire as many torpedoes as is necessary in order to see it sink and therefore allow them to be awarded the sinking and raise their personal score on the way to Ace status and beyond to Knights Cross league of Nazi superheroes[208][209].
(4) Escorts are not present or active in the SC107 sized convoy models because the flotillas of U-boats are out of range of the RDF type 271 radar and would not react fast enough to see or prevent the onslaught of the wave of torpedoes inbound to the convoy, see Appendix B on the effectiveness of the RDF 271. As such the escorts do not feature in the modelling of the SC107 sized convoys. In the case of the TM1 convoy the Escorts are included but only to examine the effectiveness of manoeuvring a subset of U-Boats to fire at them in such that any of the torpedoes that miss the escorts go on to enter the convoy and have a good probability of hit against the merchant ships in the convoy.

5.4 MODELLING OF A CONCENTRATED AND SYNCHRONISED FINAL ATTACK PHASE OF A WOLF PACK ATTACK ON A CONVOY 2: OPTIMISATION OF THE COUNTERFACTUAL

5.4.1 Torpedo track geometric considerations against the SC107 convoy.

The following facts about the torpedoes and the U-boat's fire control system used in the counterfactual are taken as established[210][211]:

(1) The BM is a very approximate simulation of what happens in a real convoy of individually steered ships attempting to hold station in their allocated position in the convoy while fired at by U-boat commanders who have to make a decision as to the direction of the centre of the convoy in conditions of darkness, bad weather

[208] Budiansky, Blackett's War, page 119, 150
[209] Paterson, Kretchmer, page 63
[210] ADM 213/745 German Torpedoes Attacks, figure 8b
[211] ADM 234/466 German Torpedo Development, page 4

and rough seas. The torpedoes fired are gyro stabilised based on a inputs into the electromechanical computer made by the periscope operator. The tracks actually followed by the torpedoes will vary from the direction of the centre of the convoy that was estimated by the individual commander by random amounts that we have rough estimates of from post-war Admiralty studies. As such the BM can only ever be a very approximate estimate of the magnitude of the counterfactual tactics improved use of torpedoes and the consequential numbers of ships sunk by the number of U-boats present.

(2) The counterfactual includes just the use of the G7a torpedo because it has the range to pass through a medium sized convoy at all angles to the convoy from a standoff range of 10km from the centre of the convoy and not run out of fuel within the convoy. Appendix C presents a geometric analysis for 45 degree ‘Angle on the Bow’ attack that suggest a 10km range might be optimal for the use of torpedoes against a convoy. 10km is also the maximum standoff range from the centre of a 9x5 convoy that also allows the G7a torpedoes to cross the full width of the convoy without running out of fuel when fired from the flanks of the convoy. The standoff range for the counterfactual was set at 10km for these reasons.

(3) The accuracy of aim using the G7a was the same as for the G7e for which the probability of hit with range information is readily available.

(4) The distribution of torpedo track angles away from the intended aimed direction is that of a Normal distribution is assumed but it is also compared with the effect that a flat distribution has on the results of the modelling of the counterfactual.

Figure 78 shows the data obtained by the British Admiralty on the probability of hit with a German G7e torpedo. It is assumed that the G7a has the same error but can travel at faster speeds and longer range.

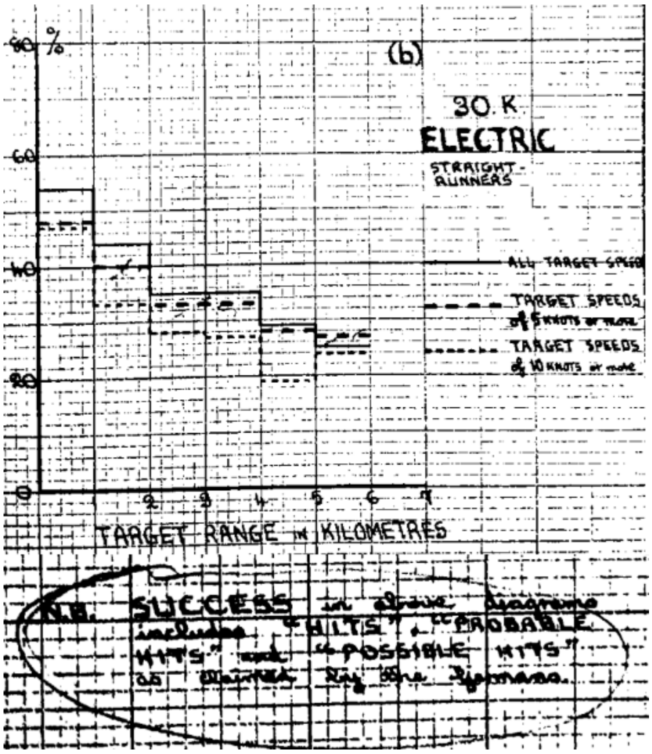


Figure 78 Accuracy of aimed fire using the G7e 30kt 5km range electric torpedo

It is interesting to see the number of torpedoes fired by the Germans from U-boats in WWII, which was 6264 for the whole war in all theatres, see Figure 79[212]. This is too few to sink enough ships to win the war with the probability of hit being 50% at best with the operational tactics and loss rates for U-boats since there were thousands of convoys and each of them had several tens of ships in them[213].

NUMBER of SALVOES FROM VARIOUS CRAFT TABLE 1.a.

3 · MONTHLY TOTALS

ALL TORPEDOES EXCEPT T.V.s are included

YEAR AND PERIOD	U-BOATS	E-BOATS	TORPEDO-BOATS	DESTROYERS & similar	Auxiliary CRUISERS	CRUISERS	CRAFT NOT SPECIFIED	TOTALS
1939:3	4							4
1939:4	189							189
1940:1	197							197
1940:2	248	55		2	2			307
1940:3	317	79	1	1	12			410
1940:4	319	26	5	9	10	4		373
1941:1	218	89			5	16		328
1941:2	406	50			6			462
1941:3	224	77	1	2				304
1941:4	249	30		3				282
1942:1	563	15	1	7	1			587
1942:2	619	58		4	6			687
1942:3	590	78	1		1			670
1942:4	627	90	2	7				726
1943:1	554	45					1	600
1943:2	288	95						383
1943:3	244	51						295
1943:4	161	65	9	5				240
1944:1	92	52	6					150
1944:2	81	62	6	5				154
1944:3	69	9						78
1944:4	5							5
DATE NOT SPECIFIED		2						2
WAR TOTALS	6264	1028	32	45	43	20	1	7433

Figure 79 Number of torpedo Salvoes fired by the Germans

The total number of ships that were sunk by U-boats during the course of the war was 2,275. The total number of ships sailing in the Allied convoys of HX and SC combined was over 24,000[214]. Of course, many of these ships made repeated journeys in the these and other convoys but it is indicative of the

212 ADM 216/745 German Torpedo Attacks, Table 1a
213 Hague, Allied Convoy System, page 116 to 122
214 Ibid, page 116

scale of the task Doenitz faced for him and his U-boat force to bring about some form of victory in the North Atlantic. The proposed counterfactual might have provided him with means for at least a limited and temporary victory but one which could have had consequences for the course of the final 2 years of the war in Europe.

The Normal distribution used in the Battle model, as discussed in section 4.4.1, is shown in Figure 80 and was created and used to set the distribution of the torpedoes paths around the line of aimed fire.

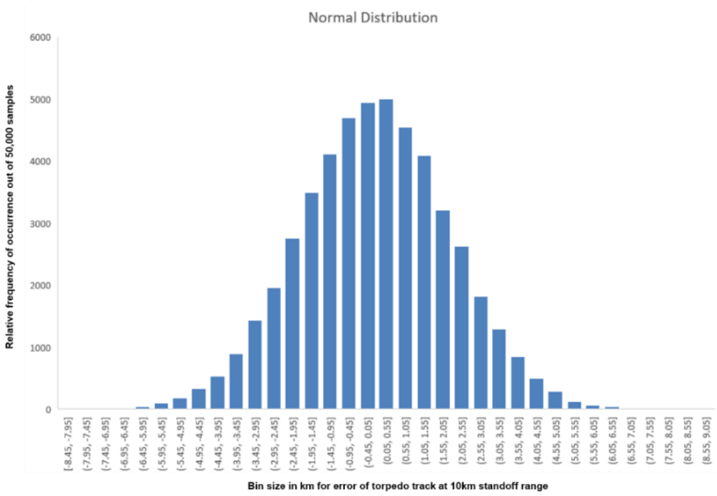


Figure 80 A normal distribution of torpedo dispersion for aim at 10km with 1 SD being 2 km

When the torpedoes travel from the flotilla of U-boats that are stood off by a distance of 10km from the convoy centre the aiming error spread of a torpedo is approximately 1.7 km wide as it passes the centre of the convoy, this is shown diagrammatically in Figure 82. The figure of 1.7km arises due to the probable aiming estimate of the U-boat commander of where the centre of the convoy is located. This figure has been set by the author to be the diagonal of nine ship array within the convoy arranged as a 3x3 matrix. Each ship is separated by approximately 0.64 x 0.46 km in size as reported in the SC107 Commodore's report, see Figure 48. If we define the size of the centre of the convoy as a 3x3 array of ship cells then the centre of the convoy is (2x0.64km) x (2x0.46km) with a diagonal of 1.6km. The aiming error of the U-boat commander was set at 1.7km to allow for inaccuracy of the ships station keeping, i.e. 0.1km greater than the 1.6km above. The spread due to torpedo guidance (Normal or flat Distribution) errors is calculated and then allowance for aiming error is implemented by multiplied by a factor to match the historic accuracies (x0.25), see Figure 78 and Figure 134 in Appendix D.

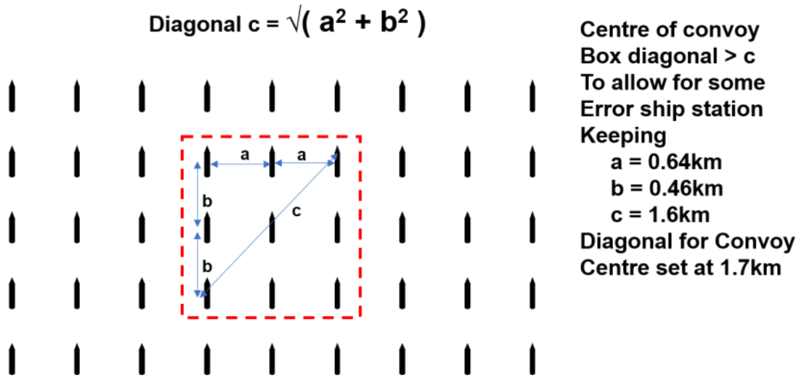


Figure 81 Centre of Convoy Definition

Appendix D shows extracts for the code that implements these calculations.

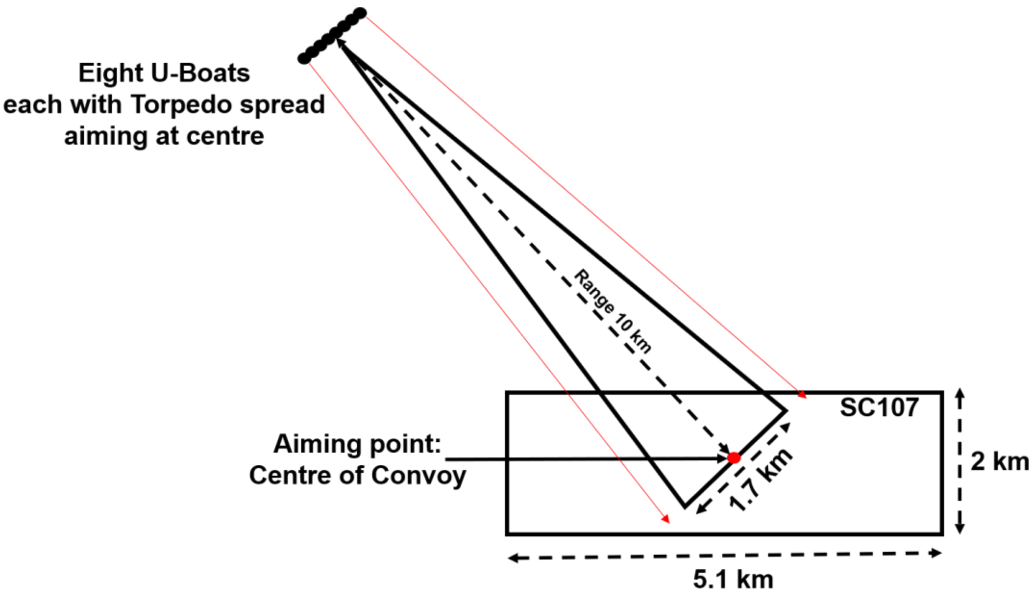


Figure 82 Approximate spread of the torpedoes in the counterfactual attack by one of the two groups of U-boats and convoy SC107

The battle model has been set up and run to represent the two flotillas of U-Boats in the counterfactual and is shown in the position with them either side of 0 degrees angle on the bow to the convoy ships, see Figure 83.

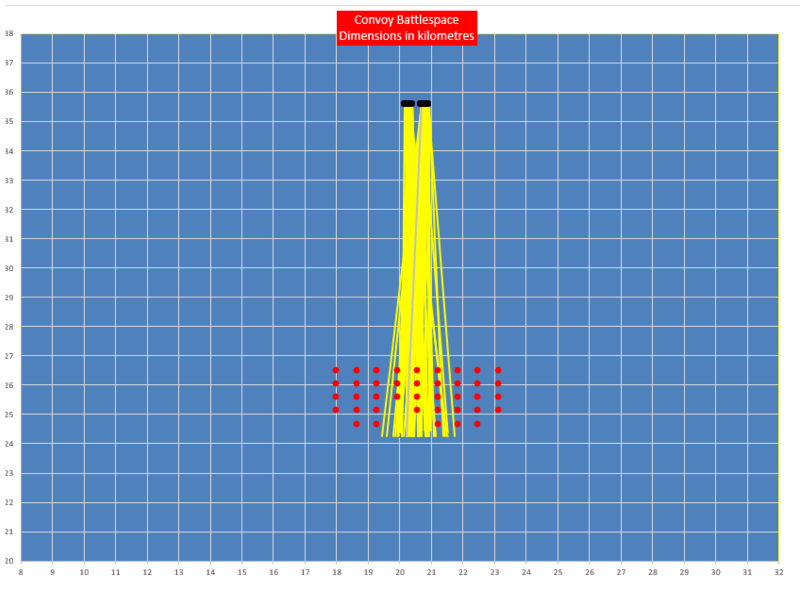


Figure 83 The modelled normal distribution of torpedo tracks Yellow lines fired at zero degrees 'Angle on the Bow' of the target ships.

5.4.2 Exercising the model over the range and angles of attack

The battle model was set up to represent the counterfactual where the two flotillas attack from both sides simultaneously and repeated runs were carried out and the number of hits on ships in the convoy recorded. Each torpedo fired in the simulation was given an error on the position it passed the centre of the convoy by means of generating a random number that selected a deviation from zero in the Normal Distribution was shown above in Figure 80.

The runs were repeated for various angles from 0 to 90 degrees angle on the bow, Figure 84shows the torpedo tracks for one run when the angle on the bow was set at 80 degrees. The formation of ships in the convoy was that of the SC107. The resilience to torpedoes of the ships represented the types of ship and their cargo in SC107 and their positions as n the night of 1st/2nd November 1942.

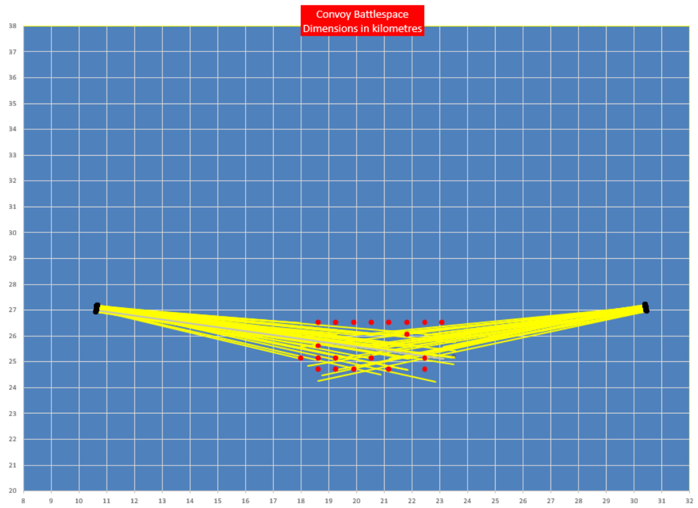


Figure 84 Battle model run showing an attack by 16 U-boats in two groups each at 80 degree angle on the bow to representation of convoy SC107

An example of the effects on the convoy can be seen in Figure 85. On the right-hand side of the figure the ships are shown in their pre-attack condition. On the left-hand side of the figure the ships show their status after the counterfactual attack has taken place. This is for just one run of the model out of the one hundred used to generate the statistical results of the model set at 80 degrees on the bow. Where a ship has been hit by a number of torpedoes equal to or greater than the resilience number allocated to it then it has been removed from the convoy for that particular run. Where the resilience has been reduced to just one then it is shown in red.

After the Attack

ROWS	COLUMNS 1	2	3	4	5	6	7	8	9	10
1	0	2	2	2	3	1	2	2	4	0
2	0	0	0	0	0	0	1	0	0	0
3	0	1	0	0	0	0	0	0	0	0
4	1	3	1	0	3	0	0	2	0	0
5	0	2	1	1	0	1	0	2	0	0
6	0	0	0	0	0	0	0	0	0	0

Before the Attack

ROWS	COLUMNS 1	2	3	4	5	6	7	8	9	10
1	2	2	2	2	3	1	2	2	4	0
2	1	1	2	2	4	3	1	3	2	0
3	1	2	1	2	2	4	3	1	1	0
4	2	3	2	1	4	2	2	2	2	0
5	0	2	2	1	0	1	2	2	0	0
6	0	0	0	0	0	0	0	0	0	0

Figure 85 A single result of one run out of 100 runs showing the effects of the attack at 80 degree angle on the bow on the left and the original pre-attack status on the right

The data on all one hundred runs was collected and a VBA module was run that accumulated the statistics and stored them in the arrays as shown in Table 9. This shows the number of times a ship in that position in the convoy was hit in the 100 runs where the 16 U-boats of the two flotillas fired a total of 6,400 torpedoes. The number of hits accumulated in each position will be influenced by the resilience of the ships and their distribution within the convoy. The lack of symmetry about column 5 arises because there was a lack of symmetry in the types of ships and their cargoes consequently this resulted in a lack of symmetry in the resilience figures awarded to the ships in the BM.

Table 9 The results in hits on ships of the 100 runs of the battle model with an angle on the bow of 80 degrees

	Number of Hits on Ships in that Location									
Column	1	2	3	4	5	6	7	8	9	
Row										Sum In Row
1	98	58	37	42	39	28	46	53	143	544
2	99	96	167	155	307	233	66	261	189	1573
3	87	176	99	186	192	346	248	75	86	1495
4	88	91	112	77	206	135	160	100	96	1065
5	0	35	56	29	0	25	68	35	0	248
Sum In Column	372	456	471	489	744	767	588	524	514	4925

The total hits were converted to probability of hit by dividing the total hits by the total number of torpedoes fired in each run of the model, which in this counterfactual setup is set at 64, times the number of runs which is 100. Therefore, the total number of torpedoes fired in the 100 runs is 6,400.

Table 10 shows the percentage hit probability for the 6,400 torpedoes fired to obtain the hits shown in Table 9. We can see in Table 10 that the probability of hit for the two flotillas attacking at angle on the bow of 80 degrees is 76.95% or rounded up this is 77%.

Table 10 The results in percentage of 6400 torpedoes fired hits on ships of the 100 runs of the battle model with an angle on the bow of 80 degrees

	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

Two further examples of the counterfactual attack are presented below, one at 50 degrees and one at 0 degrees angle on the bow.

Figure 86 shows one example of the counterfactual attack at 50 degrees out of the 100 runs completed.

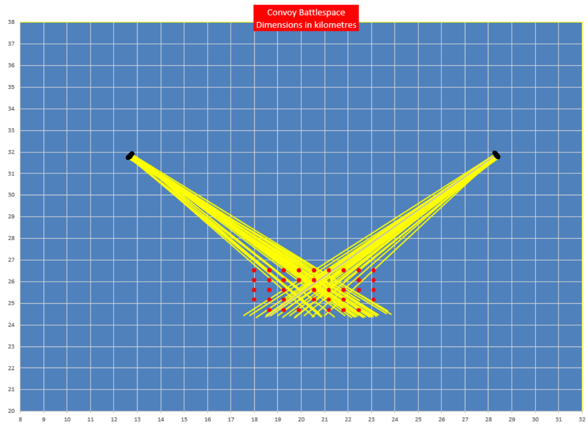


Figure 86 Battle model run showing an attack by 16 U-boats in two groups each at 50 degree angle on the bow to representation of convoy SC107

The corresponding convoy plans for that run are shown in Figure 87. By comparing this figure with the

Figure 87 A single result of one run out of 100 runs showing the effects of the attack at 50 degree angle on the bow on the left and the original pre-attack status on the right

convoy layout shown in Figure 85 we can see that an attack at an angle of 50 degrees is less efficient in terms of torpedo hits than an attack at 80 degrees. The advantage of the high 'Angle on the bow' attacks can be seen later in this thesis in Figure 90.

Tabulating the hits for the 50 degree angle we get the results shown in Table 11.

Table 11 The results in hits out of 6400 torpedoes fired hits on ships of the 100 runs of the battle model with an angle on the bow of 50 degrees

	Number of Hits on Ships in that Location									
Column	1	2	3	4	5	6	7	8	9	
Row										Sum In Row
1	2	43	70	66	53	51	65	42	3	395
2	1	7	47	83	63	91	31	9	0	332
3	6	5	24	76	113	70	29	15	3	341
4	8	8	24	57	92	71	16	16	8	300
5	0	18	44	46	0	39	61	21	0	229
Sum In Column	17	81	209	328	321	322	202	103	14	1597

The corresponding tabulation of the percentage hits out of the 6,400 torpedoes used in the 100 runs at 50 degrees are shown in Table 12 where the total hit probability is now approximately 25%.

Table 12 5 The results in percentage of 6400 torpedoes fired hits on ships of the 100 runs of the battle model with an angle on the bow of 50 degrees

	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	0.03	0.67	1.09	1.03	0.83	0.80	1.02	0.66	0.05	6.17
2	0.02	0.11	0.73	1.30	0.98	1.42	0.48	0.14	0.00	5.19
3	0.09	0.08	0.38	1.19	1.77	1.09	0.45	0.23	0.05	5.33
4	0.13	0.13	0.38	0.89	1.44	1.11	0.25	0.25	0.13	4.69
5	0.00	0.28	0.69	0.72	0.00	0.61	0.95	0.33	0.00	3.58
Sum In Column	0.27	1.27	3.27	5.13	5.02	5.03	3.16	1.61	0.22	24.95

The situation where the attack is performed as a head on to the convoy, or 0 degrees angle on the bow, is shown in Figure 88. The spread of the torpedoes where the aim point is the centre of the convoy is still the same as before but this narrow 'beam' of torpedoes now has the twin factors of low cross-section for hitting a ship as it is only the width of the ship that is presented as a target and the fact that the torpedoes only have five rows of ships to pass though before they exit the convoy.

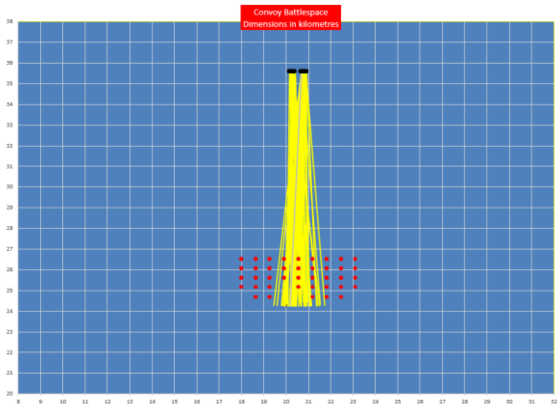


Figure 88 Battle model run showing an attack by 16 U-boats in two groups each at 0 degree angle on the bow to representation of convoy SC107

This adverse situation for attacking ships in the convoy is reflected in the example of one such attack shown in the convoy layout diagram shown in Figure 89.

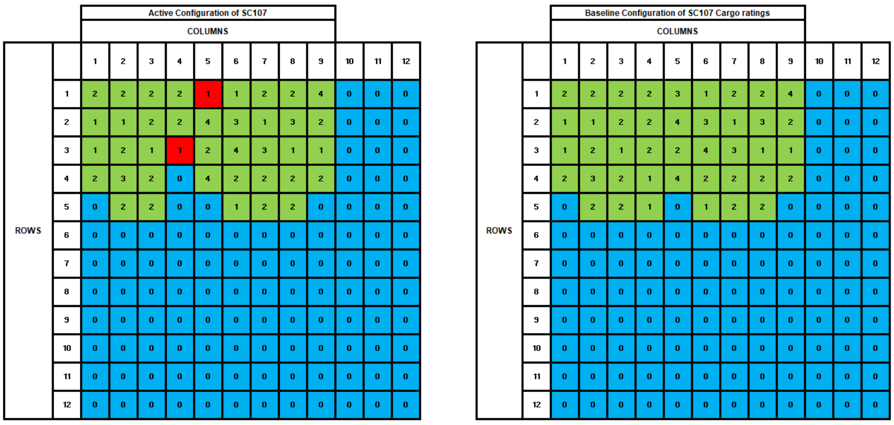


Figure 89 A single result of one run out of 100 runs showing the effects of the attack at 0 degree angle on the bow on the left and the original pre-attack status on the right

Finally, the tabulated hits for the 100 ruins of the model shown in Table 13 where it can be seen that only 418 hits were achieved out of the 6,400 torpedoes fired.

Table 13 The results in hits out of 6400 torpedoes fired hits on ships of the 100 runs of the battle model with an angle on the bow of 0 degrees

	Number of Hits on Ships in that Location									
Column	1	2	3	4	5	6	7	8	9	
Row										Sum In Row
1	0	0	3	27	64	14	2	0	0	110
2	0	0	1	28	23	18	2	0	0	72
3	0	0	5	38	39	15	2	0	0	99
4	0	0	6	27	30	20	2	0	0	85
5	0	0	1	29	0	18	4	0	0	52
Sum In Column	0	0	16	149	156	85	12	0	0	418

Table 14 shows the low percentage of hits as being approximately 7%.

Table 14 The results in percentage of 6400 torpedoes fired hits on ships of the 100 runs of the battle model with an angle on the bow of 0 degrees

	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	0.00	0.00	0.05	0.42	1.00	0.22	0.03	0.00	0.00	1.72
2	0.00	0.00	0.02	0.44	0.36	0.28	0.03	0.00	0.00	1.13
3	0.00	0.00	0.08	0.59	0.61	0.23	0.03	0.00	0.00	1.55
4	0.00	0.00	0.09	0.42	0.47	0.31	0.03	0.00	0.00	1.33
5	0.00	0.00	0.02	0.45	0.00	0.28	0.06	0.00	0.00	0.81
Sum In Column	0.00	0.00	0.25	2.33	2.44	1.33	0.19	0.00	0.00	6.53

Summarising the counterfactual when used against the SC107 convoy we obtain the plot in Figure 90.

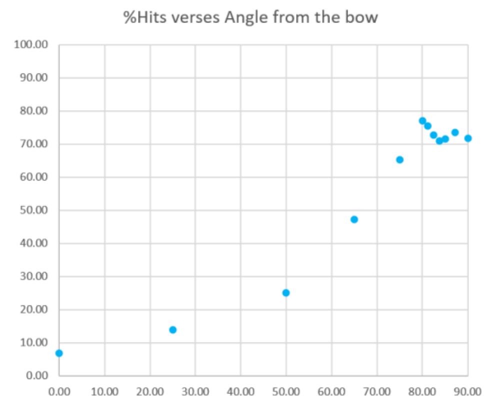


Figure 90 The hit probability for the counterfactual twin flotilla attack against angle on the bow

From the figure above we can see that the hit probability rises from the very inefficient value at 0 degrees monotonically up to a peak at 80 degrees. At angles greater than 80 degrees the plot shows a structure to the efficiency that at first falls beyond 80 degrees and then rises to a further peak that is lower than the one at 80 degrees. Subsequently it falls away again to a value of approximately 72% at 90 degrees. Similar structure can be seen in the figures in the sensitivity analysis in section 5.5 This structure to the efficiency plot is due to the sensitivity of the probability of hit to the number of row and columns of ships that the torpedo must pass through before exiting the convoy. This is combined with the fact that at high angles on the bow the spread of the torpedoes causes a percentage of torpedoes that miss the convoy completely. In reality the perfect station keeping used in the counterfactual is not representative of what is actually possible so the features in the plot shown in Figure 90 between 80 to 90 degrees would be smoothed out to some extent.

The BM was run 1000 times at the 80 degree Angle on the Bow. This was to examine the frequency of occurrence of the number of ships hit by at least one torpedo in each of the barrages of 64 torpedoes fired in each 1000 runs, see Figure 91. From the figure it can be seen that the most likely number of ships hit by at least one torpedo was 29 in a barrage of 64 torpedoes in each run. The figure also shows the resilience number given to the ship by type and cargo for this study, see Section 5.5.7 for details of these resilience figures.

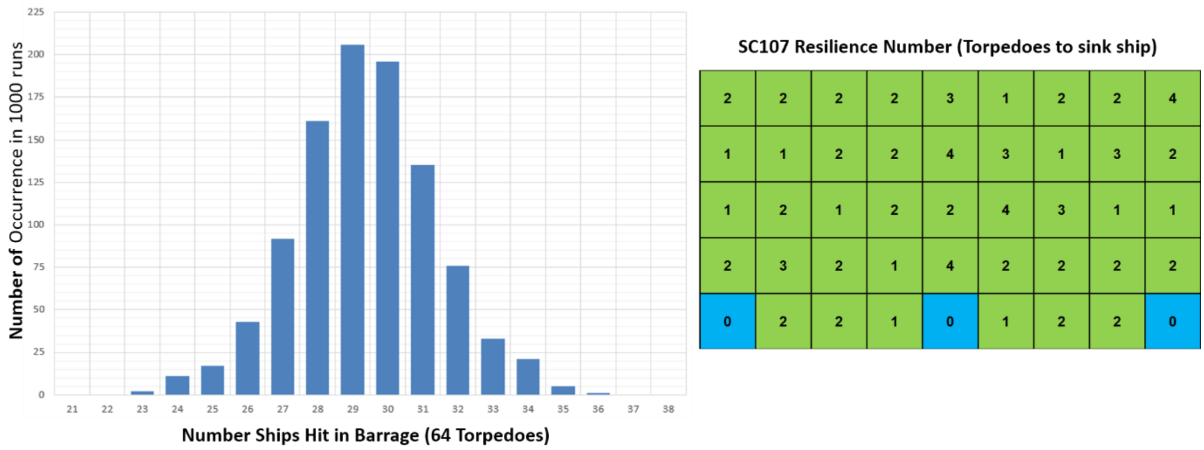


Figure 91 1000 runs of Baseline model at 80 degrees AoB

On average the counterfactual results in 29 ships being hit by at least one torpedo out the 64 fired by 16 U-boats. This means that those 29 ships would have probably have sunk even those that were hit by just one torpedo. In the case of the historical records of the attack, 15 ships were sunk by 14 original members of the Wolfpack over a period of 4 days with 2 U-boats sunk before the attack by aircraft and 1 U-boat was lost by being too close to the explosion of an ammunition ship.

The advantages that the counterfactual attack tactic bestows on the Wolf Pack is that it forces all the U-boat commanders to work as one team under the watchful eyes of the two flotilla commanders and makes use of all four torpedo tubes in each U-boat at one time. The tendency for the inexperienced and less confident U-boat commanders to wait for ships to be hit by the Ace commanders and then drift backwards for them to fire at an already sinking ship and claim a victory for themselves will be removed.

The effectiveness of the U-boats and their torpedoes may be summarised as the number of ships sunk per attack times the number of ships sunk per torpedo. Table 15 shows a comparison of the performance of the historic attack on SC107 against the counterfactual. The enhancement of the self defence of U-boats acting as a disciplined force on the surface, where they would have an 8 on 1 advantage for a flotilla if engaged by the closest escort vessel or by a very long range aircraft, have not been explored in this thesis but the topic does deserve further research as it may have substantially reduced the U-boat losses that were experienced in 1943. The 'Ships Sunk per U-boat' is the most direct metric for the effectiveness of the tactics employed and has the essential factors rolled into it relating to the effort Germany put into creating, manning and ensuring they were in the right place to attack a convoy.

Table 15 Effectiveness Comparison for Historic v Counterfactual

Event	U-boats	Attacks	Torpedoes Fired	Ships Sunk	Attacks per U-boat	Torpedoes per attack	Ships Sunk per Torpedo	Ships sunk per U-boat	Comments
Historic SC107	14	19[1]	32[2]	15	1.36	1.68	0.47	1.07	[1] 4 days [2] From range ~ 1to2 km
Counterfactual SC107	16	1[3]	64[4]	29[5]	0.06	64	0.45	1.81	[3] 5 mins [4] 10km from centre convoy [5] most probable in 1000 runs

If we define the following parameters-

U the number of U-boats in the Wolf Pack

A the number of attacks made by one or more U-boats in a period of less than 60 minutes

T the total number of torpedoes expended in all the attacks

S the total number of ships sunk from the convoy

Then various metrics can be created, these being-

The number of attacks per U-boat- A/T

The number of torpedoes per attack- T/A

The number of ships sunk per torpedo- S/T

The number of ships sunk per U-boat- $(A/U) \times (T/A) \times (S/T) = S/U$

These metrics are shown in Table 15. From the table it can be seen that the values of S/U for the two tactical options are in the ratio of 1.81/1.07 or an advantage of 1.7 in favour of the counterfactual. The survivability of the flotillas either singularly or in close formation when confronted whilst on the surface by Allied aircraft or escorts is likely to be much higher than was experienced most commonly as individual U-boats on their own[215].

5.4.3 Attacking the convoy TM-1 using the counterfactual attack method.

A brief examination is now given of the effectiveness of the counterfactual attack tactic against a convoy of high value tankers which are defended by a relatively high number of escorts. Figure 92 shows the convoy layout for convoy TM1 as might have been on the night of 8th January 1943. This may be compared to the Admiralty track chart shown previously in Figure 58.

In this case the convoy layout contains the four escorting warships shown as light grey coloured square, see Figure 92. Note all the tankers have been given a resilience of 3.

		Baseline Configuration of SC107 Cargo ratings											
		COLUMNS											
		1	2	3	4	5	6	7	8	9	10	11	12
	1	0	1	0	0	0	0	0	0	1	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	3	3	3	3	0	0	0	0	0
	4	0	0	0	3	3	3	3	0	0	0	0	0
	5	0	1	0	0	0	0	0	0	1	0	0	0
ROWS	6	0	0	0	0	0	0	0	0	0	0	0	0
	7	0	0	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0	0	0
	9	0	0	0	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	0

Figure 92 Battle model layout for TM-1 with Escorts

The escorts have been given a resilience of 1, meaning it would take just 1 torpedo to sink the ship and it would sink very quickly.

Applying the counterfactual, i.e. two flotillas each with 8 U-boats attack, as was seen above in their use against convoy SC107. Figure 93 shows an example with the angle on the bow is 80 degrees. The result shows in this particular run that four of the tankers have been sunk but none of the escorts have been.

215 ADM 219/55, U-boats greatly intensify their attack, page 1, section 2

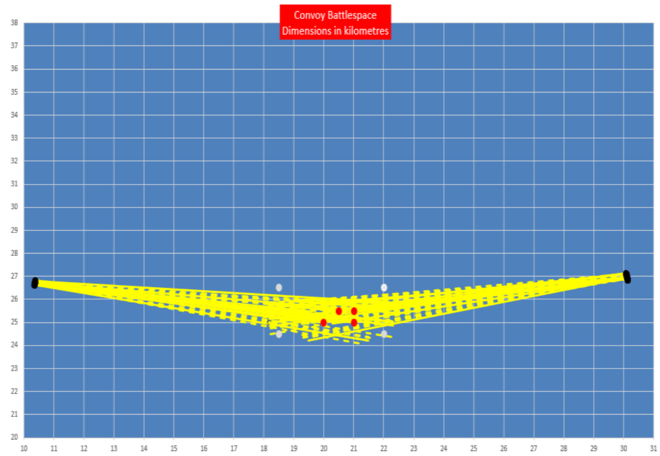


Figure 93 Counterfactual attack by U-boats in simultaneous attacks at 80 degrees on the bow

If the counterfactual was adjusted for this small convoy so as to permit two sub-sections of each flotilla to attack the escorts on that side of the convoy an example of the result would be as shown in Figure 94.

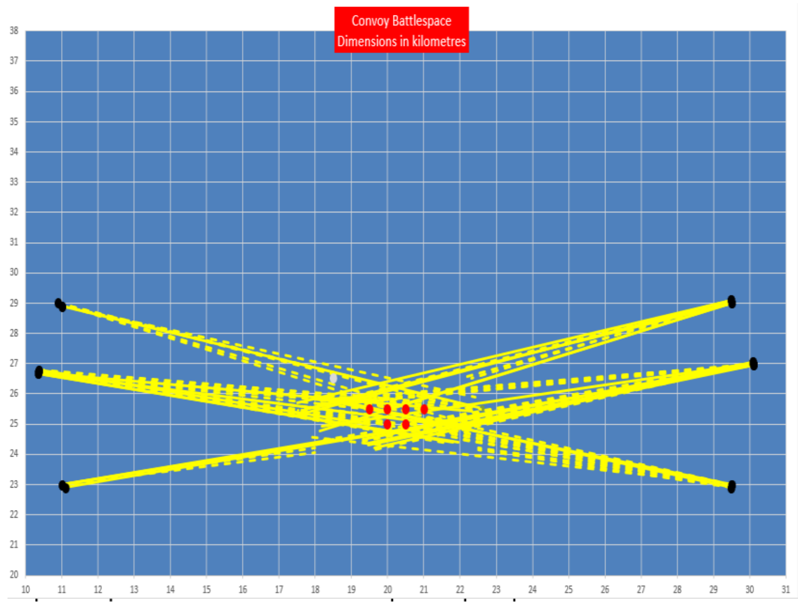


Figure 94 The counterfactual attack by U-boats in simultaneous attacks at 80 degrees on the bow multiple groups to include attacks on the escorts.

As can be seen in the figure in this particular run of the model 3 of the escorts have been sunk but only two of the tankers have been sunk. However, examination of the convoy layout shows a different story, one in which 6 surviving tankers have all been hit by torpedoes but have not sunk immediately, see Figure 95. This reflects the case of the actual TM1 convoy where the tankers were abandoned by their crews and remained afloat for several days after the attack afloat on their own on the ocean. Only one of the eight tankers survived this attack.

		Active Configuration of SC107											
		COLUMNS											
		1	2	3	4	5	6	7	8	9	10	11	12
ROWS	1	0	1	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	2	2	3	2	0	0	0	0	0
	4	0	0	0	0	2	1	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	0	0	0	0	0	0
	7	0	0	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0	0	0
	9	0	0	0	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	0

Figure 95 Results of the counterfactual attacks on TM-1 and its escorts

5.5 SENSITIVITY ANALYSIS OF THE COMPUTER BATTLE MODEL

The following subsections show the modelling of the convoy SC107 with variations from the Baseline Model described in the previous section. Each of the data points shown in the plots in the figures were computed using 100 runs of the model.

5.5.1 The SC107 baseline model

The Baseline model used in this battle model has the following characteristics;

Configuration:- SC107 12:00 Noon October 31st 1942, 42 ships in a 9 column by 5 row formation with 640 metres between the columns and 457 metres between the rows in a column

Merchant Ship Resilience:- A number between 0 and 5 representing how many torpedo hits from the barrage of volley fire arriving in a very short time in the counterfactual concentrated attack.

Speed of Convoy- the speed of the SC107 Convoy was given as 7.5kts in the Commodores report, see Figure 48 An extract of the official data for convoy SC107 in the Commodore's report.

Type of U-boat:- VII C

Number of U-boats:- 16 in total

Formations of U-boats:- divided into 2 Flotillas of 8 U-boats each

Range of U-boats from Centre of Convoy:- 10km from the geometric centre at position 5 Column 3 row

Type of Torpedoes fired:- G7a chemical propellant powered.

Aim Point of Torpedoes:- the geometric centre at position 5 Column 3 row

Speed of Torpedoes:- 30kts

Angle on the Bow of Attacks:- varied from 0 to ± 90 degrees

Maximum range of the Torpedo:- 13.2km, this is the maximum likely range given the variations in range possible in a chemically powered device and is greater than the official value of 12.527km.

Torpedo track errors:- The torpedoes fired by the U-boats in WWII had a spread of track errors and rarely followed the intended path from the U-boat to the point of aim. In the Baseline Model this spread is represented by Normal Distribution about the intended track.

Probability of torpedo fuze functioning:- Historically this was approximately 0.1 (or 10%) from 1941 onwards. In the model this results in 10% of the torpedoes that hit a ship failing to detonate and therefore not reduce the resilience value of that particular ship by 1 from its initially assigned value.

5.5.2 The Baseline Model Hit Probability

Figure 96 shows the plotted values as Hit probability for torpedoes fired against angle on the bow as previously seen and this will subsequently be referred to as the 'Baseline Model'.

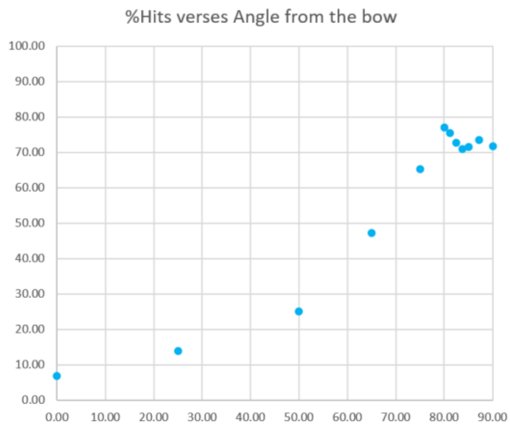


Figure 96 Torpedo hit probability against Angle on the Bow for the Baseline Model of SC107

5.5.3 Torpedo Track Errors

Figure 97 shows the dual plots of the Baseline Model (Blue Dots) and the model modified to have a flat distribution of track errors. The latter that has a greater concentration of torpedoes around the intended track than does the Normal distribution used in the Baseline Model. This is flat distribution is achieved by simply using a random number generator within the VBA code between the limits of 0 and 1 and then multiplying that by the expected 1.7 km aiming error in estimating where the centre of the convoy is by the U-boat commanders.

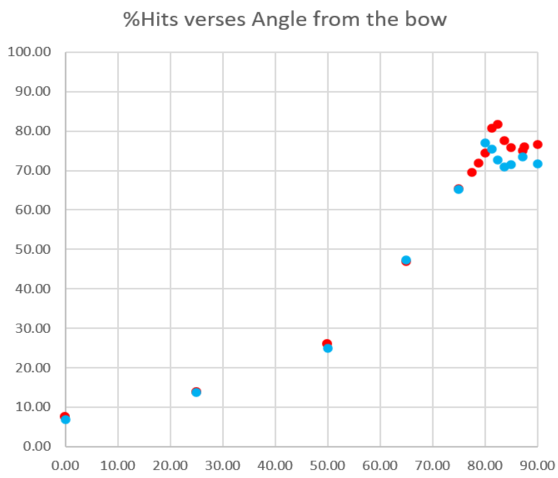


Figure 97 Hit Probability with torpedo track error distribution: Blue Dots:- Standard Model Normal distribution, Red Dots:- equal distribution

Examining Figure 97 it can be seen that there is close agreement between the two models of torpedo spread errors below 75 degrees angle on the bow. The two plots diverge above 75 degrees with the flat distribution plot rising to higher hit probabilities at 80 degrees and above. It may also be seen from the data as modelled that the double peak of the plot for the Normal distribution between 80 and 90 degree angles is transformed into a single dip climbing to a second peak at 90 degrees. This difference between the two plots is due to the torpedo tracks generated by a Normal distribution include tracks that can be several standard deviations away from the centre of the convoy whereas the flat distribution is constrained by the 1.7 km diagonal of the four ship cells assumed to be the aiming error of the U-boat commander which also agrees with the post war analysis of German torpedoes. It should be understood that the accuracy of the historic records and the subsequent post war analysis of them by British Admiralty scientists is very uncertain and leaves much to the imagination.

5.5.4 Convoy Speed

In Figure 98 the results of modelling the SC107 convoy in the form of the Baseline Model where the convoy speed is set at 7.5kts is plotted alongside the Baseline Model modified using the convoy speed set at 15kts. This higher speed would not have been practical for the slower vessels that comprise these slow convoys from whence the common nomenclature SC arises rather than the official one. Such higher, 15kts, speeds are encompassed in the HX series of convoys that derives its nomenclature from the fact that the final convoy assembly area was the city of Halifax, Nova Scotia on the east coast of Canada[216].

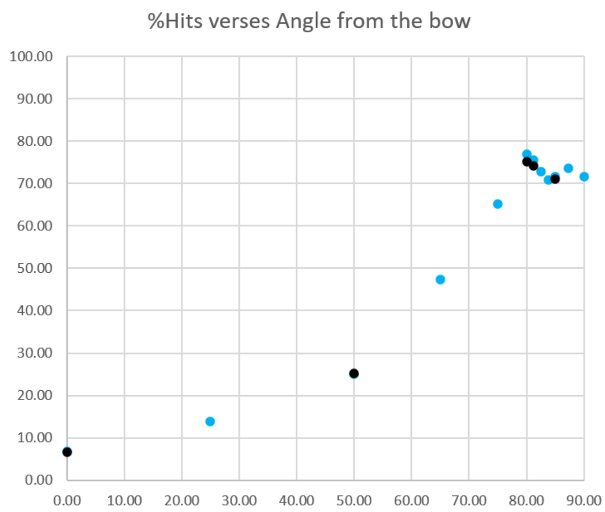


Figure 98 Hit probability for the standard model:- Blue Dots 7.5kts convoy speed and Black Dots 15kts convoy speed

Examining Figure 98 we can see that there is little noticeable difference between the Baseline Model's probability of hit and the 15kt variation on the model. This is entirely to be expected as the implementation of the Baseline Model incorporates addition of the torpedoes velocity and the convoys velocity to form the desired track from the U-boat to the intended target at the geometric centre of the convoy just as the fire control system used in the U-boats and the advanced gyro stabilised and programable German torpedoes of that era were capable of.

[216] Hague, Convoy System, page 111

The minor variations seen in the plots are probably due to the random track errors and would probably reduce with increasing the number of runs used to calculate the values for each sample plotted from 100 runs to say 1000 runs. This higher number of runs has not been chosen to be implemented due to the excessive amount of computational time required, which is 120 minutes per sample as opposed to the 12 minutes for the 100 runs used.

5.5.5 Range of U-boats from Convoy

An important variation away from the Baseline Model is to change the value of the range from the U-boats to the aim point in the geometric centre of SC107 which is set at 10km. This stand-off range of the U-boats combined with the spread of torpedoes determines the concentration level of the torpedoes as they enter the convoy. If there is too great a concentration of torpedoes along the intended track to the centre of the convoy and not enough torpedoes entering the extremes of the convoy rows then less ships will be hit. This arises because a too great a concentration in the centre of the convoy results in the torpedo barrage cutting a hole right through the convoy and many torpedoes that follow on from the first ones to hit simply pass straight through the hole in the convoy and do not hit any ships.

A variation on the Baseline Model that had different aim points for different U-boats so as to always spread the distribution of torpedoes out at even closer ranges was rejected as a sensible option. This was done because it would require a greater degree of coordination between the individual U-boat commanders than the already challenging one of just forming a close formation of U-boats in the right place at the right time and aiming the torpedoes at where they estimated the centre of the convoy was.

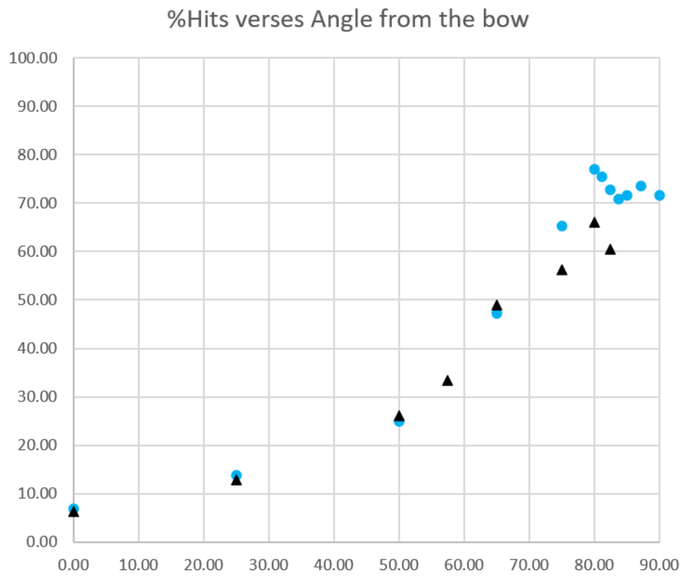


Figure 99 Hit probability of Standard Model with standoff range of U-boats from the centre of the convoy, Blue Dots:- Standard Model 10km, Black Triangles- 5km

The differences between the hit probability plots shown in Figure 99 show that the greatest divergence from the high efficiencies attained by the Baseline Model (Blue Dots) occur at higher angles on the bow values. This is due to the fact that there are greater numbers of targets to be hit at these angles within the spread of the torpedo beam. If the range is reduced (Black Triangles) more of these torpedoes hit the targets along the track to the centre and fewer reach the outer rows so the hit scores are lower. In the case of the low angles on the bow the torpedo beam the baseline model already drills a hole in the convoy and sinks all the ships falling within it before the supply of torpedoes are used up.

5.5.6 Separation of Merchant Ships in convoy

The separation of the ships within the convoy, dealt with in this section, is one of the two most important variations from the Baseline Model, the other being the number of ships in the convoy which is dealt with in a separate section below.

The separation between the ships of SC107 is likely to be an unresolved controversy in all likelihood. This arises because the available information from multiple primary and secondary sources alike has significant difference of opinion as to what these values were at the time of the night of 1st/2nd November 1942, the first night of the attacks on the convoy and the subject of this study.

The separation of the ships in a convoy are defined as follows;

- Between the Columns
- Between the Rows in a column

The official source available to the author at the present time that provides values for the two separation values has more than one set of values quoted. This arises because the principal witness who should have the written record of what these values were was the Convoy Commadore. Unfortunately, the merchant vessel on which he was based was hit by a torpedo and sank. As a result his log book recording the data for SC107 was not saved. Fortunately, the Commodore survived and was present for the board reviewing the convoys passage. He was accompanied at the meeting by the Vice Commodore who unfortunately had not kept a log of the details of the convoys. The two gentlemen did provide an account of what happened to the best of their memory but added the caveat that its accuracy would be uncertain.

However, within the official record there exists a concise typed summary of great detail that is assumed to reflect the 'Official' record of the important facts concerning the conditions and configuration of SC107 on the night that is the focus of this study. A photograph of the official document containing the details is shown in Figure 48 in a previous section above. In this the values for the separation of the ships in Convoy SC107 are stated to be;

- Between the Columns:- 700 yards
- Between the Rows in a column:- 500 yards

These distances have been converted in their metric values thus;

- Between the Columns:- 640 metres
- Between the Rows in a column:- 457 metres

They have been used in the Baseline Model of this study.

The values for these variables as reported for a 'Typical' SC convoy of the period in WWII provided by the most often quoted secondary source are[217];

- Between the Columns:- 1000 yards
- Between the Rows in a column:- 800 yards

These distances have been converted in their metric values thus;

- Between the Columns:- 914 metres
- Between the Rows in a column:- 733 metres

[217] Hague, Convoy System, page 27

These have been used in the typical Hague values of this study.

There is also an issue between the values of these separations between day and night-time operations since it was common practice to vary these separations depending the lighting conditions and the visibility at the time for safety reasons to reduce the probability that the ships might collide. These factors have not influenced the choice of the Baseline Model since they are based on the official values.

Examination of Figure 100 shows that the increased separation of the ships in the SC107 convoy would produce a reduced hit probability (Red Triangles) compared to the Baseline Model (Blue Dots). This is entirely to be expected for two reasons. First, the range of the torpedo is 13.2km and increasing the separation of the columns increases the distance of the far left or right hand columns from the centre in comparison to the Baseline Model that in turn increases the likelihood that some torpedoes will run out of fuel. Second, the increased separation of the rows in the columns greatly increases the open spaces between the rows that appear to the torpedoes as they approach at the angles on the bow between 80 and 90 degrees. The percentage increase in these open spaces for torpedoes to travel down will be directly proportional to the percentage increase in separation, i.e.;

Increase in separation = 733/457 = 1.603 or a 60% increase

This increase will be moderated by the spread of the tracks over angles away from the intended track by the Normal distribution of angles and result in a decreased percentage of torpedoes that have an uninterrupted passage through the convoy at these high angle on the bow values. From Figure 100 the actual reduction in hit probability is;

Decrease in hit probability = 59 / 78 = 0.756 or a decrease of 24.4%

Although significant this decrease in hit probability does not affect the advantages over a piecemeal approach to the attack which was normally practiced by U-boat commanders even when part of a Wolf Pack. In the SC107 attack on the night of 1st/2nd November 1942 the number of torpedoes fired at the convoy by credible reports was 14 from these 7 hits were scored from a ranges of between 400 meters to probably no more than 1500 metres. Thus a hit probability of 50% but at great risk to the U-boats.

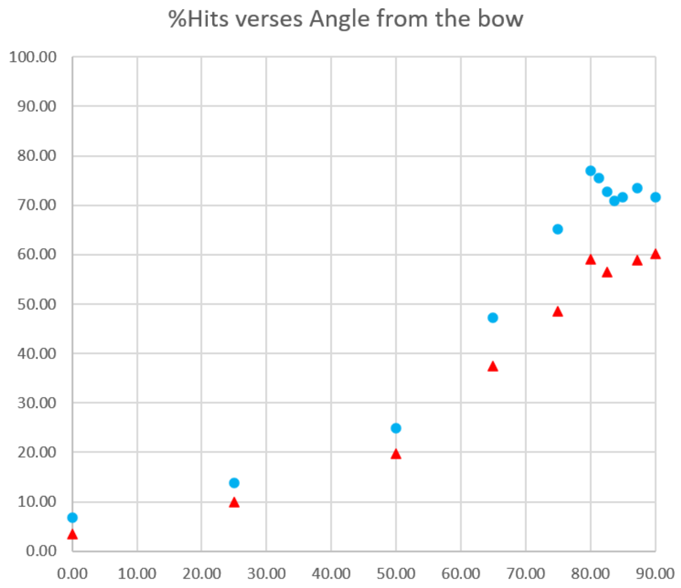


Figure 100 Probability of hit with separation of ships in the SC107 convoy, Blue Dots standard model:- Official distances, Red Triangles:- Separation for typical convoy according to Hague.

5.5.7 Convoy Size

In this sensitivity test the size of the Baseline Model of SC107 was increased by adding three additional columns making a 12 by 5 convoy. The method of assigning a resilience to torpedoes used in the original baseline was extended to these additional ships. Figure 101 shows the layout of the Baseline Model on the left and the extended version of the baseline to a 12 by 5 configuration. The ships in extra three columns on the right-hand side have the assigned values of torpedo resilience.

Baseline Configuration of SC107 Cargo ratings

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

Baseline Configuration of SC107 Cargo ratings

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

Figure 101 SC107 Layouts, Baseline on the left and extended on the right

Figure 102 shows the plots of hit probability for the Baseline and extended SC107 models at a convoy speed of 7.5 kts. The extended SC107 model produces a higher hit probability because there are more ships to hit for those torpedoes that would have exited the standard model on the left and right hand edges.

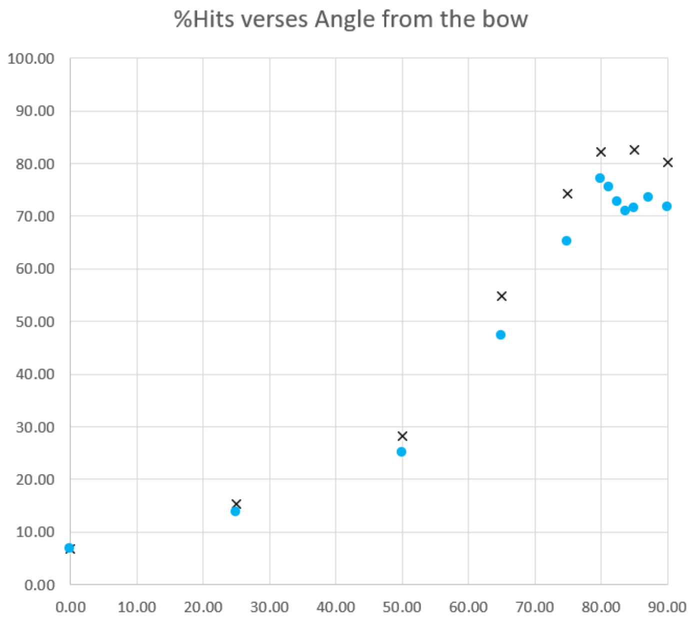


Figure 102 Hit Probability for the Standard Model and an extension of SC107 to a 12x5 sized and at 7.5kts, Blue Dots:- Standard Model, Black Crosses:- 12 columns x 5 rows version of SC107

Figure 103 shows that at the higher convoy speed of 15kts some of the increase in hits are offset by the effects of that speed on track angle changes that take some of the torpedoes towards the back edge of the convoy. The most likely number of ships sunk in these 12x5 convoys was 34. This should be compared to the likely number of ships sunk in the SC107 9x5 which was 29. Both of these BM runs used the 64 torpedo barrage.

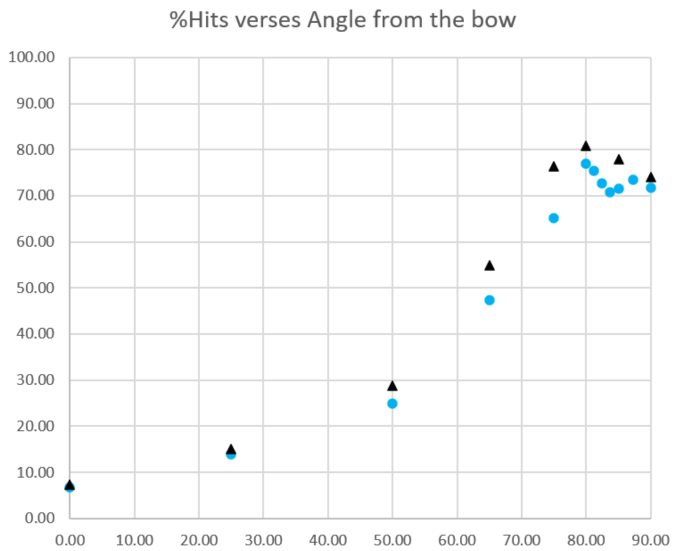


Figure 103 Hit Probability for the Standard Model and an extension of SC107 to a 12x5 sized convoy at 15kts, Blue Dots:- Standard Model, Black Triangles:- 12x5 version of SC107

5.5.8 Analysis and conclusions

Taking the data for the probability of hit at 80 degrees angle on the bow and tabulating it for the various measures studied in the previous section we get Table 16.

Table 16 Summary of Sensitivity Analysis: Probability of hit on a ship in the convoy using the counterfactual attack method

Baseline	Flat Distribution*	15kts	5 km Standoff	Separation in Convoy	Convoy Size 7.5kts	Convoy Size 15kts
77%	81%	75%	65%	59%	82%	80%

* Torpedo distribution of track angle from aim

The sensitivity analysis reported here has shown that the counterfactual is robust to variations of the key assumptions. The most sensitive factor was found to be the separation between the columns and rows in the convoy. This factor reduced the effectiveness at the peak value from 77% torpedo hits down to 59%. This is perhaps not surprising as the gaps between the ships are larger than the ships themselves so increasing the gap size reduces the 'Cross section' for hits. However, in practice the convoy spacing was critical in two respects. First, the greater the spacing the more likely that the ships would lose sight of each other and therefore disrupt the convoy. Second, the greater spacing means that the convoy will increase its perimeter and thus require more escorts to guard against U-boat Aces getting inside the escort screen.

Increasing the number of ships in a convoy results in a higher efficiency of torpedo hits when the attack is done as a standoff one, as in the 'Browning attack'. This is contrary to the findings of the research done by Blackett in his wartime analysis which assumed that 'Ace' type attack of individual U-boats would continue, as it indeed did. So Blackett's study rather than considering the effects of a Browning attack, as in the counterfactual, focussed only on the number of escorts needed to protect a convoy[218].

Finally, we can conclude that the counterfactual will result in a very efficient use of torpedoes and great devastation on convoys attacked in this manner. In such attacks the concentration of firepower in the flotillas stood off from the convoy bestow a far greater probability of survival for the U-boats. However, this outcome would be at a very sensitive time for Allies oil supplies but also at a very opportune period for the prosecution of Doenitz's attack on the main supply route to the UK. The knock-on effects of this tactic could have had an impact on the timing of allied operations including the date of the D-day landings in Northern France.

[218] Prem 3/414/3 Analysis, page 10, points 4.3 and 4.4

Chapter 6 THE SUBSEQUENT CONDUCT OF THE WAR

6.1 OVERVIEW OF THIS CHAPTER

This chapter deals with the possible sequence of events around the counterfactual, which are;

6.2 The advantages that Doenitz had in 1942 such as the U-boats were having great success in sinking Allied ships, especially tankers for relatively fewer losses of U-boats.

6.3 The key aspects of the counterfactual and its implementation

6.4 The predictable consequences

6.5 The possible impacts on the war in Europe

6.6 The likely reaction of the Allies to the introduction of the counterfactual.

6.7 Presentation of this sequence in diagrammatic form.

6.2 The Advantages Doenitz had in 1942

By mid-1942 the U-boat Force had accrued and had advantage of certain key factors in the Battle of the Atlantic, these were;

a) Tanker losses were reaching significant levels and the UK capacity to replace them was not sufficient if the losses continued at that rate, see Figure 34.
b) U-boats were being built and crews trained at an increasing rate to fulfil Doenitz's goal of a 300-boat fleet, see Section 2.2.1. and were balanced to some extent by increasing numbers of escorts being built though the balance was dependent on rising U-boast losses
c) The Allies had failed to allocate sufficient numbers of very long range aircraft to close the gap in coverage between Newfoundland and Iceland that left a mid-Atlantic zone that allowed safe operation for surfaced U-boats, see Figure 43.
d) Unknown to Doenitz the Allied capability for decryption of signals to and from U-boats had been lost when the U-boat forced updated their Enigma machines by adding a fourth wheel thus denying the Allies knowledge of where the U-boats were or had been ordered to deploy to, see Figure 29.
e) In the third quarter of 1942 escort vessels were being withdrawn from the North Atlantic convoy routes and reducing the effectiveness of the defence of the convoys there in order to support the Allied invasion of North West Africa known as Operation Torch, see Section 2.5.2. Doenitz also had to reallocate U-boats in the attempt to thwart Torch but this was quicky reduced and returned to the North Atlantic.

6.3 THE KEY ASPECTS OF THE COUNTERFACTUAL AND ITS IMPLEMENTATION

The key aspects of the counterfactual, as described in section 4.3, would be as follows;

Aspects of the counterfactual:

a) Doenitz's order is issued to all members of the U-boat Force to implement the new tactic of flotilla synchronised attack.

b) Wolf Packs now train and operate as two flotillas.

c) The torpedo standard tactic becomes the 'Browning' long range stand-off type.

Advantages of the counterfactual:

a) Higher efficiency in the use of torpedoes,

b) Reduced losses of U-boats due to concentrated defence of the flotilla against air attack by all U-boats. The 44 U-boats sunk in the critical month of May 1945 included 22 of them that had been sunk by aircraft[219]. These aircraft might well have been dissuaded from attacking 10 to 20 U-boats on the surface providing mutual close anti-aircraft fire and perhaps a significant number of them might have been shot down.

c) Further reductions in losses as concentrated defence of the flotilla against individual escorts and escort support groups. Lone escorts and even groups of escorts might have thought twice about attacking flotillas of U-boats through a barrage of several tens of their torpedoes and heavy cannon fire.

6.4 THE PREDICTABLE CONSEQUENCES

6.4.1 Abandonment of the Convoy System

Roskill reports that in March of 1943 consideration was being given to the abandonment of the convoy system by some in the Admiralty in March of 1943[220]. Roskill goes on to point out that the Allies' use of Support Groups, escort carriers and very long-range aircraft very rapidly defeated the U-boat in the summer months of 1943[221].

The introduction of the counterfactual tactic of this thesis had the potential to bring about the abandonment of the convoy system earlier than Roskill describes, possibly as early as the end of 1942.

We know from the minutes of the cabinet committee for oil and power, see Section 2.5.2, that the British government and its chiefs of staff were concerned about the falling levels of oil reserves in early 1943. How much worse would the tanker and oil crises be if the Flotilla 'Browning' tactic had been employed by Doenitz from mid-1942? The answer is a lot worse if we take the Allied disaster of convoy SC107 as an example. In that case 15 out of 42 ships were sunk and 1 out of the 5 tankers were sunk. If we now look at the counterfactual applied to SC107 as modelled in this thesis, then we see 30 ships sunk and all 5 of the tankers lost. Extrapolating this to the total shipping losses we might see a proportionately greater loss over the whole North Atlantic trade route. Such an outcome would be more than a tanker and oil crisis in the UK by the early months of 1943. It might be a disaster for the Allied war effort with tanker numbers and oil reserves diminished to a level that threatened the timing of operations such as the D-day invasion of Northern France.

6.4.2 Shortage of food in the UK.

The UK was dependent on the merchant ships of the convoys bringing food supplies for the general population as well as the growing number of Allied troops building up in the country. The counterfactual would have further hindered that supply[222][223]. Food rationing in the UK was being further restricted during the course of the war and the situation would be worse if the number of cargo ships being sunk increased[224].

---

219 Niestle, German U-boat losses, page 188
220 Roskill, The War at Sea Vol II, page 367
221 Ibid, page 368
222 Smith, Conflict over Convoys, pages 187 and 189
223 Faulkner&Bell, Decision in the Atlantic, page 222
224 Smith, Conflict Over Convoys, page 185 discusses the competing demands for ships but that in 1943 the number of ships being sunk jeopardised the supplies of food reaching the UK.

6.4.3 Shortage of ships.

The U-boat force was already sinking significant numbers of ships, see Figure 33, in 1942 but the introduction of the counterfactual would have increased this significantly and possibly beyond the capacity for replacement in 1942 and even later[225].

6.4.4 Shortage of war materials UK.

Similarly to the shortages of oil and food, the materials such as steel, aluminium, lumber and chemicals for manufacture of vital weapons, aircraft, armoured vehicles and general goods would be further reduced had the counterfactual been implemented[226].

6.4.5 US Troops: not enough in the UK to meet plans

The transfers of U.S. military personnel across the Atlantic to the UK might have also been reduced. Troops generally travelled on fast ocean liners and because of their higher speeds compared to other shipping[227]. A barrage of torpedoes fired from a flotilla of U-boats that was lucky enough to come across such a troop ship would have a much higher probability of hit by sheer numbers of torpedoes that could be fired. This reduction in troop ships would also be compounded by the fact that the troop ships had to return to the USA and would need fuel to do so and this as we have already pointed out might then be is severe short supply.

6.5 The Possible Impacts on the War in Europe

The ultimate goal of Doenitz was to disrupt the Allied operations against Germany to such an extent that it could survive and concentrate its aggression against the Soviet Union.

In reality the Allied leadership would prioritize which operations would go ahead just as they had to do historically in 1942 and 1943. The biggest and most challenging operation was the invasion of northern France, the D-day invasion that did go ahead on the 6th of June 1944 but only after the troops and supplies had been established in the UK to have an acceptable probability of success. If the counterfactual had been used by Doenitz then the operation most likely to be delayed by a significant amount of time is therefore operation Overlord, the invasion of northern France over the treacherous waters of the English Channel.

To justify such projected delays a detailed analysis of the increased Allied shipping losses and improved U-boat survival would be required, but this is beyond the scope of this thesis. The only practical calculations that can be extrapolated is that the numbers of ships sunk by the Browning of a convoy by a flotilla of U-boats would then double the number of merchant ships that were lost historically. Such an outcome would have the grave consequences highlighted in the previous subsections in 6.4 above.

Of the possible delays in the Allied operations in Europe the delay in dealing with the V weapons would posse the most significant impact on operations and life in London and the south east ports vital for the invasion of northern France. These aspects will be looked at a little closer in the following two subsections because the actual historical impact was already critical without the counterfactual making things much worse.

6.5.1 The V-Weapon campaign against London and the Channel Ports

This somewhat speculative projection of the consequences of the counterfactual is mentioned because Churchill himself stated such grave concerns about the V2. If D-Day had been delayed by the counterfactual and prevented the Allied ground forces occupying the V2 launch sites and the full

225 Smith, Conflict over Convoys, page 250 Table 4
226 Dimbleby, Battle of Atlantic, page 340
227 American Logistics in Normandy, Wikipedia

capacity of the German secret production facilities were in operation in 1945, then Churchill's fears might have been realised.

As Churchill himself made it clear in his post war publications that the V weapon attacks on London and the South East of England posed a very serious threat to the UK's population and this threat was most extreme in the case of the V2 ballistic missile. Also, the brilliant work of Dr. R.V. Jones was crucial in detecting and understanding what the V1 and V2 weapons were and the terrible damage they could do even with conventional chemical explosives in their warheads[228].

From the beginning of the intelligence assessments by Jones, the threat of long-range surface to surface missiles had been taken very seriously by the British government. The immediate response was for the RAF to send a large force of bomber aircraft to attack the missile development centre at Peenemunde on the Baltic coast. This may have taken place despite a counterfactual German victory in the Battle of the Atlantic in 1943. In the case of the V2 ballistic missile there was no credible defence once launched, as such the only way to remove the threat it posed and that was to occupy the areas where they had the range to reach their targets in the UK.

By 1944 it was clear the threat was much more serious and if Doenitz had used the counterfactual tactic proposed in this thesis the government would be very likely to be considering the possible need to evacuate London[229]. If the planned Allied landings in France in 1944 were delayed to possibly as late as 1945 the German missile offensive could have been devastating against the UK[230].

In reality, the RAF air attacks of Operation Crossbow against the V2 mobile launch vehicles was not just a failure but a major embarrassment to Churchill and his government. This was as a result of the casualties of the Dutch civilians in the city of the Hague from the RAF attempts to attack the V2s and their launchers and supply chains operating there. The thousands of British casualties in London and the surrounding areas that did take place without the counterfactual happening resulted in Churchill reprimanding his chief military assistant, General Ismay, for the failure of Operation Crossbow[231]. In the event of a Doenitz victory in 1943 followed by a serious delay in D-Day and the land forces not overrunning the launch sites within range of London and the rest of the UK before an unbridled V1 and V2 attack could be mounted would have potentially far ranging consequences for the conduct of the war in Europe[232].

6.6 THE LIKELY REACTION OF THE ALLIES TO THE COUNTERFACTUAL

6.6.1 Increased Anti-U-boat Operations in the Bay of Biscay

Besides the measures that were actually employed by the Allies to defeat the U-boats in 1943 perhaps operations in the Bay of Biscay might have been intensified with these including;

a) Bombardment of the U-boat bases by the heavy guns of the Battleships of the home fleet using armour piercing ammunition to destroy the U-boat pens, but experience showed that using battleships to bombard the German fortifications in Cherbourg was ineffective[233][234].

[228] Jones, R.V. Most Secret War, page 332
[229] Churchill, The Second World War, Vol. VI page 44
[230] Ibid, page 46
[231] Ibid, page 631
[232] Ibid, page 671
[233] Bombardment of Cherbourg, Wikipedia, see Bibliography
[234] Roskill, The War at Sea Vol II, page

b) Commando raids into the bases to destroy the U-boat headquarters and their pens similar to the St. Nazaire dry dock raid, but might be like the Diep raid[235].
c) Greatly intensified anti-submarine air patrols in the bay of Biscay[236].

The first two of these options are unlikely to have had much effect on the U-boat operations but probably would have resulted in increased losses of Allied ships and troops that would be needed for Operation Overlord.

The third option above would be the most easily achieved and possibly seen as a one sided combat for the Allies in their favour. However, as discussed previously in Section 5.2.2, the Admiralty's own analyses shows that a lone aircraft that attempted to attack a flotilla or a pair of flotillas operating in close proximity would have favoured the German forces and their concentrated anti-aircraft firepower. The Allies would have to have formations of aircraft attacking the flotillas but with a finite number of aircraft available to the Allies this would have reduced their search efficiency and the probability of finding the Flotillas[237][238].

6.6.2 The Predictable Consequences and Possible Impacts

The possible outcomes if the counterfactual proposed in this thesis was implemented have been briefly outlined in the subsections of this chapter. Figure 104 shows in diagrammatic form the logical trail from the Historic facts describing Doenitz's advantage from mid-1942, the counterfactual that was stimulated by this advantage, the predictable consequences of the implementation of the counterfactual and the possible impact on the Allied operations that led to victory of the Nazis. The possible Allied reactions to the counterfactual outlined in the previous section have not been included in the figure so as not to over complicate the logic thought process. The most likely outcome of these delays that are postulated might come about if Doenitz had used the counterfactual is that the post-war map of Europe might have been different to what historically it turned out to be.

235 St. Nazaire Raid, Wikipedia, see Bibliography
236 Doenitz, Memoires, page 411
237 Sternhell et al, Chapter 13, section 13.1.1
238 Waddington, Operational Research against the U-boats, page 240, here the formation is of just 3 U-boats but creates problems for the Allies in providing the aircraft numbers needed to find and destroy even these small units.

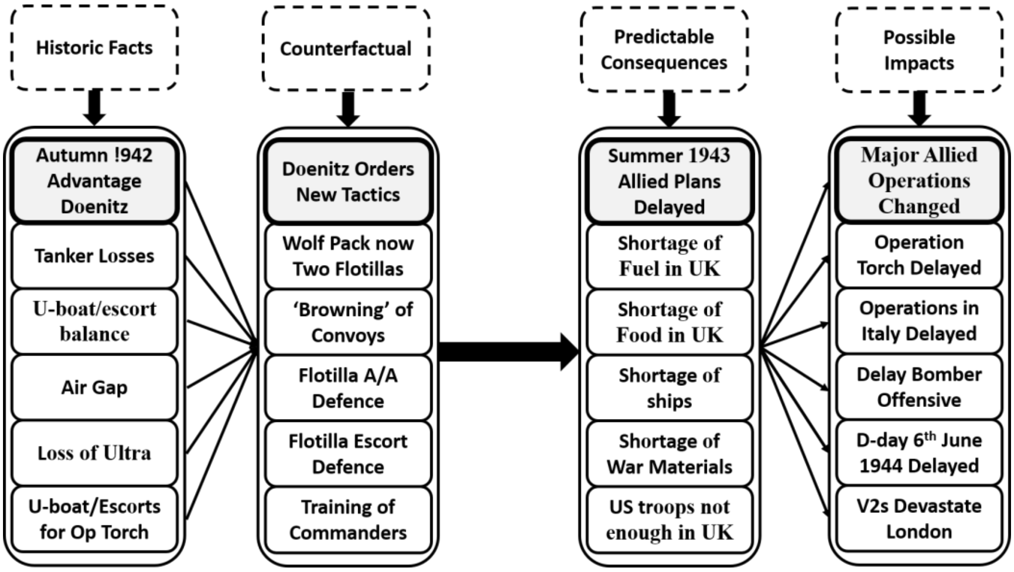


Figure 104 A collection of thoughts on the predictable consequences and possible impacts of the counterfactual

Chapter 7 SUMMARY AND CONCLUSIONS

7.1 OVERVIEW OF THIS CHAPTER

The final chapter of this thesis is divided into two sections, these are;

7.2 A summary of the contents of the thesis, including the background to the battle of the Atlantic, the key people in that campaign and the Ace U-boat cult that dominated the thinking of the Admiral Doenitz as he commanded the growing U-boat Force. This Ace approach in which each individual U-boat did its own attack separated in both time and space have been researched and described.

7.3 Conclusions are drawn on the work reported in this thesis as to the viability of the concept of the counterfactual flotilla operations of U-boats that stood off from a convoy and simultaneously fired their torpedoes at the centre of the convoy. The result on the course of the war could have been a temporary victory for Doenitz in 1942 and 1943 that caused an oil shortage in the UK and a disruption of the flow of men and materials needed for the Normandy invasion. Such a delay in itself would probably not have changed the outcome of the war in Europe but it might have changed where and when it came to an end.

7.2 SUMMARY

This summary is intended to present the essential points that have arisen during the research for this thesis. They are presented here in a concise form and include references to the sections of this thesis where they have been first reported and where the original sources of the information, opinions and analysis may be found.

7.2.1 The Opportunity Admiral Doenitz had for Temporary Victory in the Battle of the Atlantic in 1942-1943

In chapters 1 and 2 the key personalities and characteristics of the opposing forces have been described. Several important issues were identified, these are;

a) Doenitz goal for his U-boat Force was to attack Allied shipping supplies to the UK and oil supplies in particular. [Section 1.2.1]
b) Documents within the UK National Archives at Kew hold evidence that the Germany Navy carried out mathematical modelling to support research in ways to improve torpedo hit efficiency during WWII. [Section 1.2.1]
c) Admiral Doenitz desire to control every significant action, status change, observation by and order given to all the U-boats at sea by means of long-range radio transmissions betrayed the locations of the U-boats. [Section 2.5.1]
d) Unknown to Doenitz, the Allies could decode these transmissions for the better part of the war. The exception being in the period February 1942 to March 1943, where the introduction of the fourth wheel in the Enigma encoding device used by the German U-boat Force denied the intelligence vital to the Allied anti-U-boat operations. [Section 2.5.1]
e) The U-boat Force was increasing the number of U-boats at sea during 1942 towards Doenitz goal of having a fleet of 300 boats. [Section 1.2.1]
f) The toll taken on Allied shipping in the North Atlantic was significant in 1942 and crucially the losses of tankers carrying oil and fuel to the war effort in the UK was reaching crisis levels in the War Cabinet committees for Power and Fuel as well as the Chiefs of Staff committee, [Section 2.5.2]
g) The planned build-up of Allied, particularly US troops, their supplies and equipment in the UK was expected to require large numbers of ships but there was already a shortfall of 79 tankers

with losses of tankers increasing. Oil reserves were being drawn down from UK stocks at an unsustainable rate and fuel for the troop's vehicles and aircraft were threatened. [Section 2.5.2]

h) The culture in the U-boat Force was to openly exult the commanders who could claim the most tonnage that he had sunk and was rewarded with medals, hours, personal meetings with Hitler and celebrity status in the German state-controlled media. [Section 2.2.5]
i) The U-boat Ace had to personally witness the vessels that he targeted had actually sunk to guarantee that he alone being award the tonnage to his score. This resulted in the U-boat commanders wanting to get close to the targeted ship and see his torpedoes hit and explode. This exposed the U-boat to the risk that warships escorting the merchant ships would detect and attack the U-boats. It also resulted in more torpedoes being fired than necessary because just one torpedo hit was usually enough to eventually cause a ship to sink, but an Ace could not wait for that to happen. [Section 2.2.5]
j) The Allies had developed a flexible approach to tactics for anti-submarine warfare to counter the U-boats and this included a group that was installed within the Western Approaches Command headquarters in Liverpool. The group was called the Western Approaches Tactical Unit or WATU for short. Within this unit analysis of known U-boat tactics could be simulated in a battle game played on the floor of one of the rooms. This arrangement then facilitated the formulation and evaluation of new tactics for the escort forces assigned to protect the convoys. [Section 2.2.6]
k) The German Navy did not have an equivalent of WATU to evaluate Allied tactics and develop counters to these tactics. [Section 1.2.4]
l) The German Navy also lacked a dedicated unit equivalent to the British Admiralty's Operational Research Division but it may have had a similar but limited capability within its command structure. [Section 1.2.4]

7.2.2 The Disastrous convoys SC107 and TM1

In chapter 3 two convoys were presented that represented U-boat victories over the Allied convoys and these were described and analysed. The main findings of these are;

a) SC107 was a typical convoy of mostly old and relatively slow (~6 to 7.5 kts) merchant ships and they were protected by a group of escorts that varied in strength and quality during the course of the convoys voyage from the East coast of the USA and Canada to ports on the west coast of the UK, principally Liverpool. [Section 3.3.3]
b) The convoy SC107 was sighted and followed by a U-boat from its departure from its Halifax Nova Scotia stage of its journey and reported to Doenitz's headquarters. Doenitz then formed a number of U-boats into a Wolf Pack that he gave the name Veilchen. His intention was to have the U-boats straddle the intended path of SC107. He knew this path from the intercepted radio transmissions between the convoy and its shore based controllers on the Canadian coast. Doenitz had the to wait for the convoy to enter Veilchen's grasp. [Section 3.3.3]
c) The U-boats gathered around the convoy but did not attack in force, instead each U-boat commander was following the orders Doenitz had set out in the U-boat commanders handbook, which was to attack as and when they individually were in a position to do so. [Section, 1.2.7]
d) The U-boat U402 commanded by Forstner was first to attack on the night of 1st / 2nd of November and sank 5 ships. Next was U522 commanded by Schneider who sank 4 more ships that night. [Section 3.3.3]
e) During the course of the following 3 days a further 6 ships were sunk. [Section 3.3.3]
f) The escorts that were with the convoy on the first night were all from the Canadian C4 escort group of which one, RESTIGOUCHE was a destroyer while the other members of the group were flower class Corvettes. All of these ships were from the Royal Canadian Navy. [Section 3.3.3]
g) The escorts of C4 had only one functioning radar, which was on the RESTIGOUCHE. [Section 3.3.3]

h) The RESTIGOUCHE and one of the Corvettes were deployed several miles from the SC107 when the U402 attacked on the surface after dark. The escorts that were with SC107 were blind to the presence of the U-boats until after the first attack had occurred as they had no radar functioning. In essence the U-boats were unopposed on this first night of the battle for SC107. This was also effectively true for the rest of the voyage until the convoy had passed through the Air Gap in the middle of the Atlantic. [Section 3.3.3]
i) In the case of convoy TM1, a supposedly fast convoy of tankers, it was sent from the Caribbean to Gibraltar in early 1943. It was protected by a force of four warships of the Royal Navy. [Section 3.3.4]
j) The escorts were all equipped with the RDF 271 radar sets but only two of them were functioning at the time that Doenitz tasked Wolf Pack Delphin with attacking TM1. [Section 3.3.4]
k) The result of the battle for TM1 was similar if not worse than SC107 as seven out of the original 9 tankers were sunk by the U-boats and the oil, fuel and tankers themselves were lost. [Section 3.3.4]

7.2.3 The Battle Model

In Chapter 4 a Battle Model (BM) is described that has been created for this study. The following key points came out of applying this Battle Model to the case of convoy SC107;

a) The model is a convoy centric one which has a frame of reference in which the convoy is stationary. [Section 4.3.1]
b) The physical basis of the model is a kinematic one and represents the motion of the torpedoes when fired from the known or estimated locations of the U-boats involved in the attacks on the 1st and 2nd of November 1942. [Section 4.3.2]
c) The torpedoes are assumed to be aimed at the ships that the historical documentation say they were but the BM includes a probability that any given torpedo will have an error in the direction that it travels. These errors are representative of the errors that historical documentation indicate that the German torpedoes and the U-boat fire control system would experience in action. The distribution of the torpedoes about their aimed direction was implemented as a Normal Distribution with a spread that matched the expected dispersion at 10 km range. A flat distribution was also tested and compared with the Normal one. [Section 5,2.3]
d) The BM was defined so as to represent all the parameters that describe SC107 including its speed, separation of merchant ships in their columns and rows as well as the location of the individual ships in the convoy. [Section 4.4.1]
e) The concept of a merchant ship's resilience to torpedo hits was defined by the type of ship and the type of cargo carried and this determined the likely number of torpedoes needed to sink it in a short period. In the case of a merchant ship carrying dense and heavy cargo, such as a quantity of steel, it might sink in a few tens of seconds whereas a ship carry lumber that is bulky and has its own natural buoyancy might not sink at all even after several torpedo hits. [Section 5.4.2]
f) The BM of SC107 was run using the known attack positions for the U-boats, ships in the convoy and the number of torpedoes known to have been fired a total of 1000 times. The data collected on which ships were actually hit in each of these 1000 runs of the attack was then tabulated and the number of ships hit on each run summed and compared with the historic data. There was found to be a good match between these numbers, [Section 4.4.1].

7.2.4 The counterfactual

In Chapter 5 the background to the counterfactual suggested by the analysis of the historic records is;

a) The alternative to the lone Ace tactics promoted by Doenitz was of local commanders taking charge of groups of U-boats organised to fight as flotillas, as their surface craft comrades did in the German and Allied navies. Such a tactic was considered by Doenitz as unworkable for U-boats and he chose to control all of them himself. [Section 5.2.1]

b) The British Admiralty had studied operational efficiency as a science and under Prof, Blackett and had created the Admiralty Operational Research Division. Some of these studies involved looking at how German Wolf Packs of U-boats could be made more effective in anticipation of the Germans doing so themselves. These studies revealed that flotillas of U-boats might attack convoys simultaneously in close formation. A separate Admiralty study examined the advantages of submarine attacks taking place at great stand-off ranges instead of getting close to a convoy and targeting individual ships but instead firing at the convoy as a whole. This latter tactic was referred to as 'Browning' a convoy. [Section 5.2.3]

c) These British Admiralty studies indicated that the U-boats could greatly increase their efficiency at sinking Allied ships but also improve their survivability against attack by staying on the surface and defending themselves as a flotilla. [Section 5.2.3]

d) These factors suggested that Doenitz might have achieved an even greater impact on Allied shipping in 1942 if he had changed tactics away from that of lone Ace getting in close and counting his tonnage sunk. If he had moved instead to tactics that are of a flotilla of U-boats standing-off from a convoy and 'Browning' it with a simultaneous barrage of torpedoes his goal of stopping the supplies to the UK might have come close to being realised, albeit temporally. It is this observation that forms the basis of the counterfactual adopted in this thesis, [Section 5.2.3]

The BM was then set up to represent the counterfactual attacking SC107 in the first instance and then convoy TM1. The key changes to the set-up of the BM from that of the use of it when reproducing the historic case to that of the counterfactual are as follows;

a) The resilience used for each ship were representative of what would happen if the convoy was attacked by a synchronised firing of 64 torpedoes in a barrage from two flotillas, each firing 32 torpedoes from either side of the zero 'Angle on the Bow' direction. This change to the resilience was necessary because now the ships hit by a single torpedo would not stop and drift out of the convoy before the next U-boat would attack hours later as normally happened historically. In the counterfactual, the ships that had a resilience of 4 could be hit by 4 torpedoes in a matter of a few tens of seconds and not drift out of the convoy before the barrage had passed. This aspect needed to be represented in the model set-up and was implemented. [Section5.4.2]

b) The U-boats in each flotilla were placed evenly on either side of the central location of their flotilla and the locations of each flotilla were calculated relative to the centre of the convoy at a range of 10 km. [Section 5.4.2]

c) The type of torpedo modelled was that of the G7a variety which had the range in excess of the U-boat standoff from the centre and allowed the torpedo to reach the opposite side of the convoy from which it first entered. [Section5.4.1]

d) The 'Angle on the Bow' for each pair of flotillas was used to calculate the positions of the launch points and was run for values of the pairs with ± 0, 25, 50, 75, 80, 82.5, 85, 87.5 and 90 degrees. The BM was operated for each of these angles with 100 runs and the data recorded. [Section 5.4.2]

e) The optimum angle, i.e., the one that scored the most torpedo hits, was found to be at 80 degrees from the direct head on angle to the convoy. Using the baseline setup this gave a torpedo probability of hit of 75%. [Section 5.4.2, page 101]

f) The number of ships sunk per U-boat present in SC107 had this tactic been employed would have been on average 29 for 16 U-boats, or 1.81 in the one attack. [Section 5.4.2]

Next the BM was applied to the case of convoy TM1. The essential details of this exercise are;

a) All the merchant ships were given a resilience of 3, as is appropriate for tankers. [Section 5.4.3 , page 101]
g) The presence of escorts has been included in the model for TM1 but it is assumed that they played no active part in the defence of the convoy except as additional targets for the barrage of torpedoes arriving simultaneously from the unseen flotillas of U-boats. [Section 5.4.3]
b) The flotillas were placed at 80 degrees angle on the bow and at a range of 10 kilometres from the centre of the convoy. Again, two flotillas each of 8 U-boats fired all four torpedoes from each boat making a total of 64 torpedoes. [Section 5.4.3]
c) 100 runs were performed and it was found that most the tankers would have been sunk and often all of them. [Section 5.4.3, page 103]
d) When the attacking flotillas were split up into three groups, 2 – 4 – 2 formation such that the two smaller groups could fire their torpedoes at the nearest escort and still have their torpedoes that missed the escort enter the convoy it was found that it was possible to sink all of the tankers and most of the escorts in one barrage. [Section 5.4.3]

7.2.5 Sensitivity Testing

Following the exercises with SC107 and TM1, a number of set-up changes were made to the SC107 BM in order to facilitate the sensitivity of the model to parameter changes being investigated. These sensitivity investigations covered;

a) A Baseline model was defined so as to represent all the parameters that describe SC107 including its speed, separation of merchant ships in their columns and rows as well as the location of the individual ships in the convoy. [Section5.5.1]
b) Torpedo Track Errors, in this the Normal Distribution was compared with the Flat Distribution using the Baseline model over the interval between 0 to 90 degrees Angle on the Bow (AoB). The Flat distribution resulted in slightly higher performance. [Section 5.5.3]
c) Convoy Speed, the convoy speed was compared for 7.5kts and 15kts but resulted in no significant difference in performance over the AoB range used. It should be noted that the torpedo speed used was 30kts. [Section 5.5.4]
d) Stand-off Range, for this the effects of range was compared at 5 km as opposed to 10 km with the result that 10km was significantly better performance at all angles. [Section 5.5.5]
e) Separation between ships; this was looked at in the context of the baseline model being that of the historic record for SC107 based on the official primary sourced data in the Commodores report, which is slightly smaller distances than many secondary sources suggest. This was found to have the largest difference in the effectiveness of the counterfactual than the other factors used in the sensitivity analysis. However, this did not seriously alter the conclusion that the counterfactual was a big improvement in the number of ships sunk in a convoy for one salvo. [Section 5.5.6]
f) Convoy Size, increasing the size of the convoy had the effect of improving the effectiveness of the counterfactual because the torpedoes that would have exited a convoy without hitting a ship now had more opportunities to hit. This shows that the Blackett's recommendation for larger (i.e. more ships) per convoy was wrong for a Browning of the convoy as in the counterfactual rather than the individual Ace type of close in attack assumed by Blackett that looked at the attack being thwarted by an escort. [Section 5.5.7]
g) The conclusions of the sensitivity studies is that of the parameters tested the only significant change in hit probability was for increased separation from the historic record value of SC107 to the generally claimed values for a typical convoy in the literature. This difference in hit probability was from 75% for recorded separation of SC107 down to 60% for claimed value. [Section 5.5.8]

7.2.6 The Predictable Consequences for Allied Operations in Europe

Finally, this thesis has briefly considered in chapter 6 what the possible consequences would be if Doenitz had made use of the counterfactual tactic across the U-boat fleet from mid-1942 and into 1943. The main consequences that are somewhat inevitable under the circumstances imagined are worsening of the already factual shortages in the UK in 1942 and 1943, these are;

a) The most significant two of these shortages being the shortage of tankers and the products they transport. The situation with a shortage of tankers, oil and fuel was already ringing alarm bells in London in early 1945 without the counterfactual. [Section 6.4.2]
b) Secondly, the shortage of ships to transport the fuel, goods and materials needed was also hitting the UK in early 1943 and any worsening of that situation made the build-up for the various invasion plans for the Mediterranean and Normandy look threatened for the 1943 and 1944 timeframe. [Section 6.4.3]
c) One potentially very serious impact of these delays could be the delay in Allied troops taking the areas of France, Belgium and the Netherlands that were to be used by the Germans for launching V2 rockets from their hard to see and harder to hit mobile launch vehicles. [Section 6.5.1]
d) These delays and their impacts would not have changed the outcome of the war in Europe but it might have had changed how and where it ended. [Section 6.6.2]

7.3 CONCLUSIONS TO BE DRAWN

The conclusions of this thesis may be summarized as follows;

7.3.1 Background

Admiral Doenitz had a formidably powerful capability at his disposal in the form of the U-boat Force toward the middle and end of 1942. However, Doenitz did not make the most of it because he was unwilling to allow any local command of the U-boats by Wolf Pack or flotilla commanders. Instead, he decided only he and his immediate subordinates could decide what individual U-boats could do up to the point that they were within striking distance of the convoy targets he needed to destroy. He then let them decide if, where and when they would attack as individuals. His decision may have been partly influenced by the cult of the U-boat Ace who had to build up a score of hundreds of thousands of tons of ships sunk to gain the accolades and awards of that status. However, the U-boat commanders themselves had to see the ship sink to guarantee they were credited with the tonnage sunk.

The German Navy did have a capability to conduct scientific analysis of tactical and technological methods to improve torpedo hit probability and this was revealed by the discovery of documents in the NAK archives, never before referenced. A particular document has been cited in this thesis that demonstrates the German Navy had this OR capability during the course of WWII but never used it fully to improve U-boat tactics as in the counterfactual proposed in this thesis[239].

By the end of the first quarter of 1943 there were already major convoy victories attained by the U-boats even using the Ace tactics. Two of these have been studied in detail in both the primary documentation and by mathematically modelling the engagements using a Battle Model (BM). This BM reproduced the historic results accurately.

Doenitz’s failure to make the most of the U-boats in his Wolf Packs in a mass surface attack at night may have robbed him of the victory he wanted. However, the British Admiralty operational researchers

[239] ADM 292/209 Tactical Use of Torpedoes: Accuracy of Torpedo Fire, English translation of a German document from WWII.

had seen the tactics involved and recognised it at the time as possibly a dangerous development that never materialised.

7.3.2 Counterfactual

This study has revealed British Admiralty Operational Research studies carried out during WWII not previously referenced elsewhere, that show that the underlying concepts of enhancing the effectiveness of U-boats attacking convoys were credible. Two separate Admiralty studies identified the following methods: standing off and firing at the convoy from a distance rather than fire at the individual ships, a 'Browning' attack, and the simultaneous attack of all the U-boats in a Wolf Pack at once in a barrage of torpedoes. These two tactics when combined might have caused a very significant increase in the losses of ships in a convoy if delivered from the optimal distance and angle relative to the convoy[240][241].

A counterfactual has been presented that has local commanders rather than the distant U-boat Force Command in France or Germany deciding what each U-boat should do. These local flotilla commanders synchronised and concentrated the unleashing of Browning style attacks on convoys from relatively safe stand-off ranges from the convoys. The BM was then set up to evaluate the counterfactual barrage of torpedoes and this confirmed that if such an attack had been carried out on a convoy by just 16 U-boats then severe losses of ships in the convoy would occur. As many as 70% of the ships in a typical convoy could be hit by torpedoes in a period of as little as 5 minutes. The modelling showed that the losses caused by the counterfactual tactics would increase with the size of the convoy. This would counter Blackett's notion that bigger convoys have fewer ships sunk.

This study has also revealed British Admiralty Operational Research studies of the time not referenced elsewhere that indicated that a U-boat might have a 10% chance of shooting down an attacking aircraft at altitudes below 2,000ft[242]. If extrapolated to the capabilities of a flotilla of U-boats defending themselves as a unified anti-aircraft system they would have a high probability of shooting down such an attacking aircraft. This might then have made the effectiveness of very long range aircraft and escort carrier aircraft much less and possibly have turned the tables for a time at the critical period in late 1942 to the summer of 1943 reducing the number of U-boat losses and resulting in a growing U-boat fleet into the summer of 1943.

Finally, the application of the counterfactual across the U-boat fleet in 1942 and 1943 could have caused significant delays to the inevitable Allied victory in Europe and that might have changed the post-war map of Europe.

240 MFQ 1/583/15 Diagram Showing the possibilities of a U-Boat Browning a Convoy, 1940
241 ADM 219/55 How U-boats can greatly intensify their attacks on shipping 1943
242 ADM 219/60 Note on expected casualties due to A/A fire from U-boats 1943

APPENDICES

Appendix A: US Analysis

A.1 Geometric Modelling

The US post-war analysis of submarine warfare carried out against enemy submarines is very useful and some examples are shown and compared to the results of the application of the Battle Model to the counterfactual of this thesis.

The first example is the analysis of probability of hit for a torpedo passing through a convoy of multiple columns, see Figure 105[243].

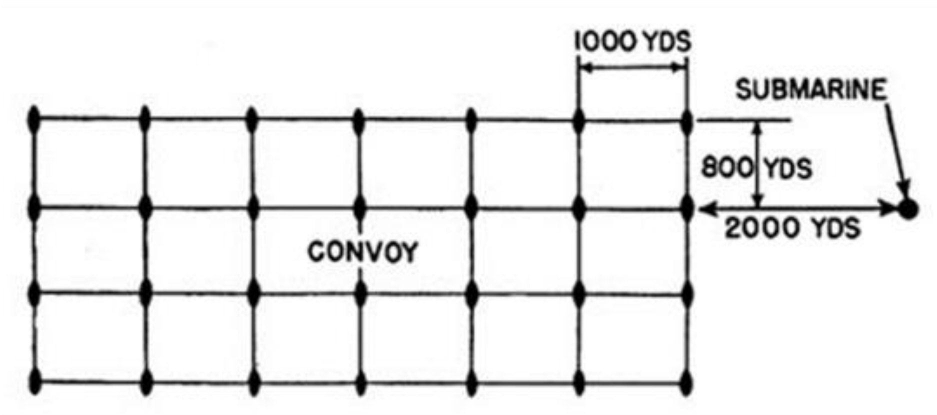


Figure 105 Convoy layout from US post-war studies

The U.S. studies also provided a simple equation for calculating the probability of hit of a torpedo fired into such a convoy, see Figure 106. This is the standard approach of calculating the chance of hitting a target in just one attempt subtracted from 1 to give the chance of missing. This chance of missing the target with one attempt is then raised to the power of n, the number of attempts and then subtracting the chance of missing the target in n attempts from 1 to give the chance of hitting a target with n attempts.

A torpedo fired from 2000 yd abeam can pass through several columns. If it is fired at random, its probability of encountering a ship while passing through the first column would be 1/800 where l is the length of a ship in yards. For l = 140 yd, the chance of a hit in passing through three columns (5000-yd range torpedo) would be

$$\text{Probability of hit} = 1 - \left(1 - \frac{140}{800}\right)^3$$
$$= 44\%.$$

Figure 106 An extract from the US study showing the calculation of probability of hit for a torpedo

A simple use of this equation to look at the probability that a torpedo would hit a ship by the time it had passed through nth column is shown for up to 9 columns of ships in a convoy has been done for this thesis and is shown in Figure 107.

---

243 Sternhell and Thorndyke, Antisubmarine Warfare. Page 104

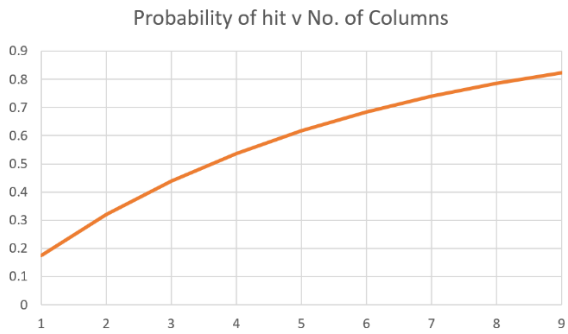


Figure 107 Probability of hitting a ship for a torpedo as it passes through a convoy of 9 columns of ships using the Sternhell and Thorndyke equation.

From the figure it can be seen that it is in agreement with the Battle Model when applied to the counterfactual attack by two flotillas firing simultaneously at either flank (80 degrees on the bow) of a convoy under ideal conditions that resulted in a hit efficiency of between 70 and 80 %.

A2. Uncertainty modelling

In the US research study of NDRC: Volume 2B covering antisubmarine warfare consideration has been given to the fact that the merchant ships in a convoy are not held rigidly in a matrix as in the simpler representations of Sternhell and Thorndyke, but are loosely holding their station around the intended location in the convoy matrix, see Figure 108[244].

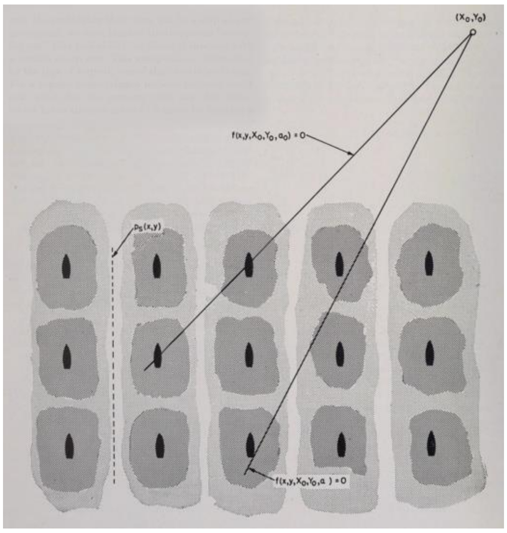


Figure 108 An extract from the NDRC Vol 2B study showing probability of ship locations

The study treated the torpedo/ship problem as a probability function sweeping out an area and was applicable to both straight running and pattern following torpedoes. No numerical predictions were reported in the document for this topic.

244 NDRC, Division 6 Vol 2B, Summary technical report, page 124.

Appendix B: Radar Equation

B. 1 Modelling of the Radar Cross Section (RCS) of a U-boat

One of the key issues for the viability of the counterfactual is the question of how detectable would be a U-boat on the surface by the type of radar in use by the Allies on their escort vessels during the 1942 and early 1943 period. Also, of interest is the question of the detection by radar when a U-boat is on the surface and 'Trimmed down' so that the only portion of it above the water is the Conning tower. These questions have examined during the research for this thesis in two ways. First, by using an electromagnetic modelling tool, CST Studio Suite, and by examination of the primary documentation on the topic of RDF 271 models of 1942 and 1943.

B.1.1 Modelling of the Radar Cross Section of a U-boat

A computer model of a U-boat Type VIIC has been used with the CST electromagnetic modelling tool to investigate the radar signature of a U-boat at the centimetric wavelengths used by the British radar RDF Type 271.

The model was originally a full representation of the Type VIIC that included the full hull details as well as the conning tower, main deck gun and other above deck items such as cables. The RCS modelling required that the computer model of the U-boat be cut to remove those parts of the hull and propulsion system that would remain below water in normal operational conditions leaving only those parts that were above water in normal operational conditions. Figure 109 shows this model as represented in the CST computer simulation. The figure also shows the plane wave representation (Red rectangle) of the radar pulse as it arrives from the radar when in the bows-on azimuth angle of 0 degrees. Also shown in the figure and the electric field vector (e), the magnetic field vector (h) and the direction arrow showing the velocity vector of the plane wave from the radar.

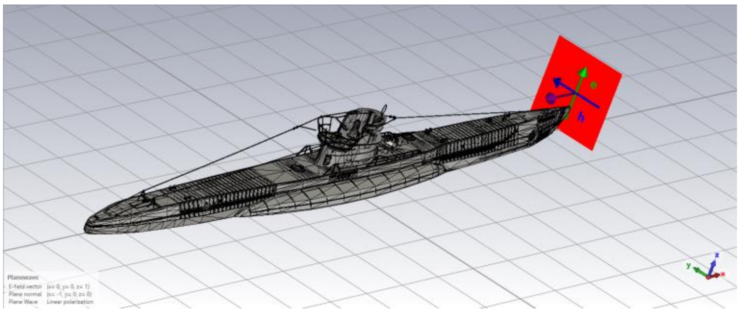


Figure 109 CAD model of a U-boat Type VII C in the CST EM modelling tool showing one of the directions of illumination by Radar (Red rectangle with EM vectors shown).

A close-up view of the U-boat seen from the bows looking back toward the conning tower is shown in Figure 110. The smooth surface of the steel casting forming the conning tower can be clearly seen in the figure. In modern terms this part of the U-boat would be said to be 'Stealthy' due to its smooth surface curving away from the viewpoint. Other aspects are shown in a faceted form of the original model. These facets tend to produce a false RCS signature due the lobing effect for each facet. However, the conning tower is the dominant feature and is correctly represented by the smooth surface added to it. The CST solver used is the Asymptotic solver using 'Shooting Bouncing Rays' and 'Physical Optics', the latter introduces diffraction effects to make a more accurate representation of the scattering of electromagnet waves

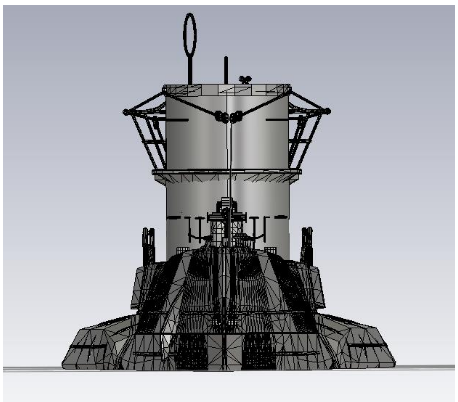


Figure 110 The CAD model looking from the bow toward the conning tower.

The RCS of the U-boat at 3GHz is plotted in Figure 111 and shows that the RCS as detected by a radar illuminating the U-boat from the bow direction, 0 degrees in the plot has a value of approximately 21 dB Square metres. As can be seen in the view of the U-boat shown in Figure 110 the U-boat, the top of the hull and the conning tower are both above the sea surface and therefore contribute to the strength of the radar echo from the U-boat. The RCS is quoted in dBsm, where dB stands for decibel and sm for square meter.

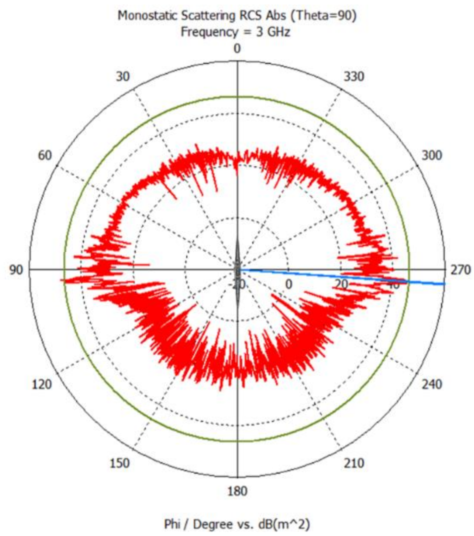


Figure 111 The Radar Cross-section of the U-boat at 3 GHz predicted by CST EM modelling tool. The bows on value of RCS is at 0 degrees azimuth and the stern on at 180 degrees.

In the event that the U-boat had been trimmed down so as to only expose its conning tower above water as in Figure 112.

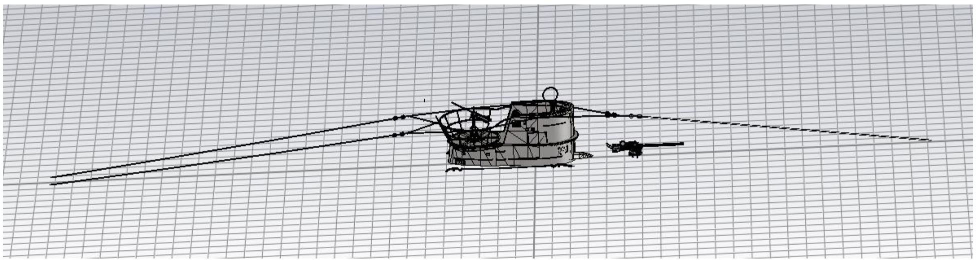


Figure 112 The computer model of a trimmed down U-boat

The computed plot for the RCS in trimmed down state with just the conning tower contributing to the radar echo is shown in Figure 113. From the figure it can be seen that the RCS of the U-boat at 0 degrees on the bow is approximately the same as in the case for the U-boat showing the top of the hull as well as the conning tower, i.e. approximately 21 dBsm.

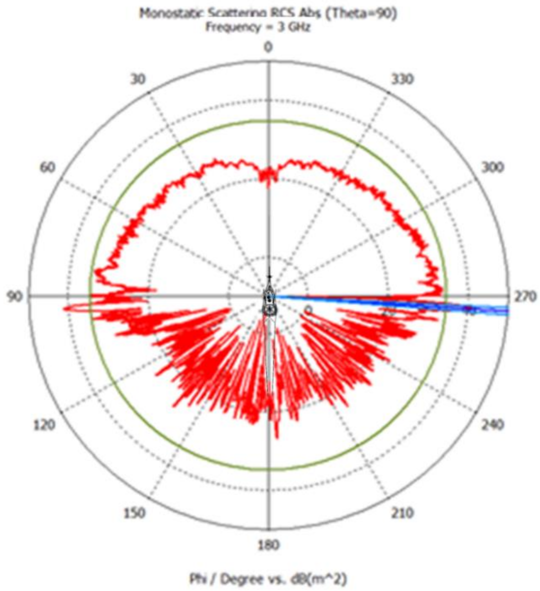


Figure 113 Radar Cross Section plot for a trimmed down to conning tower only above water U-Boat at 3GHz (~10cm wavelength)

We may therefore conclude that trimming down the U-boat so it has mainly the conning tower and deck gun visible above the surface does not reduce the detectability of the U-boat to the 10 cm(~3GHz) RDF Type 271 radar used by the escort vessels.

Consider now the case where the radar is at an azimuth angle of 90 or 270 degrees, i.e. illuminating the U-boat with its 10 cm wavelength radar beam. Comparing the RCS plots of Figure 111 and Figure 113 it can be seen that the RCS in both cases rises from the value at azimuth angle 0 degrees (21 dBsm) to the value at 90 or 270 degrees of 39 dBsm in both fully surfaced and trimmed down conditions of the U-boat. This is due to the dominance of the conning tower in the radar reflectivity of the U-boat.

We may conclude that trimming down of the U-boat to a submerged hull but with a conning tower above water offers no significant reduction in RCS and consequently no reduction in the threat posed by the radar to the U-boat at any angle of azimuth. It should be noted though that the RCS modelling did not include a representation of the surface of the ocean which will both positively and negatively change the visibility to radar depending on the sea state.

B.3 The Documented Performance of the RDF Type 271 Radar

During WWII the Admiralty undertook studies on the performance of the radar sets it introduced to all of the service branches. The naval surface radar sets, such as the 10cm wavelength sets such as RDF 271, as used on the escort vessels in the Battle of the Atlantic, generated the radio waves using a magnetron device. This enabled the set to generate the higher frequencies/shorter wavelength radio waves but at significantly higher power than the alternative vacuum valve devices used up that point. In 1942 the RDF 271 emitted a 7 Watt radio pulse that gave the radar set an effective detection range of a U-boat of between 2 and 4 miles. It should be noted that the data does not reveal the aspect angle of the U-boats profile[245].

The studies looked at the reported detections of U-boats in various sea states, these can be seen in Figure 114, Figure 115, Figure 116 and Figure 117.

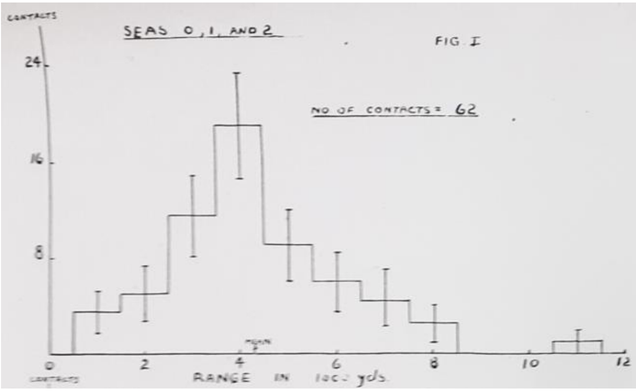


Figure 114 Wartime plots of detections of U-boats against range using the radar RDF Type 271P in sea states 0, 1 and 2.

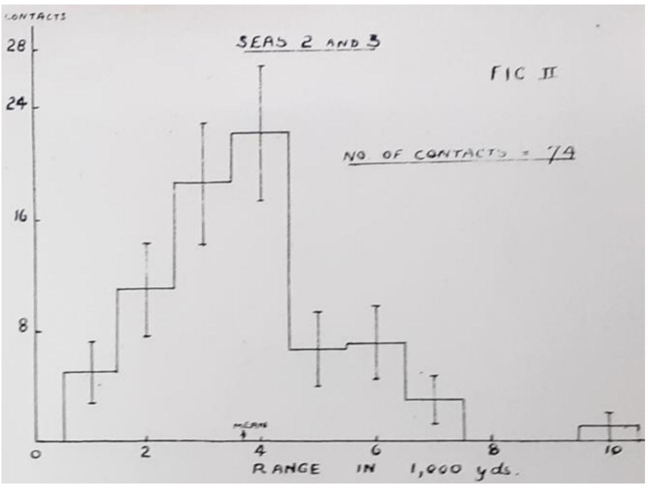


Figure 115 Wartime plots of detections of U-boats against range using the radar RDF Type 271P in sea states 2 and 3.

245 ADM 219/29 Operational Use of 271P Radar in A/S warfare

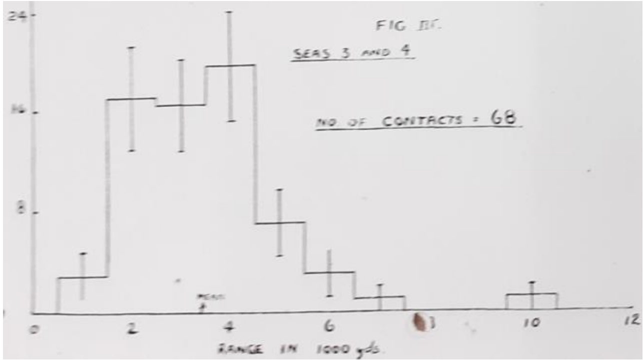


Figure 116 Wartime plots of detections of U-boats against range using the radar RDF Type 271P in sea states 3 and 4.

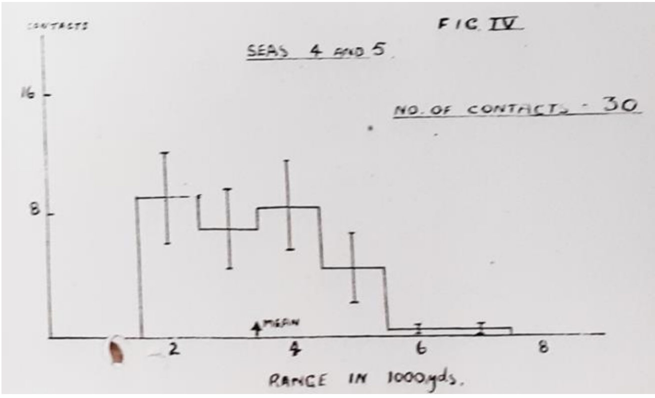


Figure 117 Wartime plots of detections of U-boats against range using the radar RDF Type 271P in sea states 4 and 5.

The conclusion drawn by the ADM219/29 report is that for a destroyer equipped with an RDF Type 271P, the ranges for the reliable detection of a U-boat in sea states 2 or lower is around 4,500 yards or 4,120 metres. The detection range for sea states 3 and higher is reduced to less than 3,000 yards, 2,740 metres. The height above sea level at which the radar is mounted also affects the detection range and this varies depending on the type of vessel. In the case of corvettes with RDF271 in sea states 2 or lower, the maximum range of a U-boat is 3,900 yards, or 3570 metres. For sea states 3 and higher the corvette mounted RDF271 the detection range of a U-boat is reduced to 3,700 yards, or 3,380 metres, for higher sea states.

	Number of detections by range band (miles)					
Period	*0–1*	*1–2*	*2–3*	*3–4*	*4–5*	*Over 5*
Jan/Apr 1942	1	2	1	1	–	–
May/Aug 1942	–	8	3	3	–	–
Sep/Dec 1942	6	19	8	–	–	–
Jan/Apr 1943	18	27	13	7	6	1
May/Aug 1943	–	7	22	4	–	3
Sep/Dec 1943	3	13	10	2	9	8
Jan/Apr 1944	4	6	6	8	3	5
May/Aug 1944	1	1	–	–	–	–
Sep/Dec 1944	–	4	3	1	–	–
Jan/May 1945	–	–	1	–	–	–

Figure 118 Post war analysis of the performance against a surfaced U-boat of RDF Type 271 and derivatives due to increased power transmitted and other design improvements.

A post war analysis of reported detection ranges shows how the performance of the RDF271 improved as more powerful magnetrons were used in the sets. From Figure 118 it can be seen that this post war analysis of the detection ranges are similar to those available in the December 1943 analysis shown in Figure 114 to Figure 117, i.e. maximum range against a surface U-boat being 2 miles, or 3,200 metres in Sep/Dec 1942 with an increase to 3 miles, or 4,830 metres, in Jan to April 1943 although the higher number of total sighting in this latter period would appear to raise the probability of detecting a target in this data at the longer ranges[246]. The post war study figures cover all sea states.

The figures given above are important when considering the feasibility of the proposed counterfactual for U-boat tactics when attacking a convoy as discussed in the main sections of this thesis. An important question that needs to be considered in this study is: at what range would the RDF Type 271 radar sets be capable of detecting a surfaced U-boat in both the bows-on azimuth angle and at the Port and Starboard Quarter views of 90 and 270 azimuth angles. It is also important to understand how this theoretical detection range might change with the development of the RDF Type 271 over the war years 1941 to 1945.

If we assume that an escort is holding station 6km from the convoy centre then its RDF271 would be probably be capable of detecting a U-boat 3 km away from it. If a flotilla U-boats is 10km from the centre of the convoy then it will probably be not detected by an escort until it is too late to prevent the counterfactual barrage of torpedoes being fired at the convoy.

B.4 An analysis of the theoretical performance of the RDF TYPE 271 radar

The equation that predicts the ratio of the radio frequency power received by a radar receiver to the electrical noise in the receiver circuits, or signal to noise ratio (S/N) is given by[247];

If we now rearrange radar equation to show the range of U-boat we have;

$$R = \sqrt[4]{((C/(P_t))} \text{ ……………………………..(1)}$$

Where C is a constant for a given set of circumstances and P_t is the power transmitted by the radar set.

If we compare the case of the detection range of that of a U-boat that using the original power output of the first models (1941-42) of the RDF Type 271 radar, which was 7 kW to the radar as in Figure 114 to Figure 117 to that of a later version of the 271 radar in the latter part of 1943, which produced 70 kW of power;

P_{t1942} is equal to 5kW, peak power

P_{t1943} is equal to 70kW, peak power

We obtain $R_{1942}/R_{1943} = \sqrt[4]{(P_{t1943}/ P_{t1942})} = \sqrt[4]{(70kW/5kW)} = \sqrt[4]{14} = 1.93$

Assuming all other factors associated with the radar, the target and their environment remain the same.

Thus, for each factor of 14 increase in power we will only get a 1.93 increase in effective detection range.

[246] Kingsley, F.A.(Ed), " The developments of Radar Equipments for the Royal Navy, 1935 – 45", Naval Radar Trust 1995…Page 145; Monograph 5: Cochrane, C.A. "Development of Naval Warning and Tactical Radar Operating in the 10cm Band, 1940 -1945"
[247] http://www.ece.uah.edu/courses/material/EE619-2011/RadarRangeEquation(2)2011.pdf

The historically recorded data is reported to have increased the typical detection range of a U-boat in 1942 from 2 to 3 miles to over 5 miles in the mid to late 1943 period**[248]**.

We may thus conclude that the counterfactual may be viable still in late 1943, i.e. the escorts are unlikely to detect the U-boats as they approach the convoy to their firing point. However, the counterfactual proposes that Doenitz employ the tactics in late 1942 when he has all the advantages in his favour.

---

[248] Kingsley….page 223

Appendix C: Geometric Alignment of Convoy Matrix

C1 A Geometric Model

In this additional analysis a simple geometric model of a convoy matrix was created and single location for a U-boat to observe the ships of the convoy chosen. This was at an angle on the bow of 45 degrees and at a various ranges from the convoy centre. The 45 degree angle was chosen simply as the mid point between the two extreme possibilities of 0 and 90 degrees.

The objective was to determine how many ships were intercepted by a ray emanating at the U-boat's location. The number of rays used was set by defining their angular separation, which was set at 1/10 of a degree. Figure 119 shows the configuration of the model

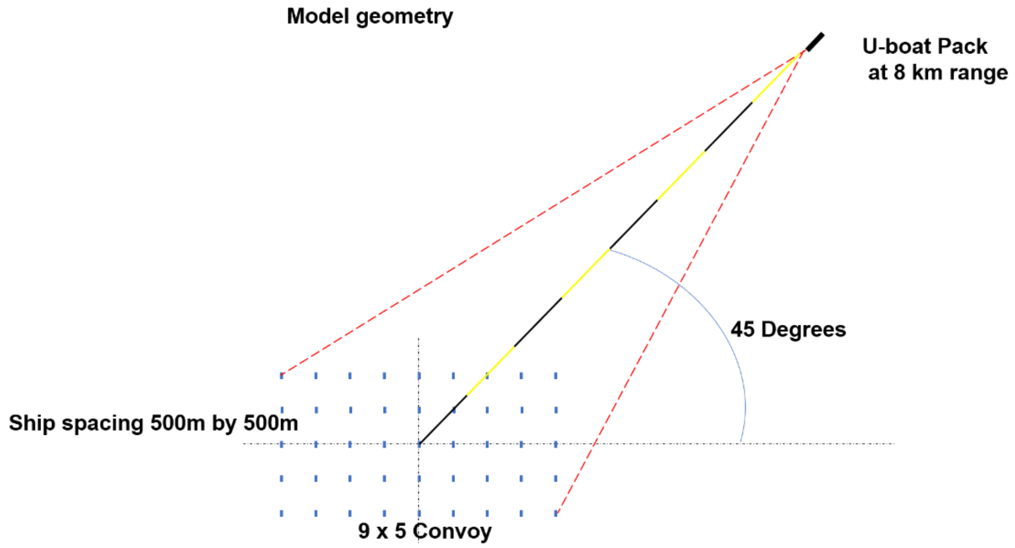


Figure 119 Geometric model configuration

An example is shown in Figure 120 where a ship is calculated to have intercepted 6 rays emanating from the U-boat's location for the given configuration.

Such calculations will be used in determining the total number of interceptions may be expected for all ship locations given the size of the ship, number and location of the ships in the convoy, location of the U-boat and the density of rays per degree used.

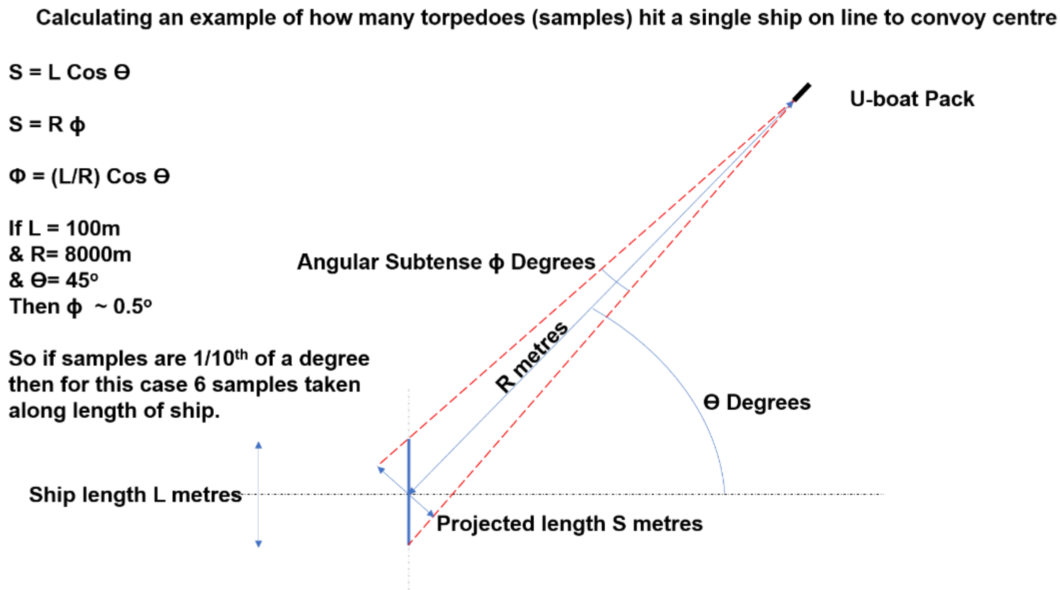


Figure 120 The model configuration shown for one example interception.

The following eight figures show the tabulation of the numbers of intercepts of the rays counted for the configuration used at various ranges of the U-boat from the centre of the convoy from 20km down to 6 km in 2km steps. The target ships are arranged in a fully filled 9x5 matrix of 45 ships and not the 42 ship 9x5 matrix of SC107 where 3 positions on the matrix were left empty on the rear row of the convoy.

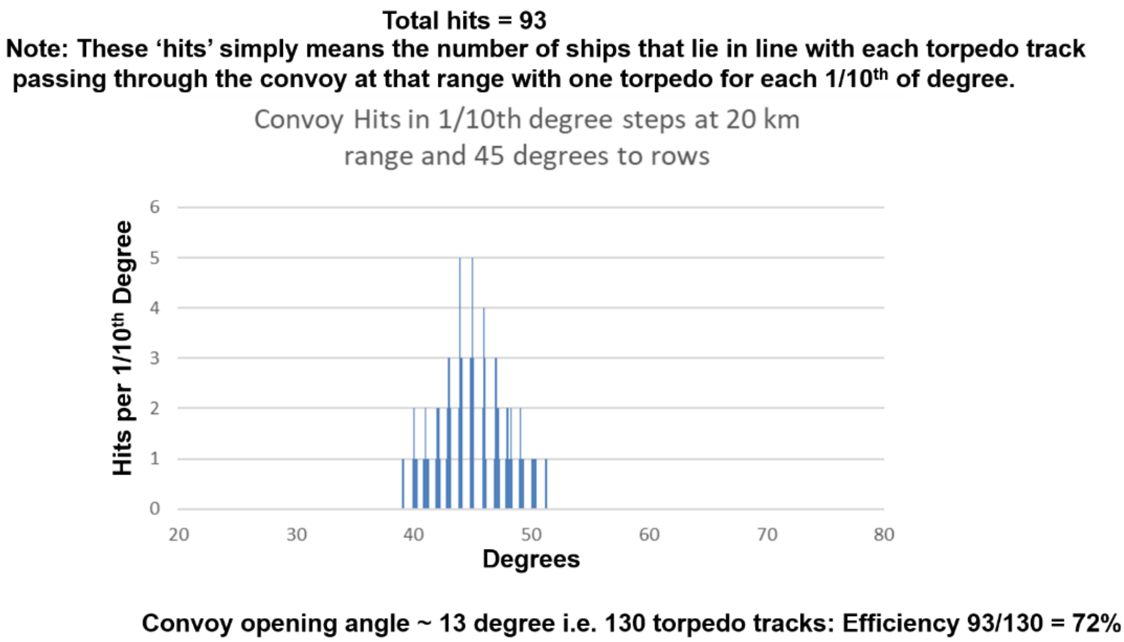
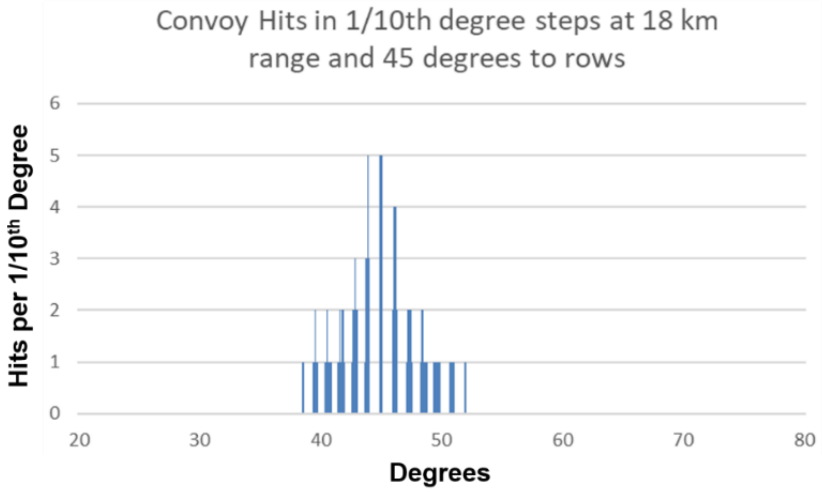


Figure 121 The ray intercepts from 20km

Total hits = 103

Note: These 'hits' simply means the number ships that lie in line with each torpedo track passing through the convoy at that range with one torpedo for each 1/10th of degree.

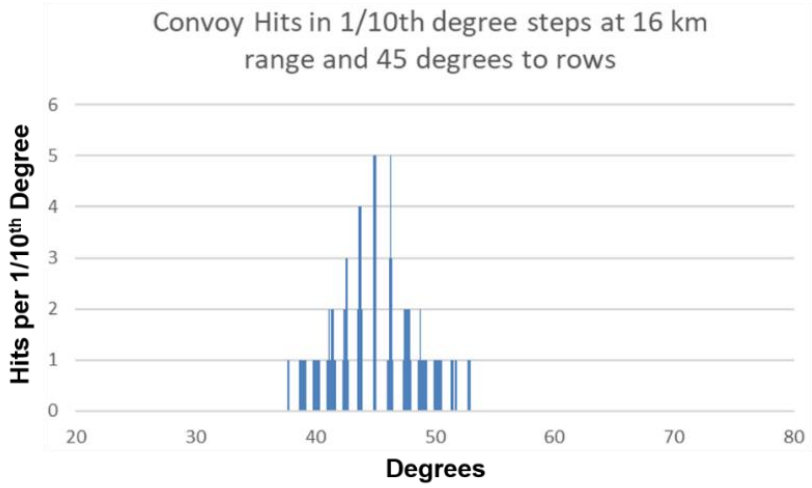


Convoy opening angle ~ 15 degree i.e. 150 torpedo tracks: Efficiency 103/150 = 68%

Figure 122 The ray intercepts from 18km

Total hits = 112

Note: These 'hits' simply means the number ships that lie in line with each torpedo track passing through the convoy at that range with one torpedo for each 1/10th of degree.

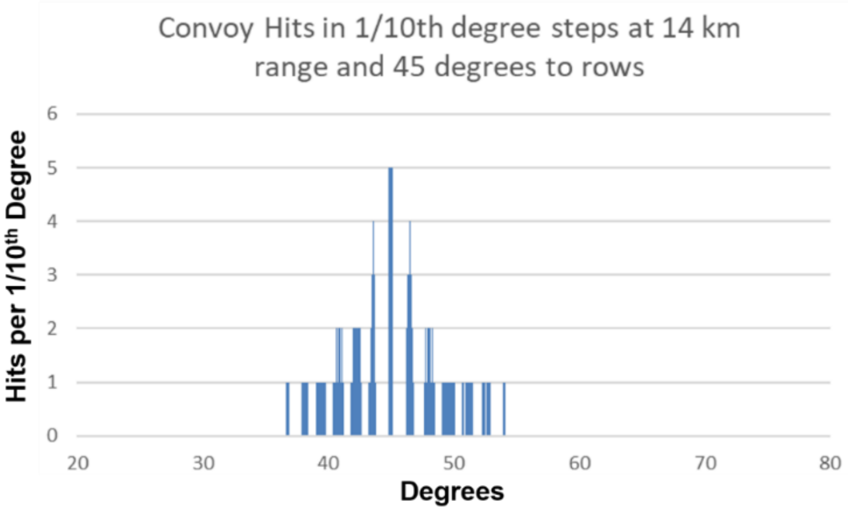


Convoy opening angle ~ 17 degree i.e. 170 torpedo tracks: Efficiency 112/170 = 65%

Figure 123 The ray intercepts from 16km

Total hits = 128

Note: These 'hits' simply means the number ships that lie in line with each torpedo track passing through the convoy at that range with one torpedo for each 1/10th of degree.

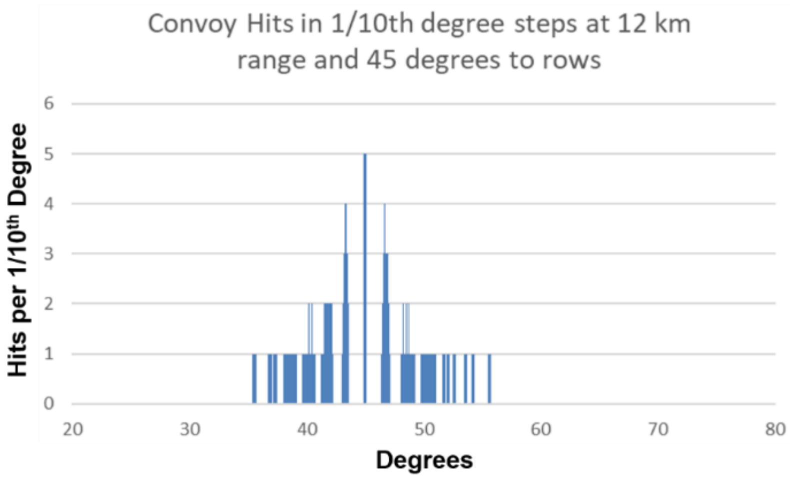


Convoy opening angle ~ 18 degree i.e. 180 torpedo tracks: Efficiency 128/180 = 71%

Figure 124 The ray intercepts from 14km

Total hits = 151

Note: These 'hits' simply means the number ships that lie in line with each torpedo track passing through the convoy at that range with one torpedo for each 1/10th of degree.

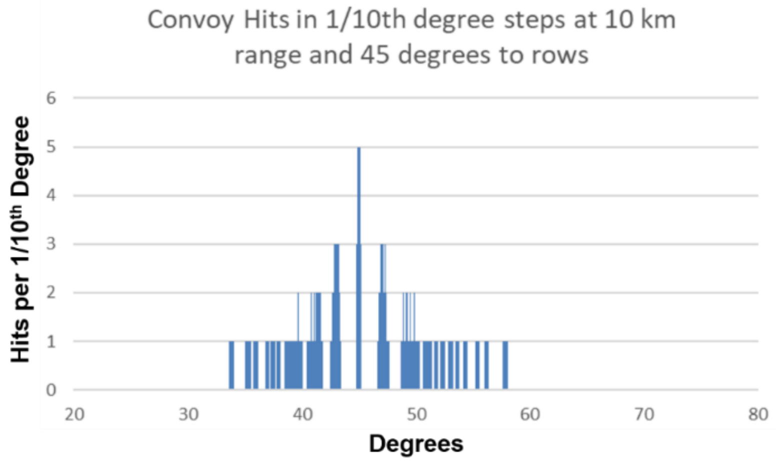


Convoy opening angle ~ 20 degree i.e. 200 torpedo tracks: Efficiency 151/200 = 75%

Figure 125 The ray intercepts from 12km

Total hits = 185

Note: These 'hits' simply means the number ships that lie in line with each torpedo track passing through the convoy at that range with one torpedo for each 1/10th of degree.

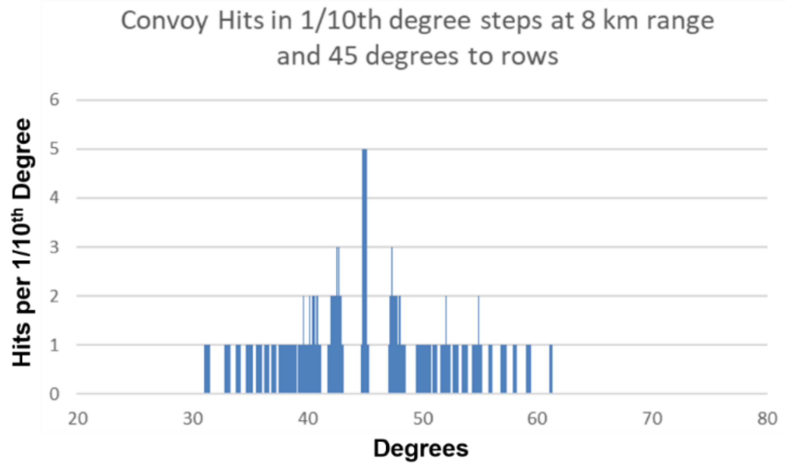


Convoy opening angle ~ 24 degree i.e. 240 torpedo tracks: Efficiency 185/240 = 77%

Figure 126 The ray intercepts from 10km

Total hits = 224

Note: These 'hits' simply means the number ships that lie in line with each torpedo track passing through the convoy at that range with one torpedo for each 1/10th of degree.



Convoy opening angle ~ 30 degree i.e. 300 torpedo tracks: Efficiency 224/300 = 75%

Figure 127 The ray intercepts from 8km

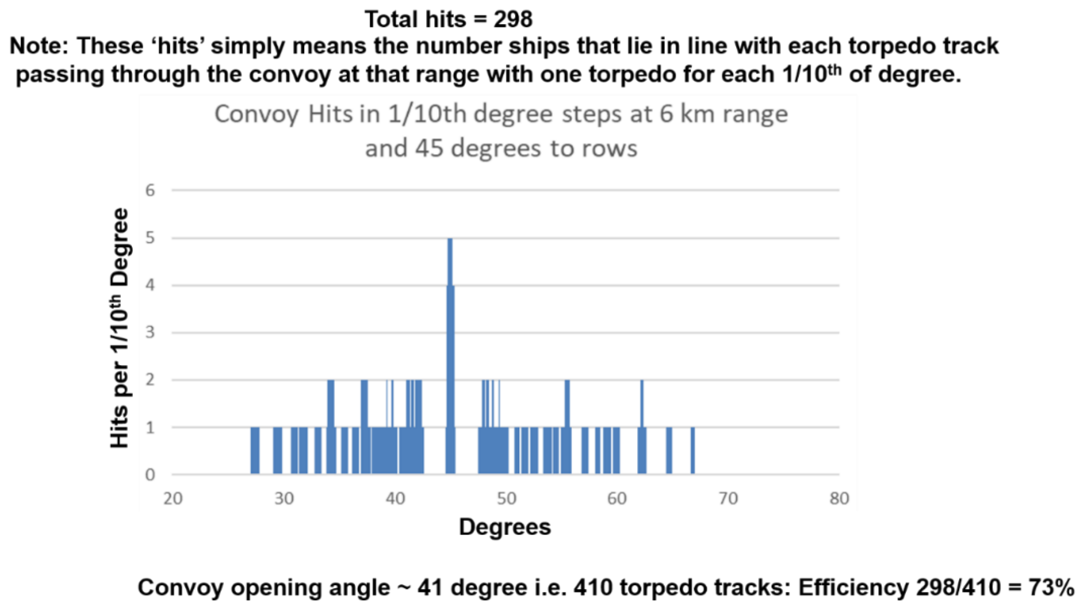


Figure 128 The ray intercepts from 6km

Examination of the sequence of plots in the 8 figures above show that number of interceptions, or hits, of the rays on the ships in the convoy is highest at the closest range and falls monotonically as the range increases, as one would expect as fewer rays fall upon a ship the further away it is, see Figure 129. However, we have defined an efficiency for the model configuration as can be seen in the figures above.

The efficiency is defined in terms of the number of hits that have occurred in total for a given range and also the total number of rays that fall upon the convoy as seen from the U-boat. The efficiency is defined as;

Efficiency = Total number of hits / Total number of rays falling upon convoy

Note that the rays used in this simple model are not actual torpedo tracks but just potential paths evenly spaced at $1/10^{th}$ of a degree apart in order to purely examine the effects of the geometry of the rays and matrix.

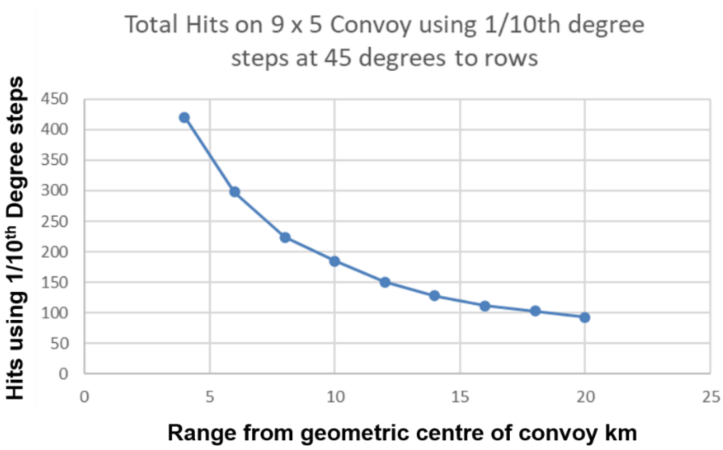


Figure 129 Total intercepted rays with range

This efficiency function is plotted in Figure 130 and is clearly not a monotonic function. From the figure we can see that the most efficient use of rays is obtained at 10km from the centre of the convoy.

It was this analysis that was used to determine the range used in the counterfactual use of the Battle Model.

A finer scales analysis in terms of the number of rays per degree and use of a range of angular positions of the U-boat relative to the convoy might reveal a ‘topographic’ map of geometric efficiency around any given convoy configuration for an individual U-boat. Similarly, such a topographic map for the distribution of U-boats used in a flotilla might also inform future modelling of the counterfactual for optimal performance prior to full battle modelling.

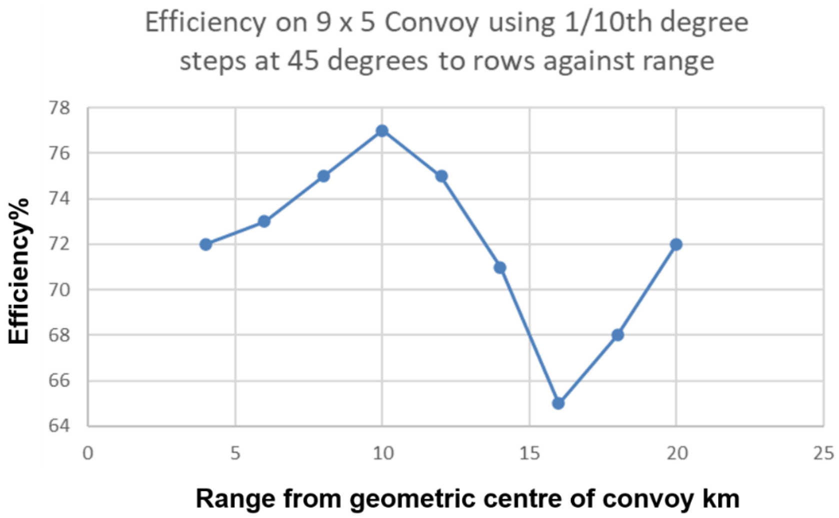


Figure 130 Efficiency of intercepts

Appendix D: Examples of code from the SC107 Battle Model

The examples of code shown here are a representative sample of key parts of the Excel Workbook created in the course of this work. There however many hundreds of lines of code in the multiple spreadsheets used and the logical architecture of hierarchical entities employed in the realisation of the BM algorithms but the space available does not permit all of this work from being shown here.

Step 1, setting up the locations of the U-boat in the two flotillas at the desired Angle on the Bow (80 degrees in this case is shown in Figure 131.

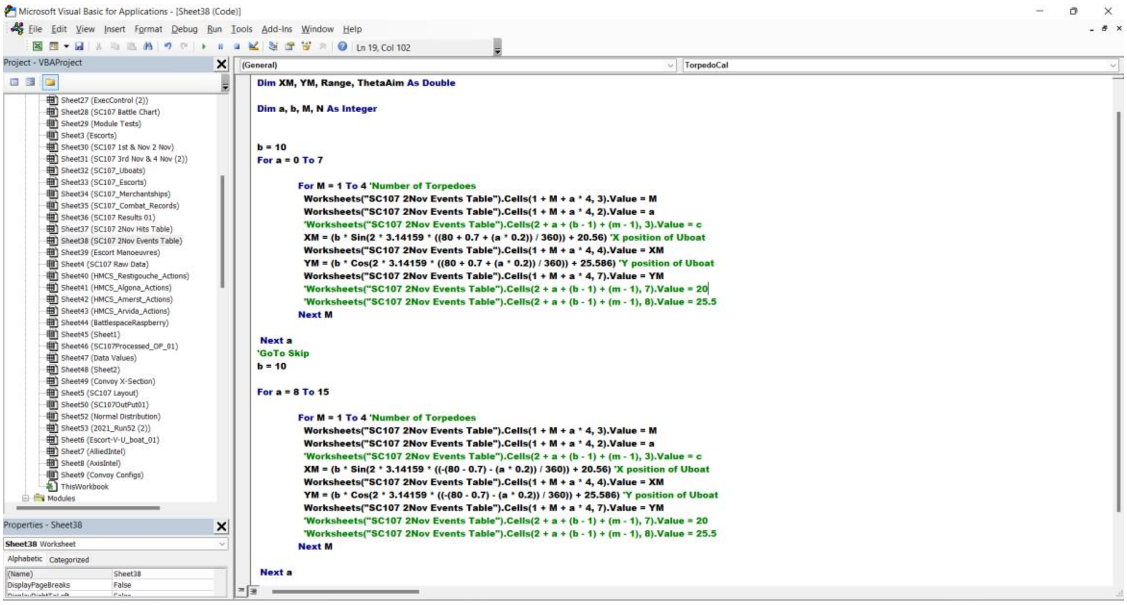


Figure 131 Setting up the U-boat locations around the convoy

Step 2, extract from the BM is ready to run now using the Exec Control in Spreadsheet 27, run of 1000, see

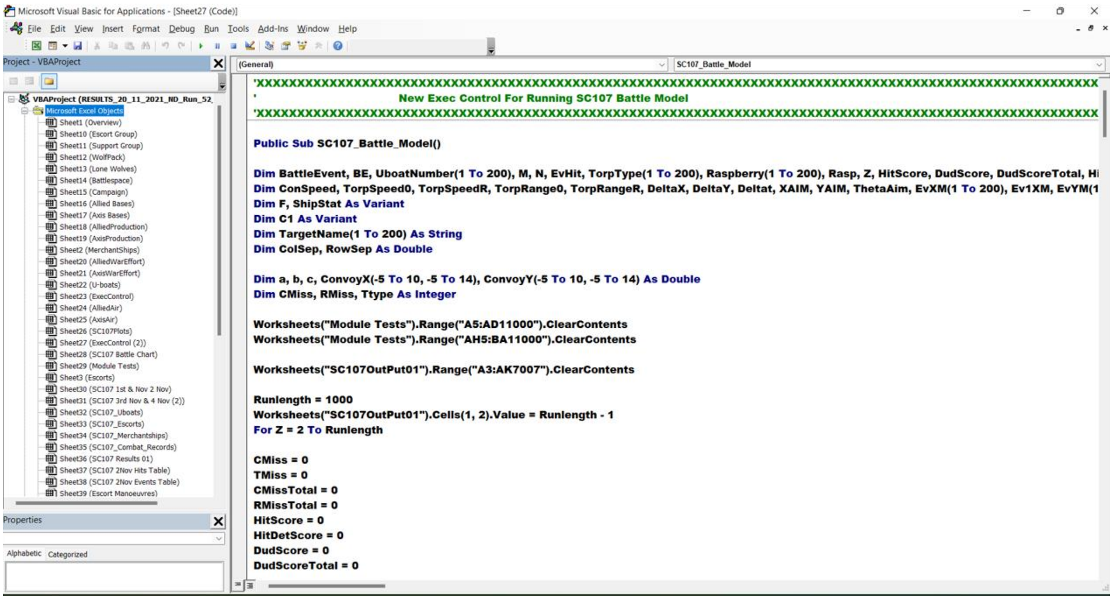


Figure 132 Extract from the Executive Control code

Step 3, extract from the Exec Control reading data from the script Spreadsheet including recently calculated U-boat locations

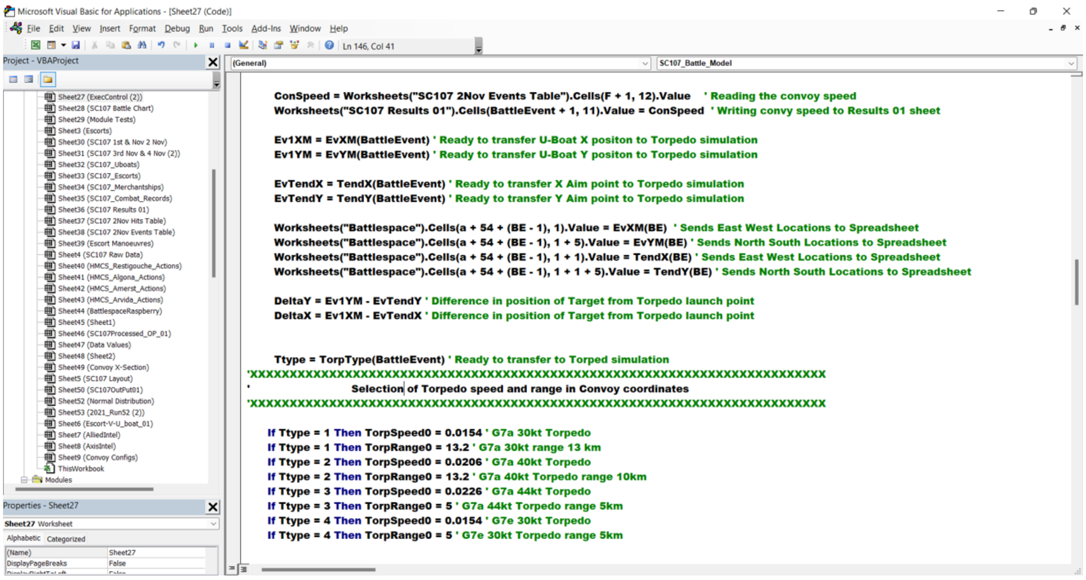


Figure 133 Extract from the Exec Control reading in data

Step 4, extract from Module 1 that shows the start of the torpedo launch with the reading in of the X and location of the U-boat and then calculates the aim point with aim and track errors taken into account.

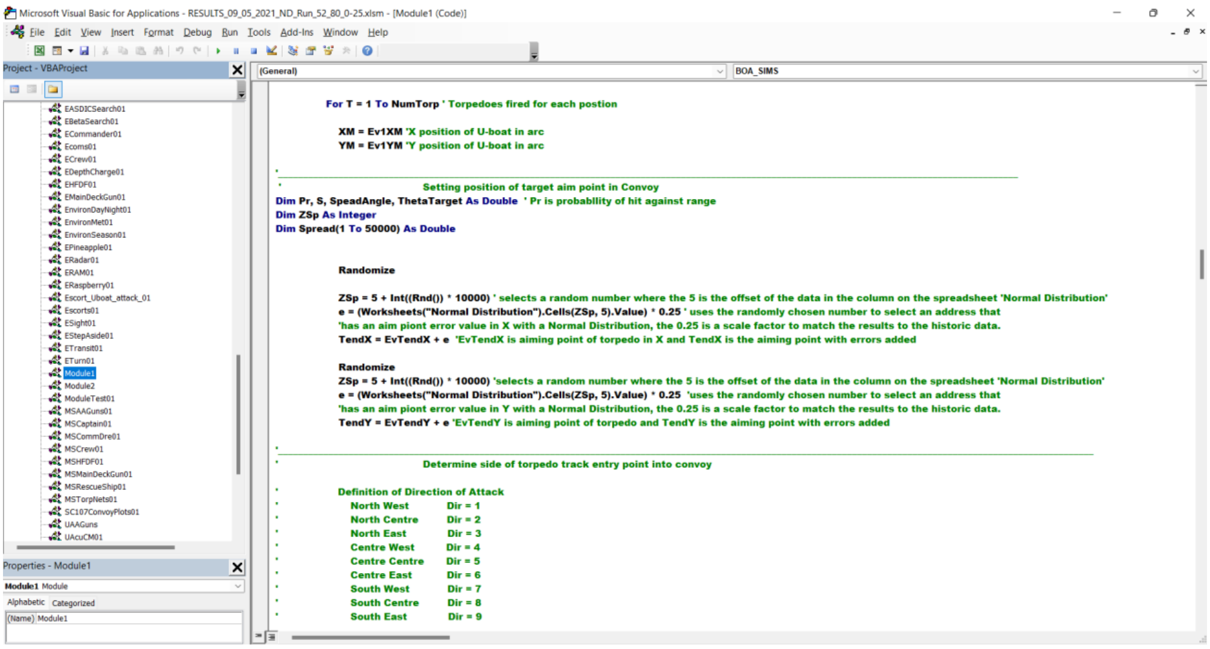


Figure 134 Extract from Module 1 showing Torpedo start and aim points in X and Y including aim and scaling for historic guidance errors.

Step 5. Extract of code from the main torpedo running code in module 1, here the torpedo is running inside the convoy and the code is testing each time step to see which ship cell it is in.

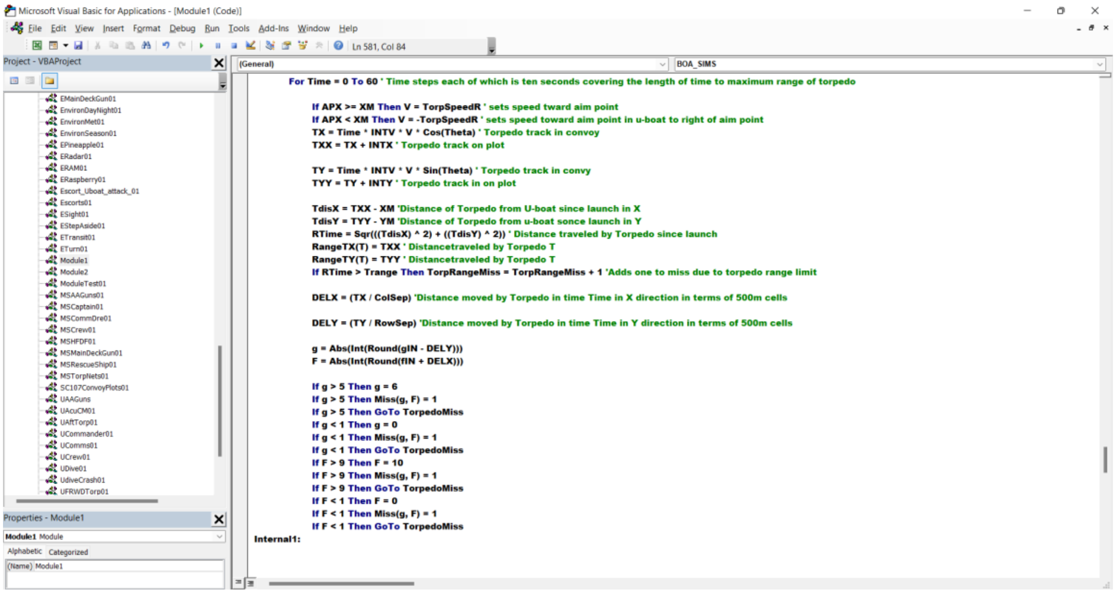


Figure 135 Extract from the torpedo running inside the convoy code

Step 6, extract from module 1, here the torpedo is running inside a ship cell and the code is testing each for each time step to see if the torpedo has hit a ship in length and width criteria. If it is a hit it sets a flag and records where it was. It is then ready to transfer back to the Exec Control code. It also tests to see if the fuze functioned.

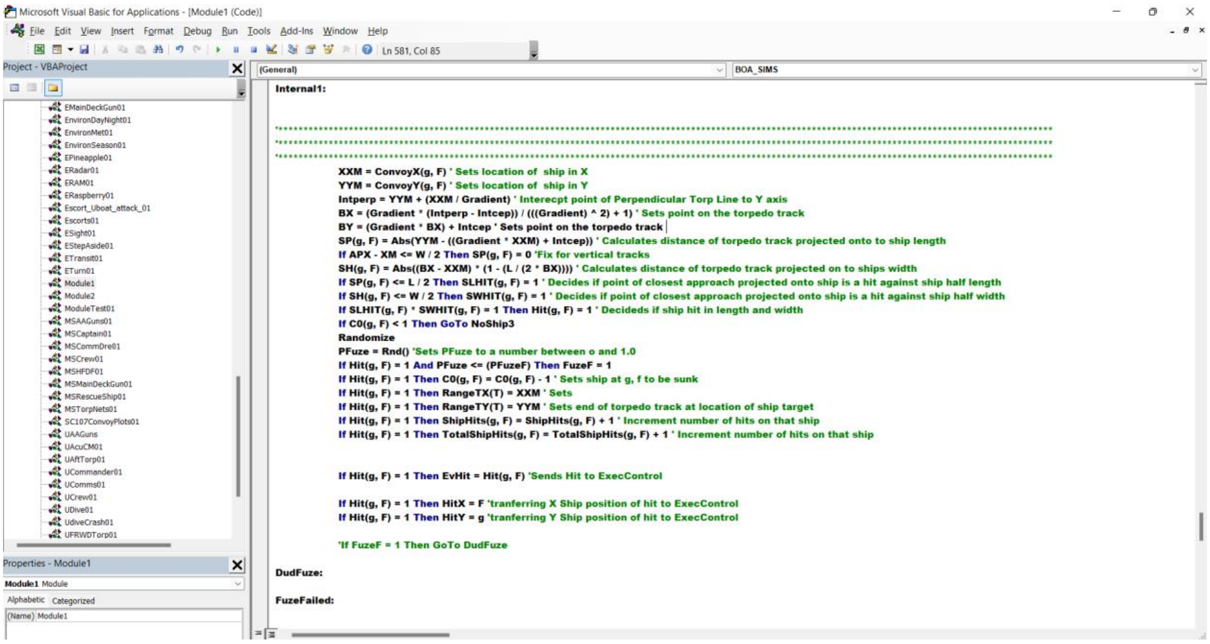


Figure 136 Extract from module 1, here the torpedo is running inside a ship cell and deciding if the ship has been hit.

BIBLIOGRAPHY

Primary Sources

UK National Archives (Kew)

ADM 1/17561 Report from Captain Roberts on his visit to Germany 1945

ADM 1/14793 A/S Warfare in relation to Future Strategy, Memorandum by the First Lord of the Admiralty

ADM 199/716/45 SC convoys. Reports: SC107

ADM 199/719/76 TM1 Board of Inquiry

ADM 199/1148 Atlantic Convoy Conference: minutes of meetings, Washington March 1943

ADM 199/2016 Analysis of U-Boat Operations in the vicinity of Convoy TM1, 3rd - 11th January 1943

ADM 199/2495 Summary of Analysis of U-boat Attacks on Atlantic Convoys 1940 - 1942

ADM 213/745 German Torpedo Attacks 1939-1945, Nov 1947

ADM 219/29 Operational Use of 271P Radar in A/S warfare Dec 1943

ADM 219/23 Relative Safety of Freighters and Tankers in Convoys 1943

ADM 219/37 Statistical Analysis of Effect of Surface Escort of Convoys, Jan 27 1943

ADM 219/46 Note on variation of losses with size of convoy 1943

ADM 219/54 The number of torpedoes required by U-boats to sink a ship 1943

ADM 219/55 How U-boats can greatly intensify their attacks on shipping

ADM 219/60 Note on expected casualties due to A/A fire from U-boats

ADM 219/74 Effect of sea, swell, wind and visibility upon U-boat hunts by surface vessels with North Atlantic convoys, 1943

ADM 219/99 Pack Tactics by Submarines 1944

ADM 219/250 Cost and Efficiency of Depth Charges, Hedgehog and Squid 1948

ADM 219/311 Handbook of theory and practice of DF plotting

ADM 219/334 Analysis of U-boat hunts by surface craft 1944

ADM 223/3 Intelligence Papers 1941-1942

ADM 223/4 Intelligence Papers 1943

ADM 234/466 Technical Staff Monographs 1939 - 1945: German torpedoes and development of torpedo control

ADM 292/209 Tactical Use of Torpedoes: Accuracy of Torpedo Fire, English translation of a German document from WWII.

CAB-79-59-20 War Cabinet: Chiefs of Staff Committee, 15th February.

FO-954-31B-327. From Foreign Office to Washington No 1741 18th March 1942

FO-954-31B- 543. From Foreign Office to Washington No 7955 Personal Telegram from PM to President No. 233) 17th December 1942

HW 18/343 “Extracts from reports containing information about the activity of German U-boats”

MFQ 1/583/15 (Diagram Showing the possibilities of a U-Boat Browning a Convoy, 1940). This was extracted by the archivists from ADM 199/2057 Anti-submarine Monthly Reports Vol 1, 1939 – 1940, Folios 222 and 223.

MFQ 1/587/19 Diagram of the relative positions to convoys of U-Boats when first detected by surface escorts, 1943. (Note; this diagram was extracted from Anti-submarines Monthly Reports Volume I, 1940

MFQ 1/587/26 British, Allied and Neutral Shipping Losses April 1943, National Archives Kew

POWE-34_24_War Cabinet Executive Committee: Oil and Power, Petroleum Division, minutes of meeting 6th January 1943

PREM 3/414/3 Analysis of the value of escort vessels and aircraft in Anti U-boat campaign

Library and Archives Canada

RG24 Vol. 7794 File: 98-21-18. Deck log for H.M.C.S "RESTIGOUCHE" for period of 26th August, 1942 to 21st November, 1942.

U.S. Library of Congress

Sternhell and Thorndyke, Antisubmarine Warfare in WWII, https://www.loc.gov/resource/dcmsiabooks.antisubmarinewar51ster/?sp=9&r=-1.131,-0.064,3.262,1.523,0

NDRC: Summary Technical Report of Division 6 , Vol. 2B, A Theoretical Basis for Screening, Chapter 8 Sonar screens https://www.loc.gov/resource/dcmsiabo11oks.theoreticalbasis02koop/?sp=7&r=-0.24,-0.065,1.473,0.687,0 accessed ….11/09/2021

Churchill Library University of Cambridge

Churchill Archives Centre, Churchill College Cambridge, Lake Papers

Secondary Sources

Theses

Habersham-Wright, David “Wolves Without Teeth: The German Torpedo Crisis in World War Two” (2010) Electronic Theses and Dissertations. 599. https://digitalcommons.georgiasouthern.edu/etd/599

Llewellyn-Jones, Malcolm “The Royal Navy on the Threshold of Modern Anti-submarine Warfare, 1944-1949”, Dept. of War Studies, Kings College, London, 18th February 2004

Beall, Thomas Reagan, Lt USN, "The Development of a Naval Battle Model and its Validation using Historical Data" Masters Thesis, Postgraduate Naval College, Monterey California, 1983.

Books

Baird, Jay W. "To Die For Germany – Heroes in the Nazi Pantheon" Indiana University Press, Bloomington and Indianapolis 1992

Blair, Clay 'Hitlers U-boat War', The Hunters 1939 – 1942, Cassell & Co 2000

Blair, , Clay 'Hitlers U-boat War', The Hunted 1942 – 1945, Cassell & Co 2000

Brown, Captain Eric 'Winkle' RN. "Wings on my Sleeve", Weidfeld & Nicolson 2006

Budiansky, Stephen 'Blackett's War' Vintage Books 2013

Chalmers, W.S. Rear Admiral RN "Max Horton and the Western Approaches, Hodder and Stoughton, 1954

Campbell, John "Naval Weapons of World War Two", Conway Maritime Press Ltd. 1985

Carruthers, Bob et al 'The Official U-boat Commander's Handbook' CODA Books Ltd. 2012

Churchill, Winston "The Second World War" vol. IV 'The hinge of fate', Penguin Books 2005

Clausewitz, Carl von, 'On War, Oxford World Classics, Oxford University Press, 2008

Connolly, Peter "Greece and Rome at War", Frontline Books 2016

Dimbleby, Jonathan "The Battle of the Atlantic" Penguin 2016

Dixon, Jeremy "The U-boat Commanders Knight's Cross Holders 1939-1945, Pen & Sword 2019

Doenitz, Admiral Karl, "The Conduct of the War at Sea", 15th January 1946. Printed by Amazon UK 2019.

Doenitz, Admiral Karl, 'Memoirs' Cassel Military Paperbacks, Cassel & Co, 2000

Douglas W.A.B., Sarty Roger, Whitby Michael, "No Higher Purpose" Volume II Part I, Vanwell Publishing Ltd. 2002.

Erskine, Ralph & Smith, Michael "The Bletchley Park Code Breakers", Biteback Publishing 2011

Faulkner, Marcus & Bell, Christopher M. "Decision in the Atlantic", Brecourt Academic 2019

Grove, Eric 'The defeat of the enemy attack upon shipping 1939-1945', Routledge 2019, Volume 1A

Hague, Arnold "The Allied Convoy System 1939-1945" Naval Institute Press, 2000

Hara, Tameichi Captain JIN, "Japanese Destroyer Captain", Naval Institute Press 2011

Haslop, Dennis 'Britain, Germany and the Battle of the Atlantic' Bloomsbury, first published 2013, paperback edition 2015

Jones, R.V. 'Most Secret War' Penguin 2009

King, Ernest J. Fleet Admiral U.S. Navy, Whitehall, Walter Muir, Commander U'S. Navy " Fleet Admiral King A Naval Record, Eyre & Spottiswoode 1953

Kingsley, F.A. et al. 'The Development of Radar Equipment for the Royal Navy 1939-45' Macmillan Press Ltd 1995

Macintyre, Capt. Donald "U-boat Killer- Fighting the U-boats in the Battle of the Atlantic" Uncommon Valor Series, First published Eeidenfeld & Nicolson 1956

Mallmann Showell, Jak P. "Dönitz, U-boats, Convoys The British Version of His Memoirs from the Admiralty's Secret Anti-Submarine Reports. Frontline Books, 2013

Martindale, Dougie "Günter Prien and U-47 The Bull of Scapa Flow", Naval Institute Press Frontline Books 2018

Mayne, Richard O. "Betrayed, Scandal, Politics and Canadian Naval Leadership, UBC Press 2006

McCue, Brian, "U-boats in the Bay of Biscay, An essay on operational research" Alidade Press2008

Middlebrook, Martin "Convoy SC122 & HX229 Climax of the Battle of the Atlantic March 1943" Pen & Sword Maritime 2011

Milner, Marc 'Battle of the Atlantic' The History Press 2011, first published 2003, paperback 2011

Ministry of Defence(Navy) "The U-Boat War in the Atlantic 1939 – 1945" Her Majesty's Stationery Office, 1989

Morse, Philip M, and Kimble, George E., "Methods of Operational Research" Military Operations Research Society, 1998, Kindle edition.

Niestle, Axel, "German U-boat losses during World War II", Frontline Books 2014

NOAA, National Oceanic and Atmospheric Administration, https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-floor-features

Padfield, Peter "Dönitz The Last Führer" Lume Books, 2021

Paterson, Lawrence "Otto Kretschmer The Life of the Third Reich's Highest Scoring U-boat Commander" Greenhill Books 2018

Percy W. Nelles https://en.wikipedia.org/wiki/Percy_W._Nelles , accessed 27th Sept. 2021

Rohwer, Jurgen "Axis Submarine Successes in World War Two", Naval Institute Press, Annapolis, Maryland, Greenhill Books London 1999

Roskill, S.W. Captain RN, "The War at Sea 1939 – 1945" Vol.II

Syrett, David "The Battle of the Atlantic and Signals Intelligence: U-boat Situation and Trends, 1941 – 1945, Navy Records Society, Routledge 1998.

Smith, Kevin, "Conflict Over Convoys" Cambridge University Press, 2002

Terraine, John "Business in Great Waters" First published Le Cooper Ltd 1989, Pen & Sword 2009

United States Navy, Motor Torpedo Boats Tactical Orders and Doctrine, July 1942 https://maritime.org/doc/pt/doctrine/part3.htm Accessed 20th October 2021

Vause, Jordan “U-boat Ace, The story of Wolfgang Luth”, Pen and Sword Greenhill Books 2017, originally published 1990.

Waddington, Professor C.H., Operational Research Against The U-Boat. Caliver Books ^ Partizan Press, 2020

Washburn, Alan; Kress, Moshe, “Combat Modelling” Springer 2009

Waters, John m, “Bloody Winter”, Naval Institute Press, Blue Jacket Books 1994

Williams, Mark, “Captain Gilbert Roberts R.N. and the anti-U-boat school” CASSELL Ltd. 1979

Research Articles

McCue, Brian “USING SIMULATED ANNEALING TO SOLVE A PROBLEM OF “ECOLOGICAL” INFERENCE”, Military Operations Research Society, Phalanx , Vol. 47, No. 2 (June 2014), pp. 32-39, Accessed through https://www.jstor.org/stable/10.2307/24910611 downloaded 11th April 2019.

McCue, Brian, Applying “Hughes’s Salvo” Equations” to engagements between U-boats and Convoy Escorts. Military Operations Research, Vl 19 No. 4 (2014), pp 41-50. https://www.jstor.org/stable/24838525

Redford, Duncan “The March 1943 Crisis in the Battle of the Atlantic, Myth and Reality”, History, Vol. 92, No.1 (305) (January 2007), pp. 64-83

Strong, Paul Edward, “Wargaming the Atlantic War”, MORS Wargaming Special Meeting October 2017, Working group 2. https://www.professionalwargaming.co.uk/171210WATU-MORS.pdf Accessed 3rd October 2021.

Internet

Admiralty Trilogy, Surface Torpedo Tactics: Rules and Reality, http://www.navweaps.com/index_tech/tech-067.php. Accessed 23rd October 2021

Allied Bomber Offensive https://en.wikipedia.org/wiki/Strategic_bombing_during_World_War_II Accessed 30th October 2021

American Logistics in the Normandy https://en.wikipedia.org/wiki/American_logistics_in_the_Normandy_campaign Accessed 6th November 2021

Board Gaming Geek https://boardgamegeek.com/boardgame/21488/petteia accessed 18th November 2021 30th October 2021

Bombardment of Cherbourg https://en.wikipedia.org/wiki/Bombardment_of_Cherbourg Accessed 1st November 2021

Brooks, John “British Destroyers at Jutland: Torpedoes in Theory and Action, British Journal of Military History, Vol 3 No 3 (2017) https://bjmh.gold.ac.uk/article/view/757

Depth Charge https://en.wikipedia.org/wiki/Depth_charge Accessed 7th November 2021

Hedgehog (weapon) https://en.wikipedia.org/wiki/Hedgehog_(weapon) Accessed 7th November 2021

MIT Museum Whales Mistaken for Submarines https://collections.mitmuseum.org/object/af-nb-0074/

Mid-Ocean Escort Force https://en.wikipedia.org/wiki/Mid-Ocean_Escort_Force accessed 26th September 2021

National Maritime Museum "Enigma" https://www.nmrn.org.uk/explore/curators-highlights/enigma?gclid=CjwKCAjwtfqKBhBoEiwAZuesiDdJeP0aJlmwgDGsbDdZ7n1VY2bxpw324qzSz-kBh06pDv0Jkl1LyBoCFhkQAvD_BwE, Accessed 7th October 2021

Navweaps.com "Were the best good enough" http://www.navweaps.com/index_tech/tech-067.php, Accessed 23rd October 2021

NOAA, National Oceanic and Atmospheric Administration, https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-floor-features

NavyNews https://issuu.com/navynews/docs/200305/44 Accessed 3rd October 2021

Operation Avalanche https://en.wikipedia.org/wiki/Operation_Avalanche Accessed 30th October 2021

Operation Big Ben https://en.wikipedia.org/wiki/Operation_Big_Ben Accessed 30th October 2021

Operation Bolero https://en.wikipedia.org/wiki/Operation_Bolero Accessed 30th October 2021

Operation Crossbow https://en.wikipedia.org/wiki/Operation_Crossbow Accessed 30th October 2021

Operation Husky https://en.wikipedia.org/wiki/Allied_invasion_of_Sicily Accessed 30th October 2021

Operation Overlord https://en.wikipedia.org/wiki/Operation_Overlord Accessed 30th October 2021

Operation Torch https://en.wikipedia.org/wiki/Operation_Torch Accessed 30th October 2021

St. Nazaire Raid https://en.wikipedia.org/wiki/St_Nazaire_Raid Accessed 1st November 2021

QF 4-inch naval gun https://en.wikipedia.org/wiki/QF_4-inch_naval_gun_Mk_XVI Accessed 7th November 2021

SONAR https://en.wikipedia.org/wiki/Sonar#ASDIC, accessed 24th September 2021

Torpedo Vorhal Trechner Project http://www.tvre.org/en/aiming-with-the-periscope accessed on the 3rd October 2021

Uboataces.com http://www.uboataces.com/torpedo-tv.shtml Accessed 6thOct. 2021

Warsailors HX Escorts https://www.warsailors.com/convoys/hxescorts.html

Battle of the Atlantic https://en.wikipedia.org/wiki/Battle_of_the_Atlantic, Accessed 7th October 2021

Depth Charges https://en.wikipedia.org/wiki/Depth_charge, Accessed 7th October 2021

Hedgehog https://en.wikipedia.org/wiki/Hedgehog_(weapon), Accessed 7th October 2021

Woods Hole Institution https://www.whoi.edu/oceanus/feature/new-instrument-sheds-light-on-bioluminescence/ Accessed on 8th October 2021

Excel Workbooks

Lloyd Peter, "Data on Tankers Sunk 1942" created by author, 24th July 2021