Operation Sealion: Simulating the Naval Component of a 1940 German Invasion of Britain

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Abstract

In this thesis, we will study the naval component of Operation Sealion, the proposed 1940 German invasion of Britain. This never happened as during the Battle of Britain, the Luftwaffe did not achieve the level of air superiority required for the invasion to start. We aim to answer the question of whether the Germans could have gotten a sufficient force ashore. We developed two counterfactual scenarios, a 2-sigma scenario and a 6-sigma scenario, where the Luftwaffe win the Battle of Britain by a small and large margin, respectively. We used these counterfactuals to wargame the final German preparations, such as the laying of minefields. In the 6-SD wargame, the Germans were able to lay approximately 75% of their planned minefields, but only 20% in the 2-SD wargame. We then developed a simulation of the initial three days of Operation Sealion, where around 120,000 German troops would be shipped across the Channel using barges and transports, with the Royal Navy attempting to sink them. During each run of the simulation, parameters such as the effectiveness of British destroyers against barges were chosen from a prior distribution, allowing us to estimate dependencies between different quantities. We discovered that the most critical factor in Operation Sealion was the effectiveness of minefields. We found that if the outcome of the Battle of Britain was similar to reality or even slightly in favour of the Luftwaffe, as in the 2-SD simulation, then the Germans would not be able to get a sufficient force ashore, hence the invasion would be unsuccessful. However, if the Luftwaffe had won the Battle of Britain by a very large margin, as in the 6-SD simulation, then the Germans could have gotten a large army ashore, potentially paving the way for a successful invasion.

Acknowledgements

I would like to thank my supervisors, Professor Niall MacKay and Professor Jamie Wood, for their continuous guidance and support throughout the duration of this research project. Their patience, time and kindness has been invaluable to me, and I feel very grateful to have had them as my supervisors.

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Finally, I would like to thank my family for their unconditional love and encouragement.

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.

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1 Introduction

1.1 Background

In the summer of 1940, soon after the collapse of France, Hitler turned his attention towards Britain.[1] Although he wanted a negotiated peace, once it became evident that they showed no appetite for doing so, he started to draw up plans for an invasion of Britain, codenamed Operation Sealion, and a huge effort was put towards ensuring it could be made a reality.[2]

One crucial prerequisite that Hitler required to launch the invasion was the destruction of the RAF,[3] which resulted in the Battle of Britain. Britain eventually prevailed, resulting in the Germans never launching the invasion, even though much of the preparations had been completed. While some have even questioned whether Hitler was serious about invading[4] the heroics of Fighter Command have long stayed in the British psyche, and are seen by many as what stopped an invasion of Britain from happening.[5]

However, the debate hasn't stopped there; various narratives exist over what would have happened had the British lost the Battle of Britain[6]. Some are convinced that the true stumbling block to the invasion was the Royal Navy which was numerically much stronger than the Kriegsmarine, and so, even if the Battle of Britain had been lost, they believe that an invasion would have ultimately ended in failure.[7] While others are more optimistic towards German chances of a successful invasion.[8]

Any efforts aimed at resolving this question require a counterfactual narrative, where the Germans achieve a level of success during the Battle of Britain, where the trigger to set off the invasion is met.

This narrative is provided by a recent paper,[9] which uses a statistical technique called weighted bootstrapping to support long-held assertions that the Luftwaffe made various mistakes during the Battle of Britain, such as changing their main target to London, and not targeting airfields. The bootstrapping paper argues that, had the Germans picked a better strategy, then the probability of British success in the Battle of Britain would have gone down drastically.

We will use the bootstrapping paper to provide a credible counterfactual narrative where the Germans meet the level of air superiority required for the invasion

[1] ADM 223/484, German Plans for the Invasion of England in 1940, p1-p3
[2] OKW Directives for the Invasion of the UK, Directive Number 16
[3] OKW Directives for the Invasion of the UK, Directive Number 16
[4] Egbert Kieser, Operation Sea Lion: The German plan to invade Britain,1940, p265-p269
[5] Operation Sea Lion: Hitler's Cancelled Invasion of Britain, Warfare History Network
[6] Christina Goulter *et al*, The Battle of Britain Debate
[7] Anthony J. Cumming, The warship as the ultimate guarantor of Britain's freedom in 1940
[8] Robert Forczyk, We march against England: Operation Sea Lion, 1940-41, here Forczyk is much more critical of the Royal Navy's ability to intercept and sink the invasion fleet
[9] Brennen Fagan *et al*, Bootstrapping the Battle of Britain

to start, and this thesis will aim to inform historical analysis of what would have happened, had the German attempted to make a crossing.

This bootstrapping paper will create a narrative which will allow us to wargame the 10 days leading up to invasion, something which never occurred in reality due to the requirement of air superiority not being met by the Germans. During these 10 days the Germans will carry out vital final preparations, such as the laying of minefields. These minefields were to be crucial in preventing the Royal Navy from attacking the invasion fleet. This will give us a sense of the order of battle on the day of invasion, as well as giving us an estimate of the proportion of minefields laid.

This wargame will then provide the basis for the overarching aim of this research project, which is to develop a simulation of the naval component of Operation Sealion. Such a simulation is complex, due to the various parameters involved, such as proportion of minefields laid, effectiveness of destroyers against barges and effectiveness of Ju-87s (dive-bombers) against destroyers. However this will be necessary in order to allow us to gauge which of these parameters could have had a decisive effect on the outcome of the operation, and will ultimately allow us to provide an answer to the question of whether the Germans could have got an army ashore.

Before developing a simulation of Operation Sealion, we decided to create a simulation of the Kanalkampf campaign, as a proof of concept. The Kanalkampf campaign was a period during the Battle of Britain, during which the Luftwaffe intensified attacks on British convoys passing through the Channel, hoping to force the RAF to engage them. As the Kanalkampf campaign happened in reality, whereas Operation Sealion did not, this will allow us to compare results from an actual campaign with our simulation, and calibrate it to produce results that are plausible when compared to what actually happened. Only then will we move to our actual simulation of Operation Sealion.

As stated previously, the fundamental question that this thesis aims to answer, is whether the Germans could have landed an army ashore, and so the land campaign subsequent to an invasion will not be within the scope of this thesis.

In the rest of this introductory chapter we will first cover a literature review on Operation Sealion, then we will cover the planning of the invasion, until finally we briefly outline the wargames and simulation.

1.2 Literature Review

1.2.1 Primary Sources

In order to gain a better insight into the values of the parameters in our simulation, such as the effectiveness of Ju-87s against destroyers, a wide number of documents were used from the UK National Archives at Kew.

The following is a list of the primary sources that were accessed in order to give us a deeper insight into the values that our parameters should take:

> ADM 219/4, Air strikes on surface vessels, 1942 Dec
>
> ADM 219/173, A study of the relative merits of bombs and torpedoes for attacking ships from aircraft, 1944
>
> ADM 199/1189, Anti-aircraft defences: policy, 1940-1942
>
> ADM 199/81, British and Allied merchant ships sunk or damaged by enemy action: reports, 1941
>
> ADM 1/17699, ADMIRALTY (5) and COMMONWEALTH OF NATIONS (21): Investigation into the accuracy of naval gun fire: proposed appointment of Canadian liaison officer, 1945
>
> ADM 1/16523, ADMIRALTY (5) and ARMAMENTS (11): Naval Gun Accuracy Committees: report and recommendations of Oliver Committee (1944) and setting up of permanent committee in DNO, 1944
>
> ADM 219/1, Minelaying: minelaying by MLs and MTBs, 1942
>
> ADM 219/33, Detection of E-boats and interception by coastal forces, 1943
>
> ADM 219/475, Defence in mining war against UK: analysis, 1951

Of particular importance was ADM 199/1189, which provided a statistical analysis of the effectiveness of Ju-87s against British naval vessels. More specifically, it gives us numerical data such as the the number of bombs that were dropped, and the number of bombs that hit their target. This meant we could then assign to each Ju-87 a probability that it successfully hits a destroyer, which we then implemented into our simulation.

Various documents were also obtained with the aim of finding out how the British would have responded to an invasion. Some of the most useful were:

> AIR 75/7, German Invasion, May 1940, 1938-1940
>
> ADM 223/484, German plans for the invasion of Britain, 1940
>
> ADM 199/687, Possible invasion of Great Britain: countermeasures, 1939-1941
>
> ADM 199/2212, War diary summaries: situation reports, 1940 Sept. 1-15

ADM 1/10561, PREPARATION FOR WAR (MILITARY) (46): Possible invasion of Great Britain by Germany: naval appreciation, 1940

Amongst the most useful was ADM 1/10561, from which we were able to discern that the British were aware that a invasion on the south coast was most probable, and that the Germans would likely use a decoy invasion to tie down Royal Navy ships elsewhere. From this document, we also know that the British were aware that the Kriegsmarine would attempt to use their surface vessels to divert attention from their barges and transports. It also provides us with a valuable insight into potential British counter-measures, such as using smaller vessels for offshore reconnaissance, in order to gain the earliest possible indication of an invasion.

ADM 199/687 was also very useful, as it provides us with a detailed look at how the British coastal forces would have dealt with the invasion fleet. In particular, an emphasis was placed on fighting taking place at the shortest possible distance, with a focus being placed on barges and transports, with German warships only being engaged if necessary.

1.2.2 Secondary Sources

The secondary sources which I have used most extensively in the development of this research project are as follows :

"Invasion of England 1940" by Peter Schenk, which provides a very detailed look into the German planning for Operation Sealion. It details the struggles of the German Navy in developing the suitable transports required for the invasion, as well as providing the operational plan of the Luftwaffe, Kriegsmarine and Army during the invasion.

"Operation Sea Lion" by Ronald Wheatley, which, like Schenk, also provides a very deep investigation into German plans for an invasion.

ADM 223/484, from the National Archives, contains a document titled "German Plans for the Invasion of England in 1940" produced by German historian Kurt Assmann, and provides a detailed look into the evolution of the German plans for invasion. It also gives us an insight into the German plans for a decoy operation, as well as the numerous disputes between the German Army and Navy over the question of a broad or narrow crossing.

"The warship as the ultimate guarantor of Britain's freedom in 1940" is an article by Anthony J Cumming, which argues against the notion that ships could not survive against a large number of aircraft, and that ultimately it was the Royal Navy, not the RAF, which stopped the Germans from initiating an invasion of Britain.

"The Royal Navy in the Battle of Britain" by Karl Larew, like Cumming also argues that the Royal Navy would have been less vulnerable to

the Luftwaffe than made out, and that Operation Sealion was ultimately doomed from the start, due to the much stronger Royal Navy.

"Operation Sea Lion" by Peter Fleming provides an overview of the planning involved in Operation Sealion, as well as describing the British response to an impending invasion.

"We march against England, Operation Sea Lion 1940-1941" by Robert Forczyk puts a spotlight on some of the key factors that would influence the outcome of Operation Sealion.

"Sea Lion" by Richard Cox is a fictional book attempting to determine what would have happened had the Germans pressed ahead with their plan to invade Britain.

"Gold from Crete" by C.S. Forester is a book which contains a short fictional story of a hypothetical early German invasion of Britain, right after Dunkirk, as opposed to September. Forester believes this is when the Germans had the best chance of invading Britain; however, even then it ultimately ends in a defeat for the Germans.

"Silent Victory" by Duncan Grinnell-Milne describes the evolution of plans for invasion, as well attempting to give us an insight into German thinking at the time. In this book, Grinnell-Milne argues that it was ultimately the Royal Navy, not the RAF, that prevented Operation Sealion from ever happening.

1.3 Planning of Operation Sealion

In this section, we will describe the German plan to invade Britain, starting with its conception, through its evolution, up to its final form. We will also describe the operational plans of the Luftwaffe and the Kriegsmarine in the event of invasion, as well as British preparations for the invasion. Much of the content in this section will come from Schenk, Wheatley and ADM 223/484, as they provide a very detailed look at the German invasion plans.

1.3.1 Initial conception of invasion

As early as the autumn of 1939, preliminary plans were being made by the Kriegsmarine for a potential invasion of Britain. It quickly became evident that if such a colossal undertaking was to successfully take place, then there would have to be a successful repression of the Royal Air Force, as well as the ability to prevent the Royal Navy from entering the route of the invasion fleet. Hitler initially seemed uninterested, until the collapse of France, at which point he appears to become lukewarm to the idea, provided certain conditions are met.[10]

[10] ADM 223/484, German Plans for the Invasion of England in 1940, p1-p3

On July 16th 1940, Hitler released his famous directive number 16, which initiates planning for an invasion of Britain, codenamed Operation Sealion. The landing was to be across a "broad front from the neighbourhood of Ramsgate to the area west of the Isle of Wight". [11]

He adds that certain conditions have to be met in order for an invasion to proceed. Some of these are:[12]

> Destruction of the RAF to a level where they cannot offer resistance in any meaningful way.
>
> Minefields either side of the Straits of Dover, to prevent any British naval reinforcement for entering and attacking the invasion fleet.
>
> Divert British naval resources elsewhere, to ensure there are less available to attack the invasion fleet. British ships to be put under air attack to ensure strength is further depleted.
>
> Routes of the invasion fleet must be cleared of mines.
>
> Construction of coastal artillery, to reduce the ability of the Royal Navy from attacking the invasion fleet.

At a meeting between Hitler and the Chiefs of the Armed Forces on 21st July, Hitler himself stated that this was a very dangerous operation, and that it was not at all comparable to the landings as done in Norway. He felt that the most difficult part of the operation would be resupplying the troops. Again, he emphasised the need for air superiority, as well as the use of minefields and artillery to protect the invasion fleet.[13] He wanted the navy to have finished preparations by the 15th of August,[14] and the whole operation to be finished by the 15th of September, but he acknowledged that such a date could only be determined by when air superiority was achieved.[15]

Hitler wanted to know how long it would take the Kriegsmarine to complete preparations, to which they responded by saying that much of the preparations, such as assembling the barges in the invasion ports, minelaying and minesweeping in the Channel, could only take place once air superiority was achieved, and that it would certainly not have preparations completed by 15th August. This crucial period of final preparations never occurred in reality, as the level of air superiority required was never achieved by the Germans. And so it will be necessary for us to wargame this period, which will allow us to get a sense of whether these preparations would have been feasible.[16]

On the 19th of July, a Naval Staff Appreciation said that there were several glaring problems facing the German Navy with regards to Operation Sealion.

[11] OKW Directives for the Invasion of the UK, Directive Number 16
[12] OKW Directives for the Invasion of the UK, Directive Number 16
[13] ADM 223/484, German Plans for the Invasion of England in 1940, p14-p15
[14] ADM 223/484, German Plans for the Invasion of England in 1940, p5
[15] ADM 223/484, German Plans for the Invasion of England in 1940, p14-p15
[16] ADM 223/484, German Plans for the Invasion of England in 1940, p16

Some of their most significant concerns were:[17]

> The invasion path goes through a treacherous area of water that not only makes the initial crossing very difficult, but also increases the difficulty for further logistical supplies.
>
> Many of the ports from which the invasion fleet must set off have been damaged or have a small capacity.
>
> No knowledge of the location of British minefields in the Channel, creating significant risk for the invasion fleet.
>
> Admission of the fact that the Luftwaffe cannot keep the much stronger Royal Navy out of the Channel, and so it must have the help of minefields and U-boats, as well as the use of diversionary attacks to divert the Royal Navy away from the invasion fleet. And even if the initial wave were to pass through safely, the Royal Navy could stop any further troops and supplies from landing.

Already at this early stage, the German Navy was sceptical about the plan, and viewed it as a last resort. Instead, they believed that Britain could be forced to make peace via attacks on her shipping by aircraft and U-boats. This would remove the need for an ambitious and potentially very dangerous landing operation, that could lose them a significant proportion of both their Navy and Army.[18]

One of the most pressing issues facing the Kriegsmarine was one of shipping capacity. Such an invasion would require an enormous amount of shipping transport, and so the German Navy carried out Herculean efforts to ensure that such an invasion could be made feasible.[19]

German Naval Staff estimated that the shipping requirements for the invasion plan would be:[20]

> 1722 barges
>
> 155 transports
>
> 471 tugs
>
> 1161 motorboats

However, the German Navy was able to meet the challenge by requisitioning barges and other naval vessels from across occupied Europe,[21] and virtually all naval requirements were achieved by mid to late September, in time for the invasion.[22]

[17] ADM 223/484, German Plans for the Invasion of England in 1940, p10-p13
[18] ADM 223/484, German Plans for the Invasion of England in 1940, p5
[19] Peter Schenk, Invasion Of England 1940, p150-p151
[20] ADM 223/484, German Plans for the Invasion of England in 1940, p19
[21] Ronald Wheatley, Operation Sea Lion, p100-p101
[22] Ronald Wheatley, Operation Sea Lion, p112

1.3.2 Initial invasion plan

While the Kriegsmarine was grappling with the enormity of their situation, the German Army was pushing ahead with invasion preparations, and by the end of July they had already developed a plan for the invasion.[23]

The first wave would consist of 13 infantry divisions. Six of these divisions were to land between Ramsgate and Bexhill and would depart from Calais, four divisions would land between the Isle of Wight and Brighton and would depart from Normandy, and the final 3 divisions would land in Lyme Bay and would depart from Cherbourg.[24] Each of these 13 divisions had a first echelon, which consisted of 6,762 men, and a second echelon which consisted of 12,376 men.[25] In the initial wave, the first echelon of men totalling 87,906, would land and the second echelon, consisting of the rest of each division, approximately 160,000 men in total, would closely follow behind. The second wave would then follow, which consisted of 3 motorised divisions and 6 panzer divisions. Finally, the third wave which consisted of 9 infantry divisions and 8 reserve divisions would then land.[26]

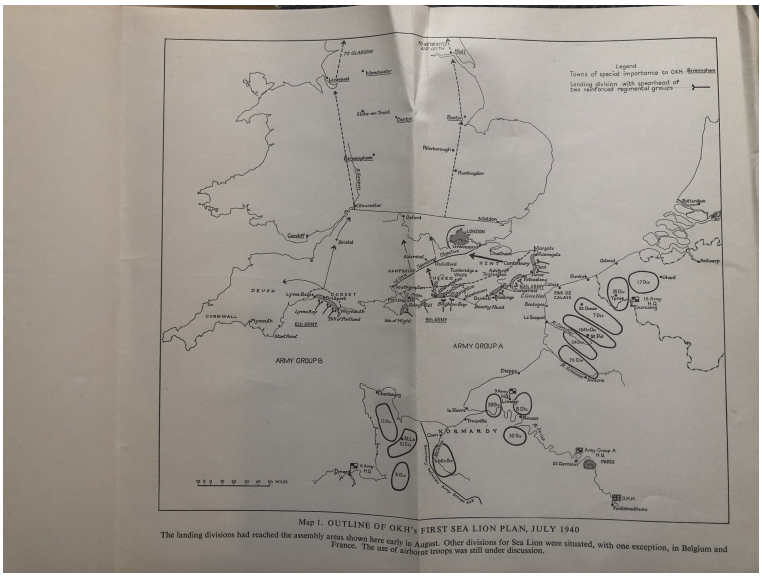


Figure 1: Initial German invasion plan[27]

As we can see, this plan involves a landing on a wide front and it consists of a large number of troops. This plan is clearly taken from the view of giving the highest probability of success to the land operation, and does not factor in the

[23] Ronald Wheatley, Operation Sea Lion, p152
[24] Ronald Wheatley, Operation Sea Lion, p152-p153
[25] Peter Schenk, Invasion Of England 1940, p188
[26] Ronald Wheatley, Operation Sea Lion, p152-p153
[27] Ronald Wheatley, Operation Sea Lion, Map 1

limitations of the German Navy.

Unsurprisingly, the German Navy's response to this plan was more than sceptical, and they had numerous problems with it. They argued that even if the first wave did manage to get across successfully, it could not be a given that successive waves would manage to get through, as there were large gaps between when successive waves of troops would embark. Also, owing to the wide front and the much stronger Royal Navy, there was no guarantee that they could prevent the Royal Navy from interfering with the invasion fleet, even accounting for the assumed dominance of the Luftwaffe over the skies and the planned minefields.[28]

The Kriegsmarine therefore considered an invasion on the scale, and on a front, as large as the one proposed by the German Army to be completely unfeasible. However, they did consider a crossing on a much smaller front in the Channel Straits to be somewhat feasible. They also stated that the earliest date at which the invasion preparations could be ready was mid-September.[29]

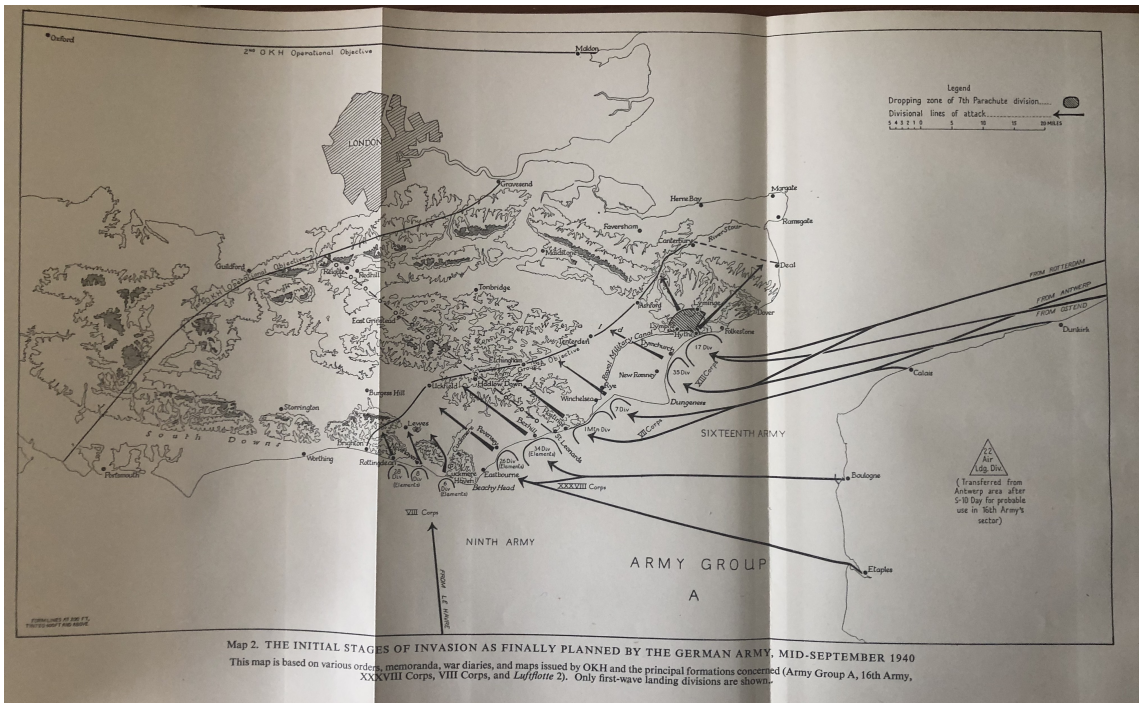
It was decided that, pending the result of the air war occurring over Britain, if some sense of reasonable air superiority was not achieved, then Operation Sealion would be delayed until the following year.[30]

The question of how wide a front the invasion was to take place across brought many disputes between the German Army and the German Navy. The German Navy wanted to ensure that the invasion front would only go across the Dover Straits, as that narrow area gives them the best chance of repelling the Royal Navy. The German Army protested, stating that it would make it very difficult for the Army to achieve its objectives. After much discussion and argument between the two sides, Hitler stepped in and supported the German Navy's idea of a narrow front, but he did appease the German Army by ensuring that a landing would also take place at Brighton.[31]

1.3.3 Final invasion plan

The final plan ended up looking very different from the initial plan; it was on a much smaller scale and was to be across a narrow front. The first wave would consist of 9 infantry divisions, down from the original 13. The second wave would consist of 4 panzer divisions, 2 motorised infantry divisions and 3 infantry divisions. The third wave would consist of 6 infantry divisions.[32]

[28] ADM 223/484, German Plans for the Invasion of England in 1940, p20-p22
[29] ADM 223/484, German Plans for the Invasion of England in 1940, p22
[30] ADM 223/484, German Plans for the Invasion of England in 1940, p23
[31] ADM 223/484, German Plans for the Invasion of England in 1940, p28-p31
[32] Peter Schenk, Invasion of England 1940, p14-p15



Map 2. THE INITIAL STAGES OF INVASION AS FINALLY PLANNED BY THE GERMAN ARMY, MID-SEPTEMBER 1940
This map is based on various orders, memoranda, war diaries, and maps issued by OKH and the principal formations concerned (Army Group A, 16th Army, XXXVIII Corps, VIII Corps, and *Luftflotte* 2). Only first-wave landing divisions are shown.

Figure 2: Final German invasion plan[33]

[33]Ronald Wheatley, Operation Sea Lion, Map 2

There were to be 4 landing zones, labelled B,C,D,E:[34]

Landing Zone B - west of Folkestone to Dungeness

Landing Zone C- Dungeness to Cliff's end

Landing Zone D- Bexhill to Beachy head.

Landing Zone E- Brighton to Selsey Bill.

The transport fleet for each landing zone, according to Schenk, were as follows:[35]

Landing Zone B	Landing Zone C	Landing Zone C	Landing Zone D
• 75 tow formations from Dunkirk • 25 tow formations from Ostend • 8 transports from Ostend • 49 transports and 98 barges from Rotterdam	• 100 tow formations from Calais • 57 transports and 114 barges from Antwerp • 14 pusher boats	• 165 tow formations from Boulogne	• 100 coasters and 200 motor fishing vessels from Le Havre • 50 steamers from Le Havre

Table 1: Table of the German transport fleet

The primary method of transport was a tow formation, which would consist of a tug at the front and 2 barges towed behind it, the first unpowered, followed by a powered one. These tow formations would be between 300-500m long.[36] Schenk estimated that for a barge, it would take 15 hours for the crossing, and 6 hours to unload.[37]

Schenk also estimated that the first echelon troops would have been ready a couple of hours after disembarking, with the majority of the second echelon being landed by the evening of S+1. He believed it would take until the evening of S+3 for the heavy vehicles and supplies to disembark their transports. Here S-day refers to the day the landing occurs; so the invasion fleet embarks on the afternoon of S-1, and lands on the dawn of S-day. The first and second echelon troops would consist of approximately 120,000-140,000 men in total.[38]

The Germans aimed to protect their invasion fleet by laying extensive minefields across the Channel, hoping to seal off the invasion route from the Royal Navy.[39]

[34] ADM 223/484, German Plans for the Invasion of England in 1940, p75
[35] Peter Schenk, Invasion Of England 1940, p16-p17
[36] Peter Schenk, Invasion Of England 1940, p63
[37] Peter Schenk, Invasion of England 1940, p230-p231
[38] Peter Schenk, Invasion of England 1940, p230-p231
[39] Peter Schenk, Invasion Of England 1940, p328

Minefields are of crucial importance, as not only do they sink ships, but they also act as force multipliers by forcing the British destroyers to move much more slowly when transiting these areas. This creates an element of uncertainty, which in turn would allow them to be much more vulnerable to German destroyers and Ju-87s.

The Germans would want their minefields to act as they later did, during the Soviet evacuation of Tallinn, where intense attacks by dive-bombers forced the Soviet warships to move out of the cleared channels, and into the minefields, resulting in the loss of many warships.[40] Hence, one crucial aspect of our wargame will be to find out whether it was feasible for the Germans to lay these extensive minefields as they had planned. A plan for the German minefields can be found on page 22 and 23.

1.3.4 Luftwaffe plan for Operation Sealion

In the lead up to Operation Sealion, the Luftwaffe would be involved in bombing coastal artillery, attacking any British ships in harbour, as well as laying mines.[41] The main roles of the Luftwaffe during Operation Sealion were the following:[42]

> Attack Royal Navy ships attempting to transit the minefields, and enter the invasion route
>
> Provide air support to the Army
>
> Fight off any RAF planes over the Channel

Probably the most important question with regards to the air component of Operation Sealion was whether the Ju-87s would have been able to sink a significant number of destroyers. While the Ju-87s were well suited to the anti-shipping role and had managed to sink a number of destroyers at Dunkirk, the Royal Navy was still able to carry out its main objective.[43]

We aim to provide clarification to this question, by using our Operation Sealion simulation to investigate whether the Ju-87s would have been able to substantially reduce the fighting ability of the Royal Navy. The effectiveness of the Ju-87s will be picked from a distribution, which will allow us to see if there is any correlation between effectiveness of the Ju-87s and the number of men landed.

[40] Victor J. Kamenir, The Soviet Dunkirk: The Tallinn Offensive, `https://warfarehistorynetwork.com/the-soviet-dunkirk-the-tallinn-offensive/`

[41] Peter Schenk, Invasion of England, p243-p244

[42] Peter Schenk, Invasion of England 1940, p241

[43] Dunkirk evacuation, Wikipedia, `https://en.wikipedia.org/wiki/Dunkirk_evacuation`

1.3.5 Kriegsmarine plan for Operation Sealion

The Germans had decided that they would use their 4 operational cruisers as part of a decoy invasion,[44] with the aim of diverting British naval resources elsewhere, meaning that the Kriegsmarine would have only 7 destroyers and approximately 20 torpedo boats to protect both flanks of the invasion fleet.[45]

In contrast, the Royal Navy had in the vicinity of the invasion area around 40 destroyers and 10 light cruisers. According to Schenk, these were located in Plymouth, Portsmouth and more generally on the south coast.[46] Schenk assumes that were the invasion to occur, then the Royal Navy would send approximately 20 destroyers and 3-5 light cruisers against each flank. In this scenario, it seems unlikely that the German Navy would be able to protect even just one flank of the crossing by itself.[47]

And so, perhaps the most critical component of Operation Sealion, was the extensive German minefields planned in preparation for the invasion. Mines were seen as crucial to preventing the Royal Navy from interfering with the invasion fleet. The minelaying was only planned to start around nine days before invasion, and would occur at night, presumably to stop the British from interfering and seeing where they were being laid. The majority of all German naval forces were to take part in the minelaying with the Luftwaffe also expected to contribute.[48]

One of our great unknowns is, not only how effective would these minefields have been, but also their capacity to carry out this minelaying and the proportion of the minefields they would have been able to lay. We aim to provide clarity to this question, by first developing a wargame to investigate how much of the planned minefields the Germans would have really been able to lay, and then developing a Sealion simulation to see how effective the minefields would have been in protecting the invasion fleet from the Royal Navy.

[44] Peter Schenk, Invasion of England 1940, p335
[45] Peter Schenk, Invasion Of England 1940, p344
[46] Peter Schenk, Invasion Of England 1940, p344
[47] Peter Schenk, Invasion Of England 1940, p344
[48] Peter Schenk, Invasion Of England 1940, p328-p333

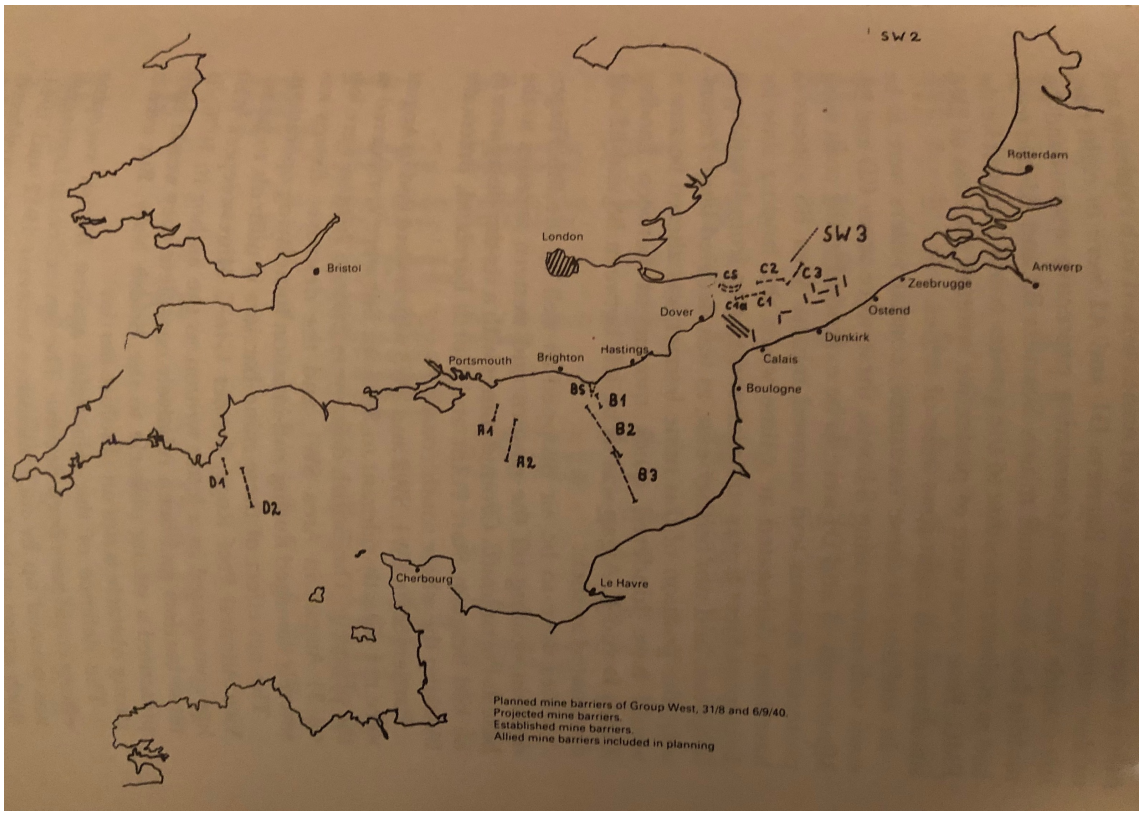


Figure 3: German minefield locations. The minefields labelled A,B and C were called Anton, Bruno and Caesar, respectively.[49]

[49] Peter Schenk, Invasion of England 1940, p331

To be laid on night before	Mine barrier	Length (nautical miles)	Average distance between mines (m)	Minelayers	Escort	Base	Mines	Explosive buoys	Cable-cutting buoys	EMG simulator
S-2	B 1	5.2	32	4 destroyers, 4 torpedo boats 35,	S boats (motor torpedo boats)	Le Havre	300 EMG	480	28	–
S-2	C 1	8.2	40	*Roland, Königen Luise, Preussen, Grille*	2 torpedo boats 23/24, S boats	Ostend	400 EMC/D	800	150	–
S-2	C 1a	2.0	40	2 torpedo boats 23/24, 2 torpedo boats 35	–	?	95 EMD	190	20	–
S-3		Reserve								
S-4	B 2	19.4	30	*Togo, Stralsund, Schwerin, Schiff 23, Tannenberg,* 6 minesweepers, 4 torpedo boats 35, 1 destroyer	Other destroyers and boats	Le Havre	1200 EMG	1900	235	500
S-4	C 3	8.6	40	As C1	4 torpedo boats 23/24, 2 torpedo boats 35, S boats	Ostend	400 EMC/D	800	150	–
S-5		Reserve								
S-6	B 3	19.4	30	As B2	As B2	Le Havre	1200 EMG	1900	235	500
S-6	C 2	8.6	40	As C1	As C3	Ostend	400 EMC/D	800	150	–
S-7		Reserve								
S-8	A 1	5.4	40	4 destroyers, 4 torpedo boats 35,	S boats	Cherbourg	200 EMC	300	100	–
S-8	A 2	16.3	55	*Togo, Stralsund, Schwerin, Tannenberg*	4 torpedo boats 23/24, S boats	Cherbourg	550 EMC	700	250	–
S-9	D 1	5.4	40	As A1	As A1	Cherbourg	250 EMC	300	100	–
S-9	D 2	16.3	55	As A2	As A2	Cherbourg	550 EMC	700	250	–

Figure 4: German minefield plan[50]

1.3.6 British preparations for invasion

The British had been preparing for a possible invasion ever since the collapse of France. Many coastal batteries had been strengthened and minefields were laid across the south coast. When the German embarkment ports started to fill up with the invasion fleet, the RAF began to focus on attacking these ports, which proved to be quite successful; however, the Germans had enough barges in their reserves to replace them.[51]

The Royal Navy also used destroyers to bombard invasion ports that were filling up with barges and transports.[52] They also realised that the Germans would attempt to make landings at many different points, and believed that the Germans were willing to risk very high losses.[53]

The British used a combination of submarines and aerial reconnaissance to ensure the earliest indication of invasion.[54] They considered the invasion most likely to take place on the south coast, and were well aware that a decoy operation could also take place to divert British naval resources elsewhere, and

[50] Peter Schenk, Invasion of England 1940, p333
[51] Peter Schenk, Invasion Of England 1940, p346-p349
[52] ADM 199/60, Night Bombardment of Calais
[53] ADM 1/11317, Invasion - General Naval Appreciation
[54] Peter Schenk, Invasion of England 1940, p348

that German warships could be used to draw British destroyers away from the barges.[55]

The Royal Navy decided that its heavy combatants, such as battleships and battlecruisers, would not move down south in the event of an invasion, unless German heavy ships were also present. They believed that the task of dealing with the invasion fleet was better suited to cruisers and smaller ships.[56] They were also well aware of the threats posed by the German minefields, but decided that destroyers would be allowed to go straight through known or potential minefields in order to attack the invasion fleet. In particular, emphasis was placed on getting as close to the invasion fleet as possible, with the Royal Navy iterating that "close action must be the general rule, so that the biggest percentage of hits may be obtained with every outfit of ammunition".[57]

From the perspective of the British, the most important question would have been how many destroyers would be able to pass through the German minefields and how effective they would have been against the German transport fleet.

1.3.7 The end of Operation Sealion

With the German air offensive ultimately failing to achieve air superiority over Britain, and with the final decision for the commencement of Operation Sealion having already been delayed numerous times before, it was decided on 17th September that the invasion would be postponed indefinitely. And on 19th September the decision was made to disperse the invasion fleets, with many of the vessels going back to their previous duties. The German Armed Forces never seriously considered Operation Sealion again. They carried out a few exercises over the winter, but by spring 1941, Hitler's attention had fully turned towards an invasion of the Soviet Union.[58]

1.4 Counterfactual Battle of Britain

We know that Operation Sealion was never put into effect, due to the inability of the Luftwaffe to achieve air superiority over Britain, but was this always a foregone conclusion? A recent paper[59] argues that had the Luftwaffe put an emphasis on attacking RAF airfields, then a level of air superiority required to start Operation Sealion could have been achieved. To do this, they used a statistical technique called weighted bootstrapping in order to create several counterfactual narratives. This paper will form the prelude for our thesis.

[55] ADM 1/10561, Invasion, General Naval Appreciation
[56] ADM 1/11130, Operation of Capital Ships In South Part Of The North Sea
[57] ADM 199/687, Tactical notes on Operation "P.E."
[58] Peter Schenk, Invasion Of England 1940, p351-p355
[59] Brennen Fagan *et al*, Bootstrapping the Battle of Britain

The 5 counterfactual campaigns modelled in the paper were:[60]

Counterfactual 1

The Luftwaffe does not switch to bombing London in early September, and simply continue attacking airfields.

Counterfactual 2

The entire air offensive begins three weeks earlier than when it actually occurred.

Counterfactual 3

Combines both counterfactual 1 and counterfactual 2, so the entire air offensive begins 3 weeks earlier, and no switch to London as the main target is made.

Counterfactual 4

The Luftwaffe places an emphasis on attacking aerodromes, attempting to destroy the RAF on the ground.

Counterfactual 5

This counterfactual combines both counterfactual 4 and counterfactual 2, so the air battle begins 3 weeks earlier, with an emphasis on attacking aerodromes.

[60] Brennen Fagan *et al*, Bootstrapping the Battle of Britain

A British victory in this paper meant that the level of Luftwaffe air superiority required to set off Operation Sealion is not met. In the paper, it was suggested that this trigger could be met by forcing RAF fighter squadrons in 11 Group to retreat to 12 Group.[61]

The results seem to suggest that had the Germans followed an optimal strategy, the probability of British success could have been drastically reduced. In particular, it appears that an early start dramatically reduces the probability of British success. If we assume the original probability of British success was 50%, then an early start would reduce this to 0.3%, a change of approximately three standard deviations.[62]

The results also reinforces the common view that the switch to targeting London was a major mistake, with the probability of British success being reduced from 50% to 9.1% in Counterfactual 1, a change of approximately one standard deviation.[63]

Likewise, targeting airfields, as in Counterfactual 4, would have substantially reduced the likelihood of British success, with the probability of British success being reduced from 50% to just 1.1%, a change of approximately two standard deviations.[64]

This paper suggests that had the Luftwaffe not made the switch to targeting London, or had they employed better tactics by targeting airfields, then the Luftwaffe would certainly have had, at the very least, a substantial chance of achieving the air superiority required to trigger Operation Sealion.[65]

1.5 Our approach

In this section, we aim to provide an overview of the steps we took during this research project to answer the fundamental question of whether the Germans could have landed an army ashore. We will briefly describe how we wargamed the final German preparations for Operation Sealion, in particular the laying of minefields, before finally giving a quick outline of the simulation.

1.5.1 Wargame

The bootstrapping paper above will allow us to develop a counterfactual narrative where the requirements for launching Operation Sealion are met, and Hitler gives the go ahead to launch the invasion. However, it will not simply suffice to move onto the simulation straight away, as there was still a crucial period of around 10 days before invasion, when the Germans would be carrying out vital final preparations, such as the laying of minefields. This never occurred in

[61] Brennen Fagan *et al*, Bootstrapping the Battle of Britain
[62] Brennen Fagan *et al*, Bootstrapping the Battle of Britain
[63] Brennen Fagan *et al*, Bootstrapping the Battle of Britain
[64] Brennen Fagan *et al*, Bootstrapping the Battle of Britain
[65] Brennen Fagan *et al*, Bootstrapping the Battle of Britain

reality, as it was only to be done once the Germans had achieved air superiority, something which the Luftwaffe never obtained.

And so, using the bootstrapping paper as our foundation, we decided that the best way to gauge the extent to which the Germans could have carried out their invasion preparations would be through wargaming it. We wargamed the 10 days leading up to the invasion date to give us a better understanding of the order of battle on the invasion day. In particular, we were interested in the proportion of the planned minefields that would have been laid, and at what cost to the Kriegsmarine. We also wanted to investigate whether the air superiority of the Luftwaffe would lead to a significant reduction in the strength of the Royal Navy.

We played two versions of the wargame, a 2-sigma version which roughly corresponds to Counterfactual 4 in the Battle of Britain paper, where the probability of British success in the Battle of Britain is reduced by approximately two standard deviations. In this wargame, the RAF numbers are reduced by 4 fighter squadrons from 34 to 30, and all fighter squadrons in 11 Group are forced to retreat back to 12 Group. The location of 11 and 12 Group can be found in the wargame map in Appendix A.

We also played a 6-sigma version, which corresponds to a hypothetical scenario where the probability of British success in the Battle of Britain is reduced by 6 standard deviations. Similar to the 2-SD wargame, all British fighter squadrons in 11 Groups are forced to retreat to 12 Group but the RAF numbers are further depleted by 8 Squadrons, from a total of 30 squadrons to 22, with the Luftwaffe having a much stronger level of control over the English Channel and Dover. In the 2-SD wargame, we can consider the Luftwaffe to have air superiority over the Channel, as while the RAF is still able to dispute them, the Germans are the dominant force. Whereas in the 6-SD wargame, we can consider the Luftwaffe to have air supremacy over the Channel, as they are in complete control of it and the RAF can only offer very limited opposition.

We found in the 2-SD wargame, that even though the Germans did have some measure of air superiority, they were only able to lay around 20% of their planned minefields, due to them not being able to lay mines during the day.

However in the 6-SD wargame, the Germans had complete air supremacy over the Channel, and so mines could be laid during the day, resulting in around 75% of the planned minefields being laid. However they lost more ships while doing so, when compared to the 2-SD game.

In particular, our wargames seemed to suggest that the Germans did need to have a strong level of air superiority for their invasion preparations to be successfully implemented uncontested. Although we found out that their final preparations were not feasible in the 2-SD wargame, they were much more successful in the 6-SD wargame.

1.5.2 Kanalkampf simulation

Before developing a simulation of Operation Sealion, we decided to first create a simulation of the Kanalkampf campaign. This was a campaign during the Battle of Britain, lasting approximately 1 month, during which the Luftwaffe made intensive attacks on British convoys in the English Channel, hoping to not only sink ships but to also engage RAF fighters.[66]

We decided to use the Kanalkampf simulation as our proof of concept, due to there being many similarities between it and Operation Sealion, such as it occurring in the English Channel, as well as Ju-87s having an emphasis on sinking British ships, with the RAF fighters attempting to prevent this. However, the crucial difference is that the Kanalkampf campaign happened in reality, whereas Operation Sealion never did. And so, once we produced results from 10,000 runs of this simulation, we were able to compare it to the actual results and see if our model gives a reasonable estimate of the actual campaign. Only when we were satisfied with the results of our Kanalkampf simulation, did we then move on to creating our Operation Sealion simulation.

1.5.3 Operation Sealion simulation

Once we had all the necessary components needed to create our Operation Sealion simulation, including reasonable estimates of the various parameters required, such as proportion of minefields laid and the effectiveness of Ju-87s against destroyers, we moved towards actually developing it, using our Kanalkampf simulation as a basis.

Once we had finished developing our Sealion simulation, we ran it 10,000 times, for 2 different versions of the code. Version 1 of the simulation corresponds to the 2-SD wargame, where the Germans only managed to lay around 20% of their planned minefields, and Version 2 corresponds to the 6-SD wargame, where the British have a further depleted RAF, and the Germans lay approximately 75% of their planned minefields.

During each run of the simulation, the values of the parameters, such as effectiveness of a destroyer against barges, would be drawn from a prior distribution. So we get both a summary output of results, and a means of estimating dependence between different quantities. This allows us to control and understand the effects of noise on the results. Hence, not only will our simulation give us an estimate of the number of men landed, it will also allow us to identify which of these parameters could have had a crucial impact on the outcome of the invasion.

A recent paper[67], titled "The Case for Campaign Analysis: A Method for Studying Military Operations", advocates our choice of method for this re-

[66] Battle of Britain, World War II Database

[67] Rachel Tecott & Andrew Halterman, The Case for Campaign Analysis: A Method for Studying Military Operations

search project. We want to find out whether the Germans could have landed an army ashore. To do this, we developed a scenario where the Germans win the Battle of Britain, allowing Operation Sealion to commence. We then created a simulation of Operation Sealion, assigning to each of our parameters a distribution from which the values would be picked during each run of the simulation. We would then run the simulation and interpret the results. This method is precisely what is recommended in the paper.[68]

[68]Rachel Tecott & Andrew Halterman, The Case for Campaign Analysis: A Method for Studying Military Operations

2 Wargaming the build-up to Operation Sealion

2.1 Conception of a wargame

Before we move on to the simulation, there are various aspects of a potential German invasion of Britain that must be decided upon. As described in the previous chapter, there was a crucial period of 10 days starting from when Hitler was to give the approval to start Operation Sealion, during which vital preparations were to be done, such as minelaying and assembly of the transport fleet in the invasion ports. In particular, the minefields were of utmost importance to the German invasion plans, and it will be crucial for us to have a sense of their ability to lay these minefields.

From the minefield plan shown in Figure 3 and 4, we can see that the Bruno and Ceasar minefields, labelled B and C in the figures, were both extensive and dense. They were to be laid across the narrowest part of the Channel, in order to seal off the Royal Navy from invasion zone B,C and D, where the bulk of the German army would land. The Anton minefield, labelled A in the figures, was to protect invasion Fleet E, who were to make a landing in Brighton. We ignored minefield D for the purpose of our simulation.

As the approval to start final preparations was never given, due to the inability of the Luftwaffe to gain air superiority, it is up to us to assess the German capacity for carrying out these preparations, and we will aim to do so in this chapter. We decided that the best way to evaluate the feasibility of the German preparation plans was through developing a wargame, as not only will it allow us to play out the German preparation plan, but it will also give us an insight into how the British might have responded, and how successful their response would have been.

As stated in the previous chapter, the decision to give the order to start Operation Sealion was dependent on the Luftwaffe having air superiority over the RAF. Thus, the basis under which our wargame will be played will be dependent on the bootstrapping paper,[69] which was described in Chapter 1.

For Hitler to have given the order for Operation Sealion to be launched, a certain level of air superiority was required, and it is suggested in the bootstrapping paper that the minimum requirement would be the retreat of RAF fighter squadrons from 11 Group into 12 Group; the location of which you can find in the wargame map, in Appendix A. We estimated that this minimal requirement could be achieved through Counterfactual 4 as described in Chapter 1. In this counterfactual, the Luftwaffe place an emphasis on attacking airfields, and the probability of British success in the Battle of Britain is reduced by approximately 2 standard deviation.[70] We estimated that in this scenario the number of RAF fighter squadrons would be reduced from 34 to 30. It is shown in the bootstrapping paper that this would have not been unlikely in reality, had the

[69] Brennen Fagan *et al*, Bootstrapping the Battle of Britain
[70] Brennen Fagan *et al*, Bootstrapping the Battle of Britain

Luftwaffe gone after a better strategy such as targeting aerodromes. This 2-SD game will allow us to gauge whether this "narrow" margin of victory would have allowed the Germans to complete their invasion preparations as they had planned.

We also decided to play a 6-SD wargame, where the number of fighter pilots available to the RAF is reduced by a further 8 squadrons from 30 to 22. Whereas the 2-SD wargame was not too unlikely in reality, the 6-SD wargame would have necessitated the Luftwaffe to start operations at least three weeks earlier than when it actually started, and would also have required the Luftwaffe to put an emphasis on targeting airfields. Thus, the 6-SD wargame would not have been likely in reality, as it would have required a much more different and aggressive strategy from Hitler and Goring from the offset. Hence, we considered the 2-SD wargame to provide a more reasonable counterfactual.

In both of these wargames, British fighter squadrons in 11 Group were forced to retreat to 12 Group, as this was seen as the minimum to trigger the launch of Operation Sealion. However in the 6-SD wargame, the further reduction in the strength of the RAF fighter squadrons results in the Germans having a strong level of air superiority over Kent and Sussex as well as Dover. Crucially, in the 2-SD wargame, the RAF can still contest the Luftwaffe over the Channel, whereas this is not possible in the 6-SD wargame.

Ultimately from these 2 wargames we want to find out how the German preparations plans would have played out, and at what cost to the Kriegsmarine. We also want to investigate how the British would have responded to the German preparations and how effective their response would have been. This will give us an indication of the order of battle, come the invasion day, and also the proportion of planned minefields laid, both of which we will then implement into our simulation. Playing 2 different versions of the wargame will allow us to see whether the different levels of air superiority would have any effect on the outcome of German preparations.

Thus we will have 2 versions of our Operation Sealion simulation, one corresponding with the 2-SD wargame as a basis and the other with the 6-SD wargame as the basis.

The briefing and map of our wargame was developed by historian Dr. Ian Horwood, and they can be found in the appendix, along with the order of battle for our wargame. Each wargame was played over one day, with Dr. Ian Horwood acting as umpire. The combat rules were taken from Paddy Griffith's "Wargaming Operation Sealion". At the start of each day, the British and Germans would decide on their plans for that day and would then carry them out. For example, the British might want to use their fighters to provide air cover over certain regions, such as Dover, whereas the Germans might attempt to attack British naval bases using their dive-bombers. Any fights that occur between British and German units are resolved by the umpire. Similarly, at the start of each night, the British and Germans would decide on their plans for

that night and would then carry them out. For example, the German might attempt to lay certain minefields, whereas the British might attempt to bomb the German invasion fleet. Again, any fights between German and British units are resolved by the umpire. The wargame starts on day S-10 and ends on day S-1, the day before invasion.

In the 2-SD game, Professor Niall MacKay and I played as the British with Professor Jamie Wood and Dr. Christopher Price as the Germans. In the 6-SD wargame, Professor Jamie Wood and I played as the Germans, with Professor Niall MacKay and Dr. Christopher Price playing as the British. Dr. Brennen Fagan was recording what was happening during the wargames.

In the rest of this chapter we will describe the outcome of the two wargames that we played, as well as any variations that we would expect were we to play them again. We will also describe the implications for our Sealion simulation.

2.2 Outcome of the 2-SD wargame

The main objective of the German Navy was to lay their planned minefields. However, they were forced to do this during the night, as they could not provide sufficient protection during the day, owing to the much stronger Royal Navy, and also they did not want the British to see where their minefields were laid.

The British destroyers largely stayed in their ports during the day, due to possible attacks by Ju-87 dive bombers, and would only go out during the day if there were other German naval vessels out as well.

During the night, both sides would go out into the Channel, the Germans to lay their minefields and the British to obstruct any minelaying by the Germans. There were numerous clashes, with losses on both sides, however, the British could afford losses of destroyers due to the abundance of them; they had 76 in home waters.[71] Whereas the Germans could ill afford any losses to their minelayer fleet, as they only had 14 of them,[72] and so any losses would have seriously hindered their ability to lay the minefields in the required time frame. Also, any losses to their destroyers or R/S boats would be disastrous, as not only were there so few of them compared to the Royal Navy, but they would also be vital in attempting to prevent the Royal Navy from attacking the invasion fleet come the day of the invasion.

As a result of this disruption by the Royal Navy, the Germans were not able to come close to completing all of their planned minefields. We estimated that they had laid around 20% of the minefields, and given the importance placed on them, we can assume this would have a huge effect on the outcome of the invasion.

With respect to the air, German bombers were focused on attacking ports where Royal Naval vessels were, in an attempt to reduce their strength. The retreat of

[71] Peter Schenk, Invasion of England 1940, p343-p344
[72] Peter Schenk, Invasion of England 1940, p329-p330

fighters from the 11 Group to 12 Group did not stop the RAF from being able to interfere with the bombing raids, and as a result, they were largely ineffective and losses were minimal, however it did force the destroyers in Dover to move to Portsmouth.

British bombers mainly focused on attacking ports where the invasion fleet were assembling, and they were quite successful but the Germany Navy had lots of barges in reserve, so in the context of Operation Sealion, it would not have made much difference.

We estimated that the Germans lost 8 S-boats as well as 8 R-boats, with the British losing around 5 destroyers and the Germans only managing to lay approximately 20% of the planned minefields. The RAF lost approximately 35 fighters, with the Luftwaffe losing around 25 fighters and 50 medium bombers.

2.2.1 Could the 2-SD wargame have turned out differently?

One of the major aims of the Luftwaffe was to reduce the strength of the Royal Navy, as that was the biggest hurdle to the success of Operation Sealion. However, it was hindered in its ability to do this, as there was still a reasonably strong RAF force, so it was forced to do two jobs in attacking both RAF airfields and British naval ports. While they did manage to force the destroyers at Dover to move to Portsmouth and sink a few destroyers, the number of destroyers lost would not have made a significant impact during Operation Sealion, as they were easily replaceable.

The Germans could only effectively attack Royal Navy vessels through their dive-bombers. As medium and high altitude bombers were virtually useless for precision bombing, hitting a destroyer would require a lot of luck.[73] And while the RAF was forced to retreat from 11 Group to 12 Group, their strength was such that they would always be able to interfere with any potential attacks by Ju-87s.

Ju-87s were notoriously vulnerable to fighters, even with fighter escorts, to such an extent that during the Battle of Britain, the Luftwaffe were forced to put them into reserve due to unsustainable losses.[74] This in turn meant that the use of Ju-87s to attack harbours was not very effective. Hence, there does not seem to be much that the Luftwaffe can do to reduce the fighting capacity of the Royal Navy. However, if the RAF was to be further weakened, it could allow the Ju-87s to act with more impunity, and thus lead to either a significant reduction in the strength of the Royal Navy, or reduce their capacity to disrupt German minelaying.

[73] Dive bomber, Wikipedia, in the section titled Accuracy it details the struggles of horizontal bombers against moving ships

[74] Junkers Ju 87 'Stuka', The Battle of Britain Historical timeline, `https://battleofbritain1940.com/junkers-ju-87-stuka/`

We also had a discussion on whether the Germans could possibly have been minelaying by day, as this seemed the only way the Germans could have completed their planned minefields in the expected time frame. However this would give the British the chance of engaging German minesweepers and destroyers, which would favour the British, as even equal losses would have a disproportionately negative effect on the Germans, due to their already small fleet, hence it was seen as unfeasible. This scenario only seems possible if the Luftwaffe were to be given much stronger control over the Channel; then the Ju-87s would pose a much larger threat to any Royal Navy ships attempting to disrupt German minelaying attempts during the day.

Thus, it seems that even though we only played the 2-SD wargame once, we can be quite confident that were we to play it again many more times, we would expect the results to be approximately the same. There does not appear to be much scope for the Germans to increase their ability to reduce the strength of the Royal Navy, or increase the proportion of minefields laid. And the British largely continue their earlier tactics, with the RAF attempting to disrupt every Luftwaffe raid with the minimum number of fighters possible, and the Royal Navy only leaving port if there are also German vessels in the Channel.

2.2.2 Implications for our 2-SD simulation

Using the 2-SD wargame as a basis for our simulation, we estimated that the proportion of planned minefields laid would have been approximately 20% $\pm$ 10% , and as described above there does not appear to be much scope for the Germans to increase this. Hence, we believe this gives us a reasonable estimate of the proportion of minefields laid for our 2-SD simulation.

With regard to the order of battle, we estimated that the Germans would have lost 8 of their S-boats as well as 8 of their R-boats, with the British losing around 5 destroyers. This would have had a negligible effect on the strength of the Royal Navy, as they simply would have been replaced by more destroyers from further north, and so the order of battle for the Royal Navy in our 2-SD simulation is unaltered. However, no such replacement existed for the Kriegsmarine, and so they would have started the invasion with 8 S-boats less, severely affecting their ability to protect the flanks of their invasion route.

The RAF was quite successful in sinking barges; however, the Germans had enough in reserve to replace them, so with regard to our simulation there will be no change in the German transport fleet.

2.3 Conception of a 6-SD wargame

As a result of the 2-SD wargame, we realised that reducing the strength of the Royal Air Force by 4 fighter squadrons, and forcing the fighters to retreat from forward airfields, does not result in much difference. The game largely followed the German preparation plans, and while the Germans did what they were supposed to do, they were ultimately still unable to lay a significant proportion

of their planned minefields. In particular, it seems impossible to achieve their planned minefields by only minelaying at night. The British carried on as before, ensuring that every raid by the Luftwaffe was met with RAF fighters, with the Royal Navy only venturing out into the Channel if there were other German vessels out as well.

Hence, we decided to play another wargame where the number of RAF fighter squadrons is further reduced, limiting the ability of the RAF to interfere with every raid. This would result in the Ju-87s becoming a much larger threat to British destroyers, and giving the Germans an opportunity to lay mines during the day. The briefing for the second wargame was similar to the first, however, in this wargame the number of RAF fighter squadrons was reduced by a further 8 squadrons, from 30 to 22, giving the Luftwaffe a much stronger hold over Kent and Sussex, as well as the Channel. Consequently, the RAF would choose not to contest raids over Kent, Sussex and the Channel, in order to preserve their force.

2.3.1 Outcome of the 6-SD wargame

In this setup, just as before, the RAF are forced to retreat from 11 Group to 12 Group; however, their strength has been reduced to such an extent that the Luftwaffe has complete control over Kent and Sussex, as well as the Channel. In particular, it reduces the ability of the RAF to disrupt any attacks by Ju-87s on Royal Navy vessels.

As with the 2-SD wargame, the main objective of the Germans is to lay as high a proportion of the planned minefields as possible. During the last wargame, the Germans carried out minelaying largely at night, due to fear of the Royal Navy. However, in this game the Germans opted to carry out the minelaying during the day as well. The importance of minefields in Operation Sealion was seen as so great, that a decision was made to lay them at any cost, as the Germans believed that failing to do so would result in the invasion being defeated. Thus, the Germans were willing to go to great lengths to lay as many mines as possible, even if it meant losing a large number of their minelayers and surface vessels.

The British took note of where the German minefields were being laid during the day, and tried to create free channels in these areas during the night, and they would record the location of these swept channels. It is also important to note that the Germans would not be aware of where these swept channels were. However, the utility of these swept channels is questionable, as it is unknown how feasible it would be for British destroyers, amongst all the chaos of an invasion, to find and safely navigate through these channels.

The Germans took advantage of having air superiority over Dover and the Channel, by using large numbers of dive-bombers to scare off any Royal Navy ships attempting to attack German vessels out during the day. However, the British were also aware of the importance of these minefields, and decided that with

their abundance of destroyers it would be worthwhile to press ahead with attacking the German minelayers and their escorts. While the dive-bombers could not completely stop a determined attack by British destroyers on the German ships, they could disrupt them to an extent that German minelayers were able to lay a significant proportion of their mines and were given a opportunity to escape.

The RAF attempted to provide cover for British naval bases, as well as any Royal Navy ships venturing out during the day. However, due to its much weakened state, it was usually forced to pick between the two, resulting in British destroyers becoming much more vulnerable to Ju-87s. As with the 2-SD wargame, RAF bombers carried out night-time raids on the invasion fleet, which again were quite successful, however any losses to the German transport fleet could be easily replaced.

In total, the Germans lost 9 minelayers, 8 of their S-boats as well as 2 torpedo boats. However, we estimated that they were able to lay approximately 75% $\pm$ 10% of their planned minefields. The British lost 9 destroyers, 1 destroyer escort, as well as 4 motor torpedo boats. For the British, these losses can be easily replaced, but this is not possible for the Germans. However, with the importance placed on the minefields by the invasion plans, it was decided that these losses would have to be accepted. We estimated that the RAF lost approximately 50 fighters, with the Luftwaffe losing around 50 fighters and 50 medium bombers as well.

2.3.2 Could the 6-SD wargame have turned out differently?

Ultimately, we do not think there is much that the Germans can, or should, do differently. The minefields are of greatest importance, and must be given the highest priority. All efforts must go towards laying as much of the planned minefields as possible, even at the risk of losing ships that would later provide the protection for the invasion fleet. In order to lay the 75% of planned minefields, the Germans were required to lay mines during the day, as it does not seem feasible to achieve the required amount by only laying at night.

Likewise, the German air strategy is fairly straightforward: an emphasis must be placed on the bombers to attack any British naval bases that have ships, as well as attacking any British ships that come out of port and into the Channel. The much weakened RAF no longer has the ability to disrupt raids by Ju-87s on British destroyers in the Channel, and so this advantage must be utilised as much as possible to achieve the ultimate objective of the German preparation plan, which is to lay the planned minefields.

For the British, we also do not believe that they should deviate too much from the British plan in our wargame. They want to keep enough destroyers near the Channel, in order to interfere with any possible minelaying attempts by the Germans, as well as fend off the initial waves of a potential invasion. However, they must also keep enough of their destroyers further up north, away from the

range of the Ju-87s, to be used only once the invasion has begun, or to replace any losses to destroyers based in the south. Likewise, the RAF must ensure that where possible, cover must be provided to the Royal Navy, whether in port or out in the Channel.

Hence, we believe that our German and British plans were fairly optimal for both sides respectively, and if we were to play the 6-SD wargame again, we would be reasonably confident that we would get quite similar results again.

It is not a coincidence that in both the 2-SD and 6-SD wargames, we believe that if we were to play them again, we would get results that were very close to the original results. In fact, this should become quite self-explanatory upon realization that ultimately, both the British and German decisions are dictated by the minefields. The Germans will do everything in their power to lay as high a proportion of the minefields as they can, and every effort that is made during these 10 days, is done so with a view of making sure the minefields are as complete as possible. Analogously, with the buildup of transports in the invasion ports, the British will be aware that an invasion is imminent, and so, they will do everything in their power to disrupt the minelaying. Everything in our wargame is designed to either achieve or thwart the German preparation plans. Hence, there is a limited scope for any deviation from our strategies in the 2-SD and 6-SD wargames.

2.3.3 Implication for our 6-SD simulation

We estimated that the Germans were able to lay approximately 75% $\pm$ 10% of their planned minefields, which we then implemented in our 6-SD simulation. As explained in the previous section, we believe that were we to play the 6-SD wargame many times again, we would expect most of the results to be in the region of this value, so we believe it provides a stable estimate for our 6-SD simulation.

We estimated that the British lost 9 destroyers, but these would have been easily replaced by destroyers from further north, so the order of battle for the Royal Navy does not change for our 6-SD simulation. We estimated that the Germans lost 9 minelayers, 2 torpedo boats as well as 8 S-boats, which could not be replaced, hindering their ability to protect the flanks of their invasion route.

The loss of 8 S-boats would create a large headache for the Kriegsmarine, as the S-boats were the only form of defence on the eastern flank of the invasion route. This means that some of the destroyers and torpedo boats that were to be used to protect the western flank would have to be diverted to the eastern flank, and so the already small German fleet would have to be further stretched.

As with the 2-SD wargame, any losses to the German barges could be easily replaced, as they had quite a large reserve, so the German transport fleet will remain the same for the 6-SD simulation as well.

2.4 Conclusion

We found wargaming to be a useful tool in creating a reasonable picture of the days leading up to the invasion. It showed us how important air superiority was in the German ability to carry out their invasion preparation plans, with only 20% of minefields being laid in the 2-SD wargame and 75% being laid in the 6-SD wargame. During the 2-SD wargame, the Royal Navy lost approximately 5 destroyers and 35 fighters, whereas in the 6-SD wargame, the Royal Navy lost 9 destroyers, 1 destroyer escort and 4 motor torpedo boats, along with 50 fighters. We estimated the Germans to have lost 8 S-boats and 8 R-boats, as well as 25 fighters and 50 medium bombers in the 2-SD wargame, however, in the 6-SD wargame, we estimated they had lost 9 minelayers, 8 S-boats, 2 torpedo boats along with 50 fighters and 50 medium bombers.

In the 2-SD wargame, the Germans only laid mines during the night, leading to a very porous and incomplete minefield. Whereas in the 6-SD wargame, by minelaying during the day and night, the Germans managed to complete around 75% of their planned minefields. The main reason the Germans were able to lay mines during the day in the 6-SD wargame was due to the much weakened RAF, ensuring that the Luftwaffe had a much stronger level of air superiority over the Channel than in the 2-SD wargame. Hence, the Ju-87s were much more effective at disrupting British destroyers from attacking German minelayers and their escorts.

German air policy for both wargames was to attack Royal Navy ships out in the Channel, as well as in the ports. However, in the 2-SD wargame, the Luftwaffe also had to divert significant resources towards attacking RAF airfields, limiting their ability to disrupt the Royal Navy, whereas in the 6-SD wargame, this was done to a much smaller extent, due to the weakened RAF.

We found in both wargames that the British had quite a similar strategy. The Royal Navy was to only go out during the day if the German Navy also went out, and during the night, the Royal Navy would try to sweep free channels, as well as disrupt any German minelaying attempts. With regards to the air, the RAF would try to provide cover for naval bases, as well as maintaining RAF policy of disrupting as many German raids as they could, using the minimum number of fighters possible. While this was possible in the 2-SD wargame, in the 6-SD wargame, the Luftwaffe had a effective air supremacy over Kent and the Channel, and could only offer sporadic support to any Royal Navy ships venturing out into the Channel, resulting in higher losses to the Royal Navy. In both wargames, RAF bombers were focused on attacking the transport fleet in the invasion ports; however, the losses to the invasion fleet in both scenarios could be easily replaced.

From our wargames, it is clear that in the 2-SD wargame where the Germans just meet the minimum requirement to trigger Operation Sealion, the level of air superiority achieved is not sufficient for the Germans to carry out their preparations as planned. Whereas in the 6-SD wargame, the increased level of

air superiority allows the Germans to carry out a great deal of their invasion preparations, with 75% of the minefields laid as opposed to only 20% in the 2-SD wargame.

We will use these two wargames as a basis to develop two different versions of the Operation Sealion simulation, a 2-SD simulation and a 6-SD simulation respectively.

3 The Kanalkampf simulation

3.1 Background

Before we developed a simulation of Operation Sealion, we first decided to create a simulation of the Kanalkampf campaign. The Kanalkampf campaign was a period lasting approximately one month, from the 10th of July to early August,[75] during which the Luftwaffe conducted an intense campaign against British convoys in the Channel, hoping to sink ships as well as destroy the RAF fighters in the air. During this campaign, the RAF were aware that it had to preserve its fighter squadrons, and so was only able to provide limited cover to British convoys in the Channel, resulting in quite high losses to the convoys.[76]

We decided to use the Kanalkampf simulation as a proof of concept, as there are many similarities between the Kanalkampf campaign and Operation Sealion. They not only both occurred over the same area, but they both also placed an emphasis on using Ju-87s to sink British ships. Hence, we can use our Kanalkampf simulation as a basis for the Sealion simulation. As the Kanalkampf occurred in reality, whereas Operation Sealion did not, this means that we can take our results from the simulation and compare it to the actual results of the campaign, and see if they give a reasonable estimate.

3.2 Mechanics of the simulation

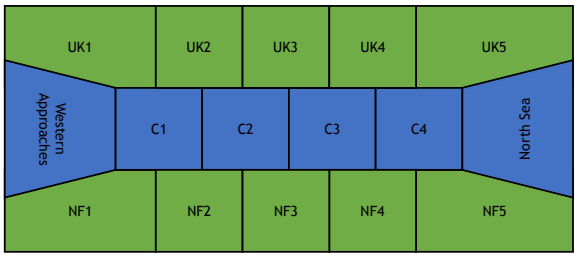


Figure 5: Map for the Kanalkampf simulation

This is the simplified map that we decided to use for our Kanalkampf simulation. This map was constructed by looking at an actual map of the English Channel and then splitting it up into squares. The UK squares represent the English south coast, with the NF squares representing the French coast around the Channel. The C squares represent the Channel, with the Western approaches

[75] John Keegan, The Second World War, p94
[76] Battle of Britain, World War II Database

and the North Sea flanking either side. For simplicity, we can assume that the distance between each square is 1 unit.

Each UK square hosts a single squadron containing 30 British fighters, we do not distinguish between different types of fighters. Likewise, each German square contains a squadron of 30 German fighters, but they also contain a single squadron of 30 Ju-87 dive-bombers. The Channel squares are populated with British ships, representing convoys, with there being 30 British ships in each Channel square.

Once the simulation starts, each fighter squadron and Ju-87 squadron is randomly assigned a target square in the Channel. The code then generates the sequence of squares that the squadron must go through, before getting to this target square. This sequence is chosen through Dijkstra's algorithm, which gives the shortest possible sequence. Once the squadron reaches its assigned target square, it returns back to its original square by following the reverse path. The British ships in the Channel squares are static for the duration of the whole simulation, as they travel much slower than aircraft and have to mimic convoys passing though the Channel.

After each time step, the planes move one step along their chosen path and enter the new square in their given sequence. The code then goes through each square, checking whether there are any opposing units. In our simulation we use a hierarchical combat model. So for each square, British fighters fight German fighters first, then British fighters fight any Ju-87s that are present, followed by the remaining Ju-87s attacking any British ships in the same square. We decided to use this "top down approach", as it allows simplification when dealing with simultaneous fights. Once all the fights were resolved, the next time step would then occur, and they would move to the next square in their path. Then the same process would occur, with each square being checked for any potential fights. We felt that this hierarchical approach was sufficient for our model because even if the Ju-87s attempted to attack British ships while the British and Germans fighters were fighting, they would still be heavily disrupted and their combat effectiveness would decrease as a result.

Once the planes were returned to their original bases, they would rest for 1 time step during which any losses incurred would be replaced. Once this time step was over, they would be assigned more targets, and so the process would repeat again.

Each time step corresponds to 2 hours, which means we assign to each day, 6 time steps; we ignore night-time. This means that every squadron has approximately two sorties per day. As the actual Kanalkampf occurred over approximately 30 days, this means the simulation runs for 180 time steps.

At the most simplistic level, in our Kanalkampf simulation, German dive-bombers are sent out into the Channel to attack British convoys, RAF fighters would attempt to shoot down them down, with the German fighters attempting to provide protection for the Ju-87s. We did this to capture the basic essence of

what was actually happening during the Kanalkampf campaign. We decided to run the simulation 10,000 times, as we felt this value was large enough to ensure a very small relative error. On the next page, we have a flowchart aimed at giving a simplified look at our simulation.

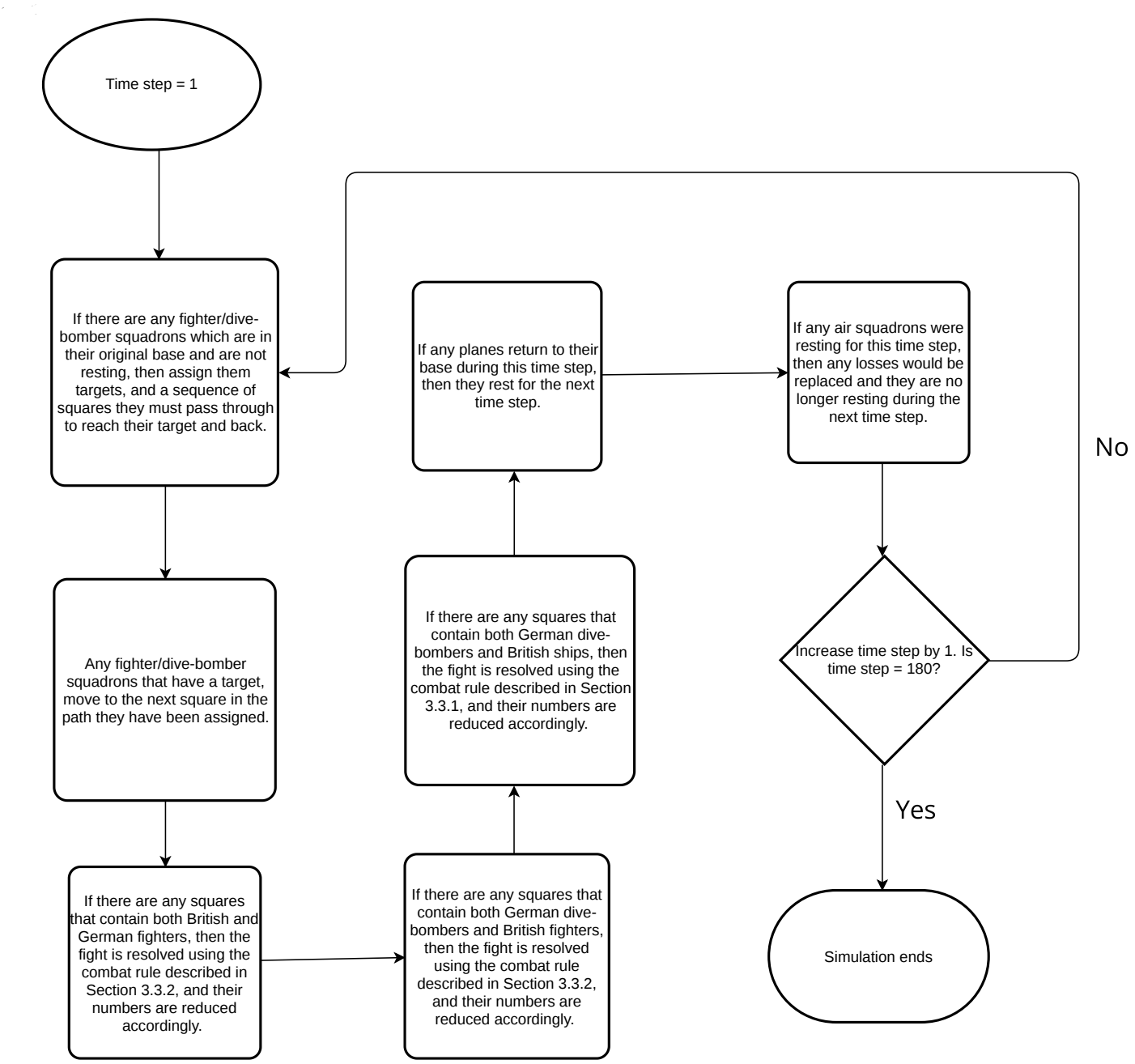


Figure 6: Flowchart describing the mechanics of the Kanalkampf simulation

3.3 Parameters of our simulation

In order to create a realistic simulation of the Kanalkampf campaign, we needed to first set out the various parameters of our simulation.

The parameters that we will have to assign are:

Effectiveness of Ju-87s against British ships

Combat rule for when British fighters meet German fighters

Combat rule for when British fighters meet Ju-87s

3.3.1 Effectiveness of Ju-87s against British ships

One parameter that we need to decide upon, is the effectiveness of Ju-87 dive-bombers against British ships. This is because the Ju-87s were the only way the Germans could effectively sink Royal Navy vessels from the air, as level bombing was already very inaccurate against static targets and would fare even worse against moving ships.[77]

ADM 199/1189, from the UK National Archives in Kew, contains a document titled, "Tactical summary of attacks by German aircraft on H.M. Ships and Shipping. September 1939 to February 1941", written by the Naval Staff, which proved to be very useful in the context of answering this question, as it contains detailed statistics on the effectiveness of Ju-87 operations against various types of Royal Navy vessels, as shown in Figure 7.[78] From this we can see that 647 bombs were released against destroyers, escort vessels and corvettes, with 6 ships being sunk. And since each Ju-87 only carried a single bomb, we can conclude that each Ju-87 has a $\frac{6}{647}$ probability of sinking a British destroyer.

We decided it would be best to use Lanchester aimed fire as our combat rule for when Ju-87s were attacking British ships, meaning that the number of losses suffered by a squadron of destroyers is determined by the number of Ju-87s attacking the destroyers, multiplied by the combat effectiveness of the Ju-87s. We decided Lanchester aimed fire would be suitable as it directly corresponds to assigning each Ju-87 a probability of sinking a ship per sortie and each Ju-87 can acquire a target. If a Ju-87 were to miss their target ship, they would not hit another ship, hence there is no density effect that would cause our combat rule to become "unaimed". At the start of each simulation, the probability would then be chosen from a Beta distribution centred at $\frac{6}{647}$, with α=6 and β=647. Since we have a reasonable estimate of the probability that a Ju-87 hits a destroyer, but we don't know the exact value of that probability, we felt that a Beta distribution would be best equipped to deal with this. We will employ this combat rule in a stochastic manner for our simulation.

[77] Junkers Ju 87 Stuka, The Aviation History Online Museum

[78] ADM 199/1189, "Tactical summary of attacks by German aircraft on H.M. Ships and Shipping. September 1939 to February 1941"

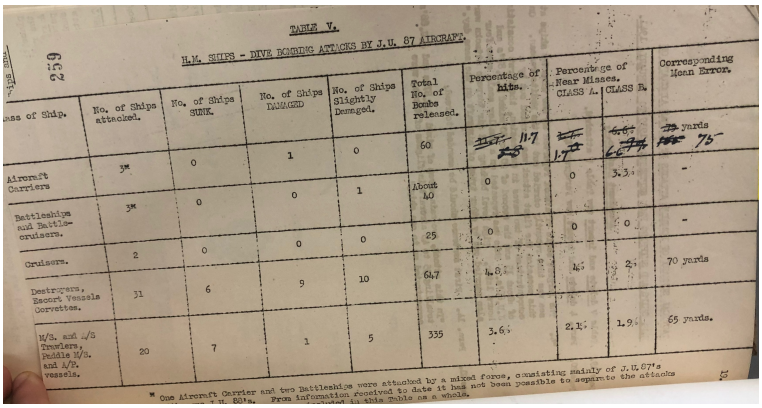


TABLE V.

H.M. SHIPS - DIVE BOMBING ATTACKS BY J.U. 87 AIRCRAFT.

Class of Ship.	No. of Ships attacked.	No. of Ships SUNK.	No. of Ships DAMAGED	No. of Ships Slightly Damaged.	Total No. of Bombs released.	Percentage of hits.	Percentage of Near Misses. CLASS A.	CLASS B.	Corresponding Mean Error.
Aircraft Carriers	3*	0	1	0	60	11.7	1.7	6.7	75 yards
Battleships and Battle-cruisers.	3*	0	0	1	About 40	0	0	3.3	-
Cruisers.	2	0	0	0	25	0	0	0	-
Destroyers, Escort Vessels Corvettes.	31	6	9	10	647	4.8	1.5	2.	70 yards
M/S. and A/S Trawlers, Paddle M/S. and A/P. vessels.	20	7	1	5	335	3.6	2.1	1.9	65 yards.

* One Aircraft Carrier and two Battleships were attacked by a mixed force, consisting mainly of J.U.87's. From information received to date it has not been possible to separate the attacks [illegible] in this Table as a whole.

Figure 7: Analysis of the effectiveness of Ju-87s against British ships[79]

3.3.2 Fighters vs Fighters and Fighters vs Dive-Bombers

Another parameter that must be determined is the combat rule for fighter on fighter and fighter on dive-bomber engagements.

The combat rules that we decide upon were obtained from a paper,[80] which attempted to use Lanchester models to fit the Battle of Britain. This paper suggests that in the Battle of Britain, both British and German losses were approximately proportional to German numbers. However there is an asymmetry in the Battle of Britain, as the Germans are the attackers over enemy territory, while the British were defenders over safe territory. In our Kanalkampf/Sealion simulation, this asymmetry would not longer exist, as they would both be contesting the Channel, so we can assume our air combat will be a sum of duels, hence, we use Lanchester's linear law, meaning that the number of losses suffered by a fighter squadron is determined by the number of fighters in that squadron, the number of enemy fighters attacking it, as well as the combat effectiveness of the enemy fighters attacking it.

We decided to use a geometric mean instead of an arithmetic mean, as the former is better able to handle a large imbalance in numbers of aircraft, where the more numerous side would have difficulty in finding sufficient targets and the less numerous side would have insufficient numbers.

Taking these changes into account, we found that if we take a coefficient of 0.032, this roughly reproduces the actual Battle of Britain results for the first-phase.[81] However, instead of using this value, we increased it by approximately 50% to 0.05, to compensate for the expected increase in fighting intensity during Operation Sealion. We felt it was reasonable for the British fighters to have the

[79] ADM 199/1189, "Tactical summary of attacks by German aircraft on H.M. Ships and Shipping. September 1939 to February 1941"

[80] Ian Johnson & Niall MacKay, Lanchester models and the Battle of Britain

[81] Ian Johnson & Niall MacKay, Lanchester models and the Battle of Britain

same combat effectiveness against German dive-bombers as German fighters, as during the Kanalkampf campaign the losses suffered by German fighters and dive-bombers were similar.

And so, it was decided that we should base our air combat on the following rules:

1. Number of British fighters lost = $0.05\sqrt{(BF)(GF)}$
2. Number of German fighters lost = $0.05\sqrt{(BF)(GF)}$
3. Number of German dive-bombers lost = $0.05\sqrt{(BF)(GB)}$

Here BF is the number of British Fighters, GF is the number of German Fighters and GB is the number of German dive-bombers.

The combat rule we decide to use was based on the three sets of equations above. However, instead of having a fixed value of 0.05, they will instead become priors, which will be chosen from a distribution. These priors, which we shall label γ and λ, can be thought of as the effectiveness of German fighters and British fighters respectively.

Both parameters would be chosen from a Beta distribution centred at 0.05, with $\alpha = 23.7$ and $\beta = 450.3$. These values of alpha and beta ensure that the Beta distribution is centred at 0.05 and has a standard deviation of 0.01 . At the start of each simulation, the values of these 2 parameters would be randomly picked from each distribution. So by running the simulation a large number of times, this will allow us to see whether any of these parameters have a large impact on the outcome of our results.

Hence, the final form of our air combat rule becomes:

1. Number of British fighters lost= $\gamma\sqrt{(BF)(GF)}$
2. Number of German fighters lost= $\lambda\sqrt{(BF)(GF)}$
3. Number of German dive-bombers lost= $\lambda\sqrt{(BF)(GB)}$

In our simulation, we will use a stochastic version of these rules.

3.4 Table of parameters for the Kanalkampf Simulation

Parameters	**Distribution**
British Fighter Effectiveness	Beta distribution centred at 0.05
German Fighter Effectiveness	Beta Distribution centred at 0.05
Ju-87 Effectiveness	Beta distribution centred at 0.009

Table 2: The parameters of the Kanalkampf simulation

3.5 Outcome of Kanalkampf simulation

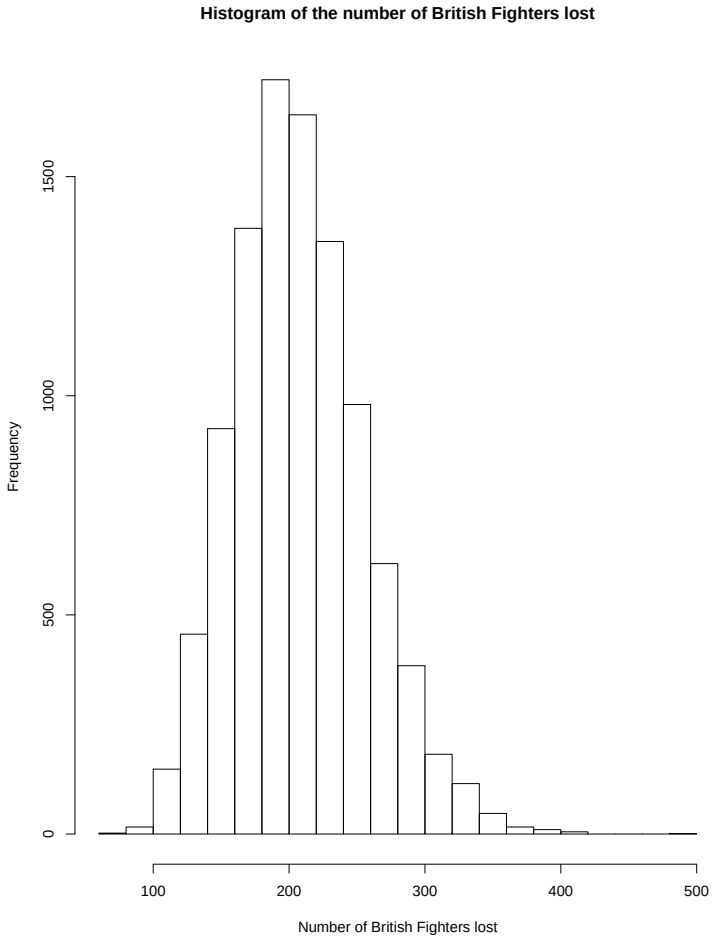


Figure 8: Number of British fighters lost in the Kanalkampf simulation

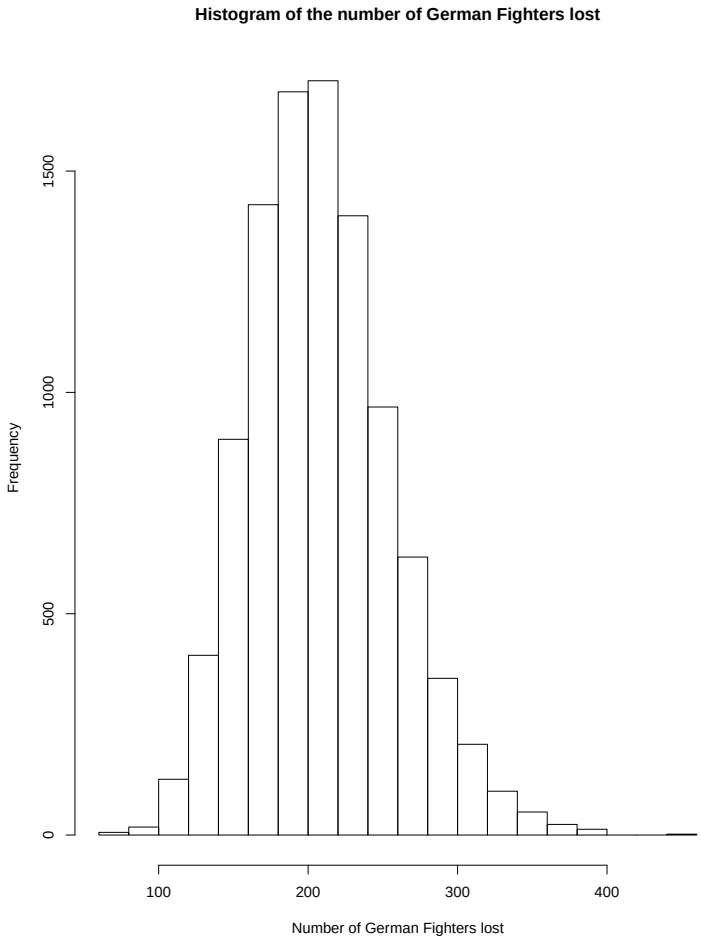


Figure 9: Number of German fighters lost in the Kanalkampf simulation

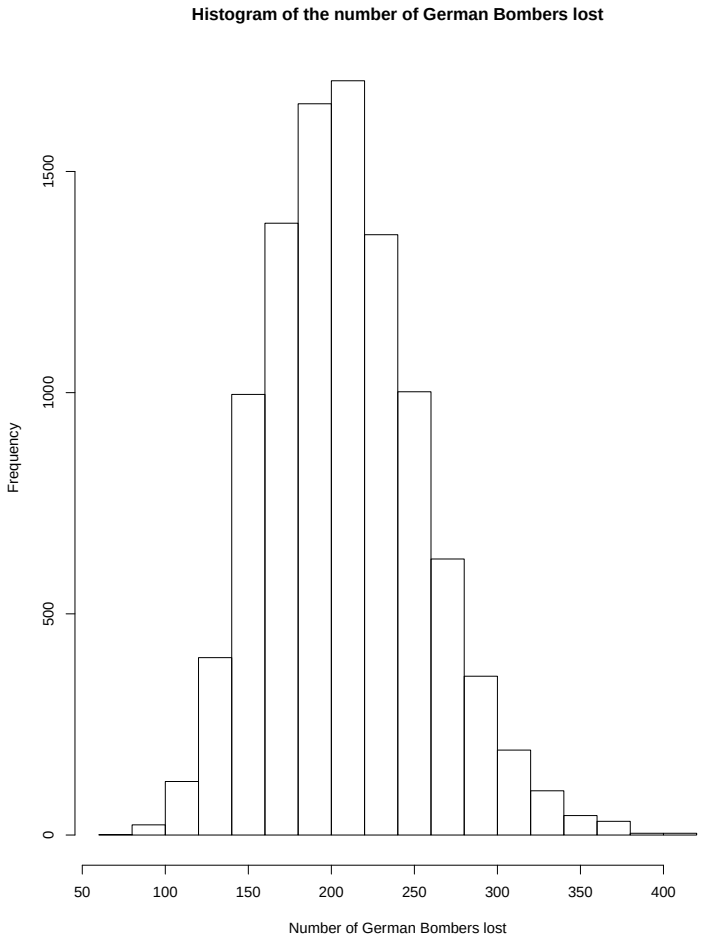


Figure 10: Number of German dive-bombers lost in the Kanalkampf simulation

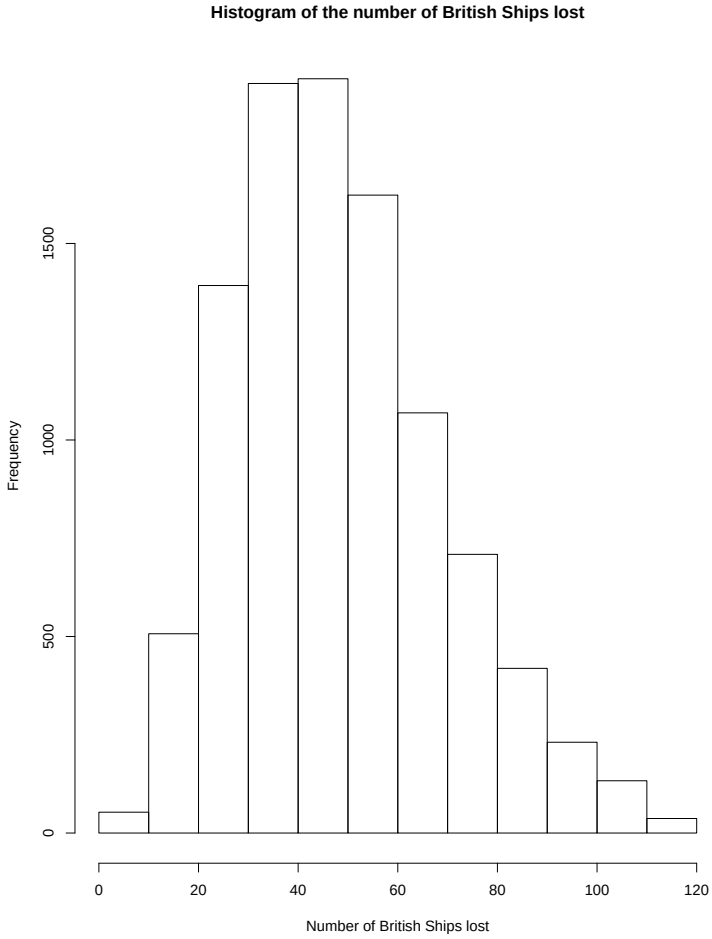


Figure 11: Number of British ships sunk in the Kanalkampf simulation

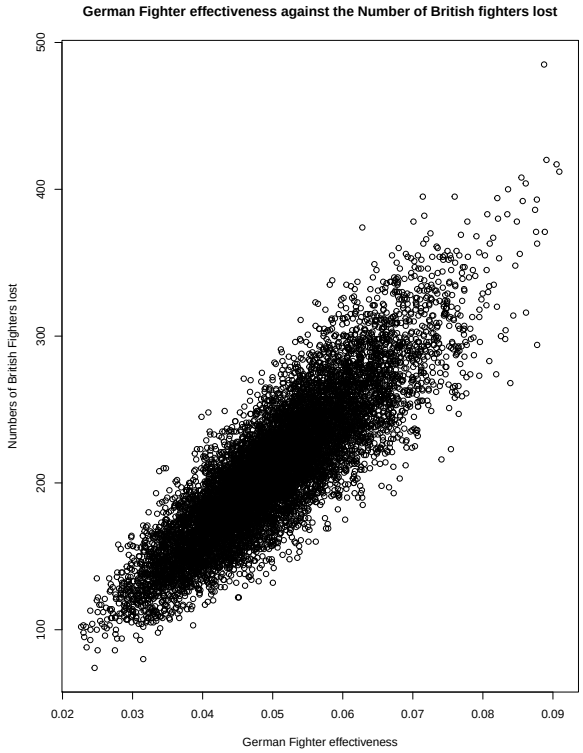


Figure 12: German fighter effectiveness against the number of British fighters lost in the Kanalkampf simulation

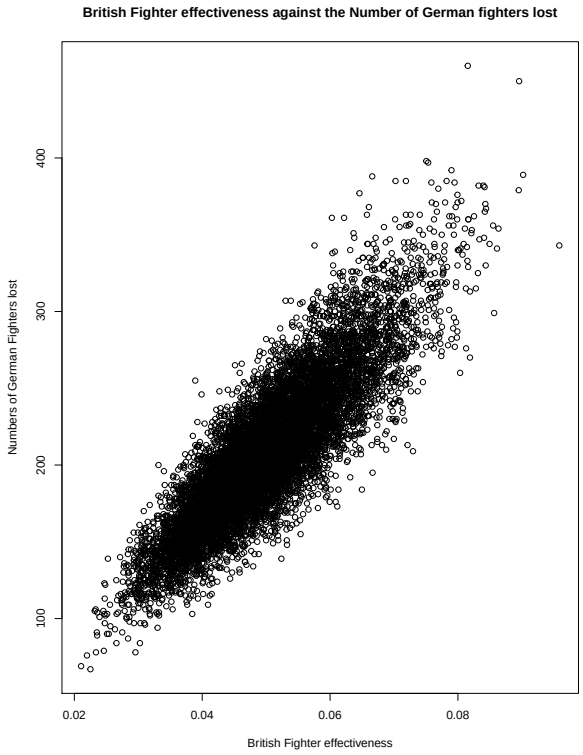


Figure 13: British fighter effectiveness against the number of German fighters lost in the Kanalkampf simulation

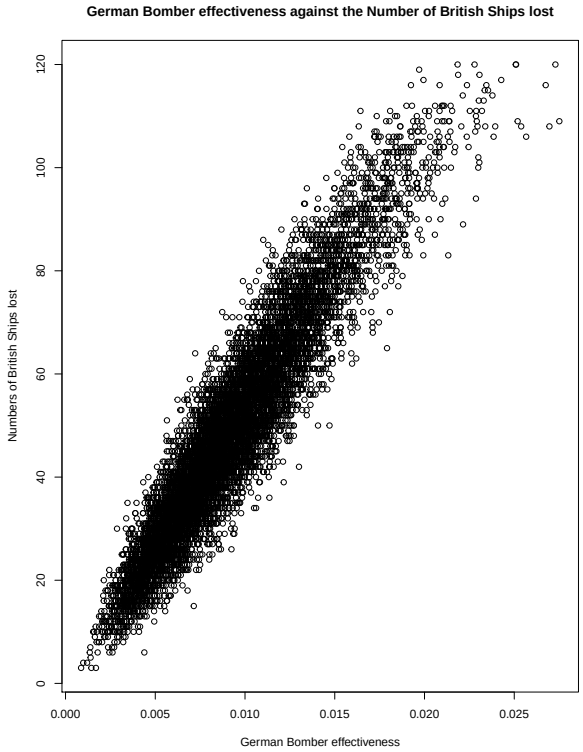


Figure 14: German dive-bomber effectiveness against the number of British ships sunk in the Kanalkampf simulation

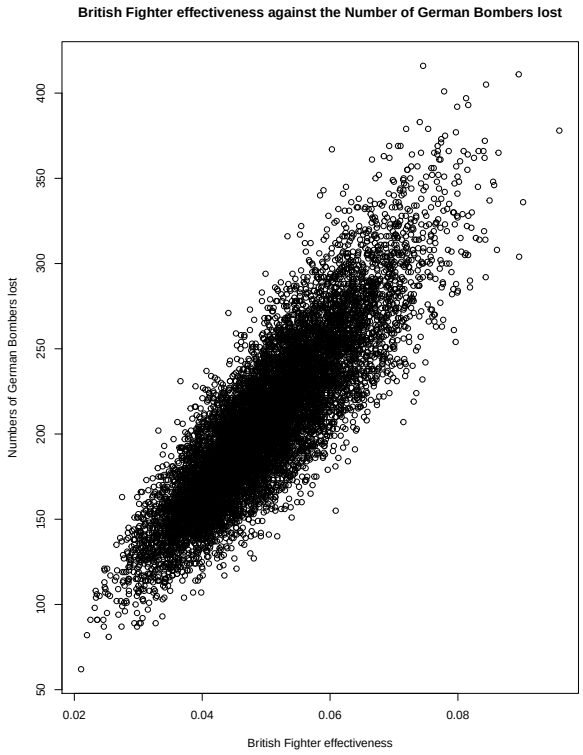


Figure 15: British fighter effectiveness against the number of German dive-bombers lost in the Kanalkampf simulation

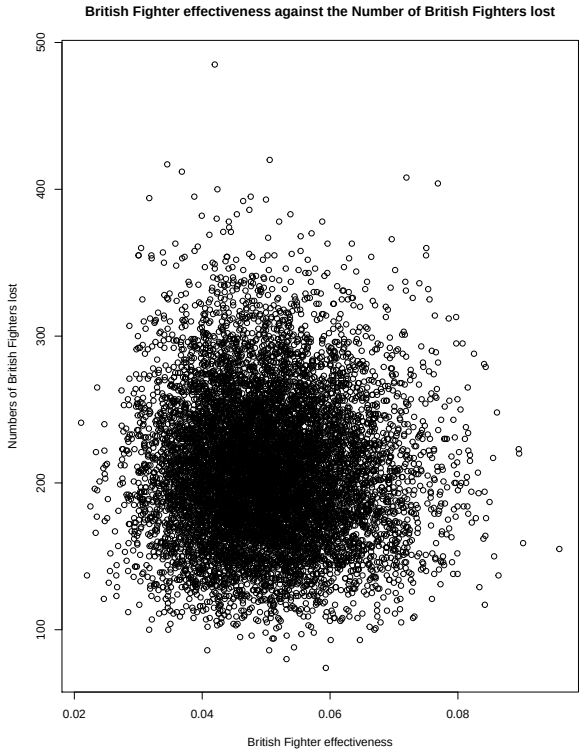


Figure 16: British fighter effectiveness against the number of British fighters lost in the Kanalkampf simulation

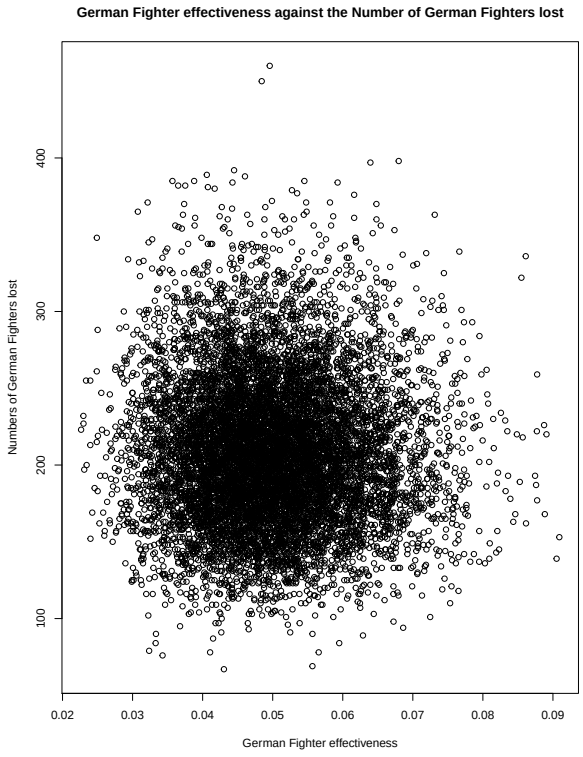


Figure 17: German fighter effectiveness against the number of German fighters lost in the Kanalkampf simulation

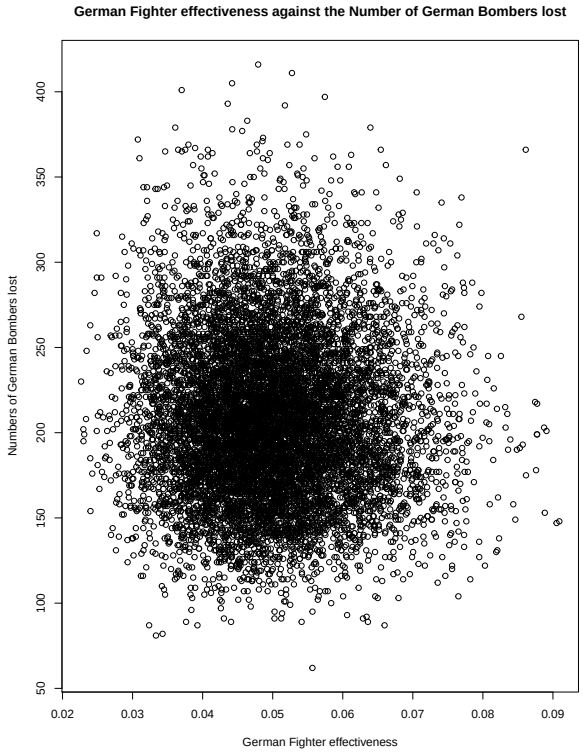


Figure 18: German fighter effectiveness against the number of German dive-bombers lost in the Kanalkampf simulation

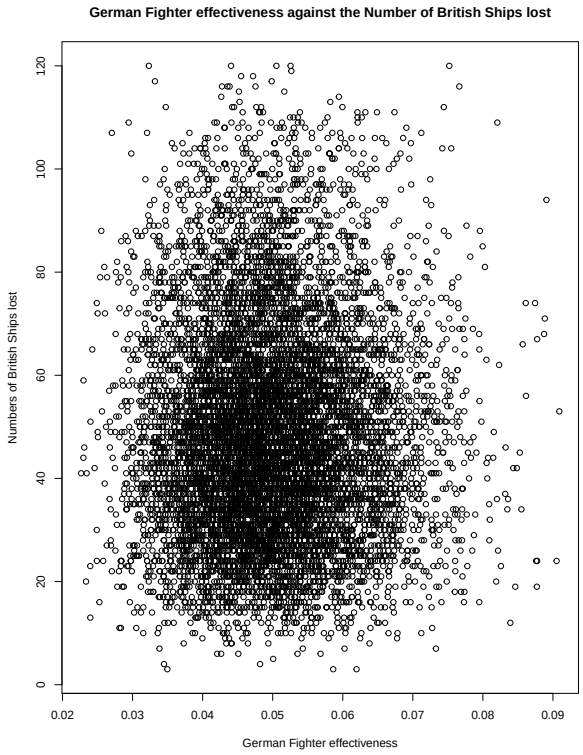


Figure 19: German fighter effectiveness against the number of British ships sunk in the Kanalkampf simulation

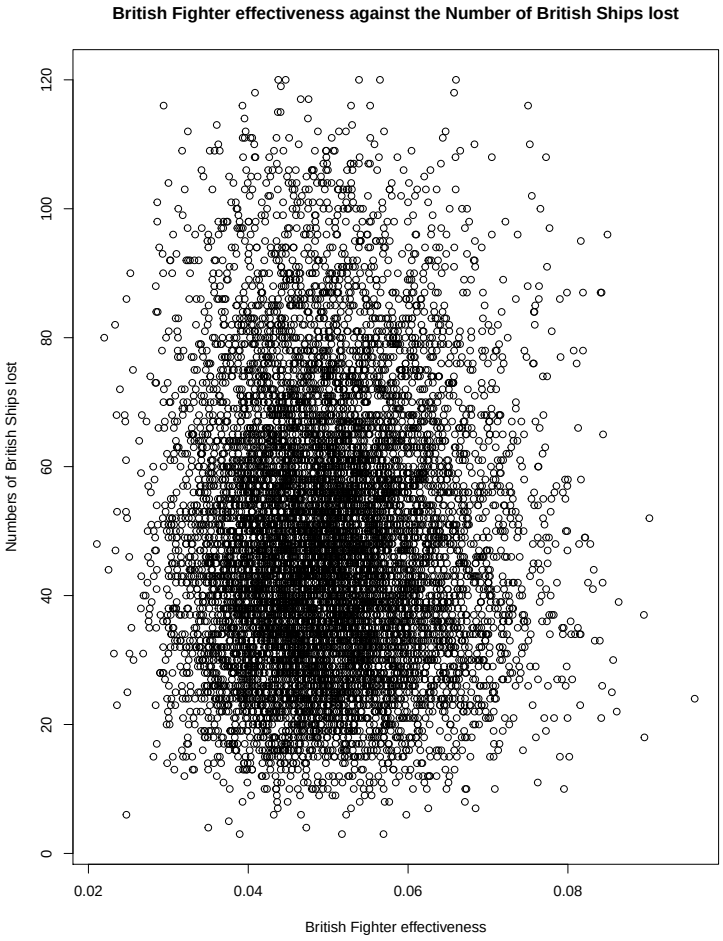


Figure 20: British fighter effectiveness against the number of British ships sunk in the Kanalkampf simulation

3.6 Analysis of results

In our Kanalkampf simulation, both the German and British fighters had approximately 300 sorties every day, with the German dive-bombers also having approximately 300 sorties every day. Fighter Command averaged approximately 500 sorties every day during the actual Kanalkampf campaign; however, the sortie rate for the Luftwaffe was thought to be lower,[82] hence, we felt our numbers would give a reasonable approximation of the actual campaign, allowing us to compare our results.

During the actual campaign, the British lost approximately 120 fighters. The Germans lost approximately 80 fighters, 20 dive-bombers and 100 medium bombers. With regard to British naval losses, approximately 35 merchant ships were sunk along with 4 destroyers and 7 fishing vessels.[83]

We can see from Figure 8 and Figure 9 that the number of British and German fighters lost are both centred at around 200. This is higher than the losses during the Kanalkampf campaign, which was around 100 for each side. This is to be expected as the air combat model was designed for Operation Sealion, where the aerial fighting would have been much more intense. Similarly, for the same reason, in Figure 10 the number of German dive-bombers lost during our simulation is concentrated around 200, approximately twice the number of German bombers that were lost during the actual campaign. In section 3.3.2, we noted that in the paper by Johnson and MacKay, the British and German fighter effectiveness was calculated at 0.032 during the Battle of Britain. However we increased it by around 50% to 0.05 to compensate for the expected increase in combat intensity during Operation Sealion. If we had used the value of 0.032 as our combat effectiveness for German and British fighters, we would get losses of approximately 130 fighters for both the Germans and British, with the Germans also losing around 130 dive-bombers, which is a much better approximation of the air losses suffered during the actual campaign.

From Figure 11, we find that the number of British ships sunk is centred is around 40 ships, which is a very close approximation to the actual result.

Figure 12 shows us that there is a positive correlation between German fighter effectiveness and the number of British fighters lost. This is certainly to be expected, as a higher German fighter effectiveness should result in more British fighters being shot down, and so, it confirms to us that our model is working as intended. Figure 13 shows a similar relationship between British fighter effectiveness and the number of German fighters lost, which again is to be expected. Figure 14 shows positive correlation between German dive-bomber effectiveness and the number of British ships sunk, which we also expected. Likewise, Figure 15 shows that there is positive correlation between British fighter effectiveness and the number of German bombers lost, which again is what we anticipated.

[82] Basil Collier, The defence of the United Kingdom, p170-p171

[83] Kanalkampf, Wikipedia, `https://en.wikipedia.org/wiki/Kanalkampf`

Figure 16 shows that there is no correlation between British fighter effectiveness and the the number of British fighters lost. This is because of our air combat model, where the number of British fighters lost is given by $\gamma\sqrt{(BF)(GF)}$, where γ is German fighter effectiveness. This means that the number of British fighters lost directly depends on the effectiveness of the German fighters, not on the effectiveness of the British fighters. Hence, this lack of correlation is to be expected. Analogously, Figure 17 shows no correlation between German fighter effectiveness and the number of German fighters lost, as the air combat model means the number of German fighters lost does not depend on the effectiveness of the German fighters. Likewise, for the same reason, in Figure 18 there is no correlation between German fighter effectiveness and the number of German dive bombers lost.

Figure 19 shows no correlation between the effectiveness of German fighters and the number of British ships sunk. One possible explanation for this could be that as Figure 18 shows, there is no correlation between German Fighter effectiveness and the number of German dive-bombers lost. Hence, we can't assume that a higher German fighter effectiveness must result in a stronger protection for the dive-bombers, and so more British ships being sunk. This could be because the crucial difference is not German fighter effectiveness, but rather, the mere fact that it is a contested airspace as opposed to having complete air supremacy, where the RAF cannot interfere with German raids.

Figure 20 shows no correlation between the effectiveness of British fighters and the number of British ships sunk. As Figure 15 shows that a higher British fighter effectiveness results in more dive-bombers being destroyed, this suggests that the numerical loss of dive-bombers induced by having a higher British fighter effectiveness is not of significant worth. And since Figure 14 shows positive correlation between dive-bomber effectiveness and the number of British ships sunk, this seems to imply that in our simulation, the effectiveness of dive-bombers takes precedence over any variation in the number of Ju-87s brought about by a varying British fighter effectiveness.

In our model, the Luftwaffe would send out fighters and dive-bombers into the Channel everyday, with the aim of engaging RAF fighters and sinking British convoys. Likewise, the British would also send out fighters to provide protection for their convoys. This mimics what happened during the Kanalkampf campaign, and since our results give a reasonable approximation of the losses suffered during the campaign, we can be quite confident that our simulation provides a plausible model of the Kanalkampf campaign. We can now use this model to provide a foundation for the Operation Sealion simulation.

4 Operation Sealion simulation

With the Kanalkampf simulation providing results that validated the model, we then moved towards creating the Operation Sealion simulation, using our Kanalkampf model as a basis.

4.1 Mechanics of the simulation

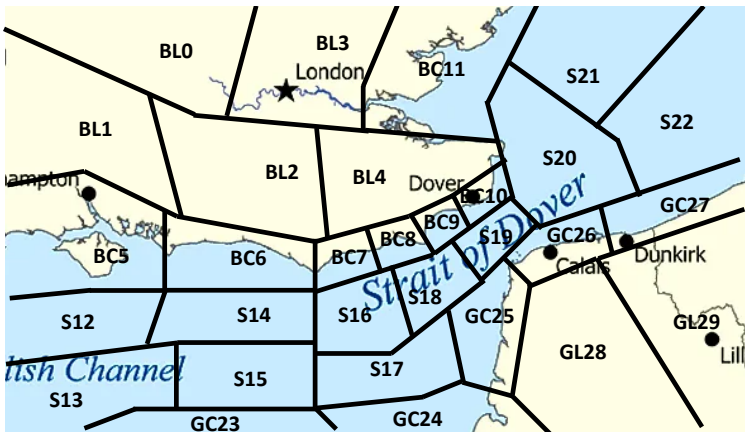


Figure 21: Operation Sealion simulation spatial structure

Our Sealion simulation will only deal with the first 3 days of the invasion. This will allow us to simulate the crossing of the first and second echelon troops, of the first wave of the invasion. The first wave as set out in the final German invasion plan would consist of four invasion fleets; Fleets B,C,D and E. These fleets were made up of barges and larger transports. Fleet B would consist of 200 barges and 57 large transports, and would travel from Dunkirk to Folkestone. Fleet C would also consist of 200 barges and 57 transports, and would travel from Calais to Dungeness. Fleet D would consist of 330 barges and would travel from Boulogne to Bexhill. Fleet E would consist of 300 barges and 50 transports, and would travel from Le Havre to Brighton. In total, there would be approximately 120,000 German troops distributed amongst these barges and transports. Figure 21 shows the map that we decided to use for our Sealion simulation; it shows the invasion area with squares superimposed into it, which we obtained by making adjustments to our Kanalkampf map. Our Kanalkampf map had a very simple structure, however, for the Sealion simulation we had to make changes to the map, as we did not have ships attacking other ships in the Kanalkampf simulation. We had to ensure that the squares in our Sealion map had the right connectivity and size. The squares have to be small enough so that we can distinguish between the various routes of the German invasion fleet. However, the squares also have to be big enough so that if any British destroyer is within attacking distance of a German barge, then they both belong to the same square.

We will run the simulation 10,000 times for two different versions of the code, corresponding with the 2-SD wargame and the 6-SD wargame. In the 2-SD simulation the RAF will have 38 fighter squadrons, but in the 6-SD simulation, they will have 30 fighter squadrons. Potentially even more importantly, in the 2-SD simulation, only approximately 20% of the planned minefields are laid, whereas in the 6-SD simulation around 75% of the planned minefields are laid. All other aspects of the simulation are the same. In both simulations, the Germans will have 31 fighter squadrons and 9 dive-bomber squadrons. Each RAF Fighter squadron has 15 planes, with Luftwaffe fighter squadrons having 20 planes, and the German dive-bomber squadrons having 15 Ju-87s each. The RAF squadrons will be based in the squares BL0, BL1 and BL2 with the Luftwaffe squadrons based in squares GL28 and GL29. The Royal Navy has 10 destroyer squadrons, of size four, resulting in there being 40 destroyers in total, which gives a reasonable approximation of the actual number of destroyers available in the vicinity to the Royal Navy.[84] These destroyer squadrons will be based in the squares BC5 and BC11, representing Portsmouth and Harwich, respectively. We decided to place them here as many of the destroyers based on the south coast would have been near these two bases at the start of the invasion.

The German Naval Plan was to place "all destroyers and torpedo boats west of the western minefields and all S-boats east of the eastern minefield".[85] However in the 2-SD wargame, 8 S-boats were sunk, and in the 6-SD wargame, again 8 S-boats were sunk, as well as 2 destroyers. This meant that the Germans would only have approximately 7 destroyers, 12 S-boats and 15 torpedo boats to protect both flanks of the invasion. As Schenk notes, "the torpedo boats were of limited use as being only lightly armed and would have been hard pressed to stand up against British destroyers".[86] Hence, it does not seem feasible that the Kriegsmarine could offer much resistance to Royal Navy. As they were not being used to escort the barges and transports, and were instead placed outside of the minefields, we decided that we could simplify our simulation by excluding them, and instead doubling the effectiveness of the minefields. Capital ships were not included in this simulation, as the Germans did not plan to deploy them in the invasion area, and the heavier units of the Royal Navy were instructed not to enter the Channel unless the heavier units of the Kriegsmarine did so.

The simulation starts at 2pm on day S-1. The barges would begin to set off towards the invasion beaches from 4pm, as it takes them around 15 hours to make the transit, and they must reach there by 7am. The barges leave their embarkment ports in a staggered manner, as it would be impossible for them to set off all at once, so the barges leave their ports in groups of 10 during each time step. In this simulation, each time step is 10 minutes. The larger transports were expected to arrive around 2-3 hours after the first barges had arrived. These transports would also have to leave the ports in a staggered manner, with three leaving port during each time step. Once they reached their

[84] Peter Fleming, Operation Sea Lion, p159
[85] Peter Schenk, Invasion of England 1940, p199
[86] Peter Schenk, Invasion of England 1940, p335

designated invasion beaches then they would start the unloading process, which is described below.

The barges would take 6 hours to unload, [87] during which they would remain stationary at the beach. This corresponds to 36 time steps, and so we coded it so that once it had been unloading for 3 hours, half of the troops would be unloaded. Once the full 6 hours was completed, then the remaining half of the troops would also be unloaded. Following these barges would be the larger transports. It was estimated that the larger transports would take up to 48 hours to unload, which is 288 time steps. Like the barges, they would also be unloaded in a staggered manner at regular intervals.

Once the British were aware that an invasion was taking place, their destroyers would then be sent out into the Channel, to attack the German invasion fleet. The British destroyers, while attempting to enter the invasion route, would have to pass through German minefields. These minefields would be placed on the line joining BC6-S14-S15 to BC7-S16-S17 (Bruno minefield), BC5-S12 to BC6-S14 (Anton minefield) and BC10-S19 to S20 (Caesar minefield).

The mechanics of the simulation are similar to that of the Kanalkampf simulation. At the start of the simulation, each fighter and dive-bomber squadron would be randomly assigned a target square and a sequence of squares they must traverse before reaching that square. As the simulation runs through the time steps, they would then travel through that path until they eventually reach the target square, where they would then return to their original base, by following the reverse path. They would then remain stationary in their base for a rest period, during which they would reload their ammunition, and their losses would be replaced. They would then be assigned a new target square and the process would start again. The planes would be grounded 1900-0700 in the simulation, as that roughly corresponds to night-time.

The same process happens to the destroyers; however, at the start they remain stationary in their base for between 8-12 hours, to mimic the delay they would have before realizing that an invasion was taking place. These destroyers would then be assigned target squares in the Channel and invasion beaches, which they would then move towards, attacking any German ships in the same square as them, while doing so. Unlike the planes, they would be able to sortie during night-time.

For the German invasion fleets, since we already know their invasion routes, we can simply code it so that they follow this route. Fleet B would go through the sequence of squares GC27, GC26, S19, BC9. Fleet C would go through GC26, S19, S18, BC8 with Fleet D going through GC25, S18, S16, BC7 and finally Fleet E would go through GC23, S15, S14, BC6. The paths assigned to each Fleet approximate their actual invasion route.

The movement of units in our Sealion simulation is quite different to that of the

[87] Peter Schenk, Invasion of England 1940, p230-p231

Kanalkampf simulation. In the Kanalkampf simulation we had that one time step results in the movement of a unit by one square; however, it is different in our Sealion simulation. In our Sealion simulation, each air and ship squadron has a speed, which determines how many time steps it stays in that square before moving onto the next one. For example, a British destroyer has a speed attribute of 6, so it must remain in that square for 6 time steps before it moves onto the next one. German barges have a speed attribute of 30, while the transports have a value of 20. The German/British fighter planes have a speed attribute of 1 with the dive-bomber having a speed attribute of 2.

The combat model follows the same hierarchical theme as the Kanalkampf simulation. So during every time step, the code goes through each of the squares, checking whether there are any opposing units in the same square. So for a given square, it first checks whether there are any British and German fighters in it. Then the code checks whether there are any British fighters and German dive-bombers in the square, before checking whether there are any German dive-bombers and British destroyers. Finally, it then checks whether there are any British destroyers and German barges/transports in the square. At each stage of this hierarchy, if opposing units are found, then this fight is resolved using the combat rules described in the next section. Additionally, if a British destroyer moves between two squares where there is a minefield at the boundary, then the British losses are calculated using the rule described in the next section.

While we used the same air combat model in our Sealion simulation as the Kanalkampf simulation, we made an adjustment that ensures fighter planes only have two rounds of ammunition, so they can only take part in at most two fighting interactions. In the Kanalkampf simulation they had unlimited ammunition, and so they could be involved in many engagements. We also ensured that the German dive-bombers only have 1 round of ammunition, with the British destroyers having 12 rounds worth of ammunition.

Viewed through simplified lens, in this simulation, the German Army would attempt to cross the Channel and enter the invasion beaches, using barges and transports. British destroyers would leave their bases, and would travel through German minefields in order to attack the invasion fleet. Concurrently, Ju-87s would attempt to sink British destroyers, with RAF fighters attempting to shoot down the dive-bombers. German fighters would also be sent out into the Channel to provide protection for the Ju-87s. We ran both versions of the simulation 10,000 times. Since we ran the simulation 10,000 times for both the 6-SD and 2-SD simulation, we can assume that the relative error would be very small for both versions of the simulation.

4.2 Parameters of our Sealion simulation

Before we run our simulation there are some crucial parameters that we have to decide upon.

These parameters are:

> The effectiveness of British destroyers at sinking German barges and transports
>
> The effectiveness of the German minefields at sinking British destroyers

We will use the same air combat rules for the Sealion simulation as we did for the Kanalkampf simulation, so the parameters for this will remain the same. Likewise for the effectiveness of Ju-87s against British destroyers.

4.2.1 Effectiveness of British destroyers at sinking German barges and transports

One parameter that we would need to decide upon is the effectiveness of British destroyers against German barges and transports. This is a very important parameter as this would be the only way the British would be able to effectively stop the Germans from landing ashore.

Unfortunately we could not find any sources that would provide us with estimates. Hence, we decided that the best way to address this problem was through obtaining the best available expert judgements. So we asked two eminent naval historians "How many barges could a G or H-class destroy incapacitate in an hour of daylight?" There was a general agreement that 10-12 barges per hour was a reasonable estimate.[88] This seems to agree with the few anecdotes that we found when investigating this question.[89]

Hence, we decided that the destroyer effectiveness would be picked from a shifted Beta distribution centred at 2 with a standard deviation of 0.5. This is because each time step is 10 minutes, which means that on average our destroyer would sink around 12 barges an hour, approximately what we were aiming for. We decided that when the destroyers fought barges, the combat model used would be Lanchester aimed fire, as the destroyers would have lots of targets to aim at, and would only sink the barge they were aiming at. So the number of losses to a squadron of German barges is determined by the number of British destroyers attacking it multiplied by the combat effectiveness of the destroyers. We will use a stochastic version of this combat rule in our simulation.

[88] Professor Nicholas Rodger though our initial estimate of 10-15 barges per hour was reasonable. Professor Andrew Lambert provided us with an estimate of 10-12 barges per hour

[89] Peter Smith, Hold the Narrow Sea: Naval Warfare in the English Channel 1939-1945, p110, contains a short excerpt of three British destroyers easily hitting barges at night

4.2.2 Effectiveness of minefields

Another parameter that we must decide upon, is the probability of a British destroyer hitting a mine, when passing through a minefield. When a squadron of destroyers goes through a minefield, they would enter it in a line astern. Hence, the probability of n destroyers being sunk is precisely the same as the probability of the first destroyer hitting n mines. And so, the probability of n mines being struck, is given by a Poisson distribution, and so the probability that no mines are struck is given by $e^{-\lambda}$ where $\lambda = mNp$, where N is the planned number of mines, m is the proportion of mines laid, and p is the probability of hitting a mine.

If we look at the Caesar minefield, it consisted of around 1,300 mines over approximately 20km. The width of a destroyer is approximately 10m, so if you add 1 to give the width of a mine, then λ becomes:

$\lambda = \frac{1300 \times 11}{20000} \approx 0.72$, assuming all planned minefields are laid.

However, as we did not include German destroyers and torpedo boats in our simulation, we felt we could address this by doubling λ to 1.5. During the Soviet evacuation of Tallinn we found that approximately 15% of warships were sunk,[90] however the Royal Navy was not able to be as cautious as the Soviet fleet, so we estimated that $\lambda = 0.2$ would be the minimum value, with $\lambda = 1.5$ being the maximum value. We wanted most of our probability mass to lie between these two values of λ so we decided to use a Gamma distribution centred at 1 with a SD of 0.45. However, this value of λ assumes all the minefields have been successfully laid, so we need to make an adjustment.

In the 2-SD wargame, we estimated that 20% of the planned minefields were laid, with approximately 75% of the planned minefields being laid in the 6-SD wargame. Instead of having these numbers as a fixed estimate, we decided to make them priors, so we would instead pick them from a Beta distribution centred at 0.2 and 0.75 respectively, with a standard deviation of 0.1. This value would then be multiplied with the λ picked from the gamma distribution, and this will become the rate for our Poisson distribution, which we shall refer to as the minefield effectiveness. Thus, when a British destroyer squadron passes through a minefield, its losses would be calculated by randomly picking from this Poisson distribution.

[90] Soviet evacuation of Tallinn, Wikipedia, `https://en.wikipedia.org/wiki/Soviet_evacuation_of_Tallinn`

4.3 Table of parameters for the Operation Sealion simulation

Parameters	**Distribution**
British Fighter Effectiveness	Beta distribution centred at 0.05
German Fighter Effectiveness	Beta Distribution centred at 0.05
Ju-87 Effectiveness	Beta distribution centred at 0.009
British Destroyer Effectiveness	Beta distribution centred at 2
Minefield Effectiveness	Gamma distribution centred at 1 multiplied by a Beta distribution centred at 0.2 or 0.75, corresponding to the 2-SD and 6-SD wargames respectively

Table 3: The parameters of the Sealion simulation

4.4 Results of the simulation

4.4.1 2-SD Simulation

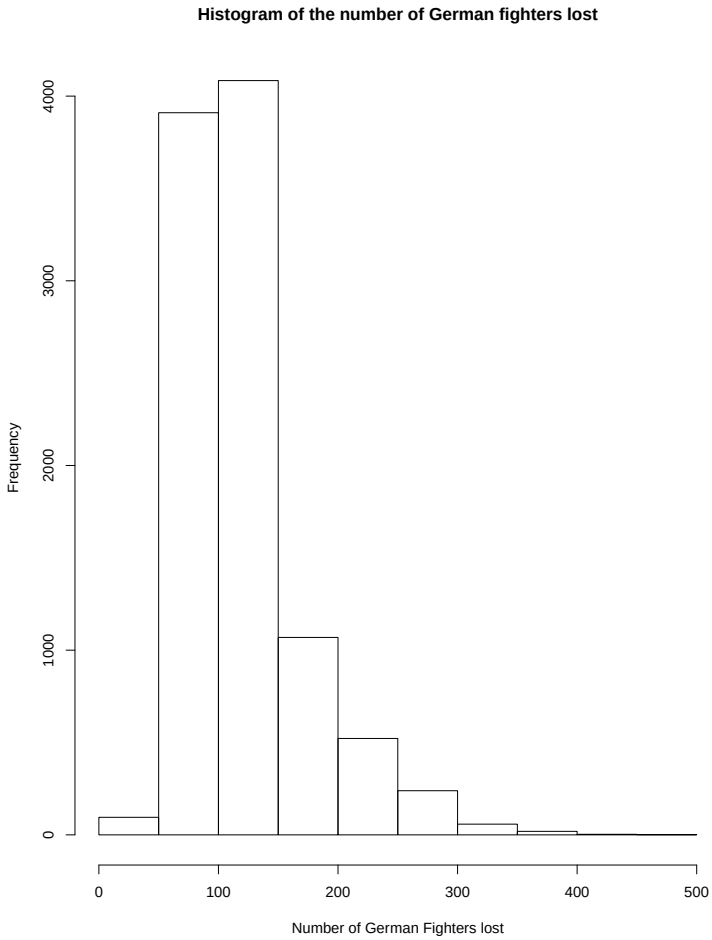


Figure 22: Number of German fighters lost in the 2-SD simulation

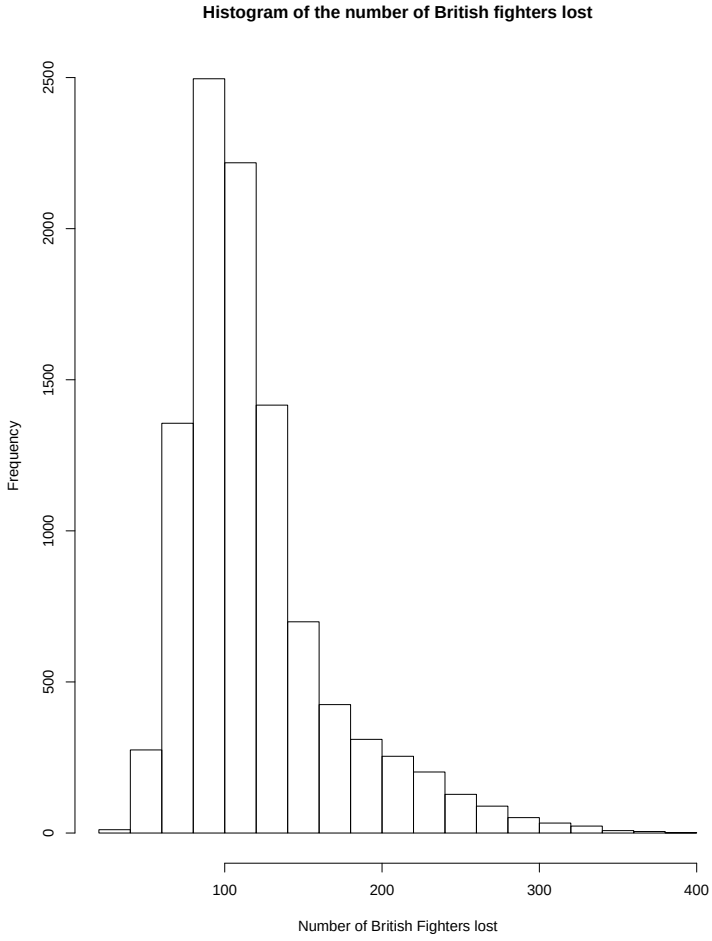


Figure 23: Number of British fighters lost in the 2-SD simulation

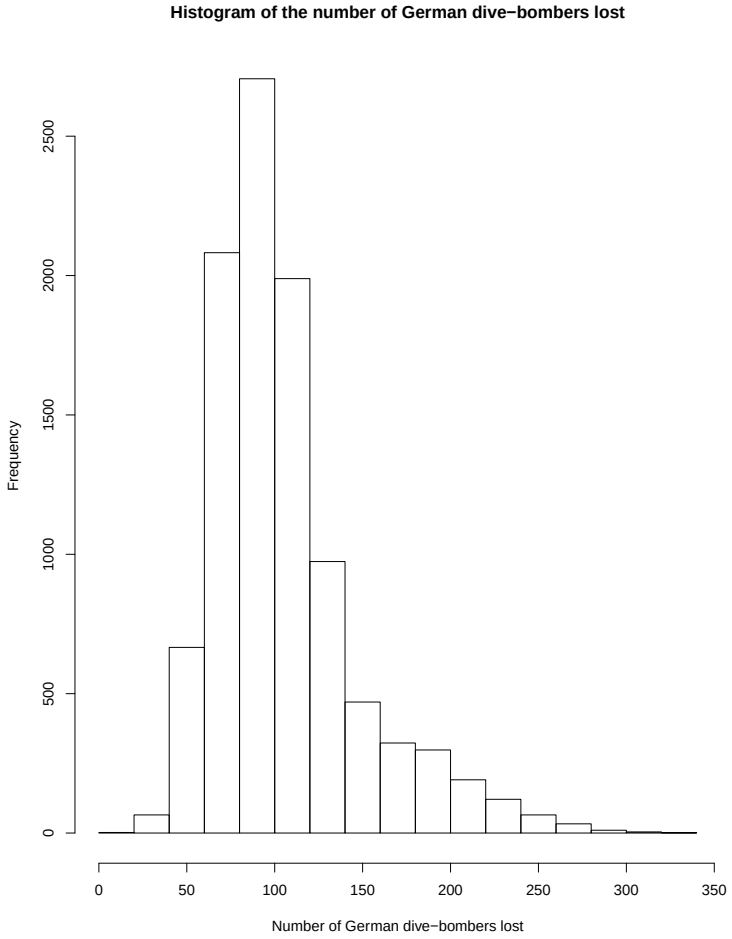


Figure 24: Number of German dive-bombers lost in the 2-SD simulation

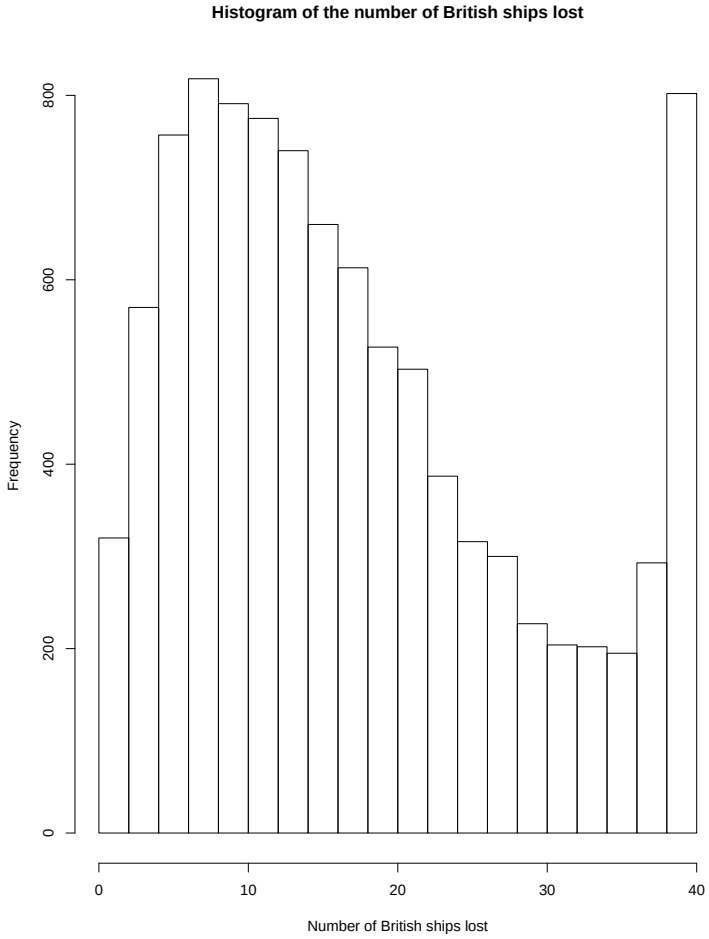


Figure 25: Number of British destroyers sunk in the 2-SD simulation

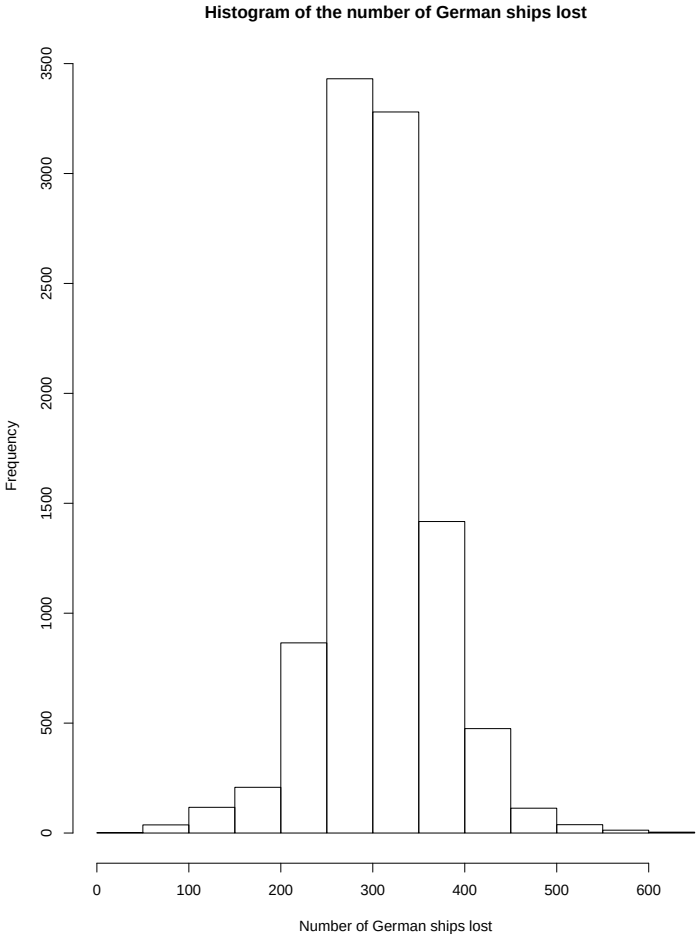


Figure 26: Number of German ships sunk in the 2-SD simulation

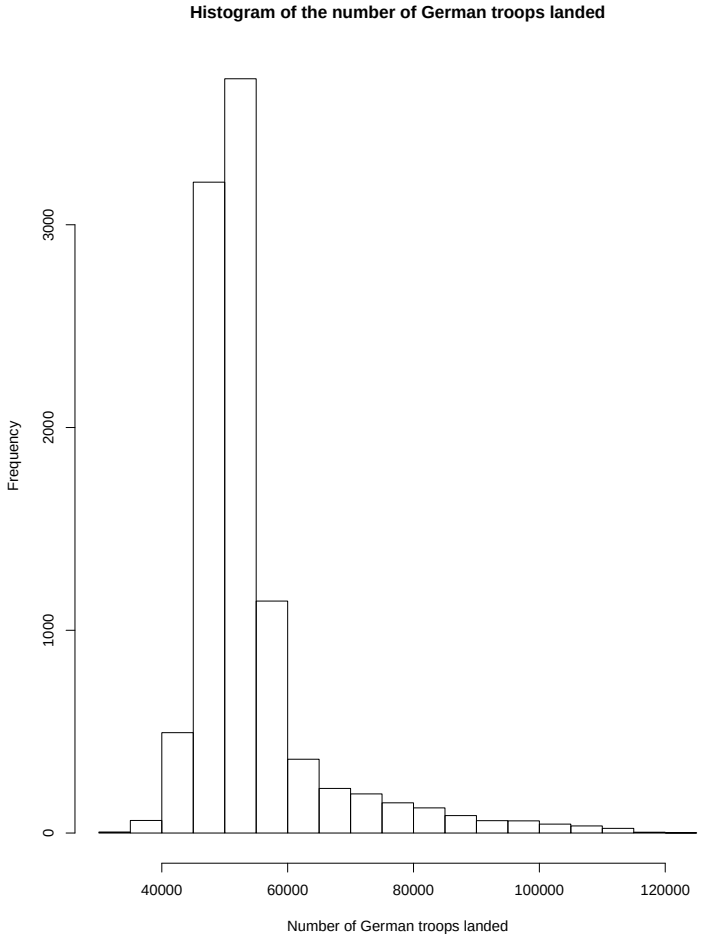


Figure 27: Number of German troops landed in the 2-SD simulation

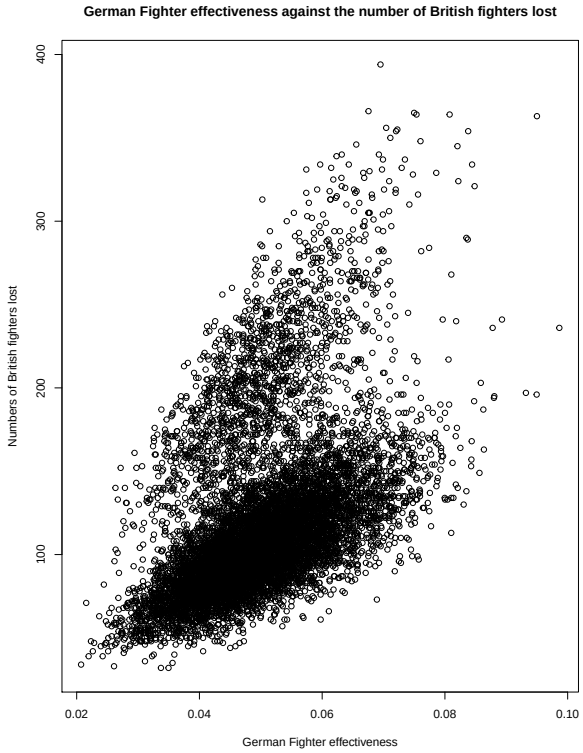


Figure 28: German fighter effectiveness against the number of British fighters lost in the 2-SD simulation

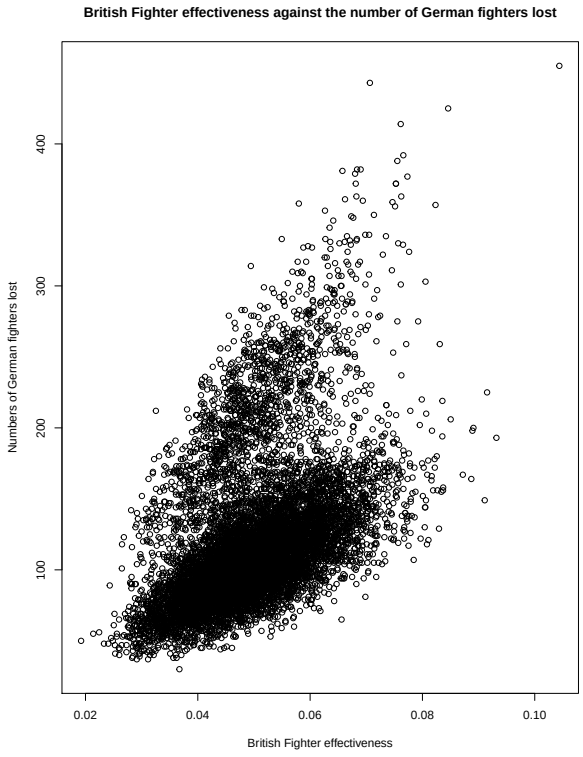


Figure 29: British fighter effectiveness against the number of German fighters lost in the 2-SD simulation

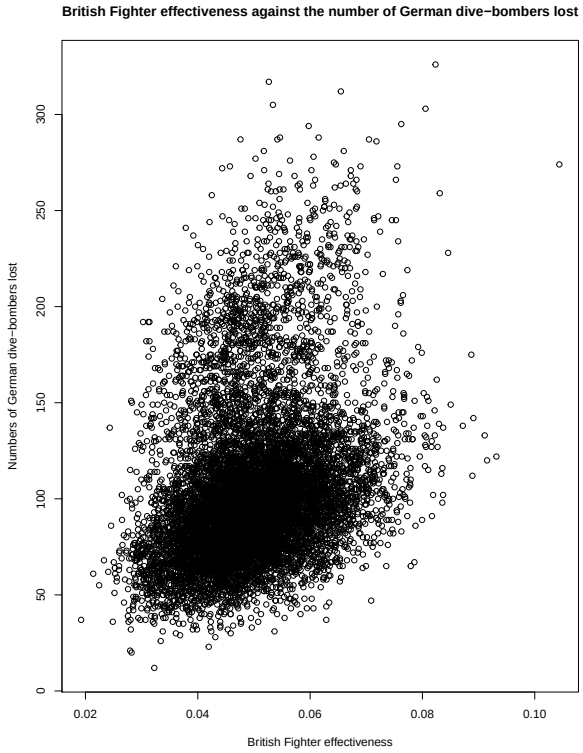


Figure 30: British fighter effectiveness against the number of German dive-bombers lost in the 2-SD simulation

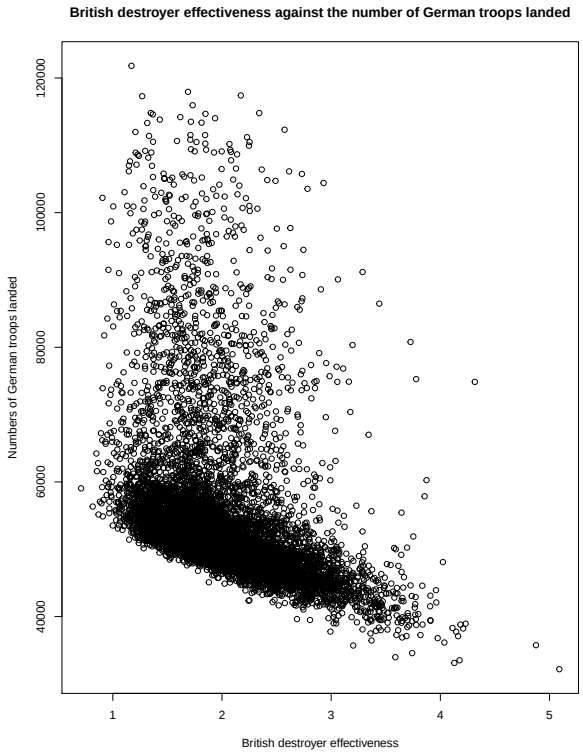


Figure 31: British destroyer effectiveness against the number of German troops landed in the 2-SD simulation

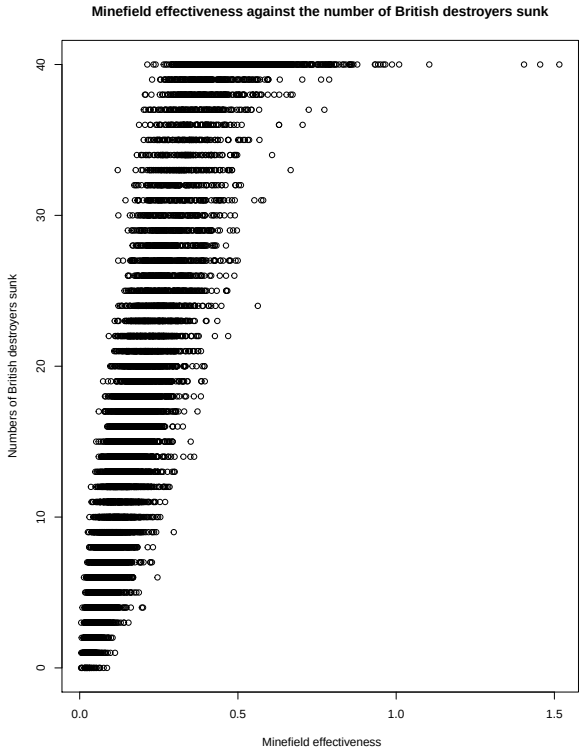


Figure 32: Minefield effectiveness against the number of British destroyers sunk in the 2-SD simulation

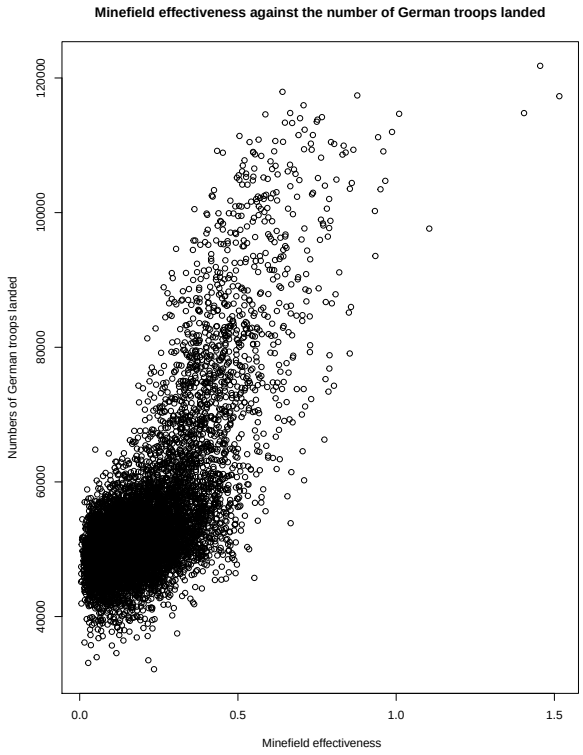


Figure 33: Minefield effectiveness against the number of German troops landed in the 2-SD simulation

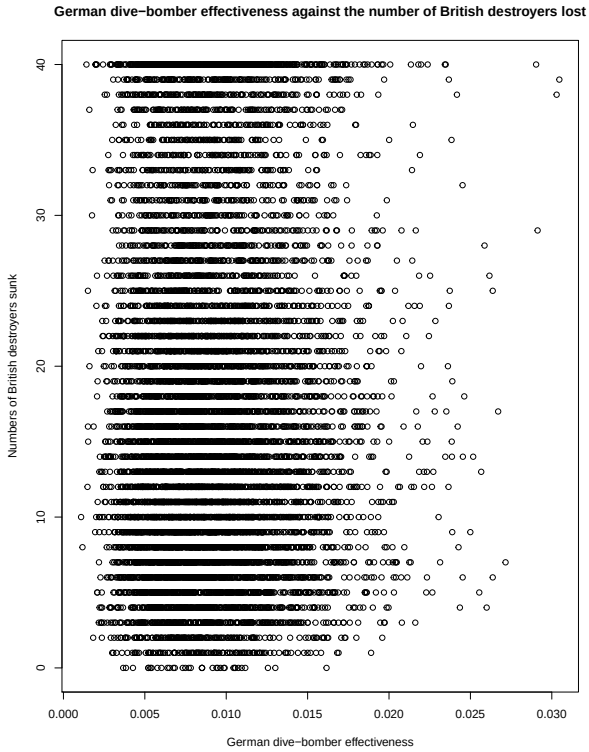


Figure 34: German dive-bomber effectiveness against the number of British destroyers sunk in the 2-SD simulation

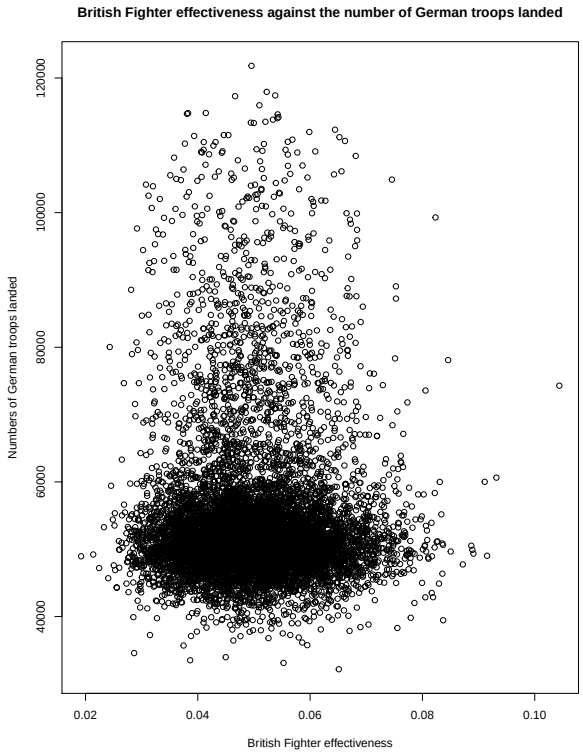


Figure 35: British fighter effectiveness against the number of German troops landed in the 2-SD simulation

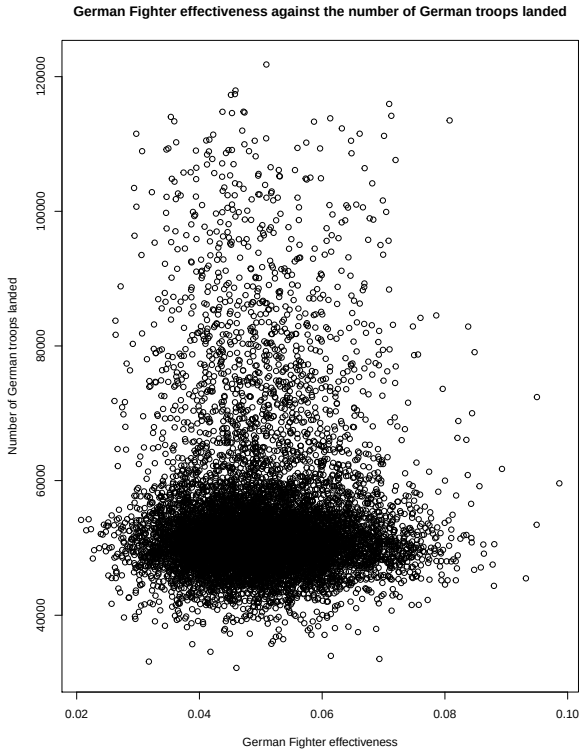


Figure 36: German fighter effectiveness against the number of German troops landed in the 2-SD simulation

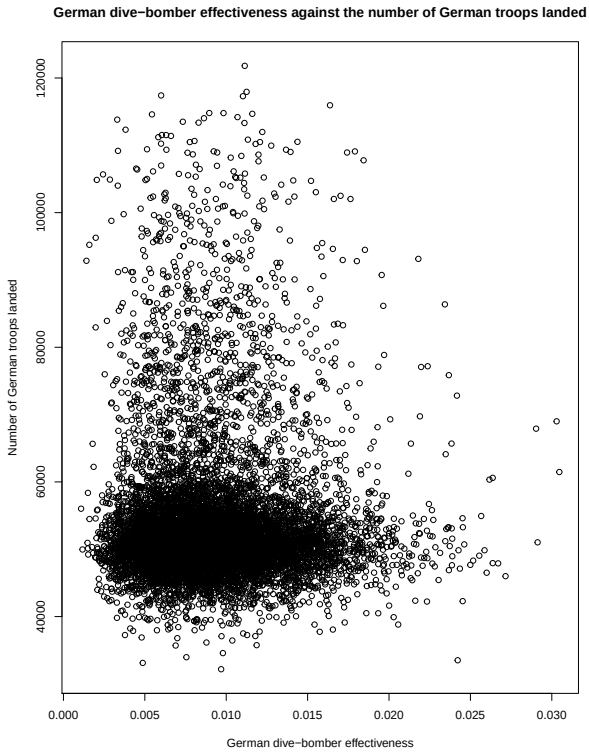


Figure 37: German dive-bomber effectiveness against the number of German troops landed in the 2-SD simulation

4.4.2 6-SD Simulation

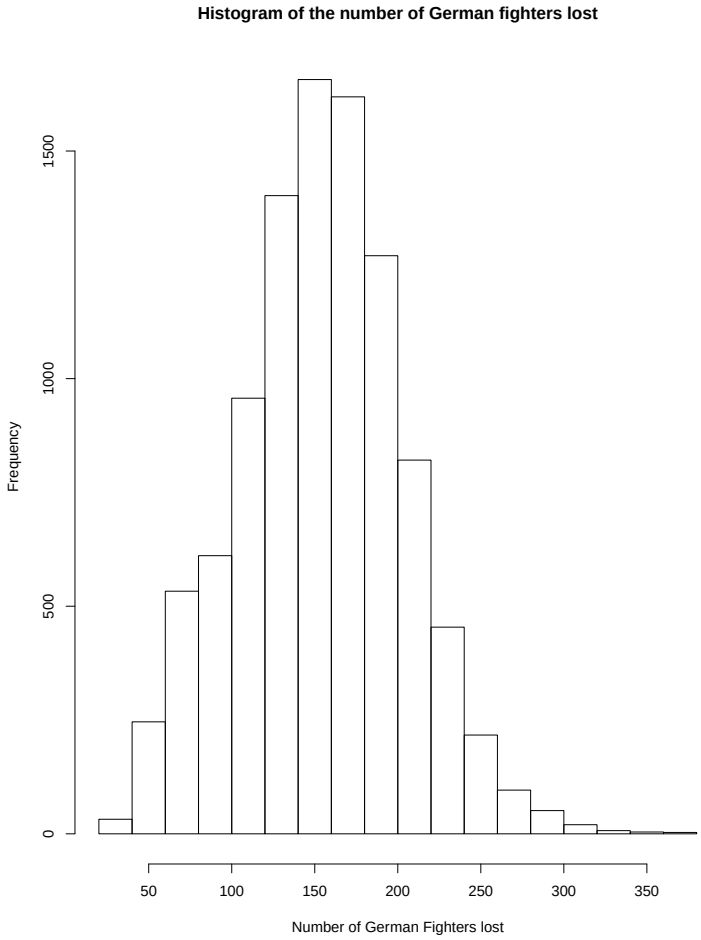


Figure 38: Number of German fighters lost in the 6-SD simulation

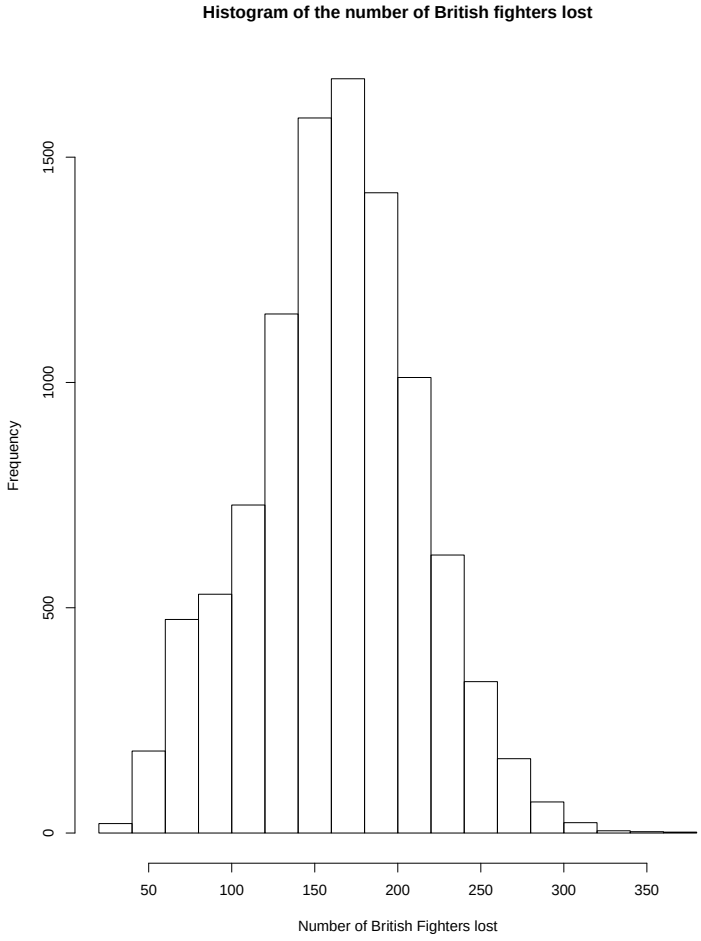


Figure 39: Number of British fighters lost in the 6-SD simulation

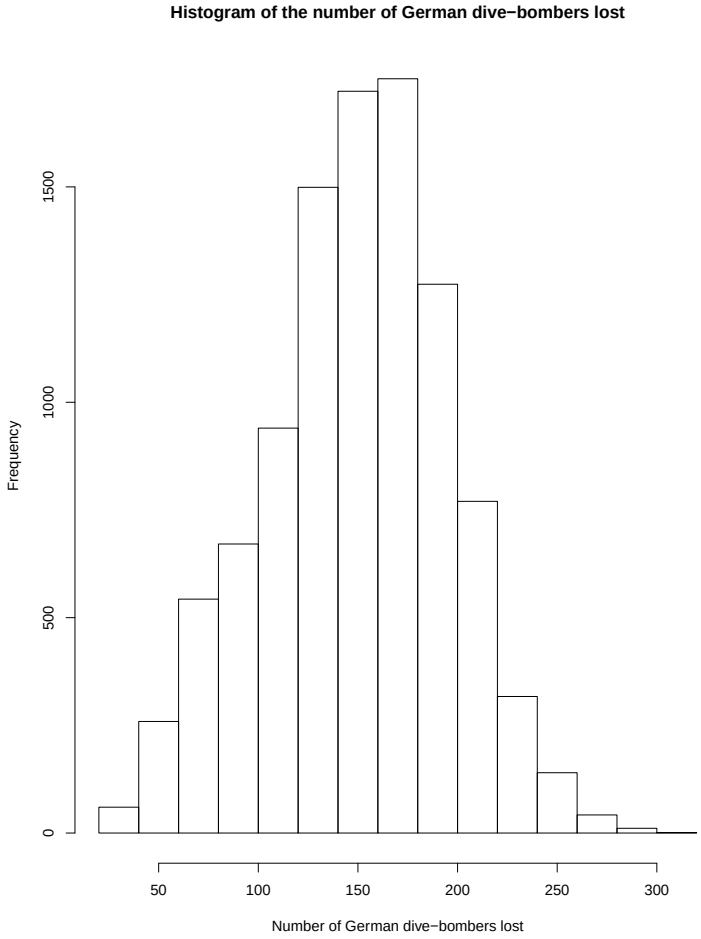


Figure 40: Number of German dive-bombers lost in the 6-SD simulation

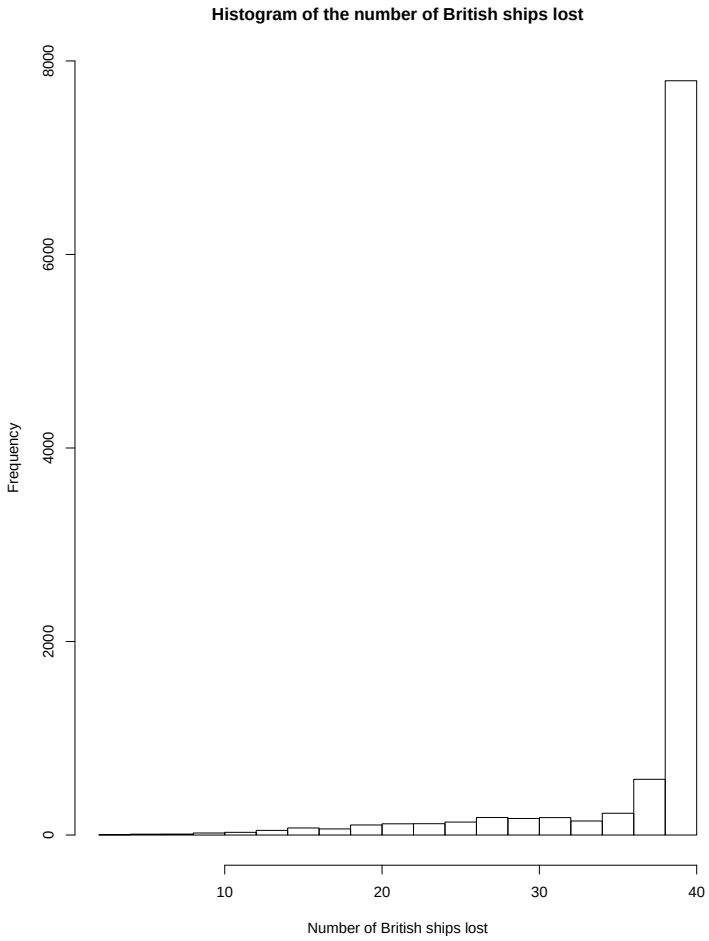


Figure 41: Number of British destroyers sunk in the 6-SD simulation

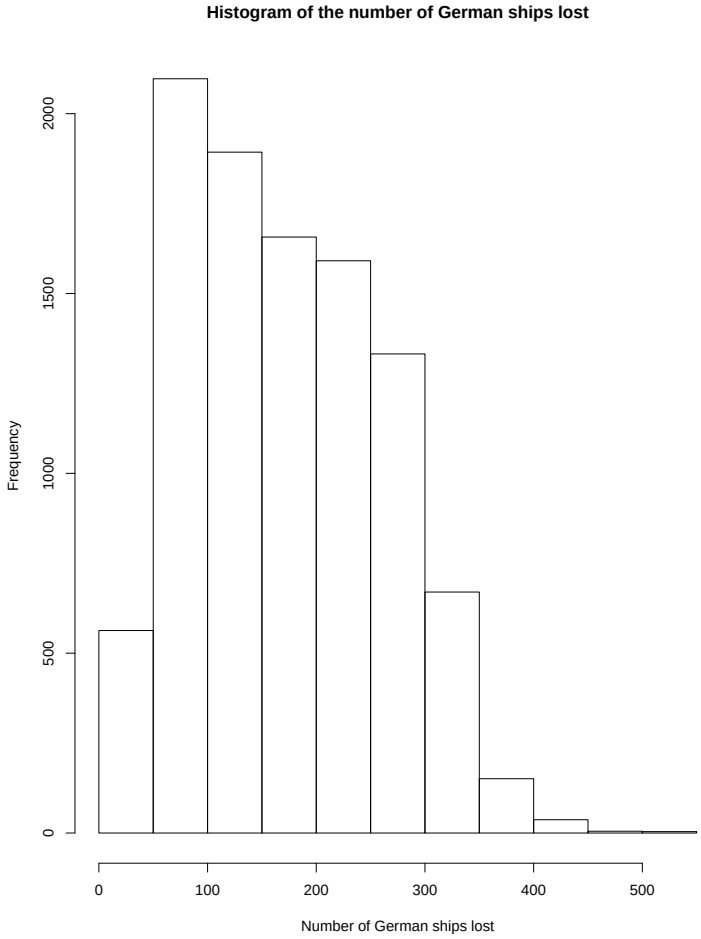


Figure 42: Number of German ships sunk in the 6-SD simulation

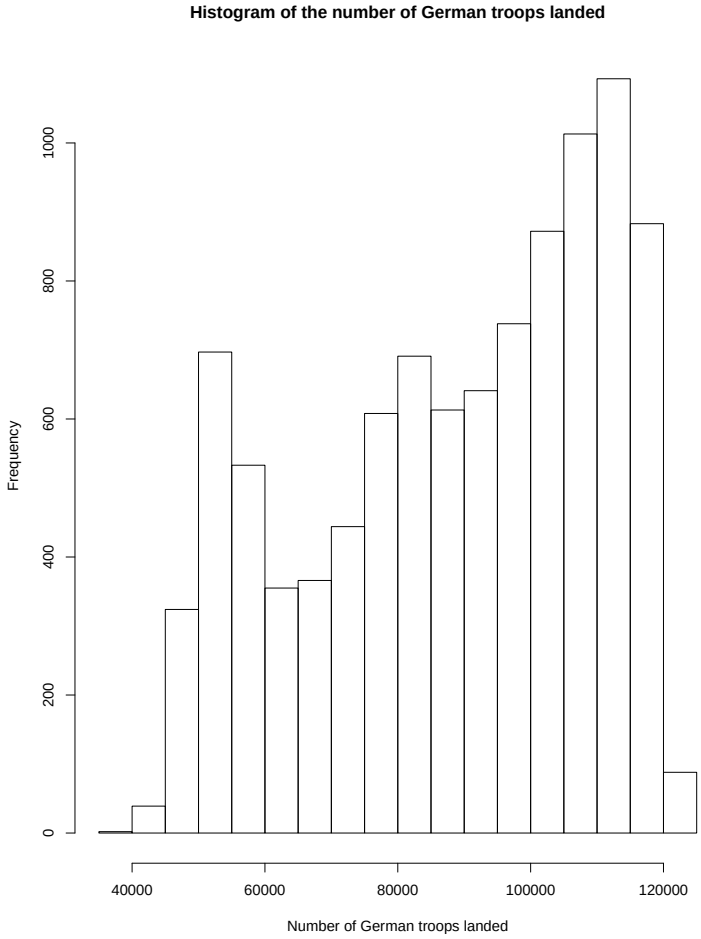


Figure 43: Number of German troops landed in the 6-SD simulation

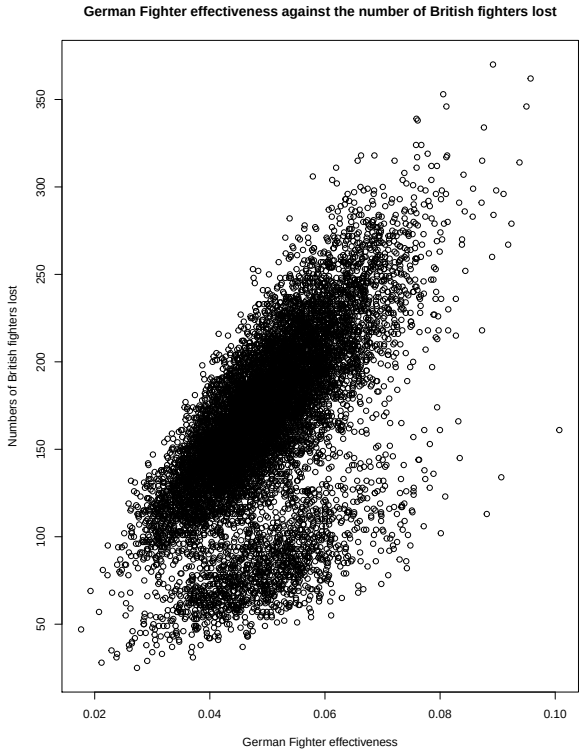


Figure 44: German fighter effectiveness against the number of British fighters lost in the 6-SD simulation

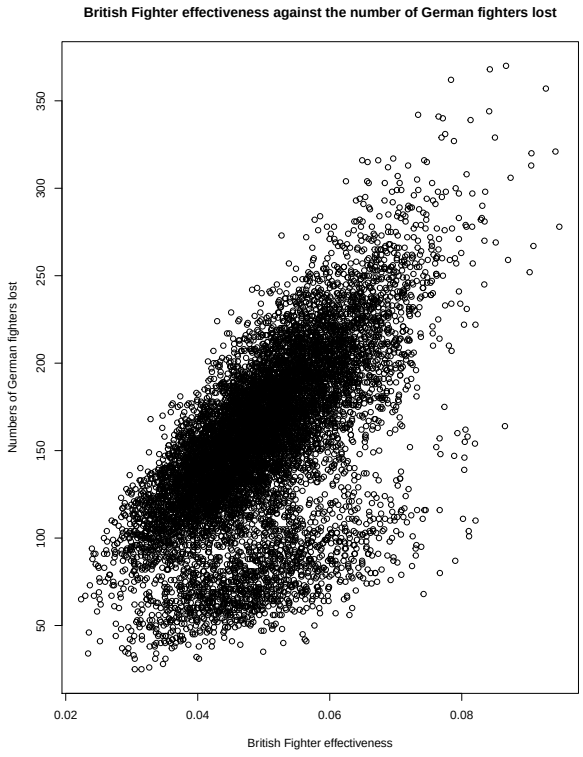


Figure 45: British fighter effectiveness against the number of German fighters lost in the 6-SD simulation

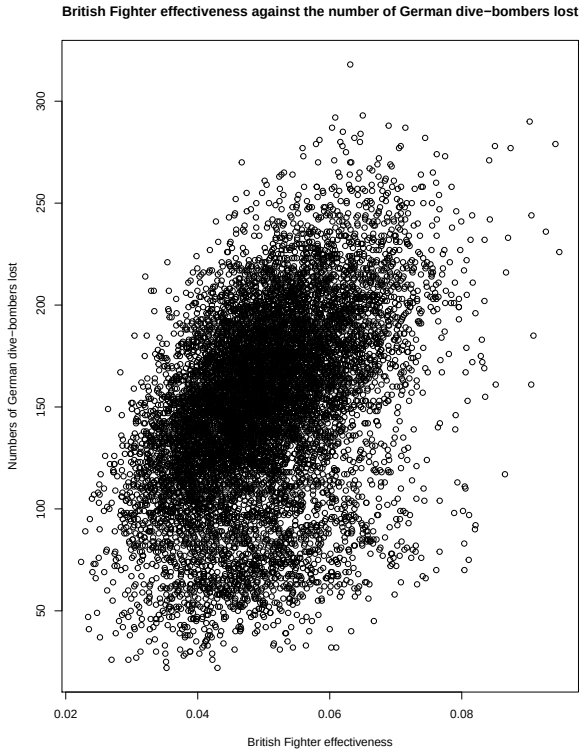


Figure 46: British fighter effectiveness against the number of German dive-bombers lost in the 6-SD simulation

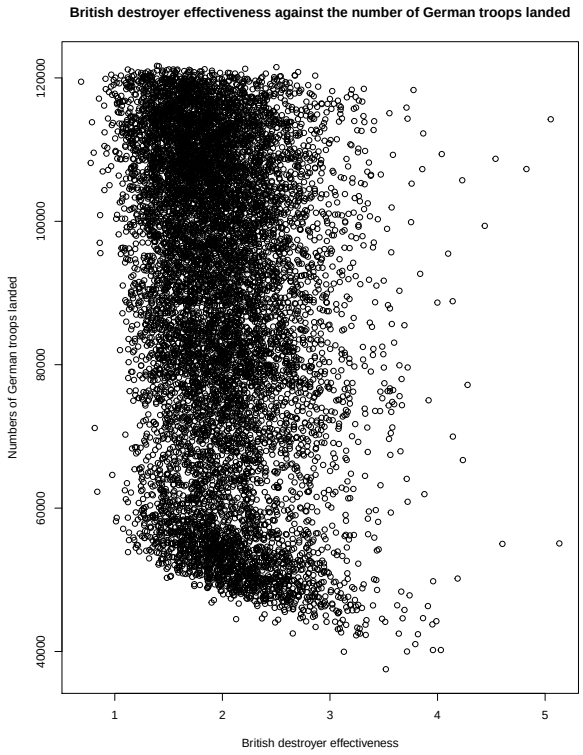


Figure 47: British destroyer effectiveness against the number of German troops landed in the 6-SD simulation

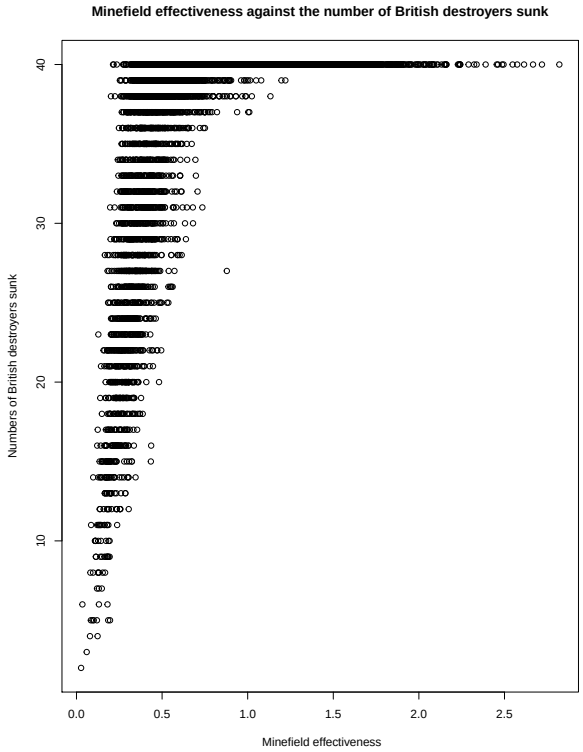


Figure 48: Minefield effectiveness against the number of British destroyers sunk in the 6-SD simulation

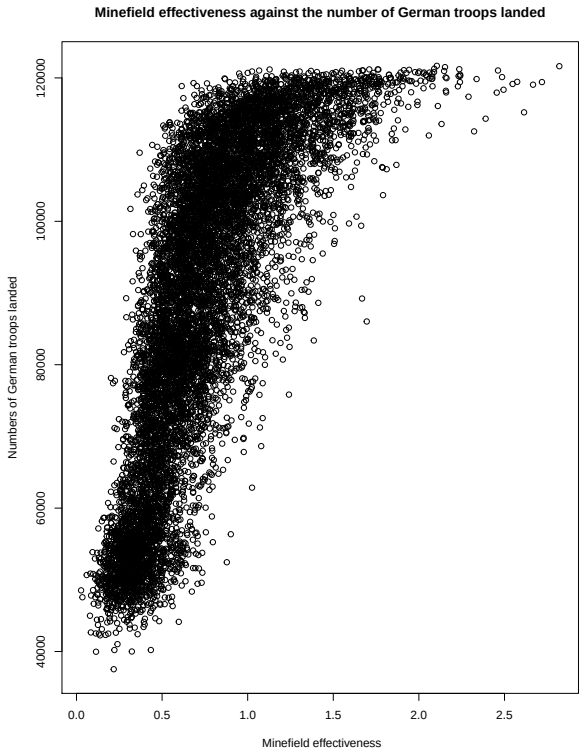


Figure 49: Minefield effectiveness against the number of German troops landed in the 6-SD simulation

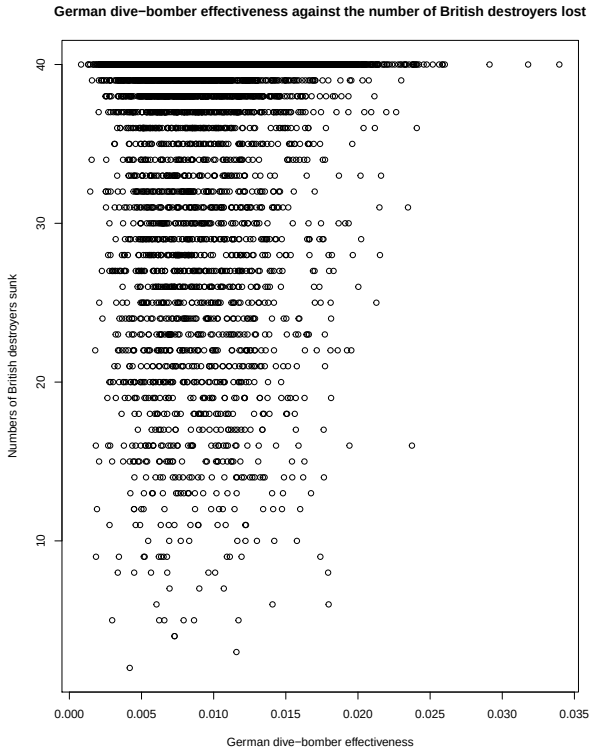


Figure 50: German dive-bomber effectiveness against the number of British destroyers sunk in the 6-SD simulation

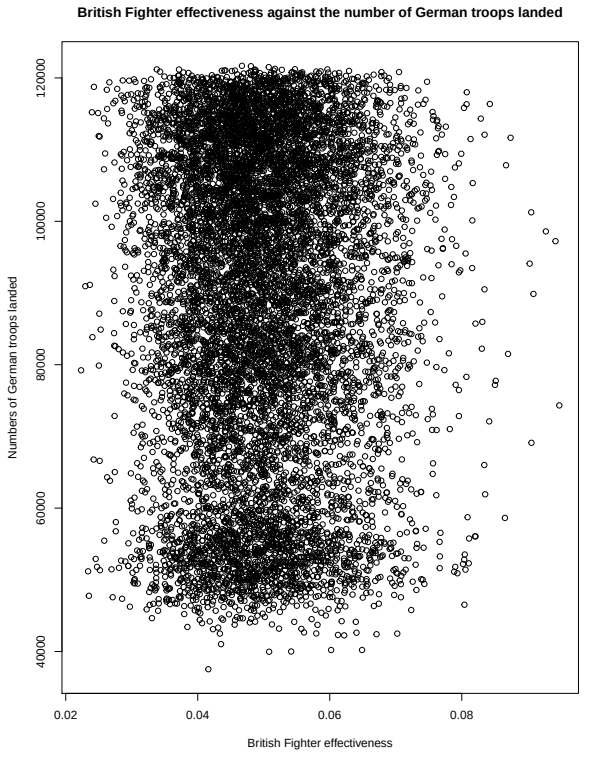


Figure 51: British fighter effectiveness against the number of German troops landed in the 6-SD simulation

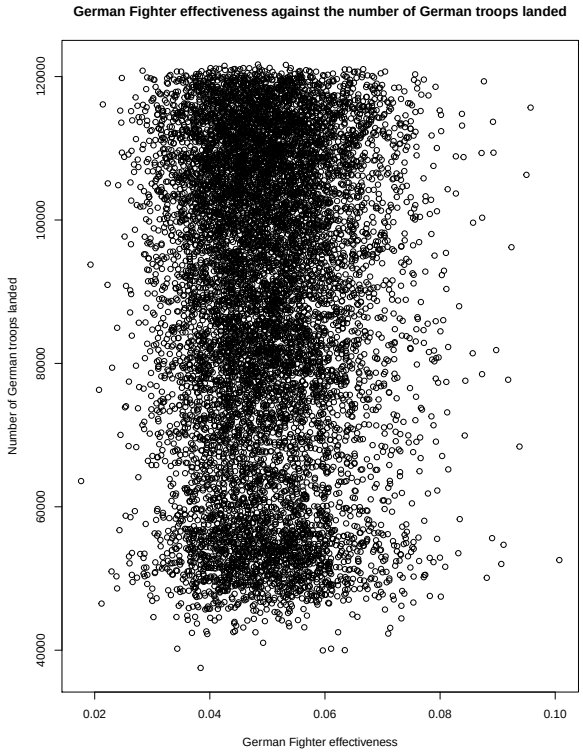


Figure 52: German fighter effectiveness against the number of German troops landed in the 6-SD simulation

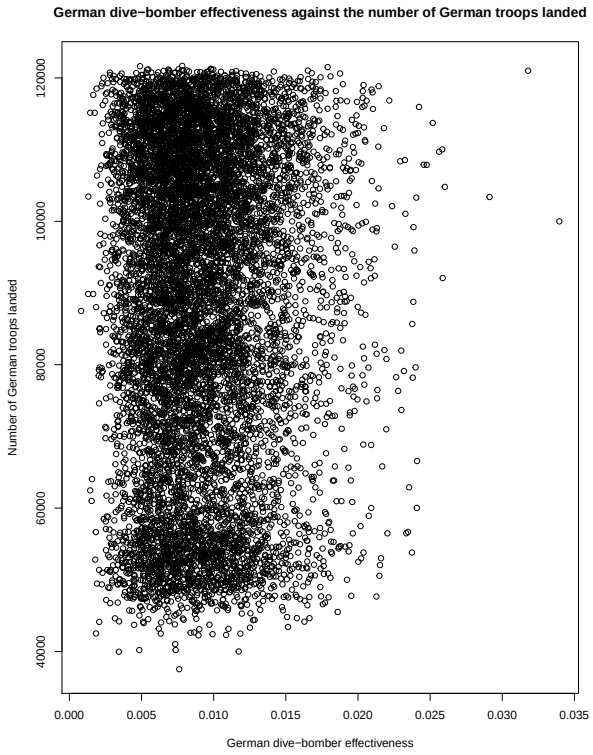


Figure 53: German dive-bomber effectiveness against the number of German troops landed in the 6-SD simulation

4.5 Analysis of Results

In the 2-SD simulation, by looking at Figures 22 and 23, we can see that the losses of the British and German fighter squadrons are all centred around 100. Likewise, Figure 24 also shows the losses of the Ju-87s in the 2-SD simulation to be centred around 100. This symmetry is to be expected, as our air combat rules are symmetric by nature. This symmetry is repeated in the 6-SD simulation, as Figures 38, 39 and 40 shows that the losses of the air units are centred around 150-170. One possible explanation for the higher figure in the 6-SD simulation is that as the the code automatically stops when all the German ships have been sunk, such a scenario would be more likely to occur during the 2-SD simulation, hence, the duration of the air combat would be shorter, resulting in lower casualties.

Figures 28, 29, and 30 display the relationship between fighter effectiveness and the number of enemy aircraft shot down for the 2-SD simulation. These all show a positive correlation, just like the corresponding figures for the Kanalkampf campaign, which is what we expected. There are slight variations in the shape, which we can assume is because in the Sealion simulation, fighter aircraft have a limited amount of ammunition, whereas in the Kanalkampf simulation, they have theoretically unlimited ammunition. The corresponding figures for the 6-SD simulation also exhibit a similar relationship when compared to the 2-SD simulation.

Figure 31 shows a negative correlation between the effectiveness of British destroyers and the number of German troops landed. This is clearly to be expected, as a higher effectiveness results in more German ships being sunk, hence fewer troops being landed. However, the corresponding figure for the 6-SD simulation shows no such correlation. One reason for this could be that, in the 6-SD simulation, the destroyers are being sunk within their first few sorties, meaning that having a higher effectiveness does not have as great an impact on the number of German troops landed. This explanation is supported by Figure 26, which shows that in the 2-SD simulation, there is a wide variance in the number of British destroyers sunk, whereas Figure 41 shows that in the 6-SD simulation, there is a very strong probability of the entire destroyer fleet being sunk.

Figure 32 shows that in the 2-SD simulation, there is a positive correlation between minefield effectiveness and the the number of British destroyers sunk. Likewise, Figure 48 shows a similar relationship for the 6-SD simulation. In both Figures the correlation begins to plateau when the minefield effectiveness reaches a value of 1. At this value, the number of British destroyers sunk is nearly always 40; that is, all the destroyers are sunk. When the minefield effectiveness is below this value, you can get a large variation in the number of British destroyers sunk. For example, in Figure 32 when the minefield effectiveness is 0.25, the number of British destroyers sunk varies between 15 and 40. One possible explanation for this large variation could be because the simulation automatically stops

when all the German ships have been sunk. So depending on the destroyer effectiveness, it may take them either a small or large number of sorties to sink the entire invasion fleet. If destroyer effectiveness is high, then they may only have to make a few sorties to sink the whole invasion fleet. Thus, they would only need to pass through the minefields a few times, resulting in the losses to the destroyer being near the lower end of the distribution. Whereas if destroyer effectiveness was low, then they would need to make a higher number of sorties, meaning they would have to pass through the minefields more often, resulting in destroyer losses being nearer the higher end of the distribution. One possible reason for the plateau when the minefield effectiveness reaches 1 could be because that is the value at which most of the British destroyers are sunk during their first sortie. So beyond this value, the destroyers would likely all have been sunk by the first few sorties, giving us the plateau. This is supported by Figure 49 which shows that when the minefield effectiveness reaches a value of 1 and beyond, the number German troops landed plateaus at 100,000-120,00; so nearly all the troops get ashore. We can explain this feature by using our suggestion above that this is the value at which nearly all the destroyers are sunk during their first sortie. So any any losses incurred are due to the initial attack by the destroyers. This explains why the losses to the German troops are minimal, and stay approximately constant beyond this value.

In both the 2-SD and 6-SD wargame, there is a positive correlation between the effectiveness of minefields and the number of German troops landed, as displayed by Figure 33 and Figure 49 respectively. This is to be expected, as a higher minefield effectiveness results in more British destroyers being sunk, reducing the ability of the Royal Navy to sink the invasion fleet. In the 2-SD simulation, we can see that that the correlation shows a steep gradient; when the minefield effectiveness is around 0.25, the number of German troops landed is between 40,000-60,000, but when the minefield effectiveness is increased to 0.75, the number of German troops landed is approximately 80,000. Figure 49 also shows a steep gradient for the 6-SD simulation. However, in the 6-SD simulation, the correlation starts to plateau when the minefield effectiveness reaches a value of approximately 1. Beyond this value, the number of German troops landed is in the region of 100,000-120,000; meaning approximately all the men get ashore. As explained in the previous paragraph, this may be because this is the approximate value at which nearly all the destroyers are sunk during their first sortie, hence the minimal losses to the German troops. This plateau does not show in Figure 33 for the 2-SD simulation, as minefield effectiveness rarely goes above 1 in that simulation. This is because the minefield effectiveness is on average lower in the 2-SD simulation when compared to the 6-SD simulation, as a higher proportion of the minefields have been laid in the latter. During the Soviet evacuation of Tallinn, minefield effectiveness had a value of approximately 0.15, which from Figure 33 and 49 we can see corresponds to around 40,000-60,000 troops being landed. If we were to assume that the Royal Navy is very successful at creating and navigating swept channels in these minefields, to the extent that minefield effectiveness is very small, certainly no more than at Tallinn, then from our

figures we can infer that at most around 40,000 men would land ashore.

For both simulations, there was no correlation between the effectiveness of Ju-87s and the number of British destroyers sunk, as shown in Figure 34 and Figure 50. This can be partly explained due to the fact that Ju-87s were not allowed to attack British destroyers if the square also contained German ships, as the risk of hitting a friendly ship was deemed too high. Hence there was very limited scope for the dive-bombers to attack British destroyers, with it only being possible when the destroyers were resting in their ports, or just about to enter the invasion area. Also, during the whole of the Kanalkampf campaign, approximately 40 ships were sunk over 30 days, and with our Sealion simulation occurring over 3 days we cannot expect the Ju-87s to contribute to more than a few destroyers being sunk. This is also the reason why in both simulations, there is no correlation between dive-bomber effectiveness and the number of troops landed, as shown in Figure 37 and Figure 53. The mines were clearly the largest obstacle for the Royal Navy in our simulation.

There was no correlation between British fighter effectiveness and the number of German troops landed, in both versions of the simulation, as shown in Figures 35 and 51. This is to be expected, as in the Kanalkampf campaign, we found that there was no correlation between British fighter effectiveness and the number of British ships that were sunk by Ju-87s. Even if such a correlation did exist in the Kanalkampf campaign, this would have a negligible effect on the number of German troops landed, as Ju-87s do not appear to play a significant role in our Sealion simulation as discussed in the previous paragraph. A similar reason can also explain why there was no correlation found between German fighter effectiveness and the number of German troops landed, in both versions of the simulations, as shown in Figures 36 and 52.

In the 2-SD simulation, a mean of approximately 50,000 troops were successfully landed, whereas in the 6-SD simulation, a mean of around 90,000 troops were landed. The results from the two simulations seem to suggest that the air war has no noticeable impact on the number of German troops landed; there is no correlation between fighter effectiveness and the number of German troops landed, nor is there correlation between dive-bomber effectiveness and the number of German troops landed. Hence we do not believe that we can attribute the difference between the outcomes of the two simulations to the reduced number of RAF fighter squadrons in the 6-SD simulation. There was a negative correlation between destroyer effectiveness and the number of German troops landed in the 2-SD simulation, however no such relationship existed in the 6-SD simulation. This seems to suggest that in the 6-SD simulation, minefield effectiveness took precedence over destroyer effectiveness. Hence, it appears that minefield effectiveness is the most significant factor in the outcome of Operation Sealion, as in both simulations they show positive correlation against the number of German troops landed. Thus, it should be no surprise that more troops were landed in the 6-SD simulation, as the crucial difference was that they had a higher minefield effectiveness on average, due to a higher proportion of the

minefields being laid.

While we aimed to make our simulation follow the Operation Sealion plan as closely as possible, there were some factors that we decided to not implement into our model. We did not include British bombers into our simulation. The RAF would most likely use their bombers to attack German ships at the invasion beaches. This would cause losses and slow the unloading process, but we did not include them, as we believe their effect would be minimal; at Dunkirk only a few thousand out of 400,000 allied troops died during the evacuation. We also decided to not include smaller British ships such as sloops and armed trawlers, as destroyers were seen to be the main vessel for sinking barges and transports. We estimated that armed trawlers would cause losses of around 5,000-10,000 troops, so we decided not to implement them into our model for the sake of simplicity. We could add some background attrition on the scale of a few thousands, but all things considered, we believe our model gives a good approximation of the number of German troops that would have landed, in the context of our 2-SD and 6-SD counterfactual.

5 Conclusion

In this thesis, we wanted to answer the question of whether the Germans could have landed an army ashore during Operation Sealion. We aimed to investigate the factors that would have an important effect on the outcome of an invasion.

Any attempts at answering this question require a counterfactual where the Germans have a level of air superiority required for Operation Sealion to commence. We developed two counterfactuals, a 2-SD and 6-SD scenario. In the 2-SD scenario, the Luftwaffe have air superiority over the Channel, but crucially it is still contested by the RAF. In the 6-SD scenario, the Luftwaffe have complete air supremacy over the Channel prior to invasion and the RAF cannot interfere. The 2-SD scenario represents a plausible counterfactual where in the Battle of Britain, the Luftwaffe put an emphasis on attacking RAF airfields. Whereas the 6-SD scenario necessitates that the Battle of Britain starts earlier, as well as requiring the Luftwaffe to choose a more optimal approach, such as not making the switch to bombing London. This requires a different strategy from Hitler and Goring from the outset, hence, is less plausible than the 2-SD scenario.

Using these two counterfactuals, we were then able to wargame the final invasion preparation plans, which included laying minefields. In the 2-SD scenario, we found that air superiority over the Channel was not enough to complete their preparations and only approximately 20% of the planned minefields were laid. In the 6-SD simulation, air supremacy over the Channel allowed them to lay around 75% of the planned minefields. We then created two versions of the Sealion simulation, corresponding to the 2-SD and 6-SD wargames respectively.

In both simulations, we modelled the landings of the first and second echelons of the first wave, equating to approximately 120,000 men.

In the 2-SD simulation, we found that the Germans were able to get, on average, 50,000 men ashore, whereas in the 6-SD simulation, the Germans were able to get, on average, 90,000 men ashore. Both of our models show positive correlation between minefield effectiveness and the number of German troops landed. We also found that there was no correlation between effectiveness of the air units and the number of German troops landed in either of our models. However, in the 2-SD simulation, there is negative correlation between destroyer effectiveness and the number of German troops landed, but no such correlation exists in the 6-SD simulation.

The results from our two simulations seem to suggest that the air war would have had very little impact on the outcome of the invasion. This may be because in both scenarios, once the RAF was aware that an invasion had started, they were willing to fight over the Channel, despite the Luftwaffe having control over it. Crucially, this meant that in both cases, the air over the Channel was a contested space where the RAF could disrupt the Luftwaffe. Another reason was that Ju-87s had limited scope to sink British destroyers, as they were unable to attack them when they were amongst German ships, for fear of sinking their own ships.

We found in the 2-SD simulation a negative correlation between destroyer effectiveness and the number of German troops landed, however, no such correlation existed in the 6-SD simulation. We believe this may be because in the 6-SD simulation, nearly all the destroyers are being sunk in their first few sorties, due to the German minefields, hence destroyer effectiveness has a smaller impact. From this, we can infer that destroyer effectiveness would have had a key role on the outcome of Operation Sealion, as long as they were not all being sunk in their first few sorties. In particular, this seems to suggest that in Operation Sealion, minefield effectiveness would take precedence over destroyer effectiveness.

From our two simulations, we can see that minefield effectiveness would have been the critical factor on the outcome of Operation Sealion. As explained above, the air war has very little effect on the number of German troops landed, hence the difference in the number of men landed between the two simulations can be solely attributed to a higher proportion of minefields being laid in the 6-SD simulation, resulting in a higher average minefield effectiveness. These results support the German view that the minefields were to be pivotal in protecting the invasion fleet from the Royal Navy.

In the 2-SD counterfactual, which we regarded as being a plausible scenario, the Germans were able to land around 50,000 men of the first and second echelon, out of 120,000. It seems very difficult for the Germans to get a sufficient number of men ashore over the whole operation, as approximately 300 transports and barges in our simulation were sunk, and these were planned to transport the

remaining elements of the first wave, as well as the following second and third wave. On average, 18 out of 40 British destroyers were sunk in this simulation. Thus, owing to the large intervals between when the first, second and third waves would land, it is almost certain that the Royal Navy would have ample time to bring destroyers from up north, down to the Channel to replace sunken destroyers. Hence, we believe that in the 2-SD counterfactual, the Germans would not have been able to get a sufficient number of men ashore.

In the 6-SD counterfactual, which we regarded as being unlikely due to it necessitating that Hitler and Goring have a different strategy from the outset, the German were able to land around 90,000 men out of 120,000 from the first and second echelons of the first wave. On average, approximately 170 German ships were sunk, nearly half the number of German ships sunk in the 2-SD simulation. In particular, an average of 38 out of 40 British destroyers were sunk during the simulation. This is more than twice the number of losses incurred during the 2-SD simulation, and the Royal Navy would have struggled to replace all of these losses, even with destroyers being sent down to the Channel from up north. Hence, in the 6-SD counterfactual, it seems plausible that the Germans could have gotten a sufficient number of men ashore.

As noted above, we can see from our simulation that the most important factor in Operation Sealion would have been minefield effectiveness. For the Germans to have successfully gotten a sufficient force ashore, they would need to have completed a high proportion of the planned minefields; certainly higher than the 20% achieved in the 2-SD counterfactual. This is followed by destroyer effectiveness which would have also been a crucial factor in the number of men landed ashore, provided the destroyers were not all being sunk by minefields during their first few sorties. It also appears that the air war has no significant impact on the number of German troops landed. However, the preceding air war in the Battle of Britain does have a large role to play, as it determines how much of the planned minefields the Germans are able to lay. We can safely assume that if the invasion had gone ahead as planned, with no counterfactual scenario, then the Germans would have been unable to lay the sufficient minefields required; just as in the 2-SD simulation. Thus, the invasion would likely have ended in failure, most likely with higher losses, as you would expect an even lower proportion of the minefields to be laid when compared to the 2-SD counterfactual. Our simulations suggest that for the Germans to have laid the minefields needed to get an sufficient number of men ashore, a counterfactual scenario is required where the Luftwaffe achieve complete air supremacy over the Channel during the Battle of Britain, something that is not met in the 2-SD counterfactual, but is met in the 6-SD counterfactual.

Hence, we can conclude from our thesis that if the outcome of the Battle of Britain was similar to that of reality, then the Germans could not have landed enough troops for a successful invasion. Even if the Germans were to win the Battle of Britain by a small margin, as was the case in the 2-SD simulation, they still would not have been able to get a large enough army ashore for

a successful invasion. However, had the Luftwaffe won the Battle of Britain by a large margin, as was the case in the 6-SD simulation, and had an utter commitment to the minefields, then they could have got a large number of men ashore, potentially leading to a successful invasion.

Appendices

A Wargame briefing and map

(Below is the briefing developed by Dr. Ian Horwood for the purpose of our wargame)

British Briefing

The continued emphasis of German air attacks on Fighter Command airfields has produced significant losses of fighter aircraft. These can still be replaced for the most part, but German operations have also caused very serious casualties among the command's pilots, who cannot be replaced at a scale commensurate with the losses.

It is considered that further efforts to contest German air attacks in the 11 Group Zone and the Dover Straight are likely to sustain casualties that will prejudice our ability to combat a German invasion if, and when, it comes. It has, therefore, been decided to withdraw 11 Group's Squadrons into 12 Group, and cease to contest German operations in the 11 Group area and the Dover Straight until such time as a German landing actually begins. Fighter Command will, however, continue to support the navy at Portsmouth.

With regard to the imminence of a German invasion reconnaissance has indicated a build-up of potential German amphibious assets for some time:

Large numbers of merchant ships and large motor launches having been building-up in Kiel since the end of August. Since early this month we have also detected large numbers of barges concentrating in Netherlands, Belgian and French ports.

None of the above has constituted proof, but it has been considered that these might be movements preliminary to invasion.

On 5 September: German army leave was cancelled, though German Army leave is stopped from time to time without special 'incident.'

On 12 September: MI14 briefed the PM that invasion is 'potentially imminent'.

RAF and RN forces are, therefore, to place themselves in readiness for an imminent invasion. They should make every effort to degrade enemy forces that might participate in such an invasion while preserving sufficient forces to combat the invasion if, and when, it occurs. The RN should avoid losses of major units with the home fleet consistent with the above objectives.

Available German heavy naval units are believed to be BCs Scharnhorst & Gneisenau + up to 6 light or heavy Cs.

German Briefing (14 September 1940)

On 16 July 1940, the Fuhrer issued Directive No. 16 On preparations for a landing operation against England:

Since England, in spite of her hopeless military situation, shows no signs of being ready to come to an understanding, I have decided to prepare a landing operation against England and, if necessary, to carry it out.

The aim of this operation will be to eliminate the English homeland as a base for the prosecution of the war against Germany and, if necessary, to occupy it completely.

I therefore order as follows:

The landing will be in the form of a surprise crossing on a wide front from about Ramsgate to the area west of the Isle of Wight. Units of the Air Force will act as artillery, and units of the Navy as engineers.

Preparations for the entire operation must be completed by the middle of August.

These preparations must also create such conditions as will make a landing in England possible, viz:

The English Air Force must be so reduced morally and physically that it is unable to deliver any significant attack against the German crossing.

Mine-free channels must be cleared.

The Straits of Dover must be closely sealed off with minefields on both flanks; also, the Western entrance to the Channel approximately on the line Alderney-Portland.

Strong forces of coastal artillery must command and protect the forward coastal area.

It is desirable that the English Navy be tied down shortly before the crossing, both in the North Sea and in the Mediterranean (by the Italians).

Planning for the operation is complete:

On S-Day elements of the 16th and 9th Armies will begin landing between Brighton and Folkestone.

West of the crossing corridor, the transport fleet will be guarded by 7DD assembling in Le Havre and 12 TBs assembling in Le Havre and Cherbourg. S and R Boats from bases in Belgium and the Netherlands will cover the E flank. Submarines will also cover the two flanks along with mine barrages.

The Naval Staff announce that the positioning of naval and transport units for Sea Lion is now substantially complete.

The Kriegsmarine and Luftwaffe are convinced that a serious blow has been dealt to RAF Fighter Command and that air supremacy has been achieved over south-east England and in the Channel (that is the 11 Group Zone and the Dover

Straight). Our raids are now essentially unopposed in the area and it seems clear that a heavily damaged Fighter Command's 11 Group has withdrawn north of the Thames. The preconditions, therefore, exist for Sea Lion to go ahead.

The final decision has now been taken by the Fuhrer to initiate Sea Lion with S-Day as 24 September. Therefore, embarkation day is 23 September.

You therefore have 9 days to make your final preparations for S-Day.

This will include the laying of minefields to protect the flanks of the Transport corridor. You will lay these minefields from S-Day – 9 (17 Sept.) to S-Day - 2. Seven DDs will escort 5 minelayers in laying minefields Anton and Bruno on either side of Transport Fleet E's route. TBs and S-Boats will escort 5 minelayers in laying minefield Caesar near Dover.

The Sea Lion plan calls for heavy naval units: the PS Admiral Scheer, CA Admiral Hipper and the light Cruisers Koln, Emden and Nurnberg to take part in demonstrations towards the north coast of England and Scotland, towards Iceland and out into the Atlantic as diversions.

Luftflottes 2 & 3 operations in the 11 Group Zone are essentially complete as far as the achievement of air supremacy is concerned. In their continuing operations Luftflottes 2 and 3 should preserve sufficient strength to cover the embarkation harbours and the channel with fighters and the invasion beaches with fighters and bombers.

(Below is the map that was developed by Dr. Ian Horwood for our wargame, as well as the order of battle)

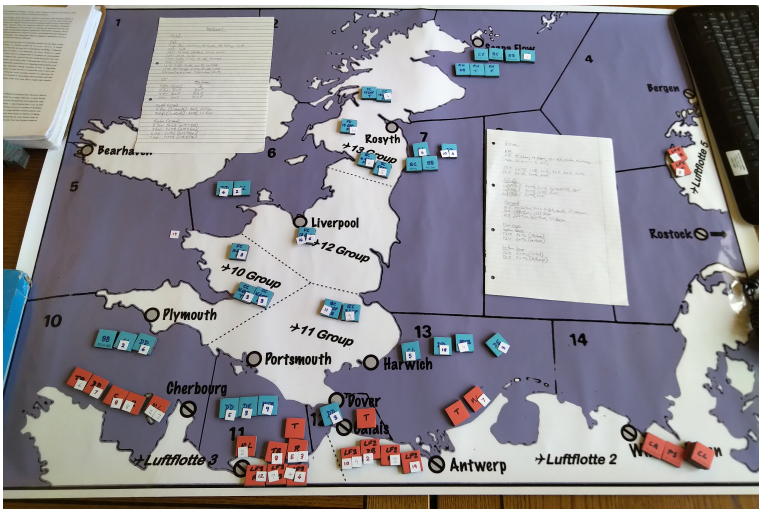


Figure 54: Wargame map

Order of Battle (British):

Royal Navy:

Scapa Flow- HMS Furious, HMS Repulse, HMS Rodney, 2xCA

Sea Zone 3- 7xSS

Sea Zone 7- HMS Hood, HMS Nelson , 4xCL , 14xDD

Sea Zone 6 - 4xDD, 2xCL

Sea Zone 13 - 3xDE, 5xCL,18xDD,9xMTB

Sea Zone 12- 3xDD

Sea Zone 11- 5xDD, 3xDE, 2xSS, 9xMTB

Sea Zone 10- HMS Revenge, 2xCL, 6xDD, 1xSS

RAF:

Fighter Command:

10 Group - 8xFighter

12 Group - 34xFighter

13 Group - 10xFighter

Coastal Command:

16 Group (Southern England) - 3xLB, 3xTorpedo

18 Group (Scotland) - 4xLB, 1xTorpedo

Bomber Command:

2 Group (in 11 Group in our map)- 11xLB

3 Group (11 group in our map) - 9xMB

4 Group (13 group in our map) - 6xMB

5 Group (13 group in our map) - 7xMB

German order of battle:

German Navy:

Kiel- Admiral Scheer, Admiral HIpper, Köln, Emden, Nürnberg, 1xSS

Sea Zone 10- 4xTB, 7xDD, 11xSS, 8xR, 8xS, 3xML

Sea Zone 11- 8xTB,3xML,8xR

Luftwaffe:

Luftflotte 2- 19xMB,2xDB,19xF

Luftflotte 3- 8xMB,7xDB,12xFighter

Luftflotte 5- 5xMB, 2xFighter

Transports

Sea Zone 11- 100 Coasters, 50 Steamers, 200 motor fishing Vessels

Sea Zone 12- 338 Tows, 1545 barges

Sea Zone 13- 25 tows, 114 trawlers, 713 barges

Minelayers:

Western Group:

Sea Zone 10 - 5xML(cherbourg)

Sea Zone 11- 2xML (le havre)

Eastern Group

Sea Zone 13- 4xML(ostend)

Sea Zone 13- 3xML(antwerp)

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