

**Title:** How were German air force resources distributed between different fronts in the years 1941 to 1943 and what are the implications of this case study for understanding the political economy of the period?

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## Abstract

This study analyses the resource distribution of the German air force, a key component in the initial German victories during the Second World War. The purpose of the analysis is to determine whether German resources were focused primarily in the East or in the West during the period from 1941 to 1943, from the German invasion of the USSR to the time that Germany lost the ability to conduct large-scale offensives on any front. Resource distribution is analysed along five dimensions. The first is the allocation of aircraft, the second that of aircraft armament and aviation technology. This is followed by discussion of the allocation of anti-aircraft guns, the losses of aircraft and finally the expenditure of ammunition. The final section draws out the implications for the field of political economy. A substantially new understanding of German resource allocation and of Germany's position relative to the Western Allies and the USSR is obtained, through extensive use of archival sources and secondary literature.

## Dedication and Acknowledgments

This work is dedicated to my mother, whose awful death on February 15 of this year could and should have been prevented. I will always remember her wonderful intelligence and kindness, which was the chief source of happiness in my life.

I would like to acknowledge the help of several people, which was instrumental in making possible the great amount of original research required to write a work in this poorly understood field. The first is my father, whose support has made it possible for me to bear the burdens of this terrible year. Of those who assisted directly with my research, Larry de Zeng stands out for his keen interest in my work and his kind and helpful correspondence. It has been a privilege to be able to assist Larry and Doug Stankey with their databases of Luftwaffe airfields and officers, respectively. Matti Salonen most generously shared his uniquely comprehensive database of German aircraft losses, which allowed me to construct a time series of losses across the three fronts of the European air war, filling one of the many great gaps in the surviving original records. Jan Warßischek, a member of staff of the Bundesarchiv-Militärarchiv, gave me access to the originals of the documents in the “Personelle und materielle Einsatzbereitschaft” (Personnel and aircraft strength) series, a rare privilege which allowed me to gain a deep insight into the allocation of German aircraft. Ulf Balke took time away from his own continuing research to explain the complex colour coding in this series to me. Ted Hooton similarly answered my questions while engaged in his own writing and was kind enough to share his pre-publication manuscript with me. Andrew Arthy was a source of ideas and a keen participant in some heated discussions on the subject of this work. Finally, Andreas Zapf provided important information about Luftwaffe ammunition consumption at the end of 1942.

Among academics, I would like to thank my supervisor, for giving his time and thought to an unusual subject and agreeing to do so while on sabbatical. Professor Philip Sabin provided the space for many of the ideas contained in this work to develop. He also gave very helpful advice. Professors Richard Muller and Williamson Murray shared their thoughts regarding the various pressures to which the German air force was subject during the war.

The fault for any errors or omissions in this work is entirely my own.

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## Introduction

The German air force, or *Luftwaffe* in German, was the lynchpin of the German war effort in the early years of the Second World War. An eminent historian has commented that the “story of the first two years of the war in the air is largely that of the Luftwaffe’s offensives” and that the early victories of the German army were critically enabled by the Luftwaffe (van Creveld 2011: 93, 351). Yet, by the end of 1943 the German offensives had collapsed and Germany was forced onto the defensive on all fronts (Overy 1995, 98-9). This work analyses the allocation of Luftwaffe resources to determine the causes of this change in German fortunes, as far as the air war is concerned. The distribution of German resources between fronts will be considered in order to determine whether the war in the East or the West played the major role in the attrition of German strength. Hence, the relative contributions of the Allies and the USSR to the outcome of the fighting in 1941-43 will be assessed. Throughout, the term ‘Allies’ will be taken to mean the main Western powers collectively, that is the British Empire and the United States. The term ‘West’ will refer to the Western front and the Mediterranean together, since the interaction of these two fronts in the greater Allied war effort is one of the key themes of this study.

Until O’Brien’s (2015) recent revisionist work, which tends to emphasise the allocation of German resources to the West, studies of the subject have tended to cautiously suggest that Western allied operations only began to exert a major pressure on German resources in 1943 (Overy 2013). This has been part of a general tendency to downplay the effectiveness of Allied air operations, perceived as centred on a rather wasteful strategic bombing offensive, as compared to more effective tactical operations in direct support of ground troops, as had been practiced by the Luftwaffe (van Creveld 2011, 98). An important study of the German war economy (Tooze 2006) has stood approximately half-way between the extreme positions, emphasising the effectiveness of RAF strategic bombing of the Ruhr from mid-1943 (ibid, 598), but being generally reluctant to ascribe a decisive role in breaking German military power to Allied air power.

This study considers the above views in the context of a large body of primary source material from the German Federal archives. This presents a significant difficulty, for these records are notoriously incomplete (O’Brien 2015, 107), having been largely destroyed during the war (van Creveld 2011, 106), at least as far as is currently known. To compound the problem, one of the main historians of the German air force has written that the form of the German air force documents suggests confusion and the absence of a systematic approach to their production, especially when compared to Anglo-American practice (Boog 1992, 708). Therefore, the present study pieces together fragments of original evidence, supported by broad-based secondary sources like the German official history of the war (Boog et al. 2006 and other volumes). The picture that emerges is more comprehensive and coherent than most of the secondary sources hitherto published, which were limited in their access to original sources and in some cases almost entirely avoided German-language sources (O’Brien 2015).

The core thesis of this work is that the Allied air forces, acting on the Western front and the Mediterranean, played by far the more important role in driving German resource allocation and in the ultimate destruction of the fighting power of the Luftwaffe. Given that the subject is prone to controversy and dispute, the argument is carefully traced through five stages. First, the allocation of German aircraft between competing military priorities is analysed. Following this, the issue of the allocation of technologies, including the armament of aircraft, is examined. Then it is the turn of the extensive German air defence force to be scrutinised.

The data on German aircrew and aircraft losses is especially comprehensive and has, in part, never been published before. The final part of the analysis, that of ammunition expenditure, gives important context to the different priorities of the Luftwaffe in the West and in the East, and its attempts to allocate specific resources between two very different kinds of campaigns. The implications for political economy, specifically for an understanding of the defence economics of the period, are presented following the analysis of resource distribution. Throughout, the focus remains the great difference between the nature of the German war effort against the Allies and that against the USSR.

## Section 1. Allocation of German aircraft

The first measure of Luftwaffe resource distribution considered in this work is the allocation of aircraft between fronts. This section begins by reviewing the number of aircraft allocated to the Eastern front and comparing this to the total number of aircraft on all fronts. Aircraft held in reserve are also considered, to provide a full picture of German resources. The analysis proceeds to consider the distribution of combat aircraft, a narrower category consisting only of those aircraft capable of directly attacking the enemy. Following this, the allocation of various classes of aircraft, such as bombers or fighters, will be considered, in order to analyse why the allocation of certain aircraft classes differed significantly from general patterns of German resource distribution. For fighters, an especially important class of aircraft, information is presented showing their distribution until the end of the war. This information demonstrates how trends established in 1941–1943 remained substantially unchanged until the final German defeat. The final part of the analysis of German aircraft distribution discusses the allocation of new aircraft types, those that entered service after the German invasion of the USSR. Throughout, the aim is to determine, with as much accuracy as the sources allow, whether German resources were primarily concentrated in the East or in the West.

The data on Luftwaffe aircraft strength presented here is taken from original German strength returns and is thus the most complete data available. Compared with sources used by other authors to discuss German strength (O'Brien 2015: 93, 193-4), these documents are preferable because they are not derivative summaries of originals, but rather original wartime reports and so include full figures for all operational units, both at the fronts and in reserve<sup>1</sup>. However, the quantity of the information contained within these documents makes their analysis exceptionally time-consuming. The reports, submitted at 10-day intervals throughout the war, show the strength of all units of the Luftwaffe. Each report is several dozen pages long and graphically represents the aircraft strength of over 500 units, therefore requiring dozens of hours to calculate the numbers presented here and in Appendix A. For this reason, reports for six dates were chosen from the greater body of data. The six dates were selected to show the evolution of Luftwaffe strength in 1941–43, as well as the situation at specific points during the three winter campaigns on the Eastern Front in this period. All these campaigns ended in German defeats, with the weakness of German air power a significant contributing factor (Overy 1995: 19, 81-97).

In discussing Luftwaffe aircraft strength, it is necessary to note that the overall number of aircraft increased relatively slowly over time. The reasons for this slow increase in German

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<sup>1</sup> Air 40/1207, the UK National Archives document used by O'Brien, is a short post-war summary of German strength derived from German originals, a copy of which was provided to O'Brien by the author of the present work

strength are manifold and they form part of a debate about the effectiveness of German resource mobilisation during the war (Overy 1992, 26-7; Tooze 2006, 670-1). Since the present work analyses the *distribution* of available German air power resources between fronts, rather than the factors determining total resource availability, this question is not discussed in greater detail here. The significance of the slow growth in overall German strength for the purpose of this study is that it emphasises that the overall German war effort was conducted in conditions of scarcity of essential equipment, including aircraft. This makes it even more important to understand how these scarce resources were allocated.

The most significant information for the purpose of understanding the role of the Eastern Front in German resource allocation decisions is German frontline strength in the East, highlighted in bold in Table 1 below. This is calculated as a percentage of all the aircraft deployed on the various fighting fronts, discounting aircraft in reserve. It is very striking that the strength on the Eastern front remained effectively unchanged during the period covered in Figure 1, with the exception of the sharp, though temporary, decline in late December 1941. That decline was caused by an increase in the number of aircraft in reserve at the expense of frontline strength as well as a reallocation of some frontline strength from the Eastern front to other theatres. This episode is particularly noteworthy, because the German army suffered a catastrophic defeat in the Battle of Moscow at this time (Stahel 2015, 245). Therefore, it is very important to observe that the proportion of the Luftwaffe's aircraft allocated to the East at this critical time fell, rather than increased. This was one of the causes of the defeat of the German forces, which had been critically reliant on effective air support during their previous successful offensives in the East (Stahel 2013, 22).

Table 1. Allocation of Luftwaffe operational aircraft, November 1941 - February 1944

Date	Total aircraft	In reserve	At the fronts	Eastern front	% East of frontline strength	% East of total strength
8 November 1941	4,747	770	3,975	2,487	<b>63%</b>	52%
27 December 1941	4,712	1,041	3,671	1,936	<b>53%</b>	41%
10 December 1942	5,712	784	4,928	2,478	<b>50%</b>	43%
10 February 1943	5,851	1,152	4,699	2,425	<b>52%</b>	41%
20 December 1943	7,093	1,315	5,778	2,454	<b>42%</b>	35%
10 February 1944	7,434	1,186	6,248	2,519	<b>40%</b>	34%

Source: BArch RL 2-III/716a, pp. 3–10a; RL 2-III/716b, pp. 100–108a; RL 2-III/722a, pp. 2–14a; RL 2-III/722b, pp. 120–132a; RL 2-III/728a, pp. 2–12a; RL 2-III/728b, pp. 96–106a

The overall pattern of German air strength, namely stagnation of absolute numbers of aircraft in the East throughout the 1941–43 period, shows that the Luftwaffe was unable to reinforce in the East even as the situation for German forces in this theatre deteriorated. The entire increase in the absolute quantity of aircraft available to Germany was absorbed by the fighting against the Western Allies, rather than the USSR. In consequence, the proportion of frontline strength allocated to the Eastern front shrank to only two fifths of the overall total in February 1944, much less than the almost two thirds attained in November 1941, at the beginning of the period reviewed here. If aircraft in reserve are included in the analysis, the relative importance of the Eastern front in terms of the proportion of aircraft allocated to the theatre falls further. This can be seen by comparing the two columns on the right of Table 1.

The calculation including reserves, in the column entitled “% East of total strength”, is an important one since many of the aircraft in reserve at any given time were new aircraft types in the process of entering service. These new types were largely deployed against the Western Allies, as will be discussed below.

It is possible to obtain a more complete picture of German resource allocation by considering only combat aircraft (Table 2), a narrower set of data than operational aircraft (Table 1). The difference between the combat aircraft and operational aircraft categories is that transport, liaison and night harassment aircraft are subtracted from the operational aircraft numbers to give the sum of combat aircraft. This calculation reflects the fact that transport and liaison aircraft were usually unarmed, while night harassment aircraft were predominantly obsolete biplanes which had little value in combat operations (Pegg 2007, 8-10; Weal 2003, 64). Thus, the sums in Table 2 represent a summary of the core German aircraft strength deployed in combat. The general trend, of a gradual increase in total strength and in frontline strength, is the same as Table 1. The difference is that the number of combat aircraft in the East did not recover to the level at which it was in November 1941, unlike the case for operational aircraft. In this sense, late 1941 marked a significant change in the course of the war in the air in the East, for the Luftwaffe was forced to permanently reduce the number of combat aircraft allocated to this front. Thereafter, the number of combat aircraft in the East was largely unchanged, much as in the case of operational aircraft. A significant difference between the situation for operational aircraft and that for the narrower category of combat aircraft was that in 1943 and later the proportion of combat aircraft allocated to the Eastern front decreased more rapidly. By February 1944, only a third of the Luftwaffe’s total combat aircraft strength was allocated to the East. Thus, combat aircraft were an even more scarce resource for Germany than operational aircraft, and the majority of combat aircraft was drawn in to the fighting against the Western Allies earlier than in the case of the broader category of operational aircraft.

Table 2. Allocation of Luftwaffe **combat aircraft**, November 1941 - February 1944

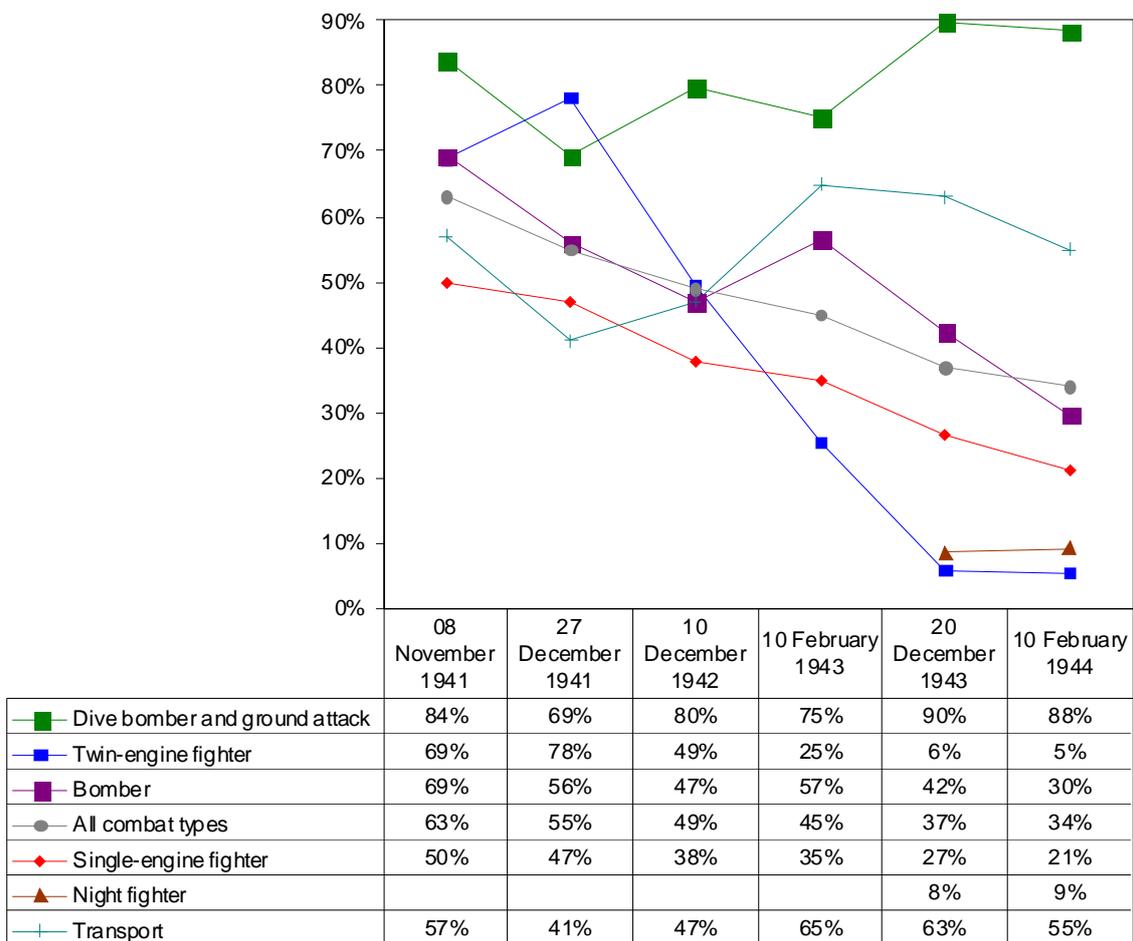
Date	Total aircraft	In reserve	At the fronts	Eastern front	% East of frontline strength	% East of total strength
8 November 1941	3,963	702	3,259	2,042	<b>63%</b>	52%
27 December 1941	3,795	927	2,868	1,571	<b>55%</b>	41%
10 December 1942	4,479	775	3,704	1,802	<b>49%</b>	40%
10 February 1943	4,740	1,066	3,674	1,671	<b>45%</b>	35%
20 December 1943	5,556	990	4,566	1,668	<b>37%</b>	30%
10 February 1944	5,703	859	4,844	1,648	<b>34%</b>	29%

Source: see Table 1

The analysis above has established that the number of Luftwaffe aircraft in the East was falling in relative terms, because such additional aircraft as became available over time were drawn into the fighting in the West. It is possible to add further depth to the analysis by looking at the distribution of specific classes of aircraft, which is summarised in Figure 1 and reported in full in tables A-1 through A-6 in Appendix A. The grey series in Figure 1, labelled “all combat types”, is taken from Table 2 above and shows the percentage of combat aircraft on the Eastern front. While the trend in the proportion of bombers in the East was broadly similar to the trend for all combat aircraft, this was not the case for single-engine

fighters. It can immediately be seen that the percentage of single-engine fighters in the East was significantly less than that of combat aircraft, throughout the period under discussion. This is important because single-engine fighters were the nearly exclusive means of destroying enemy aircraft in air combat and thus attaining air superiority. Even twin-engine fighters lacked the manoeuvrability to contest air superiority and were relegated to supporting tasks (Corum 2008: 222, 234), as discussed below. Figure 1 shows that only half of single-engine fighters were in the East in November 1941 and by the time of the battle of Stalingrad in December 1942 the proportion allocated to the East had fallen below two-fifths, with a further decline thereafter. There is a clear implication that Allied air operations forced the Luftwaffe to concentrate its air superiority force in the West and to do so earlier than is commonly assumed in the literature. Van Creveld (2011, 136-7) and O'Brien (2015, 290-1) emphasise the shift of fighters away from the Eastern front in 1943 and after, while it can be seen from Figure 1 that the proportion of German fighters in the East fell below half of the total on all fronts already in 1942.

Figure 1. Proportion of selected aircraft classes in the East, as a percentage of frontline strength



Source: see Table 1

The overall trend, of a progressive transfer of Luftwaffe forces to the West, is underlined by the change in the distribution of twin-engine fighters. In late 1941, these aircraft were concentrated in the East, where they achieved considerable success as fighter-bombers in the face of technologically inferior Soviet opposition (Vasco 2009, 122). This concentration did

not endure, for by 1943, the need to defend mainland Germany and protect naval traffic led to most twin-engine fighters being transferred westwards (Goss 2007, 24-6; Vasco 2009, 163). In the case of night fighter units, which were predominantly equipped with modified versions of twin-engine fighters (Boiten 2011, 14-15), the imbalance in favour of the West was overwhelming. There were no night fighters in the East in 1941-42, and when night fighters were finally deployed, they formed a minor part of the overall night fighter force, which remained dedicated to defence against the night bomber offensive of RAF Bomber Command. In summary, German attempts to maintain air superiority on the Eastern front were compromised by the fact that most German fighters were concentrated in the West from an early stage of the war. A significant countervailing effect can be seen in the case of transport aircraft. In the later stages of the war, the Luftwaffe transport force in the East increased as a proportion of that on all fronts. However, this came too late to help stabilise the German position in the East. The most prominent demonstration of this was that in the middle of the Stalingrad airlift, in December 1942, less than half of Germany's frontline transport aircraft force was in the East. The strain on German airlift resources imposed by the need to react to the Allied landings in North Africa (Murray 1996, 160) was one of the fundamental causes of the failure of the Stalingrad airlift. The significance of this phenomenon continues to be underestimated, with some authors insisting that the Allied operation did not relieve pressure on the USSR (O'Hara 2015, 276). It is only in the allocation of ground attack aircraft that continued German prioritisation of the Eastern front can be observed, but these aircraft were in many cases obsolete and low-performance types (Corum 2008, 316). For most classes of aircraft, a pronounced fall in the proportion allocated to the East can be observed for the entire period under review.

To demonstrate that the general trend of lower German resource allocation to the Eastern front than to the West continued until the end of the war, it is helpful to review fighter distribution until 1945 (Table 3). This information is complementary to that presented above for specific dates because the data, compiled from surviving records for post-war analysis, shows the *average* German fighter strength over successive periods of the war (see ZA 3/358, 2ff). It is particularly telling that during the period from December 1942 to July 1943, just as the great battles of Stalingrad and Kursk were fought in the East (Overy 1995: 81-94), the Mediterranean front alone absorbed almost the same proportion of German single-engine fighter strength as the East. For twin-engine fighters, the proportion in the Mediterranean was almost three times higher than that in the East. It must be noted that some of the fighters in Scandinavia operated against Soviet forces in the Arctic (Murray 1996, 136), so the strength in the East is somewhat under-reported in Table 3. However, Table 2 and others in this section fully account for the distribution of fighters in Scandinavia between East and West, and it can be seen that the under-reporting in Table 3 is minimal. The core observation to be made about fighter strength is that the Western front ultimately became the Luftwaffe's dominant concern, with the Mediterranean essentially abandoned and strength in the East stagnant at around a quarter of the overall total. A very limited attempt to reinforce the East can be observed in the final period of the war, which reinforces the general observation that it was in the West where the German fighter forces were concentrated and ultimately defeated.

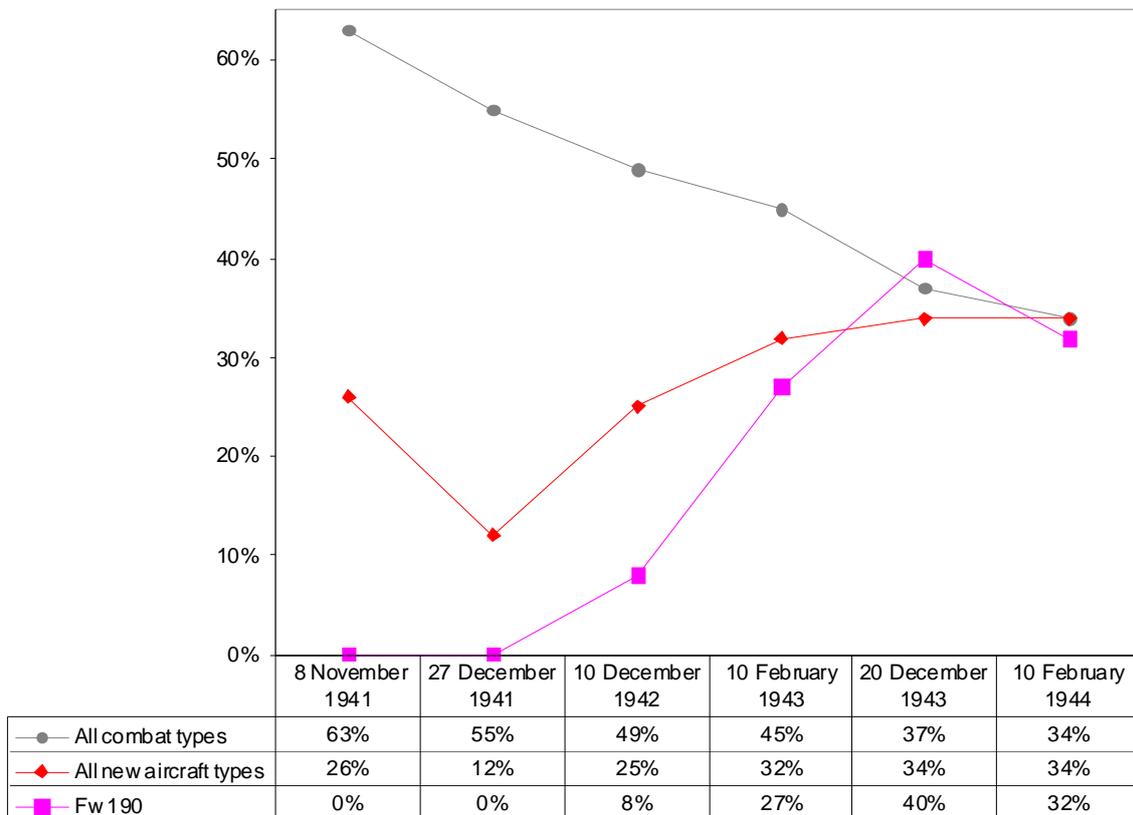
Table 3. German fighter strength by front, average percentages for successive periods from August 1942 onwards

Period	Single-engine fighters				Twin-engine fighters, including night			
	Mediterranean	West	Scandinavia	East	Mediterranean	West	Scandinavia	East
17.08.42 - 11.12.42	22%	19%	16%	<b>43%</b>	32%	47%	3%	<b>18%</b>
11.12.42 - 24.07.43	26%	33%	13%	<b>28%</b>	28%	61%	0%	<b>11%</b>
24.07.43 - 19.02.44	18%	52%	7%	<b>23%</b>	7%	84%	1%	<b>8%</b>
19.02.44 - 20.06.44	14%	58%	6%	<b>22%</b>	4%	85%	3%	<b>8%</b>
20.06.44 - 08.05.45	2%	67%	5%	<b>26%</b>	1%	79%	5%	<b>15%</b>

Source: BArch ZA 3/358

A final demonstration that the Eastern front was a lesser priority for the Luftwaffe than the West comes from observing the distribution of new aircraft types (Figure 2). These were types which were either not yet in service at the time of the German invasion of the USSR or which were only just entering mass production. The full data is reported in tables A-7 through A-12 in Appendix A. The central observation to be made is that the proportion of new types in the East was low and was markedly lower than the proportion of German combat types allocated to the Eastern front, into early 1943. The two trends, of a decline in the proportion of combat aircraft in the East and a rise in the proportion of modern types, finally converged at the end of the period under review, at around a third of the overall Luftwaffe totals for both categories. Therefore, it can be seen that during the crises of German offensives in the East in late 1941 and late 1942 Germany attempted to manage the situation with old aircraft types, while retaining the newer types in the West. The allocation of the Fw (Focke-Wulf) 190 is particularly significant. It was by far the most common new type, accounting for 5,500 out of the 59,705 German combat aircraft manufactured from the outbreak of the war until the end of 1943 (ZA 3/251, 5-6). Apart from its numerical importance, it was also notably effective as a fighter and fighter-bomber, with a powerful engine and heavy armament making it superior to many contemporary Allied aircraft (Arthy and Jessen 2004, 12). Allied pressure in the air meant that the Fw 190 was used exclusively in the West until 10 September 1942, when the first Fw 190s finally reached the Eastern front (Weal 2006, 83). By this date, 1,314 of these aircraft had already been delivered and 170 destroyed, all in the West (RL 2-III/737, 17.9.42 report). The overall picture is that the German air force in the East was not only smaller than in the West, but also had fewer of the modern aircraft types necessary for operations against its ever-stronger adversaries.

Figure 2. Proportion of new aircraft in the East, as a percentage of frontline strength



Source: see Table 1

The key findings regarding German aircraft allocation are that strength in the East was stagnant on some measures in 1941-1943 and fell substantially on other measures. The Luftwaffe in the East shrank as a proportion of the overall German force from 1941 into 1942 and by the end of 1943 was playing a clearly subordinate role compared to the war effort in the West. In the crucial contest for air superiority, represented by the allocation of fighter aircraft, the process of concentration in the West was well underway by late 1942. This explains such phenomena as the weakness of German fighter units during the final German attempts to capture Stalingrad (Ratkin 2013, 118-21).

## Section 2. Allocation of Aircraft Weapons and New Technology

With the allocation of aircraft having been considered, the analysis proceeds to the questions of the distribution of aircraft armament and that of the allocation of new aviation technologies developed during the war. The issue of aircraft armament is important because, as mentioned in Section 1, individual aircraft of the period could vary significantly in the quantity and effectiveness of the armament that they carried. Therefore, analysing the distribution of aircraft armament provides a useful additional measure of German resource distribution. The broader issue of the allocation of new aviation technologies, which became available over the course of the war, is significant because it demonstrates the degree to which German decision-making was affected by the pressures of combat on different fronts and which theatres attained priority in resource allocation.

In the field of aircraft weapons, the most significant German aircraft weapons were the 13 mm and 20 mm guns, which superseded the 7.92 mm as the main armament of both fighter and bomber aircraft, after that smaller calibre was found to be ineffective against contemporary aircraft (Jarrett 1997: 197, 211). It is a remarkable fact that even in October 1942, as the battle of Stalingrad was reaching its climax and the Luftwaffe was making a maximum effort to support the German offensive (Hayward 1998, 213), the forces in the East had less than a third of the total of the 13 and 20 mm aircraft guns available to the Luftwaffe (see Table 4). By December 1942, less than a quarter of these guns were assigned to the Eastern Front. Even with the same caveat as in the case of Table 3, that some of the guns in Scandinavia would have been allocated to operations in the East, it is clear that the Luftwaffe units fighting the USSR were conspicuously under-armed. As Table 2 shows, some 49% of German frontline combat aircraft were in the East in December 1942. Given the much smaller proportion of aircraft guns in the East, the implication is that individual aircraft on the Eastern Front were more lightly armed compared to those used in the West. This inference is supported by observations in the literature that heavily armed aircraft sub-types, like the Messerschmitt 109 fighter with additional under-wing cannon, were relatively rare on the Eastern Front (Weal 2007, 78). This had a direct effect German effectiveness in the air, for the Il-2 attack aircraft, carrying almost a tonne of armour, accounted for 29 to 32% of total Soviet air strength. The Il-2 suffered from slow speed and poor manoeuvrability, but it could absorb significant battle damage and was thus difficult to shoot down for lightly armed German interceptors (Rastrenin 2016, 16-24). This is just one illustration of the fact that the German decision to allocate most heavily-armed aircraft to the West materially inhibited the Luftwaffe operations in the East.

Table 4. Allocation of German aircraft guns, 1942–1944

	October 1942			
	West	East	Scandinavia	% East
13 mm	880	60	66	6%
20 mm	5,018	2,644	376	33%
<b>total</b>	<b>5,898</b>	<b>2,704</b>	<b>442</b>	<b>30%</b>
	December 1942			
	West	East	Scandinavia	% East
13 mm	1,013	83	52	7%
20 mm	5,723	1,983	432	24%
<b>total</b>	<b>6,736</b>	<b>2,066</b>	<b>484</b>	<b>22%</b>
	June 1943			
	West	East	Scandinavia	% East
13 mm	2,449	537	109	17%
20 mm	8,891	1,895	518	17%
<b>total</b>	<b>11,340</b>	<b>2,432</b>	<b>627</b>	<b>17%</b>
	January 1944			
	West	East	Scandinavia	% East
13 mm	4,805	1,217	221	19%
20 mm	11,476	1,794	358	13%
<b>total</b>	<b>16,281</b>	<b>3,011</b>	<b>579</b>	<b>15%</b>

Source: BArch RL 2-III/642, p.14ff

The cause for the deficit of aircraft guns in the East was that the multiple types of heavily armed German fighters that were developed were largely thrown into the strategic defence of Germany against Allied bombing (Jarrett 1997, 69). The four-engined bombers of the Allies, with their size and heavy defensive armament, caused the Luftwaffe significant difficulties from the very beginning of their employment. In one instance, a commander of one of the few Luftwaffe single-engine fighters units in the West in mid-1941, Rolf Pingel, was shot down by the gunners of a small formation of RAF (Royal Air Force) Stirling bombers on one of the first daylight heavy bomber missions (Forsyth 2011, 11). As the Luftwaffe encountered more Allied heavy bomber raids, it became apparent that great increases in defensive fighter firepower were needed, especially against the even more heavily armed American bombers. This dynamic led to the development of ever more heavily armed sub-types of fighters, including some Focke-Wulf 190s with six 20 mm cannon, the most ever mounted in a German single-engine fighter (Dill 2015, 50-4). This sub-type entered service concurrently with the most powerful weapon used by German fighters during the war, the 210 mm rocket mortar, which was used in significant numbers from July 1943 onwards both on the Western Front and in the Mediterranean, but not in the East (Forsyth 2016b, 53-7). The ultimate result of these developments, focused on the needs of defence against strategic bombing, was that the aircraft types retained on the Eastern front were ever more poorly armed in comparison to those in the West. Just 15% of Luftwaffe aircraft guns were allocated to the East by January 1944 (Table 4), a much lower proportion than the 34% of combat aircraft allocated to this theatre (Table 2). While the desperate German attempts to develop technology to confront Allied pressure have been noted in the literature (van Creveld 2011, 116-7), as has the German tendency to use older aircraft in the East (O'Brien 2015: 65, 291). What has not been sufficiently emphasised is that these aircraft possessed considerably less firepower, on average, as demonstrated here.

In the field of aviation fuel and engine technology Germany was forced into a particularly desperate effort by Allied technological superiority, which found little application in German operations on the Eastern front. The key quality variable of wartime aviation gasoline was its resistance to premature detonation during combustion, denoted by the fuel's octane rating. Fuels with a higher octane rating permitted greater compression of the fuel-air mixture in engines and hence higher power (Bailey 2008, 396-8). Greater compression was also important at higher altitudes, where the ambient air pressure is lower. Wartime engines used superchargers to maintain power at high altitude by compressing air entering the supercharger intake and thus increasing mixture pressure in the engine. Alternatively, turbochargers driven by engine exhaust air performed a similar function (Day 1983, 175-81). Therefore, high octane gasoline was required both for powerful engines generally and for high-altitude engines in particular. The two main fuel types in both Allied and German use were 87 octane and 100 octane, with the 100 octane produced by mixing a product of hydrogenation, iso-octane, with the 87 octane. While in 1940 engines could perform well with 87 octane, technology rapidly evolved so that 100 octane became essential for powerful engines (Bailey 2008, 403-4; ZA 3/267, 33). Germany had difficulty obtaining both feedstock oil for hydrogenation and the steel to build new hydrogenation plants, so there was a constant shortage of the components needed to produce 100 octane fuel (Tooze 2006, 498; ZA 3/267, 34). Whereas the RAF switched to 100 octane in spring 1940, the Luftwaffe used predominantly 87 octane, which limited maximum permissible engine pressure, for the entire war (Bailey 2008, 406-7; ZA 3/267, 42-6). The result was that air operations at high speed or high altitude were an enduring challenge for German forces. Only small numbers of Germany's most common fighter, the Messerschmitt 109, were produced with engines modified to use 100 octane fuel and these aircraft were largely reserved for use against the

Western Allies in high-altitude combat (Hermann 2013: 39, 55). The importance of the Focke-Wulf 190, already discussed above, was enhanced by the fact that it became virtually the only Luftwaffe type to use 100 octane fuel, essential for its BMW 801 engine. (Hermann 2013, 64). Therefore, the allocation of Fw 190s largely determined the allocation of 100 octane fuel, while other aircraft made do with 87 octane. A small number of fast bombers and night fighters with BMW 801 engines also used 100 octane, predominantly in the West (Medcalf 2013, 178; ZA 3/267, 42). It is regrettable that information about the allocation of 100 octane fuel between fronts has not survived, but it is reasonable to infer that since the majority of German aircraft using this fuel flew in the West; most of the fuel was expended there, and not in the East. Contemporary authors continue to focus on the bombing of German hydrogenation plants in 1944 as the cause of a fuel crisis and hence Luftwaffe collapse in that year (O'Brien 2015: 331-5). More attention should be devoted to the fact that the Luftwaffe's fuel stocks, especially of 100 octane, were very inferior compared to Allied production before 1944, and were largely expended in operations in the West. This was another way in which Allied technical superiority severely constrained German fighting power in the East.

The problem of aviation fuel interlinked with another critical cause of the growing obsolescence of German aviation technology compared with that of the Allies, namely Germany's inability to produce high-altitude engines. The deficit of 100 octane fuel was one part of the problem, but the other was that Germany did not produce the supercharging or turbocharging technology which could match the Allies. At the beginning of the war, the DB 601 fighter engine with a reasonably effective single-stage supercharger and direct fuel injection was superior to Anglo-French technology (Hermann 2013: 33). However, the British attained a decisive technical lead in mid-1942, when they introduced the Merlin 61 with two-stage supercharging. This engine gave new Spitfire sub-types and later the US Mustang, which was equipped with a licensed copy, decisive superiority in performance over German aircraft at higher altitudes (Hermann 2015: 31). Contemporary German attempts to introduce an engine with a two-stage supercharger failed completely, with both the DB 627 and BMW 801H never entering service, partly because of the absence of metal alloys needed for the superchargers (ibid: 32). Only in 1945 were a few Ta 152 fighters with DB 603L and Jumo 213E two-stage supercharged engines produced, negligible when compared with thousands of Allied Spitfires and Mustangs equipped with such engines (ibid: 31, 34). In the case of turbochargers, a more complex technology, the German position was even worse. The US introduced the Lightning and Thunderbolt fighters with turbocharged engines in large numbers from 1943 onwards, while the German BMW 801TJ never entered mass production (ibid: 33) American forces had the luxury of complaining about some difficulties with both the Lightning and Thunderbolt in mid-1943 (Cooling 1994, 277), since the Mustang with its even higher performance entered service the end of that year. At the same time Galland, the commander of German fighters, was reduced to requesting a modified single-stage supercharger for the Messerschmitt 109 in autumn 1943 (Hermann 2014, 15), an obsolete technology. For piston-engine fighters of the period, an advantage in speed and height was often decisive in combat, because it allowed attacks from above followed by zoom climbs out of reach before the defender could respond (Sabin 2012, 232). This meant that from the middle of the war German aircraft faced a severe challenge in air combat against the Allies. The obsolescence of German fighters by 1943 has been discussed (Tooze 2006, 583-4), but not in the explicit terms of engine inferiority, as here. This problem was not encountered on the Eastern front, where a Soviet analysis in mid-1943 clearly acknowledged that the Merlin XX, a long-obsolete British engine with a single-stage supercharger, was substantially superior in power and altitude performance to the most common Soviet aircraft engine, the

M-105 (Rodionov 2016: file 1943a, 719-22). The USSR experienced even worse problems than Germany with two-stage superchargers and turbochargers and did not introduce either technology during the war (Rodionov 2016: file 1945a, 30, 118). This meant that German aircraft which were obsolete in the West could fly successfully in the East. For this reason, the strenuous German efforts to produce more powerful piston engines can be considered as primarily induced by Allied pressure, another factor pushing resources away from the Eastern front.

The overall crisis caused for the German war effort by Germany's growing technical inferiority led to enormous and largely futile expenditures on offensive equipment, primarily intended to as a countermeasure to Allied attacks. In particular, the failed German attempts to design a very long-range bomber to attack either Soviet or American industry demonstrate that the threat from the Western Allies quickly became the dominant consideration in German planning. Before the war, a high priority project to attack Soviet industry, the 'Ural-Bomber', was started. By 1939, this had been abandoned for lack of resources and because of the short-sightedness of Luftwaffe commanders (Forsyth 2016a, 9-10). In late 1941, with Germany at war with the USSR, the discussions about strategic bombers resumed, but these focused on plans to bomb the United States, leading to the nickname 'Amerika-Bomber'. These discussions involved increasingly fantastical proposals to use mid-air refuelling, which was not developed by any nation during the war, or bases in the Portuguese Azores (Forsyth 2016a: 29, 37). Even in the middle of the crisis in the East at Kursk in 1943, Hitler suggested that the very long-range bomber be developed and used to support German U-boats against Allied convoys. The needs of the Eastern front were not considered to be relevant to the discussion (ibid, 60). In the end, the weight of Allied air power rendered these discussions irrelevant and in October 1943 production priorities were switched from incomplete bomber projects like the Me 264 and Fw 400 to urgent fighter programmes to defend Germany, including the Me 262 jet fighter (ibid: 70). A less ambitious German four-engine bomber, the He 177, was declared a priority in 1939 but finally completed development by late 1943 (Tooze 2006: 288, 581). However, Germany's problems with designing powerful engines, mentioned above, meant that of 581 such aircraft produced by the end of 1943 most were unsuitable for combat because their special coupled engines were a fire hazard (Tooze 2006, 448; ZA 3/251, 5-6). The only use of this aircraft on the Eastern front in 1941-43 came during the Stalingrad airlift, where five of the seven sent were lost (Goss 2016, 48). When it finally entered service as a bomber in November 1943, the He 177 was used exclusively to attack shipping in the Mediterranean, where Allied superiority was such that nine aircraft were lost on the second operational mission flown by the type (ibid: 68, 92). It can be seen that all German attempts to produce a viable strategic bomber fleet became focused on fighting the Allies, an effort which drew resources away from the Eastern front, even as technological limitations meant that the Luftwaffe was ultimately unable to field strategic bombers.

The German policy focus on developing a response to Allied bombing culminated in the *Vergeltungswaffen*, vengeance weapons. The V-1 rocket and the V-2 ballistic missile were first employed in June and September 1944, respectively, which was far too late to change the course of the war. Their use, confined to the Western front, served only to underline Allied superiority, since the total destructive power of all the V-2s launched "was the equivalent of one large-scale RAF raid" (Overy 2013, 121). The problem in terms of resource distribution in 1941-43 was that the V-1 and V-2 programmes consumed development resources in this period. The V-2 was granted extreme priority on 7 July 1943, at the same time as the great battles around Kursk and in Sicily, while the V-1 had been ordered into

production a month earlier. These decisions were preceded by extensive research programmes, with the more expensive V-2 accounting for the same resource expenditure, in relative terms, as the Manhattan project to produce the US atomic bomb (Kroener et al. 2003: 624, 628-9). Hitler and his circle were not only unable to select just one of the V-1 or V-2 projects to conserve scarce resources, they also neglected the Me 262 jet fighter, which had also advanced to the pre-production stage by mid-1943. Given the German problems with piston engines, it is not surprising that production jet engines were not ready until summer 1944 (Tooze 2006, 621), but it is reasonable to suggest that a focus on the Me 262 instead of the vengeance weapons could have brought faster results. Hitler made multiple interventions in late 1943 and early 1944 to have the Me 262 enter service as a bomber, rather than a fighter. However, it is particularly telling that he intended to use this new weapon against either Britain or the prospective Allied invasion fleet, not any Soviet target (Forsyth and Creek 2012, 8-11). In the end, no Me 262s were used in the East until the final weeks of the war (ibid, 85-6). Thus, the focus on direct retaliation to the Allied aerial offensive consumed extensive resources, while the defensive jet fighter was at first also intended as an offensive weapon and was in any case not intended for the Eastern front. The entire process of preparation for the production of these weapons in 1941-43 effectively proceeded as if the war with the USSR was a distant second priority compared with the war in the West.

The technological prioritisation of the West led directly to opportunities being missed in the East. It was only in summer and autumn 1943 that the Luftwaffe made some attempt to plan for a strategic bombing offensive in the East (Overy 2013, 229). By this time, the bomber force in the East was largely obsolete, with 351 of the 502 bombers concentrated for the Battle of Kursk in 1943 being the He 111, a type which was considered to be too vulnerable to be used over Britain as early as autumn 1941 (Medcalf 2014, 586; Tooze 2006, 582). Despite this obsolescence, the Luftwaffe's bombers had considerable success in night attacks on Soviet industrial plants in Gorky and Saratov in June 1943, just before the German offensive at Kursk (Bergström 2008, 19-20). Against a technologically inferior Soviet air force, which had no radar-equipped night fighters, the old He 111s continued to have significant success even in summer 1944, when they destroyed a large number of the far more advanced US B-17 bombers in a raid on Poltava (Hooton 2016: 219, 234). This casts doubt on Overy's (2013, 614-6) suggestion that a larger and better coordinated German bombing effort could not have caused significant difficulties for the USSR. The reason that no such effort was attempted is that Hitler decided to concentrate his few relatively modern bombers for a failed offensive against Britain from January to May 1944, in which 445 bombers were lost for no gain (Medcalf 2014, 620). The unsuitability of German bombers for this task is demonstrated by the fact that one of the types used in this campaign was the Do 217, which by this time was considered unsuitable for use against Britain like the He 111 earlier, but it was nevertheless employed only in the West (Hermann 2016, 19; also see Appendix A). Similarly, when the Luftwaffe developed the world's first guided bombs, the Hs 293 and Fritz X, these were used only against the Allies, starting in July 1943. An experienced bomber pilot attempted to persuade Hitler to deploy them against stationary Soviet warships providing artillery support around Leningrad, but instead 903 sorties were flown against Allied shipping in 1943-44, with 133 German aircraft lost (Bollinger 2010: 22, 179). As with the Me 262 jet, there was only a last-ditch attempt to use these weapons in the East in the closing weeks of the war (ibid: 193). It is very likely that neither an increased strategic bombing campaign nor the use of guided bombs would have averted defeat in the East, but it is significant that there was no serious German plan of this kind. Most German aviation equipment that was considered modern was thrown into the fighting in the West, with little thought for the position in the East.

It is to be regretted that the dramatic documentary evidence showing the concentration of German aircraft guns in the West cannot be matched with similar data about the distribution of the new technologies discussed above, but the qualitative evidence is overwhelming. The variety of acute technical challenges generated by Allied superiority forced the Luftwaffe and the wider German military to concentrate resources in the West, with the poor strategic judgment of Hitler and his associates as a further complicating factor.

### Section 3. Allocation of Anti-Aircraft Guns

Having discussed the allocation of the wide spectrum of German aircraft and aviation technology, it is necessary to mention the other main component of the Luftwaffe, the extensive air defence force. The air defence force accounted for a quarter or more of total German weapons production, depending on the period of the war, and between 14 and 31% of all munitions production (O'Brien 2015, 23). This extensive force played an important role in many battles of the war. Anti-aircraft guns were used to protect German spearheads during major ground offensives, including important incidents like the crossing of the Meuse River in May 1940, where the ground defences were critically important to sustaining the German breakthrough (Cox and Gray 2002, 155). These guns could were also used on a large scale and considerable success against fortified ground targets, including tanks and bunkers (Westermann 2001: 169, 223).

The distribution of German anti-aircraft forces is often analysed with a focus on the concentration of guns in the West to defend against bombing, with the focus on the period of the Allied bombing offensive in 1943-44 (O'Brien 2015, 304-6; Overy 2013, 406; van Creveld 2011, 136-40). As Table 5 shows, the anti-aircraft force was concentrated overwhelmingly in the West already in the summer 1942, even taking into account that some of the guns in Scandinavia. At that time, American forces had not yet commenced their bombing operations, while the British had dropped less than 100,000 tonnes of bombs in their strategic offensive, less than 7% of the RAF wartime total (Crierie 2013). The great weight of anti-aircraft fire in the West caused constant attrition of British and later American air forces, which was difficult to counter because of the essentially random nature of losses to heavy anti-aircraft barrages (Sabin 2012, 120). For the Soviet air force, the concentration of German defences in the West at a relatively early stage of the war meant that very few of the most effective German air defence technologies were encountered in the East. This was especially true of the heaviest 105 and 128 mm guns, which were particularly effective because of their heavy shells and ability to hit aircraft at high altitudes (Westermann 2001: 127-9). The fact that only a quarter of the light guns was in the East was also significant, for these were very effective against tactical aircraft flying at lower altitudes (Overy 2013, 373). Even though the proportion of Luftwaffe guns in the East was small, German air defences accounted for at least 22% of Soviet air force losses during the war, according to Soviet records (VVS Staff 1962: Chapter 6, Table 6.256). It can be suggested that a greater allocation of guns in the East would have caused significantly higher Soviet losses over time.

Table 5. Allocation of German anti-aircraft guns, 15 June 1942

<u>Equipment Class</u>	<u>All fronts</u>	<u>East</u>	<u>Scandinavia</u>	<u>% in East</u>
Heaviest guns (105-128 mm)	364	16	12	4%
Heavy guns (75-94 mm)	4,816	974	220	20%

Light guns (20-50 mm)	16,091	4,049	818	25%
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Source: BArch RL 2-III/628, report dated 15.06.1942

The growth in size of the German anti-aircraft force by the end of 1942 did not lead to an increase in the proportion allocated to the Eastern Front (Table 6). The key observation to be made is that the percentage of both heavy and light guns in the East shrank further. The distribution of searchlights and other equipment which allowed the anti-aircraft guns to find their targets was also significant. The large searchlights necessary to illuminate bombers at night required hundreds of kilograms of scarce copper per unit (Westermann 2001: 259, 274-5). It can be seen from Table 6 that a negligible proportion of these searchlights were in the East. The 60 cm searchlights that were used in the East were considered to be of limited value, due to their low power, even before the war began (ibid: 120). Even more importantly; the proportion of range finders, which measured the distance to enemy aircraft, and fire directors, which mechanically computed firing solutions, in the East was even lower than the proportion of anti-aircraft guns. Therefore, the German anti-aircraft units in the East were not only insufficiently armed, they also did not have sufficient equipment to resolve “the most difficult technical challenge” which they confronted (ibid: 112), namely ensuring the accuracy of their fire.

Table 6. Allocation of German anti-aircraft guns and supporting equipment, December 1942

<u>Equipment Class</u>	<u>Total</u>	<u>East</u>	<u>% in East</u>
Heaviest guns (105-128 mm)	663	0	0%
Heavy guns (75-94 mm)	6,348	1,049	17%
Light guns (20-50 mm)	20,451	4,429	22%
Large searchlights (150-200 cm)	4,595	170	4%
Small searchlights (60 cm)	5,086	1,189	23%
Fire directors	2,272	349	15%
Range finders	2,470	369	15%

Source: BArch RL 2-III/1162, December 1942 report

It is important to observe that at the end of 1943 the previously established trends of anti-aircraft gun distribution remained in effect, as Table 7 shows. Even though the data in Table 7 is not entirely comparable with Tables 5 and 6; because only German-produced guns are counted, while the Luftwaffe also used large numbers of captured guns (Westermann 2001: 179-81), the distribution of resources is largely similar. The absolute number of heavy and light guns in the East increased by a small margin, while the proportional share of the Eastern front in the overall German effort fell slightly compared to 1942. It is regrettable that information about the distribution of gun-laying radar is unavailable, but sound detectors are a good proxy indicator, for these were used as a partial substitute for radar (ibid: 203). The minimal allocation of sound detectors to the Soviet-German front confirms the fact that the German integrated air defence system was fundamentally oriented to the west. This is further confirmed by a fragment of data showing that of the 197 aircraft claimed destroyed by German anti-aircraft units in March-April 1943 under electric (radar) control, just 31 were claimed in the East (RM 7/227, 27-8).

Table 7. Allocation of German anti-aircraft guns and supporting equipment, December 1943 (not including captured equipment)

<u>Equipment Class</u>	<u>Total</u>	<u>East</u>	<u>Scandinavia</u>	<u>% in East</u>
Heaviest guns (105-128 mm)	1,572	0	12	0%
Heavy guns (88 mm)	8,198	1,241	454	15%
Light guns (20-37 mm)	25,272	4,865	1,192	19%
Large searchlights (150-200 cm)	6,613	247	30	4%
Small searchlights (60 cm)	6,216	1,236	422	20%
Fire directors	2,872	423	165	15%
Range finders	3,092	369	175	12%
Sound detectors	4,569	301	17	7%

Source: BArch RL 2-III/628, report dated 13.01.1944

The one way in which the Eastern front played a significant part in German aerial defensive operations is reflected in Table 8, which shows the allocation of mobile batteries. The mobile guns were a particularly scarce resource because Germany was always short of vehicles (Westermann 2001: 294). It is unfortunate that earlier data is not available, but it can be seen that in December 1943 more than half of all mobile heavy batteries and half of the light units were in the East. While this shows that the Eastern front was the main area of application of mobile units, it must also be acknowledged that stationary batteries were deployed extensively in the East (see RL 2-III/628, 13.01.1944 report). This means that the overall low proportion of anti-aircraft units in the East is only partly explained by the need for mobility, with the relentless pressure of Allied strategic bombing preventing the creation of a far more extensive defensive system to confront the Soviet air force.

Table 8. Total number of German anti-aircraft batteries and allocation of mobile batteries, December 1943 (not including captured equipment)

<u>Equipment Class</u>	<u>Total Batteries</u>	<u>Total Mobile Batteries</u>	<u>Mobile in East</u>	<u>% of Mobile Batteries in East</u>
Heaviest guns (105-128 mm)	357	70	0	0%
Heavy guns (88 mm)	1,479	231	146	63%
Light guns (20-37 mm)	1,238	320	160	50%

Source: BArch RL 2-III/628, report dated 13.01.1944

The question of the relative importance of various fronts in Luftwaffe anti-aircraft allocation could be finally resolved if data on losses of equipment was available. Surviving archival data is so sparse that both the main history of the German air defence force (Westermann 2001: 477-8, 536) and the German official history of the war (Kroener et al. 2003: 635-8) have discussed losses only in the most general terms. The data in Table 9 is therefore particularly interesting, because it presents a summary of the number of batteries lost up to July 1944. The importance of the losses in the Mediterranean is readily apparent, with many batteries lost in the German defeats in Africa in 1941 (Schreiber et al. 1995, 755-6) and 1942-43 (Cox and Gray 2002, 194-8). The majority of the losses on the Eastern front in 1941-43 came in the battle of Stalingrad and it was only with the collapse of the German frontline in the East in 1944 that the balance of losses shifted decisively towards that theatre. Of course,

losses of entire batteries exclude the many losses of individual guns during routine operations, but this is nonetheless an important demonstration of the way that the Eastern Front was not the main source of pressure on German anti-aircraft defences in 1941-43.

Table 9. Anti-aircraft batteries lost with all equipment, 1939 to July 1944

<u>Equipment Class</u>	<u>Norway 1940</u>	<u>Mediterranean 1941-43</u>	<u>Western Front 1944</u>	<u>Eastern Front 1941-43</u>	<u>Eastern Front 1944</u>
Heaviest guns (105-128 mm)	4	3	6		
Heavy guns (88-94 mm)	3	92	12	24	81
Light guns (20-50 mm)	2	57	11	26	59
Large searchlights (150 cm)		3	4		8

Source: BArch RL 2-III/628, report dated 24.08.1944

The central conclusion that can be made based on the analysis of the allocation of German anti-aircraft resources is that the overall Allied air effort, both strategic bombing and the various operations on the Western Front and in the Mediterranean, made it impossible for Germany to concentrate resources in the East. It is critical to understand that this was the case as early as 1942, as even a bold analysis in the literature concerning the importance of the resource diversion effect of Allied bombing makes the case that Germany began to feel serious pressure in 1943 (Edgerton 2011, 287-8). The error of authors like Overy (2013: 406, 627) is that they acknowledge the effect of Allied air power as a ‘second front’ against Germany, a counterpart of the ground war in the East, but they do not adequately trace this process to the early period of the Soviet-German war.

#### Section 4. Distribution of Aircraft and Aircrew Losses

In order to understand the distribution of German air force resources between fronts, it is critically important to understand how aircraft losses were distributed. It is a most telling illustration of the difficulties encountered in analysing surviving German records that even detailed studies of the subject have resorted to using fragmentary information (Overy 2013, 376; O’Brien 2015, 362), which does not give any overall picture of German losses over an extended period. It is only in the seminal work of Murray (1996) that such information has appeared, calculated manually by that author. These calculations, originally published in 1983, remain in use by authors until the present (O’Brien 2015, 292) because little new information has appeared. Murray’s calculations will be referred to below, but it is necessary to begin the analysis here by considering the losses that the Luftwaffe suffered before Germany invaded the USSR.

The losses that the Luftwaffe suffered in 1939-1941 were high. Set against Luftwaffe frontline strength in the East of some 2,700 aircraft at the time of the invasion (van Creveld 2011, 105), the losses of aircraft recorded in Table 10 are very significant. In terms of personnel, the loss of 11,000 men, not counting the wounded, was equivalent to the entire Luftwaffe strength at the outbreak of war (Boog et al. 1998, 818). The officer losses were also heavy, since the transfer of 3,295 army officers and officer candidates to build up the Luftwaffe up to the end of 1941 was considered to be close to the limit of what could be sustained with a relatively small existing officer corps (Kroener et al. 2000, 1039). Table 10

shows that an especially high proportion of officer fighter pilots was lost, higher than in the air force as a whole and much higher than in the bomber force. This was one demonstration of the way in which the Battle of Britain inflicted severe attrition on the most experienced personnel of the Luftwaffe. The total losses of single-engine fighter pilots in just three months of the Battle, July to September 1940, were 521, or fully three-fifths of the total for the entire period to mid-1941. In the same months 1,636 aircraft were lost, accounting for a quarter of the total in Table 10 (Cooling 1994, 102). The peak of German losses occasioned by the Battle was part of a longer period of high losses in the war against Britain. From August 1940 to March 1941, a period encompassing the ‘Blitz’ bombing campaign as well as the later part of the Battle of Britain, 4,278 German aircrew were lost (Maier et al. 1991, 400). The Luftwaffe had thus been severely weakened by the loss of many experienced personnel with pre-war training, before the Soviet-German war began.

Table 10. Losses of operational Luftwaffe aircraft and personnel to all causes from 1 September 1939 to 21 June 1941

<u>Aircraft Class</u>	<u>Aircraft Lost</u>	<u>Aircrew lost (killed, missing and prisoners)</u>	<u>Officers among aircrew losses</u>	<u>% of officers among aircrew losses</u>
Single-engine fighters	1,683	866	317	37%
Bombers	2,443	6,240	1,041	17%
All	<b>6,732</b>	<b>11,068</b>	<b>2,316</b>	21%

Source: BArch RL 2-III/950, p.4

The importance of German losses in the campaigns before Operation Barbarossa, the invasion of the USSR, is borne out by a comparison of losses in Table 11. The date chosen for the analysis in the table, 3 January 1942, marks a point when Barbarossa had failed and German forces were withdrawing from Moscow in disarray (Boog et al. 1998, 726). By this time, the German-Soviet war accounted for just a quarter of Luftwaffe aircraft losses and a fifth of personnel losses from the beginning of the war. Measured from June 1941, more than two-thirds of all losses were on the Eastern front, but to take this as the most significant measure would be to ignore the context of events. It should be observed that the aircraft losses counted here are of aircraft destroyed, rather the ambiguous definition, “permanently or temporarily out of action” preferred by the German official history (ibid, 848). Since destroyed aircraft were permanently out of action, by definition, this is a more useful measure of the relative magnitude of resources denied to Germany by Allied and Soviet action, respectively.

Table 11. Luftwaffe losses before and after 22 June 1941, until 3 January 1942

	<u>Aircraft Lost</u>	<u>Aircrew lost</u>	<u>Officers among aircrew losses</u>
Losses 1939 to 22 June 1941	6,732	11,068	2,316
Losses West from 22 June 1941	1,062	1,751	348
Losses East from 22 June 1941	2,552	3,270	709
% East of all losses from 1939	<b>25%</b>	20%	21%
% East of all losses from June 1941	<b>71%</b>	65%	67%

Source: As Table 10, and BArch RL 2-III/717a, pp. 1f-1g

In view of the importance of the Eastern front in 1941, it has been common to discuss the European war in 1942 as largely focused on the Soviet-German conflict (Corum 2008, 288; Overy 1995, 65-6). This is dramatically contradicted by the information in Table 2, which shows that the Western Front and Mediterranean taken together accounted for just as many losses as the East in the first eight months of 1942. Counting all the losses from 1939 to end the August 1942 presented in Tables 11 and 12, the Eastern front thus accounted for just a third of total Luftwaffe aircraft losses and less than a third of lost officer aircrew members. While attention has been paid to the importance of the Mediterranean in general terms as a draw on German aerial strength (Overy 2013, 504-5; van Creveld 2011, 103-4), the emphasis here is on the fact that in the first months of 1942, the war in the Mediterranean combined with that on the Western front as a source of German losses equivalent to the Eastern front. This is earlier than the period suggested by O'Brien (2015, 92), who focuses on the middle of 1943 as the time when the Mediterranean drew away significant German forces.

Table 12. Luftwaffe losses January to August 1942, by theatre of operations

	<u>Aircraft Lost</u>	<u>Aircrew lost</u>	<u>Officers among aircrew losses</u>
Western Front	1,113	1,890	321
Mediterranean	989	1,427	242
East	2,459	3,310	583
% East	<b>54%</b>	50%	51%

Source: BArch RL 2-III/950, pp.2-3

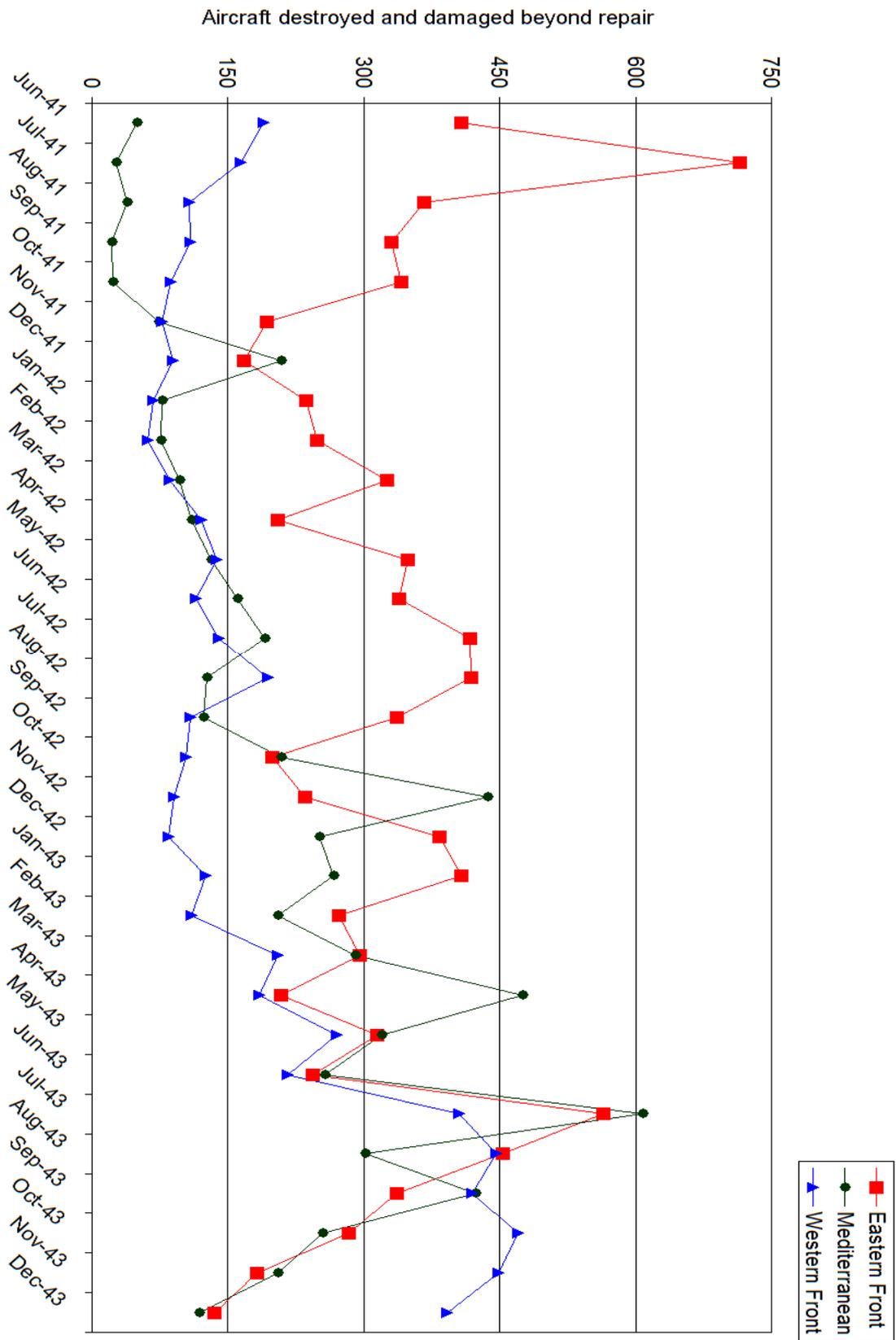
The essential interplay between the three theatres of the air war; namely the East, the Western Front and the Mediterranean, has never been adequately traced in terms of the distribution of German aircraft losses. Murray (1996, 114) constructed a time series comparing German losses against the USSR and the Allies from June to December 1942 and another comparing all three fronts from January to November 1943 (ibid, 148), but no time series for all three fronts for the entire period from June 1941 to December 1943 has been available. It has been possible to construct such a time series based on Matti Salonen's database of Luftwaffe losses. The precise nature and significance of this database is discussed in more detail in Appendix B. This time series will be discussed below and the most important trends in Luftwaffe losses highlighted. To save space in the main text, the full tables of aircraft losses are presented in Appendix B. Table B-1 in the Appendix presents losses of all classes of aircraft, while Table B-2 presents losses of single-engine fighters as deserving of particular attention due to their importance for the conduct of the air war as the primary means of destroying enemy aircraft and attaining air superiority (Boog et al. 2006, 227). The discussion below draws on the full calculations presented in the Appendix, while Figure 3 is presented for purposes of illustration here.

A review of the dynamics of Luftwaffe losses on the Eastern front shows that the highest losses in the East were suffered in the very beginning of the campaign, at the end of June and in July 1941. These losses exceeded even the losses suffered during July 1943, when the Luftwaffe strained every sinew in the offensive and defensive fighting around the Kursk salient. This is an important demonstration of the fact that the Luftwaffe could only concentrate its main force against the USSR at the very beginning of the Soviet-German war.

The dominant pattern of German losses on the Eastern Front was that they rose during every year's summer campaign and then declined in the winter, with the exception of the winter of 1942/43, when the Stalingrad airlift led to very high losses of transport aircraft (Corum 2008, 310). The lower losses during the winter campaigns on the Eastern front can be partly ascribed to the deterioration of flying conditions, but the campaigns on other fronts exerted a critically important influence on Luftwaffe resources during each of the three winters in 1941-43.

The first period when German aircraft losses inflicted by the Western Allies rapidly increased was the winter of 1941. The losses on the Eastern front had halved from October to December 1941 (see Table B-1), even as the Soviet counter-offensive around Moscow began (Stahel 2015, 308). In spite of this, the total losses suffered by the Luftwaffe in December were higher than those in October, primarily because the British offensive in Libya, Operation Crusader (Schreiber et al. 1995, 738-44), led to a tenfold increase in losses in the Mediterranean. The losses in the Western theatres then fell sharply as German forces were able to stabilise the position in Africa, but from February to July 1942 these losses increased again, to the extent that in April 1942 cumulative losses in the West and South exceeded those in the East for the second time. In the autumn, a decisive change in the course of the air war occurred, as the combination of the battle of El Alamein and the Operation Torch landings in North Africa (Cooling 1994, 224) led to a catastrophic increase in German losses in the Mediterranean. In November 1942, German losses against the Allies exceeded the losses suffered by the Luftwaffe in any month of the war on the Eastern front up to that time, with the exception of July 1941. After losses in the East briefly rose again during the Stalingrad airlift, from February 1943 onwards the monthly German losses against the Allies always exceeded the losses suffered on the Eastern Front. This was the breaking point for the German air force in the East, since the focus of the air war had moved permanently to the West. Overy (2013, 343) has acknowledged the diversion of German resources to the West by summer 1943, caused by strategic bombing, but portrayed this as a Pyrrhic victory because of unsustainable Allied losses. What emerges from the analysis here is that the combination of pressure by Allied air power, tactical and strategic, exerted a pressure on German resources that far exceeded that brought about by Soviet action. This is underscored by the fact that the shift from East to West came before 1943 in the case of German single-engine fighters. Fighter losses against the Allies were more than half of all fighter losses from October 1942 onwards (see Table B-2). Initially, this was driven primarily by a doubling of fighter losses in the Mediterranean, as a final attempted offensive against British bases on Malta contributed to heavy losses (Overy 2013, 506). From the spring of 1943, the Allied strategic bombing offensive caused a rapid increase in losses on the Western front, which combined with continued losses in the Mediterranean to make the Eastern front the least important of the three theatres of the air war. The final "wholesale pillaging" of fighter units which denuded the East of a large fraction of the remaining fighters came later in 1943 (Caldwell and Muller 2014, 99) but the rapid rise in loss rates in the West from late 1942 onwards made this change inevitable.

Figure 3. Losses of German operational aircraft by front, June 1941 to December 1943



In order to reach an overall judgment concerning the relative importance of different fronts in the distribution of Luftwaffe losses in 1941-43 it is necessary to consider summary data for this period. The only published data found on this subject aggregates losses on all fronts (Kroener et al. 2003, 705-10), so it is not useful for the analysis undertaken here. The information presented below is particularly interesting because it has never been published, as far as the author has been able to determine, possibly as a consequence of the incomplete cataloguing at the German federal archives. The data in Table 13 thus presents a significant and comprehensive review of German losses. It complements the data on German aircraft strength in Section 1 above, particularly the discussion about the relative significance of various aircraft classes. The table covers operational losses, or *Gefechtsverluste* in German, which were the losses sustained on combat missions, regardless of whether these losses were directly caused by enemy action (see BArch RL 2-III/944). Therefore, operational losses form a more complete category of losses than just those losses that were caused by direct enemy action. When non-operational losses are added to operational ones, it is possible to obtain a complete total of all German aircraft losses, presented in Table 14.

The operational loss data in Table 13 shows that the Eastern Front was the most important, but not the dominant, theatre for German aerial operations during 1941-43. The Western front and the Mediterranean theatre taken together accounted for more than half of total German losses of both aircraft and aircrew. The fact that German forces suffered greater operational losses in the Mediterranean than on the Western front shows the importance of the fighting in southern Europe for the course of the air war. This adds to the existing understanding of the importance of this theatre at the end of this period, in 1943 (Corum 2008, 317-9). There is clear evidence that over the course of 1941-43 Germany was fighting a two-front air war against the Western Allies and the USSR, notwithstanding persistent claims from official-language sources, that Soviet armed forces bore the brunt of the fighting. These claims include the false statement in the recent Russian official history that Germany lost 58,900 aircraft on the Eastern front during the war, a total which exceeds total German losses on all fronts (Zolotarev et al. 2015, 76; ZA 3/407). Not only is the statement false, in the case of the German fighter force it was in fact the Allies who accounted for a considerably greater share of the attrition inflicted on German forces. Less than two-fifths of the single-engine fighters were lost in the East in 1941-43, and a negligible proportion of the night fighter force. In the most technologically complex component of air warfare, air combat between opposing aircraft (Cooling 1994, 554-5), the Allies and not the USSR provided the decisive element in the defeat of the Luftwaffe.

Table 13. Losses of Luftwaffe aircrew and aircraft to operational causes, 22.06.1941 to 01.01.1944, by front

	Western Front		Mediterranean		East	
	Aircrew lost	Aircraft destroyed	Aircrew lost	Aircraft destroyed	Aircrew lost	Aircraft destroyed
Total (and percentage of the total on all fronts)	5,949	4,210	7,158	5,278	12,029	8,619
	24%	23%	28%	29%	<b>48%</b>	<b>48%</b>
Single-engine fighters	954	1,978	579	1,590	980	2,300
	38%	34%	23%	27%	39%	39%
Night fighters	498	465	100	62	11	7
	82%	87%	16%	12%	2%	1%

Twin-engine day fighters	175	138	259	377	461	632
	20%	12%	29%	33%	52%	55%
Bombers and ground attack	3,284	1,134	4,287	2,000	7,176	3,693
	22%	17%	29%	29%	49%	54%
Transports	43	41	1,109	643	1,159	581
	2%	3%	48%	51%	50%	46%

Source: BArch RL 2-III/1200, January 1944 report

The almost complete absence of the German night fighter force from the Eastern front was significant, for in the period 1941-43 the Soviet air force flew 28% of all its missions at night (VVS Staff 1962: Chapter 6, Table 6.233) and thereby exploited this German weakness. Many of these Soviet missions were conducted with wooden Po-2 biplanes, which flew at 90 km/h and an altitude of 1,500 m (Maslov 2016, 83-4) and were therefore very vulnerable to fighters. It has been mentioned in Section 1 that such night harassment aircraft had little combat value. However, while German forces used them on a small scale (Weal 2003, 103-5; see Appendix A), these biplanes formed an extraordinary 23% of total Soviet air force strength at the time of the battle of Stalingrad (VVS Staff 1962: Chapter 3, Table 3.108). These Soviet units suffered very low loss rates, with one aircraft loss for every 703 hours flown in combat, compared with an average of one loss per 30 to 50 hours for most Soviet aircraft (Rastrenin 2015, p.39). The combination of large aircraft numbers and low losses permitted them to disrupt German operations with occasional chance hits on vulnerable targets like fuel dumps (Bergström and Mikhailov 2001: 42, 55). The last successes for these biplanes came at the end of the Korean War, where they caused much disruption and inflicted the last American fatalities to air attack until the present day (Grier 2011). While the USAF in Korea could reinforce its night fighter defences, the German air force in the East could not, because of the heavy night fighter losses in the West. The resulting problem in the East was not confined to occasional Soviet successes for the Soviet night attack force also included larger bombers. These were quite effective in inhibiting the flow of German supplies prior to the Kursk offensive. However, even a small number of German ground radar and night fighters could form an effective defence against this threat, for the Soviet aircraft were technologically inferior. This was demonstrated in the fighting around Kursk on 21 July 1943, when German night fighters shot down eight Soviet aircraft, including three very rare Pe-8 heavy bombers, in just 17 German sorties (Bergström 2008, 71; Gorbach 2007, 276). In summary, the Luftwaffe had the technical capability to confront the considerable but technically unsophisticated Soviet threat at night, but German resources could not be made available for this purpose. Just one of the major consequences of the RAF bomber offensive for the war on the Eastern front was that Soviet air operations at night could continue largely undisturbed throughout the war.

The main conclusions about German loss distribution are reinforced by Table 14. It shows that once non-operational losses are added to operational ones to generate a single loss total for each front, the percentage weight of losses in the East falls further. This is true both for aircraft and aircrew. The table contains data only for all aircraft and for single-engine fighters, so Tables C-1 and C-2 in Appendix C provide more detailed data. The central finding is that just over two-fifths of German aircraft and aircrew losses were suffered in the East in 1941-43. Furthermore, adding the data from Table 10 concerning German losses before mid-1941, to the totals in Table 14 yields figures that suggest the fighting in the East played an even smaller role. Specifically, of the 30,067 aircraft lost from the beginning of the war, just one third was accounted for by the 9,948 losses in the East. The German records thus allow for a

more specific assessment of the relative importance of various fronts than the data presented by O'Brien (2015: 314, 328), which was largely derived from Allied post-war estimates. O'Brien's core argument is that Allied air power destroyed far more Luftwaffe resources than the war in the East (ibid: 93-4), because it destroyed raw materials needed for aircraft and aircraft factories in Germany, rather than merely German forces on the frontline. The information here shows that even if damage to German production is disregarded, Allied forces had inflicted greater attrition on the Luftwaffe than the Soviet air force had. This is why Overy's (2013, 627) view that Allied strategic bombing achieved the "suppression of German air power" only in the later years of the war is flawed. In fact, the entire air war on the Western front to early 1944 can be thought of as a strategic campaign, because there were as yet no Allied land forces in Western Europe. As Table 14 shows, this air war alone inflicted severe losses on the Luftwaffe, while the combination of this campaign with the one in the Mediterranean played the key role in weakening German air power, especially the fighter arm.

Table 14. Luftwaffe total losses (sum of operational and non-operational) of aircrew and aircraft, 22.06.1941 to 01.01.1944, by front

	Western Front		Mediterranean		East	
	Aircrew lost	Aircraft destroyed	Aircrew lost	Aircraft destroyed	Aircrew lost	Aircraft destroyed
Total	9,267	6,876	8,406	6,511	13,134	9,948
	30%	29%	27%	28%	<b>43%</b>	<b>43%</b>
Single-engine fighters	1,337	2,906	659	1,884	1,059	2,579
	44%	39%	22%	26%	35%	35%

Source: BArch RL 2-III/1200, January 1944 report

The greater importance of operations in the West in terms of German resource distribution and destruction is further underlined by a comparison of aircraft loss rates on the various fronts. The loss rate, or the number of aircraft lost in a given period as a percentage either of available strength or of sorties, has long been a key measure of the pressure that a given air force was under (Cooling 1994, 297-9). It has been used in discussions of the problems of Allied strategic bombing, with a US bomber loss rate of 9.1% during October 1943 and RAF bomber loss rates of 10% or above in early 1944 noted as demonstrations of severe difficulties encountered by the Allies (Boog et al. 2006: 85, 306). These loss rates were calculated as a percentage of sorties, while the German loss rates in Table 15 are calculated as a percentage of average strength, so the figures are not directly comparable. The facts are stark, nonetheless. German loss rates were extremely high, especially in the Mediterranean, where they reached 83% over the course of the second quarter of 1943. It is a pity that data before late 1943 is unavailable, because the Mediterranean loss rates reflect a transformation in the air war brought about by the application of Allied and particularly American air power on that front. Sabin (2012, 166) has introduced the concept of 'force gradients', whereby an air force loses effectiveness against more distant targets, because of the limitations of aircraft range and payload. This issue also affects defensive fighters, which need long range in order to effectively cover large areas. In late 1942, American long-range bombers exploited both effects to cause a crisis for the Axis by sinking warships in harbours and attacking airfields, poorly defended by short-range Axis fighters (Shores et al. 2014, 686-8). By July 1943, entire German air units were being destroyed on the ground (de Zeng 2016: Italy 12, 250). The result of large-scale and wide-ranging Allied operations in the Mediterranean, was that the German loss rate there was the highest among all fronts until late 1944. The extension of such

Allied operations to the West in 1944 led to similarly catastrophic German loss rates there. The predicament of the Luftwaffe in the East is demonstrated by the fact that the loss rate against the USSR ultimately reached a similarly critical magnitude as had been the case in the Mediterranean in late 1943, but no substantial reinforcements were forthcoming. The much commented on high number of non-combat losses (O'Brien 2015, 4; Boog et al. 2006, 166) was a result of the unsustainable attrition experienced by the Luftwaffe on all three fronts.

Table 15. Average German aircraft strength and total losses, September 1943 – September 1944

<u>September 1943</u>	<u>West</u>	<u>Mediterranean</u>	<u>East</u>	<u>% Eastern Front</u>
Average Strength	4,221	1,319	2,407	<b>30%</b>
Combat losses	217	280	223	31%
Sum of combat and non-combat losses	493	381	326	<b>27%</b>
Combat and non-combat losses as a percentage of average strength ( <b>loss rate</b> )	12%	29%	14%	
<u>4th Quarter 1943</u>	<u>West</u>	<u>Mediterranean</u>	<u>East</u>	<u>% Eastern Front</u>
Average Strength	4,600	1,156	2,517	<b>30%</b>
Combat losses	746	390	380	25%
Sum of combat and non-combat losses	1,521	562	595	<b>22%</b>
<b>Loss rate</b>	33%	49%	24%	
<u>First Quarter 1944</u>	<u>West</u>	<u>Mediterranean</u>	<u>East</u>	<u>% Eastern Front</u>
Average Strength	5,288	1,090	2,631	<b>29%</b>
Combat losses	1,505	483	536	21%
Sum of combat and non-combat losses	2,518	641	845	<b>21%</b>
<b>Loss rate</b>	48%	59%	32%	
<u>Second Quarter 1944</u>	<u>West</u>	<u>Mediterranean</u>	<u>East</u>	<u>% Eastern Front</u>
Average Strength	5,202	906	3,044	<b>33%</b>
Combat losses	2,503	544	629	17%
Sum of combat and non-combat losses	3,676	749	1,029	<b>19%</b>
<b>Loss rate</b>	71%	83%	34%	
<u>Third Quarter 1944</u>	<u>West</u>	<u>Mediterranean</u>	<u>East</u>	<u>% Eastern Front</u>
Average Strength	5,226	747	3,073	<b>34%</b>
Combat losses	2,631	361	1,020	25%
Sum of combat and non-combat losses	3,643	470	1,381	<b>25%</b>
<b>Loss rate</b>	70%	63%	45%	

Source: BArch RL 2-III/944, BArch RL 2-III/945 and BArch RL 2-III/946

Note: data for some classes of auxiliary aircraft is excluded from the above table, since the documents list only the losses of auxiliary aircraft, not the number of aircraft available

The analysis of German losses has illuminated several important points. First, the air war before the invasion of the USSR weakened the Luftwaffe considerably. Second, the air war on the Western Front and Mediterranean was very important already in 1942, earlier than often stated in the literature. The final and most important observation is that for the entire 1941-43 period, the war in the West as a whole was overwhelmingly more important as a cause of German losses in the air than the war in the East. The extremely high loss rates in

the West at the end of 1943 were merely the culmination of a process which began much earlier.

### Section 5. Distribution of Ammunition Consumption

The final section of the analysis of Luftwaffe resource distribution will consider ammunition consumption, a difficult topic which has only been considered in the context of individual campaigns in the literature (Overy 2013: 112, 472; Boog et al. 2006: 385, 408). The reports of the Luftwaffe's munitions expenditure in 1941-42 (BArch RL 2-III/632-633) do not contain statistical summaries, so it has been necessary to summarise the expenditure of several selected classes of ammunition in order to analyse the overall pattern munitions usage. The classes of ammunition were selected in such a manner as to cover the range of tasks of the Luftwaffe. Medium calibre bombs were the Luftwaffe's most common general purpose ground attack weapon and so their use shows where the focus of the Luftwaffe's bombing operations lay. It is useful to separate bombs heavier than one tonne into a separate category, because they were a scarce resource and reserved for especially important tasks. For example, the attacks on Brest and Sevastopol in the USSR showed that it was essential to use such bombs against fortifications, for smaller bombs were ineffective (Weal 2008, 10; Weal 2013, 54). Furthermore, attacks on large and heavily armoured warships like the British HMS *Illustrious* and the Soviet *Marat* also required heavy bombs, for smaller bombs could only damage them (Weal 1998, 9; Weal 2008, 16). Parachute mines dropped by aircraft were another significant weapon against shipping, important to the degree that the Luftwaffe had specialised units of mine laying aircraft (Weal 2013, 12). Their operations were considered effective enough that one unit was withdrawn from bombing Moscow in 1941 in order to lay mines in the Baltic (Weal 2013, 19). These mines were particularly effective in the initial period of the Soviet-German war, because the Soviet navy was "practically unready" to defend against their advanced firing mechanisms, which included combined acoustic and magnetic detonators (Kuznetsov and Morozov 2015: 42, 50).

It is important to consider the Luftwaffe's expenditure of munitions for its anti-aircraft guns, in addition to the air-dropped weapons, in order to gain a fuller understanding of German resource distribution. Ammunition for the heavy anti-aircraft guns was the most resource-intensive and was used on a vast scale, causing shortages by spring 1943 (Westermann 2001: 205). Air defence ammunition was also important in ground combat. The 88 mm anti-aircraft gun was, until 1943, the most powerful German anti-tank weapon and units equipped with it were used to destroy the most heavily armoured Allied and Soviet tanks, whose armour the standard anti-tank guns could not penetrate (Anderson 2015, 243; Forczyk 2012: 49-51, 78).

The data for the Luftwaffe's munitions expenditure in 1941 (Table 16) demonstrates that the Eastern Front did not form the exclusive focus of German aerial operations. Medium calibre bombs were mainly used in the East, but only 46% of the heaviest bombs.

Table 16. Expenditure of selected classes of Luftwaffe munitions, second half of 1941

	<u>All</u> <u>(tonnes)</u>	<u>East</u> <u>(tonnes)</u>	<u>% East</u>
Bombs from 250 to 500 kg	74,751	56,051	75%
Bombs of 1,000 kg and greater	6,807	3,152	46%

	All (units)	East (units)	% East
Naval mines dropped by aircraft	12,824	1,190	9%
Heavy anti-aircraft ammunition (75-94 mm)	3,390,219	937,678	28%
Heaviest anti-aircraft ammunition (105-128 mm)	151,850	2,195	1%
Heavy anti-tank ammunition	156,496	144,410	92%

Source: BArch RL 2-III/632 p.105ff; BArch RL 2-III/633 pp.1-9; munitions weights from RL 2-III/748

The use of aerial mines in the East was limited, even as the Luftwaffe mounted an extensive mining campaign in other theatres. The thousands of mines used in the West were a significant strain on German resources, for these weapons were expensive and similar in size to heavy bombs (1st Line Defence 2015: 8, 41). Indeed, they would often be used as substitute heavy bombs during large Luftwaffe raids, with 50 being dropped on Coventry in November 1940 (ibid: 9, 13). The cumulative effect of the lower use of heavy aerial munitions on the Eastern Front was a notable deterioration in the prospects for German victory in at least some operations. The Soviet defence of the naval bases of Leningrad and Sevastopol was critically reliant on naval gunfire, especially during the initial siege operations in 1941 (Isaev 2011, 378; Forczyk 2014, 83). The Luftwaffe was called upon to sink the warships, but in both cases could not provide adequate numbers of aircraft or munitions for the task (Isaev 2011, 403; Forczyk 2014, 81).

The situation with anti-aircraft (AA) ammunition presents a further important corrective to the established view of German resource distribution. The fact that less than a third of the heavy AA ammunition was used in the East in 1941 again shows the importance of RAF operations in restricting the resources that the Luftwaffe could bring to bear against the USSR. One of the consequences of this was that in the later months of 1941 German troops had insufficient anti-aircraft defences and suffered increased losses to Soviet air attacks (Stahel 2013, 294). The heavy anti-tank ammunition was almost exclusively used in the East, which was to be expected, given the extent of the ground fighting in the USSR and the comparatively small scale of operations in Africa (Overy 1995, 19).

The picture of the Luftwaffe's munitions expenditure changed in some ways in 1942, but the broad distribution between East and West remained similar (Table 17). The Eastern Front absorbed the dominant share of the Luftwaffe's bombing effort. However, the Luftwaffe's naval mining effort declined in scale significantly and the increase in the Eastern front's proportionate share should not obscure the fact that the total number of mines dropped in the East in 1942 was scarcely greater than that during the shorter period in 1941. Another major operational opportunity was thus missed, since Soviet shipping in the Caspian Sea especially was weakly defended and vulnerable to mines, as Hitler himself acknowledged (Hayward 1998: 149-55, 175). The anti-aircraft munitions expenditure again provides a strong counterpoint to suggestions that the East was the main theatre of the war. Less than two-fifths of heavy AA rounds were used in the East. This meant that the strategic defence of Germany and occupied territories in the West continued to impose a limit on the ability of the German armed forces to defend themselves from Soviet air attacks in the East. The munitions expenditure of the heaviest AA guns continued to be relatively low, but these advanced weapons were only used in the West.

Table 17. Expenditure of selected classes of Luftwaffe munitions, 1942

	All (tonnes)	East (tonnes)	% East
Bombs from 250 to 500 kg	166,138	131,542	79%
Bombs of 1,000 kg and greater	14,576	10,764	74%
	All (units)	East (units)	% East
Naval mines dropped by aircraft	4,157	1,695	41%
Heavy anti-aircraft ammunition (75 to 94 mm)	4,867,272	1,747,331	36%
Heaviest anti-aircraft ammunition (105 and 128 mm)	353,550	0	0%
Heavy anti-tank ammunition	413,722	345,992	84%

Source: BArch RL 2-III/633 p.22ff, BArch RL 2-III/634 pp.3-9; munitions weights from RL 2-III/748

It is possible to analyse the distribution of the Luftwaffe's munitions resources in 1943 most clearly (Table 18), because the relevant document contains a summary review of expenditure over the whole year. While the overwhelming proportion of German bombing took place in the East, a very interesting picture is presented by the data on the expenditure of munitions for guns mounted onboard German aircraft. The use of these munitions declined by more than a factor of two from the first to the second half of the year. It might be suggested that this class of munitions was unimportant, because of the small weight of the munitions involved. Such an assumption would be incorrect, since it has been mentioned in Section 4 that aircraft, and hence their on-board weapons, were the primary means of gaining air superiority. Thus, the practical effect of the decline in the use of this class of munitions was a sharp decline in the attrition that the Luftwaffe could inflict on the Soviet air force. This effect was reinforced by the fact that the expenditure of anti-aircraft munitions in the East remained below a third of the overall total, so there was no increase in the weight of AA fire, which might have partly compensated for German weakness in the air.

Table 18. Total expenditure of Luftwaffe munitions, 1943

	Bombs (tonnes)		
	All Fronts	Eastern Front	% East
First half 1943	154,707	132,158	85%
Second half 1943	196,559	168,129	86%
	Ammunition for aircraft guns (tonnes)		
	All Fronts	Eastern Front	% East
First half 1943	8,335	5,016	60%
Second half 1943	6,839	1,799	26%
	Anti-aircraft ammunition (tonnes)		
	All Fronts	Eastern Front	% East
First half 1943	97,911	30,475	31%
Second half 1943	117,709	31,140	26%

Source: BArch RL 2-III/636, pp.17, 125

The general view of German air munitions expenditure that emerges is complicated, but it does not wholly support the view of the Eastern Front as the dominant theatre. Most bombing

operations took place in the East, but with important caveats elucidated above, which placed significant limits on the effectiveness of the overall German offensive effort against the USSR. A critical counter to the thesis of the dominance of the Eastern Front emerges in the case of AA munitions expenditure. A majority of this class of ammunition was used in the West throughout the war, a key way in which Allied aerial operations drew essential German resources away from the Eastern front. The data on aircraft gun munitions in 1943 allows a further important point to be made, that the German ability to effectively confront the Soviet threat in the air was gravely compromised by the second half of 1943, through a deliberate shift of resources to the West.

### Relevance for Political Economy and Conclusions

The resource distribution of the Luftwaffe is relevant to political economy through one of its branches, defence economics. The issue of the destruction of human and physical capital in war is one of the core concerns of defence economics (Sandler and Hartley 2007, 1221), and the Second World War is a core object of study as the most destructive war in history. Furthermore, the war was a period of technological revolution, caused by a great acceleration of research and development in the combatant powers (Coulomb 2004, 247). The great destructiveness of the war and the pace of technological change are highlighted in Sections 4 and 2 of this work, respectively. The entire work reflects on the problem of “multiple component conflicts”, conflicts where adversaries confront each other across multiple battlefields simultaneously (Garfinkel and Skaperdas 2012, 504). Indeed, the issue of Luftwaffe resource distribution is in some sense more complex than the multiple battlefields models currently in use in defence economics, because these models focus on conflicts between two opponents (ibid, 505-10). In the European air war, there were three parties; the Western Allies, the Axis and the USSR. The present work has somewhat simplified the analysis by omitting any discussion of Germany’s Axis allies, but the core of the discussion nevertheless concerns the very complex interaction of three military forces across three different fronts; the Western front, the Mediterranean and the East. Several of the many linkages across the battlefields that arise through the aggregation of battlefield outcomes (Garfinkel and Skaperdas 2012, 505) have been discussed, particularly the way in which the results of the fighting in the West constrained Luftwaffe resource availability in the East.

In terms of aggregate military strength, the Allies greatly outnumbered the Axis, because of the far larger aggregate GDP of the Allied nations (Harrison 2015, 69). This asymmetry of economic strength allowed the Allies and the USSR to produce more military capital goods in the crucial year 1942 (ibid, 102), a year the importance of which has been repeatedly emphasised in this study. However, the critical issue from the point of view of defence economics is that Germany was forced into a symmetric qualitative arms race by the Western Allies. Such an arms race is different from a more conventional symmetric quantitative arms race, like the battleship construction race before the First World War, and involves the opposing sides attempting to gain an advantage above all in the quality of their military equipment compared to that of their opponent (Sandler and Hartley 2007, 917). As discussed in Section 2, the Allies were successful in developing and deploying aviation technology, especially engines, of superior quality which overwhelmed German air power. It can be said that Germany attempted to initiate a parallel qualitative and asymmetric race by producing rocket and jet engine technologies which the Allies had not yet deployed, having had no success in the symmetric competition over piston aircraft technology. The German problem was that the aerospace industry suffers from particularly sharp trade-offs between the quantity and quality of goods produced (ibid, 918). The misallocation of German resources, a

serious problem throughout the war (Harrison 2015, 80), resulted in Germany mismanaging the trade-off and as a result it produced a great quantity of aviation goods of inferior quality, while producing a small quantity of superior goods late in the war.

German aviation was also hamstrung by the problem of asset specificity common in aviation (Sandler and Hartley 2007, 990), namely that particular aircraft were constrained by their original design so that they were suitable only for a narrow range of operational tasks. This is why various older aircraft types were used almost exclusively on the Eastern front in the later stages of the war, because they could not perform the more complex tasks which confronted the Luftwaffe in the West. This was partly the consequence of another general issue of industrial production, the importance of economies of scale and learning effects for the efficient production of large numbers of aircraft (Schermer and Streb 2016, 255-6). Once a large factory had been organised and the workforce had learned the skills of mass production, there was an issue of path dependence, meaning that it was expensive to organise the production of a new aircraft using the same productive resources. Given Germany's smaller resource base than the Allies, it was thus forced to produce obsolete types for too long, as discussed in Section 2. The process of designing aircraft involves high fixed costs and for optimum combat efficiency performance must take precedence over cost, since even a small performance margin in aerial warfare could render an expensive investment by an opponent obsolete (Sandler and Hartley 2007: 1157, 1186). Since Germany had difficulty bearing the extreme costs of this technological contest with the Allies, it attempted to invest in human capital, namely aircrew, a choice which has been shown to have promise in 20<sup>th</sup> century aviation (ibid, 1107). The problem, as shown in Section 4, is that the Luftwaffe lost this human capital on too large a scale for this strategy to be sustained.

Few of the German problems appeared in the fighting on the Eastern front with the same urgency that they acquired in the West. This was because the economies of the USSR and Germany were of similar size and by 1942 the Soviet one teetered on the brink of collapse caused by the German offensives and the loss of Soviet labour and capital that they entailed (Harrison 2015: 110, 114). While Harrison (ibid, 86) highlights the prodigious Soviet output of armaments even after this reduction in the Soviet resource base, the analysis in this work shows that the Soviet forces were much less efficient than Allied ones in using their equipment to destroy the military goods of Germany's war machine. Soviet industry was also beset by contracting problems and collusion of the military with inefficient manufacturers (Harrison 2015, 193-6). In terms of the arms races discussed above, the war in the East was a symmetric qualitative competition in which Germany retained a reasonable advantage throughout the 1941-43 period.

The inability of Germany to sustain its position in the aviation arms race against the Western Allies meant that by the end of 1943 the Eastern front had become a distant second priority compared to the West. This process was well underway by late 1942 and was caused by Allied technical superiority and hence superior military efficiency. In the war on the Eastern Front, the German air force was able to maintain a degree of effectiveness as late as the end of 1943, but Allied pressure put a firm limit on the quantity and quality of resources that Germany could allocate to the East. In view of this, contemporary literature which emphasises Allied effectiveness in the final period of the war should be revised, to take into account the decisive nature of events in 1941-43.

## Appendix A. Aircraft Strength of the Luftwaffe, November 1941 to February 1944

It is necessary to note that the figures in tables A-1 through A-6 include most, but not all, aircraft available to the German air force. The following classes of aircraft were not counted in the totals:

- Mine sweeping aircraft
- Communications aircraft
- Weather reconnaissance aircraft
- Seaplanes
- Air-Sea rescue aircraft
- Gliders and glider tugs
- Axis units equipped with German aircraft

These classes would add several hundred aircraft to the totals below. However, these classes consisted predominantly of aircraft used for second-line duties, so it was deemed appropriate not to include them in the analysis, which focuses on the forces at the front.

Even with the above deletions, the totals calculated here are in some cases **higher** than the total numbers of aircraft of the Luftwaffe stated in the summary tables at the beginning of each original document. For example, the summary table for 20 December 1943 states that the Luftwaffe had 6,630 aircraft on strength (RL 2-III/728a, p. 1g), while the grand total calculated for the corresponding date in Table A-5 below is 7,093 aircraft. The reason for this discrepancy is that liaison aircraft were not included in the total in the original document. Some other units, which were newly created and for this reason had not yet been included in the formal established strength of the Luftwaffe, were also not counted in the original total. This illustrates the deficiency of the Luftwaffe's original record-keeping, which compounds the problem created by the loss or destruction of most of the original documents and makes research in this field so difficult.

Tables A-1 through A-6 provide the interested reader with full information about the absolute numbers of Luftwaffe aircraft in each class for the six dates analysed in the main text, as well as the percentages of aircraft in each class located on the Eastern front. Tables A-7 through A-12 present data for new aircraft types, which either entered Luftwaffe service after June 1941, the month in which Nazi Germany invaded the USSR, or were only used on a large scale in this later period.

Table A-1. Allocation of Luftwaffe operational aircraft, 8 November 1941

Aircraft Role	Total aircraft	In reserve	At the fronts	Eastern front	% East of frontline	% East of total aircraft
Single-engine fighter	1,153	265	888	442	50%	38%
Twin-engine fighter	163	31	132	91	69%	56%
Night fighter	322	53	267	0	0%	0%
Bomber	1,249	247	1,002	694	69%	56%

Dive bomber and ground attack	410	0	410	344	84%	84%
Reconnaissance	666	106	560	471	84%	71%
Transport	675	55	620	355	57%	53%
Liaison aircraft with combat units	109	13	96	90	94%	83%
<b>Grand Total</b>	<b>4,747</b>	<b>770</b>	<b>3,975</b>	<b>2,487</b>	<b>63%</b>	<b>52%</b>
<b>Main combat aircraft classes only</b>	<b>3,963</b>	<b>702</b>	<b>3,259</b>	<b>2,042</b>	<b>63%</b>	<b>52%</b>

Source: BArch RL 2-III/716a, pp. 3–10a

Table A-2. Allocation of Luftwaffe operational aircraft, 27 December 1941

Aircraft Role	Total	In reserve	At the fronts	Eastern front	% East of frontline	% East of total aircraft
Single-engine fighter	1,098	199	899	421	47%	38%
Twin-engine fighter	179	42	137	107	78%	60%
Night fighter	266	43	223	0	0%	0%
Bomber	1,237	377	860	481	56%	39%
Ground attack and dive bomber	366	79	287	199	69%	54%
Reconnaissance	649	187	462	363	79%	56%
Transport	824	99	725	296	41%	36%
Liaison aircraft with combat units	93	15	78	69	88%	74%
<b>Grand Total</b>	<b>4,712</b>	<b>1,041</b>	<b>3,671</b>	<b>1,936</b>	<b>53%</b>	<b>41%</b>
<b>Main combat aircraft classes only</b>	<b>3,795</b>	<b>927</b>	<b>2,868</b>	<b>1,571</b>	<b>55%</b>	<b>41%</b>

Source: BArch RL 2-III/716b, pp. 100–108a

Table A-3. Allocation of Luftwaffe operational aircraft, 10 December 1942

Aircraft Role	Total	In reserve	At the fronts	Eastern front	% East of frontline	% East of total aircraft
Single-engine fighter	1,439	209	1,230	468	38%	33%
Twin-engine fighter	182	14	168	83	49%	46%
Night fighter	382	51	331	0		

Auxiliary night fighter	58	44	14	14	100%	24%
Bomber	1,306	361	945	445	47%	34%
Ground attack and dive bomber	448	53	395	315	80%	70%
Reconnaissance	664	43	621	477	77%	72%
Night harassment	97	0	97	97	100%	100%
Transport	997	1	996	471	47%	47%
Liaison aircraft with combat units	139	8	131	108	82%	78%
<b>Grand Total</b>	<b>5,712</b>	<b>784</b>	<b>4,928</b>	<b>2,478</b>	<b>50%</b>	<b>43%</b>
<b>Main combat aircraft classes only</b>	<b>4,479</b>	<b>775</b>	<b>3,704</b>	<b>1,802</b>	<b>49%</b>	<b>40%</b>

Source: BArch RL 2-III/722a, pp. 2–14a

Table A-4. Allocation of Luftwaffe operational aircraft, 10 February 1943

Aircraft Role	Total	In reserve	At the fronts	Eastern front	% East of frontline	% East of total aircraft
Single-engine fighter	1,356	139	1,217	423	35%	31%
Twin-engine fighter	171	5	166	42	25%	25%
Night fighter	477	29	448	0		
Auxiliary night fighter	28	0	28	28	100%	100%
Bomber	1,468	624	844	478	57%	33%
Ground attack and dive bomber	569	226	343	258	75%	45%
Night harassment	213	0	213	213	100%	100%
Reconnaissance	671	43	628	442	70%	66%
Transport	764	81	683	446	65%	58%
Liaison aircraft with combat units	134	5	129	95	74%	71%
<b>Grand Total</b>	<b>5,851</b>	<b>1,152</b>	<b>4,699</b>	<b>2,425</b>	<b>52%</b>	<b>41%</b>
<b>Main combat aircraft classes only</b>	<b>4,740</b>	<b>1,066</b>	<b>3,674</b>	<b>1,671</b>	<b>45%</b>	<b>35%</b>

Source: BArch RL 2-III/722b, pp. 120–132a

Table A-5. Allocation of Luftwaffe operational aircraft, 20 December 1943

Aircraft Role	Total	In reserve	At the fronts	Eastern front	% East of frontline	% East of total aircraft
Single-engine day fighter	1,561	79	1,482	393	27%	25%
Twin-engine day fighter	404	63	341	20	6%	5%
Twin-engine night fighter	627	45	582	49	8%	8%
Single-engine night fighter	111	1	110	0	0%	0%
Bomber	1,519	628	891	378	42%	25%
Ground attack and dive bomber	641	101	540	485	90%	76%
Night harassment	289	0	289	260	90%	90%
Reconnaissance	693	73	620	343	55%	49%
Transport	941	305	636	400	63%	43%
Liaison aircraft with combat units	307	20	287	126	44%	41%
<b>Grand Total</b>	<b>7,093</b>	<b>1,315</b>	<b>5,778</b>	<b>2,454</b>	<b>42%</b>	<b>35%</b>
<b>Main combat aircraft classes only</b>	<b>5,556</b>	<b>990</b>	<b>4,566</b>	<b>1,668</b>	<b>37%</b>	<b>30%</b>

Source: BArch RL 2-III/728a, pp. 2–12a

Table A-6. Allocation of Luftwaffe operational aircraft, 10 February 1944

Aircraft Role	Total aircraft	In reserve	At the fronts	Eastern front	% East of frontline	% East of total aircraft
Single-engine fighter	1,616	20	1,596	339	21%	21%
Twin-engine fighter	412	64	348	19	5%	5%
Night fighter	623	22	601	55	9%	9%
Single-engine night fighter	129	1	128	0	0%	0%
Bomber	1,530	647	883	262	30%	17%
Ground attack and dive bomber	702	17	685	605	88%	86%
Night harassment	367	0	367	330	90%	90%
Reconnaissance	691	88	603	368	61%	53%
Transport	1,024	305	719	394	55%	38%

Liaison aircraft with combat units	340	22	318	147	46%	43%
<b>Grand Total</b>	<b>7,434</b>	<b>1,186</b>	<b>6,248</b>	<b>2,519</b>	<b>40%</b>	<b>34%</b>
<u>Main combat aircraft classes only</u>	5,703	859	4,844	1,648	<b>34%</b>	29%

Source: BArch RL 2-III/728b, pp. 96–106a

Table A-7. Allocation of new types of Luftwaffe aircraft, 8 November 1941

Role	Type	Total aircraft	In reserve	At the fronts	Eastern front	% East of frontline	% East of total aircraft
Single-engine fighter	Fw 190	110	66	44	0		
Twin-engine night fighter	Ju 88	31	0	31	0		
Twin-engine day fighter	Me 210	31	31	0	0		
Four-engine bomber and reconnaissance	Fw 200	40	0	40	0		
Twin-engine bomber	Do 217	100	44	56	0		
Reconnaissance	Bf 109, Bf 110, Do 217, Ju 86	84	0	84	64	76%	76%
Reconnaissance	Fw 189	82	79	3	3	100%	4%
<b>Grand total for selected types</b>		<b>478</b>	<b>220</b>	<b>258</b>	<b>67</b>	<b>26%</b>	<b>14%</b>

Source: BArch RL 2-III/716a, pp. 3a–10b

Table A-8 Strength. Allocation of new types of Luftwaffe aircraft, 27 December 1941

Role	Type	Total aircraft	In reserve	At the fronts	Eastern front	% East of frontline	% East of total aircraft
Single-engine Fighter	Fw 190	147	74	73	0		
Twin-engine night fighter	Ju 88	27	0	27	0		
Twin-engine day fighter	Me 210	42	42	0	0		
Four-engine bomber and reconnaissance	Fw 200	27	7	20	0		
Twin-engine bomber	Do 217	115	60	55	0		

Reconnaissance	Bf 109, Bf 110, Ju 86	90	33	57	26	46%	29%
Reconnaissance	Fw 189	81	79	2	2	100%	2%
Heavy transport	Ju 90	1	0	1	0	0%	0%
<b>Grand total for selected types</b>		530	295	235	28	<b>12%</b>	<b>5%</b>

Source: BArch RL 2-III/716b, pp. 100a–108b

Table A-9 Strength. Allocation of new types of Luftwaffe aircraft, 10 December 1942

Role	Type	Total aircraft	In reserve	At the fronts	Eastern front	% East of frontline	% East of total aircraft
Single-engine fighter	Fw 190	670	146	524	44	8%	7%
Ground attack and reconnaissance	Fw 190	43	23	20	0		
Twin-engine day and night fighter	Ju 88	107	25	82	0		
Twin-engine day and night fighter	Do 217, Me 210	64	0	64	0		
Four-engine bomber and reconnaissance	Fw 200	51	3	48	0		
Four-engine bomber	He 177	52	52	0	0		
Twin-engine bomber	Do 217	184	119	65	0		
Ground attack	Hs 129	37	0	37	31		
Reconnaissance	Bf 109, Bf 110, Do 217, Ju 86	105	0	105	63	60%	60%
Reconnaissance	Fw 189	144	0	144	143	99%	99%
Heavy transport	Bv 222, Ju 90, Me 323	27	0	27	0		
<b>Grand total for selected types</b>		1,484	368	1,116	281	<b>25%</b>	<b>19%</b>

Source: BArch RL 2-III/722a, pp. 2–14a

Table A-10 Allocation of new types of Luftwaffe aircraft, 10 February 1943

Role	Type	Total aircraft	In reserve	At the fronts	Eastern front	% East of frontline	% East of total
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							aircraft
Single-engine fighter	Fw 190	667	51	616	180	29%	27%
Ground attack and reconnaissance	Fw 190	169	75	94	13	14%	8%
Twin-engine day and night fighter	Ju 88	144	34	110	1	1%	1%
Twin-engine day and night fighter	Do 217, Me 210	91	0	91	0		
Four-engine bomber and reconnaissance	Fw 200	23	7	16	0		
Four-engine bomber	He 177	47	47	0	0		
Twin-engine bomber	Do 217	229	165	64	0		
Ground Attack	Hs 129	37	9	28	18	64%	49%
Reconnaissance	Ar 240, Bf 109, Bf 110, Do 217, Ju 86, Me 210	104	10	94	58	62%	56%
Reconnaissance	Fw 189	129	7	122	121	99%	94%
Heavy transport	Bv 222, Fw 200, Me 323	64	4	60	25	42%	39%
<b>Grand total for selected types</b>		1,704	409	1,295	416	<b>32%</b>	<b>24%</b>

Source: BArch RL 2-III/722b, pp. 120–132a

Table A-11 Strength. Allocation of new types of Luftwaffe aircraft, 20 December 1943

Role	Type	Total aircraft	In reserve	At the fronts	Eastern front	% East of frontline	% East of total aircraft
Single-engine fighter	Fw 190	467	0	467	173	37%	37%
Single-engine night fighter	Fw 190	17	0	17	0	0%	0%
Ground attack and reconnaissance	Fw 190	160	9	151	83	55%	52%
Twin-engine day and night fighter	Ju 88	251	11	240	33	14%	13%

Twin-engine day and night fighter	Do 217, He 219, Me 210, Me 410	162	61	101	3	3%	2%
Four-engine bomber and reconnaissance	Fw 200, Ju 290	119	35	84	0	0%	0%
Four-engine bomber	He 177	97	71	26	0	0%	0%
Twin-engine bomber	Do 217, Ju 188	210	38	172	0	0%	0%
Ground attack	Hs 129	51	0	51	51	100%	100%
Reconnaissance	Bf 109, Bf 110, Do 217, Ju 188, Me 410	277	60	217	85	39%	31%
Reconnaissance	Fw 189	101	0	101	101	100%	100%
Heavy transport	Ju 90, Me 323, Piaggio 108	54	5	49	42	86%	78%
<b>Grand total for selected types</b>		1,966	290	1,676	571	<b>34%</b>	29%

Source: BArch RL 2-III/728a, pp. 2–12a

Table A-12 Strength. Allocation of new types of Luftwaffe aircraft, 10 February 1944

Role	Type	Total aircraft	In reserve	At the fronts	Eastern front	% East of frontline	% East of total aircraft
Single-engine fighter	Fw 190	456	0	456	97	21%	21%
Single-engine night fighter	Fw 190	18	1	17	0	0%	0%
Ground attack and reconnaissance	Fw 190	203	0	203	116	57%	57%
Twin-engine day and night fighter	Ju 88	247	0	247	50	20%	20%
Twin-engine day and night fighter	Do 217, He 219, Me 210, Me 410	165	64	101	3	3%	2%
Four-engine bomber and reconnaissance	Fw 200, Ju 290	83	16	67	0		
Four-engine bomber	He 177	155	96	59	0		
Twin-engine bomber	Do 217, Ju 188	182	0	182	0	0%	0%

Ground attack	Hs 129	48	0	48	48	100%	100%
Reconnaissance	Bf 109, Bf 110, Do 217, Ju 188, Me 410	306	63	243	130	53%	42%
Reconnaissance	Fw 189	114	0	114	112	98%	98%
Heavy transport	Ju 90, Me 323, Piaggio 108	53	8	45	45	100%	85%
<b>Grand total for selected types</b>		2,030	248	1,782	601	<b>34%</b>	<b>30%</b>

Source: BArch RL 2-III/728b, pp. 96–106a

### Appendix B. Luftwaffe losses by front from Matti Salonen database

This appendix will elucidate the nature and significance of the Luftwaffe loss database compiled by Matti Salonen, as well as the limitations of the use of this database for the analysis of the distribution of Luftwaffe losses between theatres. The appendix will first describe the information contained within the database and then proceed to describe how this information was deployed for the analysis contained in this work. It will be emphasised that the calculations of aircraft losses in each theatre of operations based on the records in the database are necessarily imprecise, but they are sufficiently accurate to allow conclusions about German resource distribution to be drawn.

Two sets of tables are presented at the end of the appendix. The first set of tables presents the full set of calculations of monthly Luftwaffe losses, first for all aircraft classes and then for single-engine fighters only. The main conclusions based on these calculations were discussed in the main body of the work, so the full data is presented here so that the reader can trace how the conclusions were reached. The second set of tables presented here compares the calculations from the database with loss data from two other important sources. The first is Murray's calculations of Luftwaffe losses, based on the same primary sources from the German archives as the Salonen database. The second source is an extremely useful document taken directly from the German archives. This is a review of monthly aircraft losses from September to December 1943, inclusive. The comparison of the calculations to these independent sources confirms that the calculations performed here constitute a very good approximation of Luftwaffe aircraft losses and that the conclusions based on these calculations are therefore based on a solid foundation.

The utility of the Salonen database lies in the fact that it is a digitised version of the original German loss reports, which list the damage or destruction of individual aircraft (BArch RL 2-III/1177 and following volumes). Digitisation allows a large amount of data to be analysed relatively quickly, for the original documents are printed on microfiche and are ordered not by the date of loss, but rather by the date when the loss was reported to the Luftwaffe command (Brekken 2008), which makes summary calculations almost impossible. The resulting database is thus the most comprehensive source currently available for the analysis of Luftwaffe aircraft losses, and has been used for this purpose in published works (for example Bergström 2015: 17, 307).

The extract of the database used for the present work, for the period from June 1941 to December 1943, consists of more than 55,000 individual records of aircraft loss or damage incidents. Each record concerns a single aircraft and lists the unit to which the aircraft belonged, the aircraft type and the extent of damage sustained, reported as a percentage, and its cause. The higher command to which the unit was subordinated is also recorded. The information concerning the extent of damage should allow a determination of whether a particular aircraft was lost or only damaged, since damage of 60% or above meant that an aircraft was scrapped, while lesser damage was repaired (Bungay 2000: 194). However, in the case of some records no specific damage percentage is stated, which rendered it impossible to determine the final fate of the aircraft concerned. A further difficulty is presented by the fact that the data about the unit or even the higher command to which an aircraft belonged is sometimes incomplete. Since the main purpose of the present work is to determine the distribution of losses by operational theatre (Western, Mediterranean or Eastern), this presents a significant complication for the analysis.

The difficulty concerning indeterminate damage was resolved by performing two calculations for each month of the war considered in the analysis. In the first calculation, only those aircraft for which the damage percentage is listed, and is equal to 60% or greater, are included. In the second calculation, the aircraft for which the damage is not stated explicitly are included as well. This second calculation is justified by the fact that in some cases where the damage percentage is not stated at all, the aircraft concerned had only one crew member, the pilot, who was killed or went missing in action. In such cases, it is eminently reasonable to assume that the aircraft was lost as well. Due to time constraints, it was not possible to cross-check the fate of the aircraft against the fate of the crew in the cases when the damage sustained by the aircraft was not reported. Therefore, some of the aircraft losses included in the second calculation will be aircraft which were only damaged and then repaired. It is not possible to reduce this uncertainty without much further work, so it is stated here merely to clarify that the results obtained in the calculations cannot be considered definitive.

The question of determining the operational theatre in which a given aircraft was lost was resolved by cross-checking the operational command to which it belonged with the country or geographical region where the loss occurred. In multiple cases, secondary sources and communication with Larry de Zeng, an American author of multiple books about the Luftwaffe, helped in clarifying the position. Here too it must be emphasised that the resulting calculation is imprecise and it is most useful for analysing trends in Luftwaffe resource distribution, rather than attempting to obtain exact figures of German aircraft losses, a task which is likely to remain beyond the reach of researchers due to the loss of the majority of the original wartime documents.

The final point that must be mentioned is the method which was used to select losses for analysis from the database. Since the purpose of the work is to analyse the distribution of German resources between the fighting fronts, all losses of flying schools and other training units were omitted, as far as possible. This was not straightforward, for the training units included *Ergänzungsgruppen* (Operational Training Units), which formed the final stage of training before aircrew were sent to frontline units (Bergström 2015: 10, 50). Some of these units operated as improvised combat units on the fighting fronts, sometimes for extended periods of time (Weal 2001: 45, 55). For this reason, it was decided to include all the *Ergänzungsgruppen* losses which took place on the fighting fronts, but to exclude those which were suffered in the rear areas, such as training bases in France. The same principle

was applied to the units involved in aircraft trials and similar auxiliary units. On the other hand, glider losses were completely excluded, since instances of the combat use of gliders were relatively rare and the gliders were much less resource-intensive to build than aircraft, being unpowered and usually small. The result of the progressive exclusion of records deemed irrelevant for the analysis was that the final total of loss records included in the analysis was 24,914. This is substantially less than half of the initial number, which was in excess of 55,000. That the method was broadly correct is demonstrated by a comparison with other sources, for which see tables B-3 through B-5 below.

The nature of the database and its limitations having been described, it is now necessary to discuss the tables presented at the end of this Appendix. Table B-1 presents the calculations of total aircraft losses and the losses in each theatre of operations. As discussed above, two calculations are given for each theatre and each month. The columns headed 'possible' contain the broader calculations, where losses of aircraft which sustained an unknown degree of damage are included. Table B-2 presents the same pair of calculations, but for single-engine fighters only. These two tables taken together form the basis for the discussion of the distribution of Luftwaffe losses between theatres, based on the Salonen database, which is contained in the main body of this work.

The comparison with other sources which contain information about Luftwaffe monthly losses and the distribution of losses between theatres of operations begins with Table B-3. The first of the two sources with which comparison is made is Professor Williamson Murray's calculation of German losses, covering the period from June 1942 to November 1943 (1996: 114, 148). Murray made his calculations using the same basic archival sources (BArch RL 2-III/1177 *et seq.*) which were digitised by Salonen. Murray made the calculations himself and his precise method can no longer be remembered due to the passage of time since publication, as recounted to this author in a communication. It will be seen that the figures calculated by Murray are greater than the figures in Table B-1, which may be partially explained by his inclusion of the *Ergänzungsgruppen* losses, discussed above. These units were primarily based in the West and Mediterranean and it is telling that the biggest difference between the figures calculated by this author and those calculated by Murray concerns losses in those two theatres. Since the core thesis of the present work is that the Eastern Front was *less important* as a strain on German resources than commonly thought, it is pleasing that that Murray's figures for the Eastern Front are broadly similar and, in consequence, this work is less vulnerable to accusations of overstating its case and understating the importance of the fighting in the East. The comparison is continued in Table B-4, which is in a different format because Murray's calculation for 1943 changed and now included the Mediterranean as a separate series, not merging it with losses on the Western Front, as had been the case for his 1942 calculation.

The final comparison, in Table B-5, is the most important. This is because the comparison is not only with Murray's calculations, but also with an original document, BArch RL 2-III/944. This document contains summaries, compiled by the German air force high command, of the Luftwaffe's losses during the months of September through December 1943. It is thus a definitive source for this period. It will be seen that the loss calculations based on the database are quite similar, though not identical, to the official statement of Luftwaffe losses for the period concerned. This emphasises that the calculations performed here, based on data kindly provided by Matti Salonen, can be used effectively to analyse the trends in Luftwaffe resource distribution.

Table B-1. Total Luftwaffe aircraft losses and losses in each theatre of operations, 1941 – 1943.

Month	Total	Possible	Western Front	Possible	Mediterranean	Possible	Eastern Front	Possible
June-41	646	807	189	208	50	56	407	543
July-41	905	1,086	164	179	26	29	715	877
August-41	512	618	107	122	38	39	367	457
September-41	460	533	108	112	22	24	330	397
October-41	451	529	87	97	23	23	341	409
November-41	344	403	77	86	74	84	193	233
December-41	466	514	89	91	209	224	168	199
January-42	380	450	67	72	77	84	236	292
February-42	386	492	62	69	76	81	248	342
March-42	508	625	86	94	96	106	326	425
April-42	436	544	120	130	110	127	205	289
May-42	619	747	138	154	132	149	349	444
June-42	613	714	114	130	160	180	339	404
July-42	748	871	140	155	191	209	417	507
August-42	740	861	194	210	127	137	419	514
September-42	567	657	108	119	123	135	336	403
October-42	511	565	104	106	208	226	199	233
November-42	761	848	90	94	436	468	235	286
December-42	720	813	85	91	251	274	384	448
January-43	800	936	125	132	267	293	408	486
February-43	588	692	110	119	205	221	273	351
March-43	792	858	205	212	291	308	296	338
April-43	868	937	185	194	475	521	208	222
May-43	904	981	270	285	319	346	315	350
June-43	717	775	216	222	257	280	244	273
July-43	1,577	1,719	405	422	608	648	564	649
August-43	1,201	1,306	446	460	302	332	453	514
September-43	1,180	1,285	420	434	423	446	337	400
October-43	1,008	1,098	470	487	255	263	283	348
November-43	835	909	448	469	205	221	182	219
December-43	645	741	392	426	118	131	135	182
Total of above	<b>21,888</b>	<b>24,914</b>	5,821	6,181	6,154	6,665	9,912	12,034

Table B-2. Total Luftwaffe **single-engine fighter** losses and losses in each theatre of operations, 1941 – 1943.

Month	Total	Possible	Western Front	Possible	Mediterranean	Possible	Eastern Front	Possible
June-41	189	206	79	82	9	11	101	113
July-41	264	303	67	70	3	3	194	228

August-41	151	169	40	46	4	4	107	119
September-41	129	138	32	32	3	3	94	101
October-41	80	90	23	26	4	4	53	60
November-41	71	80	23	24	10	13	38	43
December-41	96	102	25	25	42	48	29	29
January-42	81	82	14	14	22	22	45	46
February-42	87	91	17	19	22	23	48	49
March-42	128	135	34	37	39	40	55	58
April-42	132	146	44	50	40	44	48	52
May-42	194	208	38	39	45	49	111	120
June-42	167	184	27	29	53	59	87	96
July-42	190	208	36	38	53	58	101	112
August-42	225	245	62	65	28	29	135	151
September-42	172	184	28	28	38	43	106	113
October-42	156	173	38	38	76	83	42	52
November-42	157	168	26	27	82	90	49	51
December-42	110	123	22	23	36	42	52	58
January-43	199	214	56	57	87	94	56	61
February-43	160	172	42	42	61	67	57	63
March-43	263	274	67	70	101	108	95	96
April-43	264	283	78	79	126	141	60	63
May-43	278	295	113	117	79	87	86	91
June-43	250	269	90	93	93	105	67	71
July-43	593	617	231	234	198	212	164	171
August-43	418	442	184	190	116	131	118	121
September-43	406	426	212	223	119	119	75	84
October-43	374	386	220	226	81	84	73	76
November-43	312	324	226	231	48	52	38	41
December-43	261	294	174	194	57	64	30	36
Total of above	<b>6,557</b>	<b>7,031</b>	2,368	2,468	1,775	1,932	2,414	2,625

Table B-3. Comparison of loss calculations from Salonen database with those in Murray (1996)

Month	Western and Mediterranean	Possible	Eastern Front	Possible	Total	Possible
June-42	274	310	339	404	613	714
<u>Murray</u>	299		350		649	
<b>difference</b>	<b>+25</b>		<b>+11</b>		<b>+36</b>	
July-42	331	364	417	507	748	871
<u>Murray</u>	386		438		824	
<b>difference</b>	<b>+53</b>		<b>+21</b>		<b>+74</b>	
August-42	321	347	419	514	740	861
<u>Murray</u>	371		436		807	
<b>difference</b>	<b>+50</b>		<b>+17</b>		<b>+67</b>	
September-42	231	254	336	403	567	657
<u>Murray</u>	206		332		538	
<b>difference</b>	<b>-25</b>		<b>-4</b>		<b>-29</b>	
October-42	312	332	199	233	511	565
<u>Murray</u>	324		200		524	
<b>difference</b>	<b>+12</b>		<b>+1</b>		<b>+13</b>	
November-42	526	562	235	286	761	848
<u>Murray</u>	595		224		819	
<b>difference</b>	<b>+69</b>		<b>-11</b>		<b>+58</b>	
December-42	336	365	384	448	720	813
<u>Murray</u>	366		408		774	
<b>difference</b>	<b>+30</b>		<b>+24</b>		<b>+54</b>	

Table B-4. Continued comparison of loss calculations from Salonen database with those in Murray (1996)

Month	Western Front	Possible	Mediterranean	Possible	Eastern Front	Possible	Total	Possible
January-43	125	132	267	293	408	486	800	936
<u>Murray</u>	176		282		482		940	
<b>difference</b>	<b>+51</b>		<b>+15</b>		<b>+74</b>		<b>+140</b>	
February-43	110	119	205	221	273	351	588	692
<u>Murray</u>	162		206		318		686	
<b>difference</b>	<b>+52</b>		<b>+1</b>		<b>+45</b>		<b>+98</b>	
March-43	205	212	291	308	296	338	792	858
<u>Murray</u>	256		308		314		878	
<b>difference</b>	<b>+51</b>		<b>+17</b>		<b>+18</b>		<b>+86</b>	
April-43	185	194	475	521	208	222	868	937
<u>Murray</u>	255		572		238		1,065	
<b>difference</b>	<b>+70</b>		<b>+97</b>		<b>+30</b>		<b>+197</b>	
May-43	270	285	319	346	315	350	904	981
<u>Murray</u>	331		333		331		995	
<b>difference</b>	<b>+61</b>		<b>+14</b>		<b>+16</b>		<b>+91</b>	
June-43	216	222	257	280	244	273	717	775
<u>Murray</u>	313		235		249		797	

<b>difference</b>	<b>+97</b>		<b>-22</b>		<b>+5</b>		<b>+80</b>	
July-43	405	422	608	648	564	649	1,577	1,719
<u>Murray</u>	526		711		558		1,795	
<b>difference</b>	<b>+121</b>		<b>+103</b>		<b>-6</b>		<b>+218</b>	
August-43	446	460	302	332	453	514	1,201	1,306
<u>Murray</u>	625		321		472		1,418	
<b>difference</b>	<b>+179</b>		<b>+19</b>		<b>+19</b>		<b>+217</b>	

Table B-5. Comparison of loss calculations from Salonen database with those in Murray (1996) and with original German document (RL 2-III/944)

Month	Western Front	Possible	Mediterranean	Possible	Eastern Front	Possible	Total	Possible
September-43	420	434	423	446	337	400	1180	1285
<u>Murray</u>	522		503		338		1363	
<b>difference</b>	<b>+102</b>		<b>+80</b>		<b>+1</b>		<b>+183</b>	
<u>RL 2-III/944</u>	493		381		326		1200	
<b>difference</b>	<b>+73</b>		<b>-42</b>		<b>-11</b>		<b>+20</b>	
October-43	470	487	255	263	283	348	1008	1098
<u>Murray</u>	530		285		279		1094	
<b>difference</b>	<b>+60</b>		<b>+30</b>		<b>-4</b>		<b>+186</b>	
<u>RL 2-III/944</u>	541		237		266		1044	
<b>difference</b>	<b>+71</b>		<b>-18</b>		<b>-17</b>		<b>+36</b>	
November-43	448	469	205	221	182	219	835	909
<u>Murray</u>	529		180		194		903	
<b>difference</b>	<b>+81</b>		<b>-25</b>		<b>+12</b>		<b>+68</b>	
<u>RL 2-III/944</u>	496		206		175		877	
<b>difference</b>	<b>+48</b>		<b>+1</b>		<b>-7</b>		<b>+42</b>	
December-43	392	426	118	131	135	182	645	739
<u>RL 2-III/944</u>	484		119		154		757	
<b>difference</b>	<b>+92</b>		<b>+1</b>		<b>+19</b>		<b>+112</b>	

Appendix C. Total Losses of Luftwaffe aircrew and aircraft, 1941-43

Tables 13 and 14 from the main text are reproduced here in an expanded version,

Table C-1. Losses of Luftwaffe aircrew and aircraft to operational causes, 22.06.1941 to 01.01.1944, by front

	Western Front			Mediterranean			East		
	<u>Aircrew lost</u>	<u>Officers lost</u>	<u>Aircraft destroyed</u>	<u>Aircrew lost</u>	<u>Officers lost</u>	<u>Aircraft destroyed</u>	<u>Aircrew lost</u>	<u>Officers lost</u>	<u>Aircraft destroyed</u>
Total	5,949	1,148	4,210	7,158	1,081	5,278	12,029	2,221	8,619
	24%	26%	23%	28%	24%	29%	<b>48%</b>	<b>50%</b>	<b>48%</b>
Single-engine fighters	954	294	1,978	579	177	1,590	980	307	2,300
	38%	38%	34%	23%	23%	27%	<b>39%</b>	<b>39%</b>	<b>39%</b>
Twin-engine day	175	25	138	259	62	377	461	121	632

fighters	20%	12%	12%	29%	30%	33%	52%	58%	55%
Night fighters	498	109	465	100	21	62	11	3	7
	82%	82%	87%	16%	16%	12%	2%	2%	1%
Bombers	3,214	411	1,032	3,942	478	1,491	6,120	825	2,511
	24%	24%	21%	30%	28%	30%	46%	48%	50%
Day Ground attack	70	20	102	345	71	509	1,056	252	1,182
	5%	6%	6%	23%	21%	28%	72%	73%	66%
Night Ground attack	2	0	1	5	1	11	52	4	96
	3%	0%	1%	8%	20%	10%	88%	80%	89%
Transports	43	5	41	1,109	65	643	1,159	72	581
	2%	4%	3%	48%	46%	51%	50%	51%	46%

Table C-2. Luftwaffe total losses (sum of operational and non-operational) of aircrew and aircraft, 22.06.1941 to 01.01.1944, by theatre of operations

	Western Front			Mediterranean			East		
	Aircrew lost	Officers lost	Aircraft destroyed	Aircrew lost	Officers lost	Aircraft destroyed	Aircrew lost	Officers lost	Aircraft destroyed
Total	9,267	1,574	6,876	8,406	1,231	6,511	13,134	2,375	9,948
	30%	30%	29%	27%	24%	28%	<b>43%</b>	<b>46%</b>	<b>43%</b>
Single-engine fighters	1,337	358	2,906	659	194	1,884	1,059	325	2,579
	44%	41%	39%	22%	22%	26%	<b>35%</b>	<b>37%</b>	<b>35%</b>
Twin-engine day fighters	320	46	309	288	66	452	508	128	698
	29%	19%	21%	26%	28%	31%	46%	53%	48%
Night fighters	794	149	713	112	24	75	12	3	7
	86%	85%	90%	12%	14%	9%	1%	2%	1%
Bombers	5,269	635	1,924	4,426	527	1,756	6,506	881	2,739
	33%	31%	30%	27%	26%	27%	40%	43%	43%
Day Ground attack	114	26	175	457	92	649	1,161	271	1,308
	7%	7%	8%	26%	24%	30%	67%	70%	61%
Night Ground attack	2	0	1	6	1	13	55	4	107
	3%	0%	1%	10%	20%	11%	87%	80%	88%
Transports	137	11	70	1,513	104	947	1,448	95	830
	4%	5%	4%	49%	50%	51%	47%	45%	45%

## Bibliography

### Published sources

1st Line Defence Limited. (2015). *Detailed Unexploded Ordnance (UXO) Threat Assessment. Project Name: Coventry Leisure and Water Park*. [Online]. Hoddesdon, Herts, U.K.: 1<sup>st</sup> Line Defence Limited. Available at: <http://planning.coventry.gov.uk/portal/servlets/AttachmentShowServlet?ImageName=1275900> [Accessed: 18 September 2016].

Anderson, Thomas. (2015). *The History of the Panzerwaffe. Volume 1: 1939-42*. Botley, U.K.: Osprey Publishing.

Arthy, Andrew and Morten Jessen. (2004). *Focke-Wulf Fw 190 in North Africa*. Hersham, U.K.: Classic Publications.

Bailey, Gavin. (2008). 'The Narrow Margin of Criticality: The Question of the Supply of 100-Octane Fuel in the Battle of Britain'. *English Historical Review* 123(501), pp. 394-411.

Bergström, Christer and Andrey Mikhailov. (2001). *Black Cross Red Star: The Air War over the Eastern Front. Volume 2: Resurgence January-June 1942*. Pacifica, California, Pacifica Military History.

Bergström, Christer. (2008). *Kursk: The Air Battle. July 1943*. Hersham, U.K.: Classic Publications.

Bergström, Christer. (2015). *The Battle of Britain: An Epic Conflict Revisited*. Havertown, Pennsylvania: Casemate Publishers.

Boiten, Dr. Theo E.W. (2011). *The Nachtjagd War Diaries: An Operational History of the German Night Fighter Force in the West. Volume One: September 1939 – March 1944*. Walton on Thames, U.K.: Wing Leader.

Bollinger, Martin J. (2010). *Warriors and Wizards: The Development and Defeat of Radio Controlled Glide Bombs of the Third Reich*. Annapolis, Maryland: Naval Institute Press.

Brekken, Andreas. (2008). *Luftwaffe loss data?* [Online]. Available at: <[http://www.stormbirds.com/eagles/research/original\\_losses\\_43/index.html](http://www.stormbirds.com/eagles/research/original_losses_43/index.html)> [Accessed: 8 October 2016].

Boog, Horst, (ed). (1992). *The Conduct of the Air War in the Second World War: An International Comparison (Studies in Military History)*. Oxford, U.K.: Berg Publishers.

Boog, Horst, Jürgen Förster, Joachim Hoffman et al. (eds). (1998). *Germany and the Second World War. Volume IV: The Attack on the Soviet Union*. Oxford, U.K.: Clarendon Press.

Bungay, Stephen. (2000). *The Most Dangerous Enemy: A History of the Battle of Britain*. London, U.K: Aurum Press.

Caldwell, Donald and Richard Muller. (2014). *The Luftwaffe over Germany: Defence of the Reich*. Barnsley, U.K: Pen & Sword Books.

Cooling, B.F, (ed). (1994). *Case Studies in the Achievement of Air Superiority*. Washington, D.C: Center for Air Force History.

Corum, James S. (2008). *Wolfram von Richthofen: Master of the German Air War. (Modern War Studies)*. Lawrence, Kansas: University Press of Kansas.

Coulomb, Fanny. (2004). *Economic Theories of Peace and War*. Abingdon, UK: Routledge.

Cox, Sebastian and Peter Gray, (eds). (2002). *Air Power History: Turning Points from Kitty Hawk to Kosovo*. London, U.K: Frank Cass Publishers.

Crierie, Ryan. (2013). *RAF/USAAF Monthly Bomb Tonnages (1939-1945)*. Office of Statistical Control, Headquarters, A.A.F., and British Air Ministry, London. [Online]. Available at:

<[http://www.alternatewars.com/BBOW/Stats/RAF\\_USAAF\\_Bomb\\_Tonnages.htm](http://www.alternatewars.com/BBOW/Stats/RAF_USAAF_Bomb_Tonnages.htm)>

[Accessed: 22 December 2016].

Day, John. (1983). *Engines: The Search for Power*. London, U.K.: St Martin's Press.

de Zeng, Henry L IV. (2016). *Luftwaffe Airfields 1935-45* [Online]. Available at:

<<http://www.w2.dk/lwairfields.html>> [Accessed: 22 December 2016].

Dill, Arno. (2015). 'Luftwaffe aircraft armament'. *Aérojournál* 50 (6 – December – January), pp. 44-69. [In French – Dill, Arno. (2015). 'Les armes de bord de la Luftwaffe'. *Aérojournál* 50 (6 – Décembre – Janvier), pp. 44-69.]

Edgerton, David. (2011) *Britain's War Machine: Weapons, Resources and Experts in the Second World War*. Oxford, U.K.: Oxford University Press.

Forczyk, Robert. (2012). *Panzerjäger vs KV-1. Eastern Front 1941-43 (Duel 46)*. Botley, U.K.: Osprey Publishing.

Forczyk, Robert. (2014). *Where the Iron Crosses Grow: The Crimea 1941-44*. Botley, U.K.: Osprey Publishing.

Forsyth, Robert. (2011). *Luftwaffe Viermot Aces 1942-45 (Aircraft of the Aces 101)*. Botley, U.K.: Osprey Publishing.

Forsyth, Robert with Eddie J Creek. (2012). *Me 262 Bomber And Reconnaissance Units (Combat Aircraft 83)*. Botley, U.K.: Osprey Publishing.

Forsyth, Robert. (2016a). *Messerschmitt Me 264 Amerika Bomber (X-Planes 2)*. Botley, U.K.: Osprey Publishing.

Forsyth, Robert. (2016b). 'Defending the Reich: Part 1'. *The Aviation Historian* (17), pp. 50-60.

Garfinkel, Michelle R. and Stergios Skaperdas. (2012). *The Oxford Handbook of the Economics of Peace and Conflict*. Oxford, U.K.: Oxford University Press.

Gorbach, Vitaly. (2007). *Over the Burning Salient. Soviet aviation in the battle of Kursk*. Moscow, Russia: Eksmo. [In Russian – Горбач, Виталий. (2007). *Над Огненной Дугой. Советская авиация в Курской битве*. Москва: Эксмо]

Goss, Chris. (2007). *Krvavý Biskaj: Historie V Gruppe/ Kampfgeschwader 40*. Praha, Česká Republika: Deus. [Czech translation of – Goss, Chris. (2001). *Bloody Biscay*. Manchester, U.K.: Crécy Publishing.]

Goss, Chris. (2016). *Fw 200 Condor Units of World War 2 (Combat Aircraft 115)*. Botley, U.K.: Osprey Publishing.

Grier, Peter. (2011). 'No US Ground Troop Has Been Killed in an Enemy Aircraft Attack since the Korean War: April 15, 1953.' *Air Force Magazine* 94 (6 – June), pp. 55-58.

Hayward, Joel S.A. (1998). *Stopped at Stalingrad: The Luftwaffe and Hitler's Defeat in the East, 1942-43 (Modern War Studies)*. Lawrence, Kansas: University Press of Kansas.

Harrison, Mark. (2015). *The Economics Of Coercion And Conflict (The Tricontinental Series On Global Economic Issues Volume 5)*. Singapore: World Scientific Publishing Co.

Hermann, Dietmar. (2013). *Messerschmitt Bf 109 Part 1: From the prototype to the "Friedrich" (Flugzeug Classic Extra)*. Munich, Germany: GeraMond Publishing. [In German – Hermann, Dietmar. (2013). *Messerschmitt Bf 109 Teil 1: Vom Prototyp bis zur "Friedrich" (Flugzeug Classic Extra)*. München, Deutschland: GeraMond Verlag.]

Hermann, Dietmar. (2014). *Messerschmitt Bf 109 Part 2: From the G-1 to the G-10 (Flugzeug Classic Extra)*. Munich, Germany: GeraMond Publishing. [In German – Hermann, Dietmar. (2014). *Messerschmitt Bf 109 Teil 2: Von der G-1 bis zur G-10 (Flugzeug Classic Extra)*. München, Deutschland: GeraMond Verlag.]

Hermann, Dietmar. (2015). 'Fast Cars with Altitude Sickness. Engines: The Luftwaffe Misses the Boat.' *Flugzeug Classic* 166 (4 – April), pp. 30-35. [In German – Hermann, Dietmar. (2015). 'Boliden mit Höhenangst. Triebwerke: Die Luftwaffe verliert den Anschluss.' *Flugzeug Classic* 166 (4 – April), pp. 30-35.]

Hermann, Dietmar. (2016). 'High-tech and an Economy of Scarcity. The German Aircraft Industry in the Second World War.' *Flugzeug Classic* 175 (1 – January), pp. 14-21. [In German – Hermann, Dietmar. (2016). 'Hightech und Mangelwirtschaft. Die deutsche Luftrüstung im Zweiten Weltkrieg.' *Flugzeug Classic* 175 (1 – Januar), pp. 14-21.]

Hooton, E.R. (Ted). (2016). *War over the Steppes: The Air Campaigns on the Eastern Front 1941-45*. Botley, U.K.: Osprey Publishing. **Pre-publication manuscript shared with the author by Ted Hooton**

Isaev, Alexei. (2011). *A Different 1941. From the border to Leningrad*. Moscow, Russia: Eksmo. [In Russian – Исаев, Алексей. (2011). *Иной 1941. От границы до Ленинграда*. Москва: Эксмо.]

Jarrett, Philip, (ed). (1997). *Aircraft of the Second World War: The Development of the Warplane 1939-45 (Putnam's History of Aircraft)*. London, U.K: Putnam Aeronautical Books.

Kroener, Bernhard R., Rolf-Dieter Müller and Hans Umbreit (eds). (2000). *Germany and the Second World War. Volume V: Organization and Mobilization of the German Sphere of Power. Part 1: Wartime administration, economy and manpower resources 1939-1941*. Oxford, U.K.: Clarendon Press.

Kroener, Bernhard R., Rolf-Dieter Müller and Hans Umbreit (eds). (2003). *Germany and the Second World War. Volume V: Organization and Mobilization of the German Sphere of Power. Part 2: Wartime administration, economy and manpower resources 1942-1944/5*. Oxford, U.K.: Clarendon Press.

Kuznetsov, A.Ya. and M.E. Morozov (2015). *The Black Sea Fleet in the Great Patriotic War. Short review of combat activity*. Moscow, Russia: Eksmo. [In Russian – Кузнецов А.Я. и Морозов М.Э. (2015). *Черноморский флот в Великой Отечественной войне. Краткий курс боевых действий*. Москва: Эксмо.]

Maier, Klaus A, Horst Rohde, Bernd Stegemann and Hans Umbreit (eds). (1991). *Germany and the Second World War. Volume II: Germany's Initial Conquests in Europe*. Oxford, U.K.: Clarendon Press.

Maslov, Mikhail. (2016). 'Database: Polikarpov Po-2/U-2'. *Aeroplane* 44 (523 – November), pp. 75-91.

Medcalf, William A. (2013). *Junkers Ju 88 Volume 1. From Schnellbomber to Multi-Mission Warplane: Development, Production, Technical History*. Manchester, U.K: Crécy Publishing.

Medcalf, William A. (2014). *Junkers Ju 88 Volume 2. The Bomber at War: Day and Night – Operational and Service History*. Manchester, U.K: Crécy Publishing.

Murray, Williamson. (1996). *Strategy for Defeat: The Luftwaffe 1933 – 1945*. London, U.K: Brassey's. A different edition of this work is available online at <http://www.ibiblio.org/hyperwar/AAF/AAF-Luftwaffe/> [Accessed: 8 October 2016].

O'Brien, Phillips Payson. (2015). *How the War Was Won: Air-Sea Power and Allied Victory in World War II*. Cambridge, U.K.: Cambridge University Press.

O'Hara, Vincent P. (2015). *Torch: North Africa and the Allied Path to Victory*. Annapolis, Maryland: Naval Institute Press.

Overy, Richard. (1992). *War and Economy in the Third Reich*. Oxford, U.K.: Clarendon Press.

Overy, Richard. (1995). *Why the Allies Won*. London, U.K: Pimlico.

Overy, Richard. (2013). *The Bombing War: Europe 1939-45*. London, U.K: Allen Lane.

Pegg, Martin. (2007). *Transporter Volume One: Luftwaffe Transport Units 1939-1943 (Luftwaffe Colours)*. Hersham, U.K.: Classic Publications.

Rastrenin, Oleg. (2015). 'Ordered to survive! On the question of the combat survivability of aircraft and the effectiveness of aircraft gun armament. Part 4.' *Equipment and armament yesterday, today, tomorrow* (3 – March), pp. 37-46. [In Russian – Растренин, Олег. (2015). Приказано выжить! К вопросу о боевой живучести самолетов и эффективности авиационного стрелково-пушечного вооружения. Часть 4. *Техника и вооружение вчера, сегодня, завтра* (3 – Март), стр. 37-46.]

Rastrenin, Oleg. (2016). 'The departure of the "flying tank". Part 1.' *Aviation and space yesterday, today, tomorrow* (3 – March), pp. 16-27. [In Russian – Растренин, Олег. 2016. Уход «летающего танка». Часть 1. *Авиация и космонавтика вчера, сегодня, завтра* (3 – Март), стр. 16-27]

Ratkin, Vladimir. (2013). *Aviation in the Battle of Stalingrad*. Moscow, Russia: “Russian Knights” fund. [In Russian – Раткин, Владимир. (2013). *Авиация в Сталинградской битве*. Москва: Фонд «Русские Витязи».]

Rodionov, Ivan. (2016). *Chronology of the Aviation and Aircraft Industry of Russia and the Soviet Union, 1916 to 1946. Version 11*. [Online]. Available at: <<http://www2.warwick.ac.uk/fac/soc/economics/staff/mharrison/aviaprom/>> [Accessed: 22 December 2016].

Sabin, Philip. (2012). *Simulating War: Studying Conflict Through Simulation Games*. London, U.K.: Continuum.

Sandler, Todd and Keith Hartley. (2007). *Handbook of Defense Economics. Volume 2: Defense in a Globalized World (Handbooks in Economics 12)*. Amsterdam, The Netherlands: Elsevier B.V.

Scherner, Jonas and Jochen Streb. (2016). ‘The Mirage of the German Armament Miracle in World War II’ in Eloranta, Jari, Eric Golson et al. (eds). *Economic History of Warfare and State Formation (Studies in Economic History)*. Germany: Springer.

Schreiber, Gerhard, Bernd Stegemann and Detlef Vogel (eds). (1995). *Germany and the Second World War. Volume III: The Mediterranean, South-east Europe and North Africa 1939-1941*. Oxford, U.K.: Clarendon Press.

Shores, Christopher and Giovanni Massimello et al. (2014). *A History of the Mediterranean Air War 1940-1945: North African Desert, February 1942 - March 1943*. London, U.K.: Grub Street Publishing.

Stahel, David. (2013). *Operation Typhoon: Hitler’s March on Moscow*. Cambridge, U.K.: Cambridge University Press.

Stahel, David. (2015). *The Battle for Moscow*. Cambridge, U.K.: Cambridge University Press.

Tooze, Adam. (2006). *The Wages of Destruction: The Making and Breaking of the Nazi Economy*. London, U.K.: Allen Lane.

van Creveld, Martin. (2011). *The Age of Airpower*. New York, NY: PublicAffairs.

Vasco, John J. (2009). *Zerstörer Volume Two: Luftwaffe Fighter-Bombers and Destroyers 1941-1945 (Luftwaffe Colours)*. Hersham, U.K.: Classic Publications.

[VVS Staff. (1962).] Main Staff of the Soviet Air Force. (1962). *Soviet aviation in the Great Patriotic War in numbers (1941 – 1945)*. [Online]. Moscow, USSR: No publisher stated. [In Russian – Главный штаб Военно-воздушных сил. (1962). *Советская авиация в Великой Отечественной войне в цифрах (1941 - 1945 гг.)* Москва.] Available at: <[http://stsokol.ru/vvs\\_tsifra/index.html](http://stsokol.ru/vvs_tsifra/index.html)> [Accessed: 8 October 2016].

Weal, John. (1998). *Junkers Ju 87 Stukageschwader of North Africa and the Mediterranean (Combat Aircraft 6)*. Botley, U.K.: Osprey Publishing.

Weal, John. (2001). *Jagdgeschwader 54 'Grünherz' (Aviation Elite Units 6)*. Botley, U.K.: Osprey Publishing.

Weal, John. (2003). *Luftwaffe Schlachtgruppen (Aviation Elite Units 13)*. Botley, U.K.: Osprey Publishing.

Weal, John. (2006). *Jagdgeschwader 51 'Mölders' (Aviation Elite Units 22)*. Botley, U.K.: Osprey Publishing.

Weal, John. (2007). *More Bf 109 Aces of the Russian Front (Aircraft of the Aces 76)*. Botley, U.K.: Osprey Publishing.

Weal, John. (2008). *Junkers Ju 87 Stukageschwader of the Russian Front (Combat Aircraft 74)*. Botley, U.K.: Osprey Publishing.

Weal, John. (2013). *Heinkel He 111 Kampffgeschwader on the Russian Front (Combat Aircraft 100)*. Botley, U.K.: Osprey Publishing.

Westermann, Edward B. (2001). *Flak: German Anti-aircraft Defenses, 1914-1945 (Modern War Studies)*. Lawrence, Kansas: University Press of Kansas.

Zolotarev V.A., A.M Sokolov et al. (eds). (2015). *The Great Patriotic War 1941-1945. Volume 12: Results and Lessons*. Moscow, Russia: Kuchkovo pole.

[In Russian – Золотарёв, В. А., А. М. Соколов и др. (ред). (2015). *Великая Отечественная Война 1941-1945. Том 12: Итоги и Уроки*. Москва: Кучково поле.]

#### Primary sources

Bundesarchiv-Militärarchiv (BA-MA), Freiburg-im-Breisgau, Baden-Württemberg, Germany

##### RL 2-III Generalstab der Luftwaffe / Generalquartiermeister:

[RL 2-III Luftwaffe General Staff / Quartermaster-General – responsible for administration and supply]:

BArch RL 2-III/628. Flakartillerie: Bestand und Verteilung.- Sammelakte mit Zusammenstellungen 1942 - 1944

[Anti-aircraft artillery: Strength and distribution.- Collected files with summaries]

Munition.- Munitionslagemeldungen 1939 – 1943

[Ammunition.- Ammunition situation reports 1939 – 1943]:

BArch RL 2-III/632. Bd. 4. Jan. - Dez. 1941

[Volume 4. January – December 1941]

BArch RL 2-III/633. Bd. 5 Jan. - Dez. 1942

[Volume 5. January – December 1942]

BArch RL 2-III/634 Bd. 6 Jan. - Dez. 1943

[Volume 6. January – December 1943]

RL 2-III/636 Munition: Bestand, Verbrauch.- Munitionsübersicht 1943

[Ammunition: Availability, Expenditure.- Ammunition overview 1943]

BArch RL 2-III/642 Bestand, zugänge und Abgänge an Gasmasken, Feldküchen, Handwaffen, Bordwaffen und Infanteriebeutewaffen, aufgliedert nach Luftflotten und Nachschubreserve.- Monatlichen Veränderungsmeldungen

[Availability, inflow and outflow of gas masks, field kitchens, personal weapons, aircraft guns and captured enemy infantry weapons. Divided into stocks held by air fleets (operational commands) and reserve stocks.- Monthly reports of changes]

Personelle und materielle Einsatzbereitschaft  
[Personnel and aircraft strength]:

BArch RL 2-III/716a Bd. 28 08. - 29. Nov. 1941

[Volume 28. 8 – 29 November 1941]

BArch RL 2-III/716b Bd. 29 06. - 27. Dez. 1941

[Volume 29. 6 – 27 December 1941]

BArch RL 2-III/717a Bd. 30 03. -31. Jan. 1942

[Volume 30. 3 – 31 January 1942]

BArch RL 2-III/722a Bd. 40 10. - 31. Dez. 1942

[Volume 40. 10 – 31 December 1942]

BArch RL 2-III/722b Bd. 41 10. Jan. - 10. Feb. 1943

[Volume 41. 10 January – 10 February 1943]

BArch RL 2-III/728a Bd. 52 20. Dez. 1943 - 10. Jan. 1944

[Volume 52. 20 December 1943 – 10 January 1944]

BArch RL 2-III/728b Bd. 53 20. Jan. - 10. Feb. 1944

[Volume 53. 20 January 1944 – 10 February 1944]

BArch RL 2-III/737 Kurzbericht 31. Jan. 1942 - 20. Dez. 1943

[Short reports of aircraft strength 31 January 1942 – 20 December 1943]

BArch RL 2-III/748 Munitionsübersichten 1943 – 1944

[Ammunition overviews 1943 – 1944]

Materialverluste.- Flugzeuge.- Einsatz alle Fronten.- Monatsmeldungen 1943 – 1944.

[Losses of materiel.- Aircraft.- Operations on all fronts.- Monthly reports 1943 – 1944.]:

BArch RL 2-III/944. Bd. 1. Sept. - Dez. 1943

[Volume 1. September – December 1943]

BArch RL 2-III/945. Bd. 2 Jan. - Mai 1944.

[Volume 2. January – May 1944]

BArch RL 2-III/946. Bd. 3 Juni - Okt. 1944.

[Volume 3. June – October 1944]

BArch RL 2-III/950 Fliegendes Personal, Flugzeuge.- Einsatz alle Fronten.- Zusammenstellungen. 1. Sept. 1939 - 25. Sept. 1942, 1. Jan. - 31. Aug. 1942

[Flying Personnel, Aircraft.- Operations on all fronts.- Summaries. 1 September 1939 – 25 September 1942, 1 January – 31 August 1942]

Flakgroßgerät: Verteilung auf die Kommandobehörden, Verluste ebenda.- Arbeitsunterlagen für Flakgroßgerät.- Bewegungsmeldungen (Flak-B-Meldungen): Formulare 1942 - 1944

[Large anti-aircraft equipment: Distribution among Operational Commands, Losses at the same.- Working documents concerning large anti-aircraft equipment.- Movement Reports (Flak Movement Reports): Forms for 1942-1944]:

BArch RL 2-III/1162 Bd. 3 Okt. - Dez. 1942  
[Volume 3. October – December 1944]

BArch RL 2-III/1177 through to BArch RL 2-III/1196:

**Nota Bene: information from these files is incorporated in the digital database of Luftwaffe losses shared with the author by the Finnish aviation researcher Mr. Matti Salonen**

Fliegendes, nicht fliegendes Personal, Flugzeuge: Fliegende Verbände, Flak, Ln.Truppe usw.- Einsatz alle Fronten, Heimatkriegsgebiet. Auch bekannt als:

Flugzeugunfälle und Verluste bei den Fliegenden Verbänden

Bd. 6. 30. Mai - 2. Aug. 1941 bis:

Bd. 25. 3. Dez. 1943 - 2. Jan. 1944

[Flying, non-flying personnel, aircraft: flying units, anti-aircraft units, air force communication troops etc.- Operations on all fronts, Zone of the Interior. Also known as:

Aircraft accidents and losses of the flying units

Volume 6. 30 May – 2 August 1941 through to:

Volume 25. 3 December 1943 – 2 January 1944]

An example of the format of the original files is available online, see page 5 onwards for sample records of individual aircraft losses:

<[http://www.stormbirds.com/eagles/research/original\\_losses\\_43/Jan\\_02\\_1943.pdf](http://www.stormbirds.com/eagles/research/original_losses_43/Jan_02_1943.pdf)>

[Accessed: 22 December 2016].

BArch RL 2-III/1200 Fliegendes Personal, Flugzeuge.- Einsatz alle Fronten.- Abstreichlisten Jan. - Mai 1944

[Flying Personnel, Aircraft.- Operations on all fronts.- Strike out lists January – May 1944]

RM 7 Seekriegsleitung der Kriegsmarine

[Naval High Command]

Heft X: Küsten- und Flak-Verteidigung

Kriegstagebuch Teil C X

[Issue X: Coastal and Anti-Aircraft Defence

War Diary Part C X]:

BArch RM 7/227 Bd. 2 Jan. 1943 - Jan. 1945

[Volume 2. January 1943 – January 1945]

ZA 3 Operational History (German) Section der Historical Division der US-Army /

Studiengruppe Luftwaffe:

[Operational History (German) Section, Historical Division of the US Army / German Air Force Study Group]

BArch ZA 3/251 Flugzeugproduktion, 1939-1945

[Aircraft production, 1939-1945]

Betriebsstoffversorgung [Supply of fuel]:

BArch ZA 3/267 Bd. 2 [Volume 2]

BArch ZA 3/358 Betriebsstoffversorgung, Verteilung der fliegenden Verbände auf die verschiedenen Fronten

[Supply of fuel, Distribution of flying units between different fronts]