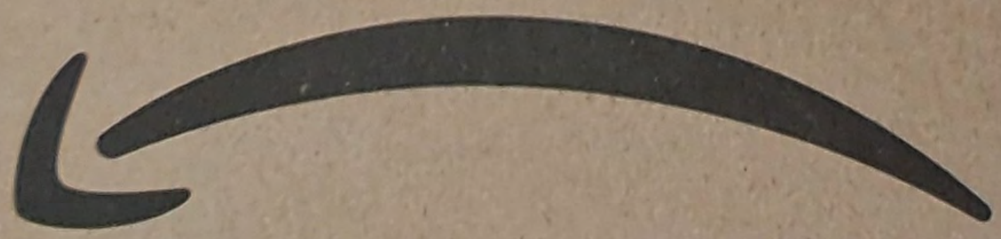
WAROC-31

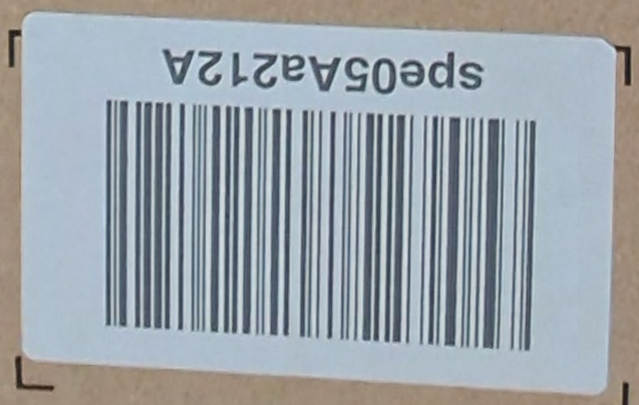
OEF-137
Dissertation
MATT BARNES

A3

DCBW 1106







The Fall and Rise of War Rockets (1871-1941)

Matthew Barnes

MA in War Studies

2024

MUSEUM OBJECT ENTRY FORM

MUSEUM NAME: | **Form No:** 137

Received from: Matthew Barnes
Address:

Tel No:

Owner (if different):
Address:

Tel No:

DESCRIPTION OF OBJECT/COLLECTION (note obvious damage, & any related information eg. when, where, or how was it found or used; names, dates & details of the people who made or previously owned it, etc. **Continue on a new sheet if necessary)**

1 - Hard bound copy of MA in War Studies
25-08-2024
Received in post.
Deposited in WAROC-31

Total no. of items: 1

REASON FOR ENTRY (tick as applicable, and sign)

- [x] **Donation** - I offer to donate the object(s) listed above to the museum's governing body.
- [ ] **Sale** - I offer to sell the object(s) listed above to the museum's governing body (price sought £.....).
- [ ] **Loan** - I offer to loan the object(s) listed above for the use of the museum's governing body for a period of ..... months.
- [ ] **Identification** - I leave the object(s) listed above for identification & undertake to collect these no later than 4 weeks from today.

I confirm that the information given on this form is correct to the best of my knowledge and belief, & that I accept the terms and conditions described overleaf.

Signed: Date: 07-09-2025

ADDITIONAL AGREEMENT (DONATIONS/SALES ONLY) (tick as applicable, and sign)

- [ ] I, the **owner**, confirm that I have undisputed title to the object(s) listed above, with full power to dispose of the items and transfer such title to the museum's governing body. OR
- [ ] I, the **depositor** acting on behalf of the owner(s), confirm that the owner(s) have undisputed title to the object(s) listed above, with full power to dispose of the items and transfer such title to the museum's governing body, & that I am authorised by the owner(s) to act on their behalf to that effect.

The title in the objects listed above, & subject to the conditions overleaf, is hereby transferred to the governing body of the museum.

Signed: Date:

MUSEUM SIGNATORY

Receipt of the object(s) described above is hereby acknowledged.

Signed: Date: 07-09-2025
on behalf of the museum's governing body

RETURN OF OBJECT TO OWNER (tick as applicable, and sign)

I, the depositor/owner, acknowledge the return of the object(s) described above in a satisfactory condition following:

- [ ] identification
- [ ] the end of the period of loan
- [ ] the museum's governing body declining to accept the donation, loan or purchase of the object(s)

Signed: **Countersigned** (for museum): Date:

© MDA/East Midlands Museums Service

WHITE - MUSEUM (FILE)
PINK - DEPOSITOR/OWNER (RECEIPT)
BLUE - MUSEUM (TO ACCOMPANY OBJECT/S)

The Fall and Rise of War Rockets (1871-1941)



By Matthew Barnes

King's College London

MA in War Studies

Supervisor: Professor William Philpott

Date of Submission: 25 August 2024

Word Count: 12,270

Abstract

Weaponised rockets were common on the nineteenth century battlefield. They then substantially disappeared from use for almost 50 years, re-emerging in WWII and remaining today as a key weapon in modern armies. Rockets may be unique among weapon technologies in having returned from obsolescence.

This dissertation recounts in turn stories of evolving technology (particularly the search for powerful but safe rocket propellants) and the evolution of effective doctrinal use, focussed on mobility and shock effect. However, it finds that the nineteenth century "fall" in rocketry use and the twentieth century "rise" were substantially due to human factors. In particular, the early nineteenth century "hype", arising from novelty, inventor-led visibility and powerful sponsorship waned. This led to a deep trough of disinvestment and disuse by the turn of the century. This reversed only with the pre-WWII emergence of new technophile national leaders and international competition to re-stimulate rocket development.

Table of Contents

Introduction 6
1. Technology 10
1.1 The gunpowder problem 11
1.2 New powders, no rockets 16
1.3 New powders and the rocket renaissance 19
1.4 Enablers of new powder rockets - why not sooner? 23
2. Doctrine 31
2.1 Early nineteenth century 32
2.2 Late nineteenth century 37
2.3 World War II 41
3. Human drivers: inventors and sponsors 45
3.1 Britain 46
3.2 Russia 52
Conclusion 56
Bibliography 60

Introduction

A "war rocket" is a military rocket designed to destroy or kill (as opposed, say, to signaling or illuminating). War rockets were introduced to Europe in the early nineteenth century by Sir William Congreve. Their adoption became widespread, then they were gradually "disadopted" (i.e. abandoned, disused) by the end of the century. By 1900, no contemporary army was fielding them. They then reappear in WWII and remain a staple of modern armies thereafter. The Congreve rocket is the ancestor of the NLAW, Javelin, Patriot and the HIMARS MLRS. The author is aware of no other obsolete weapon that has returned to military service and therefore the war rocket deserves study. A personal motivation also arises from an ancestor of the author's service in the Rocket Troop at Waterloo.

Johnson penned the *Rise and Fall of Early War Rockets*,[1] describing the nineteenth century period. This dissertation focuses on the same *Fall* but linking it through to their subsequent readoption or *Rise*. The dissertation's titular time period (1871-1941) starts with the end of the Franco-Prussia war as some authors mark rocket decline from this point. However, the reasons for this decline and subsequent readoption are under-analysed by the literature and this dissertation seeks to address this. It combines and contrasts the national readoption narratives with each other, ending in WWII, as well as contrasting and linking them with the prior disadoption.

The existing rocketry literature focusses on technological drivers. However, as Storr states: 'Technology is not a "given". It is a product of many things, all of which are human. … Its use

[1] Johnson (1994), "Rise and Fall of Early War Rockets", 374-381

depends on industrial and economic strength, supply and maintenance, training, and methods of employment'.[2] Analysis in this dissertation is therefore split between chapters covering technological, doctrinal and human drivers. It echoes many of the themes identified in the following historical article:

> *'An invention dawns, under the auspices of some enthusiast, who … forces his invention into notice and adoption prematurely. The invention is tried, found deficient in some respects, is set aside ... Meantime some collateral aid is undergoing development … which, if it only had been known simultaneously with the now abandoned invention, would have made it … sufficiently adapted to the end proposed. … The history of war rockets in Europe affords a case in point; not that war rockets are abandoned, but … they have fallen somewhat into disrepute. …. Rockets, notwithstanding their deficiencies, have taken their stand in many services. We use them with effect, so does Austria, … as they are easily conveyed over obstacles that to guns would be impassable. …. We are of opinion that no war rocket has yet been made to work in accordance with the true genius of the arm.'*
>
> *The Engineer*, 1871[3]

Both technologically and doctrinally, the performance of the rocket was patchy and did not justify the extent of its visibility and adoption, i.e. its "hype". Prophetically, the 1871 article anticipates the development of 'some collateral aid'. (This need for any invention to be

[2] Storr (2018), "Hall of Mirrors", 266
[3] Anon (1871), "The Power and Capabilities of War Rockets", 357

dependent on others is Kranzberg's Second Law of technology).[4] Ironically the same article argues that gunpowder will not be improved-upon, whereas we now know the chief development that rockets required was the creation of a superior propellant, which was invented in 1889 and harnessed for rocket use in the 1930s. In WWII, rockets matured technologically and doctrinally, typically by use of barrage (or firing at short-range in ambush, in the case of anti-tank rockets).

However, due to human factors this evolution was not monotonic and improvements in technological ability were not determinative. The 'disrepute' identified in the above quotation became a deep "negative hype". Nations disadopted and disinvested, leaving rockets in a trough of disuse, failing to make use of turn of the century technology that might have supported continued use and improvement of rockets.

This dissertation argues that the nineteenth century adoption and over-hype were a result of a combination of self-promoting inventors ('some enthusiast' in the quotation above) and sponsors, as well as a degree of novelty. The disadoption period and negative hype were a result of the absence of inventors and a waning of sponsorship and novelty. New technophile sponsors drove the WWII readoption of rockets, investing in the newly available technologies such as improved propellants, and persevering despite continuing material limitations in accuracy and safety but eventually leading to development of 'the true genius of the arm' anticipated in the 1871 article and not delivered until at least 1941.

[4] Kranzberg (1995), "Kranzberg's Laws", 7

Peer-following was also a feature of each of the adoption, disadoption and readoption phases. Storr identifies the same pattern when he says: 'adoption will tend to be an adversarial and evolutionary process … Development can be increasingly rapid … however, the overall rate of progress may be slow outside major wars. … Enthusiasts ensure that advances in technology are typically overstated in the short term (but possibly understated in the long term)'.[5]

Those able to deploy war rockets earlier in WWII gained an advantage. A greater advantage may have arisen had better rockets been available sooner. The enablers for the rebound were difficult to generate but could have been progressed sooner, given more continuous investment, and were substantially absent because of a deep negative hype and lack of sponsorship.

Note: this dissertation is limited to battlefield war rockets, and therefore the solid-fuel type. Liquid-fuelled rockets are substantially a separate topic and already well-documented in connection with the study of ballistic missiles and the subsequent Space Race.

[5] Storr (2018), 267

1. Technology

The 1871 article in the introduction talks of an invention 'tried', 'found deficient' and 'set aside' until a 'collateral aid' is developed. This technology section covers rocket propellants, first reviewing the use and limitations of gunpowder as a propellant, secondly describes the introduction of a new generation of improved "double-base" powders and, despite these, the hiatus in rocket use. Finally, it describes the reappearance of rockets, discussing how this was enabled by the harnessing of the new powders and concludes that this could have happened sooner.

Winter claims 'the introduction of the breech-loading, rifled gun in the 1860s was the most oft-cited reason for disbanding rocket troops'.[6] His book documents a range of additional reasons for rocket disadoption in a variety of countries, which this dissertation summarises and adds to. Based on primary sources not referenced by the rocketry literature, this dissertation also identifies the proximate reason for British disadoption was a safety concern around premature explosions and that the WWII readoption was despite this concern partially persisting.

Furthermore, this section discusses why the British withdrew rockets with explosive warheads in 1866, which contributed to the diminishing efficacy and popularity of rockets in the remainder of the century. Again, the primary sources link this to the safety issue and identify that experimentation with explosive warheads continued, albeit in vain.

[6] Winter (1990), "First Golden Age of Rocketry", xv

1.1 The gunpowder problem

Winter's "First Golden Age of Rocketry" follows Congreve's importation of rockets from India to Europe in 1806. The British subsequently designed and manufactured rockets at the Royal Arsenal at Woolwich. Large rocket establishments arose in France, Austria and Russia. European rocket use peaked before, or around, the time of the Crimean War (1853-6), where it was used on both sides. Significant adoption was also made by the Danes, Prussians and Italians, as well as both sides in the US Civil War, and several South American countries.[7] European powers fielded rockets in several African and Asian campaigns. This is a technology transfer and weapon proliferation from Asia to Europe to Worldwide.

The fuel of Congreve's war rockets, and prior ones, was black gunpowder. Congreve's chief development was the application (to the same powder) of industrial, or semi-industrial processes, for example in the construction and welding of the rocket cases, or in the machinery used to fill and compress the powder into the rockets. Despite these developments, the problem of preservation of the powder in storage was never wholly solved, particularly suffering from hot conditions or rough handling.

This issue constrained potential improvements to rockets. Ley tells us that 'in order to make a powder rocket large and powerful, the powder mixture had to be compressed to a much greater extent than it is in small fireworks rockets … it made the compressed powder mixture excessively brittle'.[8] This brittleness could cause the powder to come away from the inner surface of the casing, or crack internally, creating additional burning surface and potentially

[7] Winter (1990), passim
[8] Ley (1957), "Rockets", 169

uncontrolled explosion at launch. Other authors are very aware of this shortfall of rockets. However, they have not identified that the Artillery Committee minutes show that this was the proximate cause of suspension of British use in 1884, as described below.

A succession of reports concern unreliability such as that of a 1874 report from India noting that the 9 pdr Mark III Hale rocket was 'utterly unserviceable and dangerous'.[9] It suggested local production or annual supply to avoid long storage. In 1878 a rocket burst in the tube on HMS Temeraire, causing casualties.[10] The report blamed climate and rough use. The Superintendent of the Royal Laboratory at this point suggested discontinuance of production 'in view of the little good service which has been recorded as rendered by rockets', suggesting a light gun be substituted.[11] There were, however, throughout the 1870s favourable combat reports occasionally about non-explosive rockets and promising experiments with nitrocellulose explosive and carcass (incendiary) warheads continued. The Committee decided to retain rockets in service. Indeed, the enthusiasm must have been preserved as there was an 1880/1 "Special Committee on War Rockets" which appeared to remain optimistic.[12]

However, the beginning of the end for British gunpowder rockets came when the Superintendant of Experiments at Shoeburyness reported on 10 July 1882 about the results of a trial using 9 pdr rockets. All six rockets 'burst explosively close to the rocket trough'. These had been subject to 120 degree heat for three months during day time, intended to

[9] Director of Artillery (1875), "Proceedings", 233
[10] Director of Artillery (1879), "Proceedings", 77
[11] Ibid
[12] Franklin (2005), "British Rockets", 142

approximate the possible conditions in parts of Asia or Africa. On these safety grounds, it was concluded on 1 September 1882 that 'the [Ordnance] Committee cannot recommend any pattern of rocket for current use'.[13]

A further trial in 1883 found that 20 rockets fired without failure after a year's storage following a heat treatment, so it was concluded that 'rockets should not be sent to hot climates for at least one year after manufacture'.[14] This offered a mitigation and indeed processes were modified to this effect. However, the resolution followed that:

> *'the fact that the present war-rocket is dangerous to manufacture and use, that it has been a constant source of trouble and complaint since its introduction, and that its effect on an enemy is uncertain and small, the Committee are of the opinion that it is a matter for consideration whether this weapon should be retained in the Service'*[15]

On 24 September 1883 there had been rocket explosion at the Royal Arsenal.[16] Although not mentioned in the same meeting's minutes, this may have been a factor in reaching that resolution.

In September 1884, the Director of Naval Ordnance requested more trials seeking a reliable 9 pdr but was pointed towards failures in 1882. He recommended instead that 24 pdrs should be provided 'urgently' for naval service, especially in China. However, referencing the conclusion of Ordnance Committee of 1882 that they could not recommend any current

[13] Ordnance Committee (1883), "Proceedings", 1/9/82 minutes
[14] Director of Artillery (1884), "Proceedings", 704
[15] Ibid, 705
[16] Director of Artillery (1885), "Proceedings", 197

pattern of rocket, a clause was proposed for the Army Circular to the effect that the use of war rockets will be discontinued for land and Sea Service except when required for special purposes by HM Ships on stations in the Far East and Africa.[17]

Franklin and Johnson also describe the British 1866 withdrawal of rockets with shell-warheads (retaining only a non-explosive solid warhead), causing them to be 'all but useless'.[18] They say it is 'not known' why the Ordnance Board subsequently ignored requests to reintroduce explosive (or incendiary) warheads.[19] However, it is clear from contemporary minutes that experimentation with explosive/incendiary warheads continued for much of the next 20 years. It was the safety issue that prevented these being deployed: unable to wholly mitigate the risk of premature explosion of the rocket propellant, they were reluctant to issue rockets with more explosives attached as warhead.

A more accurate, spin-stabilised rocket, created by William Hale, was adopted by Britain in 1867 (and other countries before and after), which possibly extended the persistence of rockets but could not wholly arrest their decline. Franklin and Johnson also identify certain efforts made to improve the Hale rocket after 1870 but conclude that 'in spite of these modifications the rockets continued to have many short comings levelled against them in British service',[20] reproducing a list of complaints stated in the 1902 Treatise on Ammunition.[21] However, much of the text in that Treatise was the same text as in the 1877 Treatise.[22] This in

[17] Director of Artillery (1886), "Proceedings", 70
[18] Franklin and Johnson (1995), "Improvements in Rockets", 240
[19] Ibid, 241
[20] Ibid, 240
[21] War Office (1902), "Treatise on Ammunition", 415
[22] War Office (1877), "Treatise on Ammunition", 263

turn references an 1870 document (Ammunition: A Descriptive Treatise [etc]) by the same author, a Captain CO Browne, RA. As such, these complaints predate much of the ongoing experimentation and the continued deployment of rockets, in fact last used by the British in 1899. The Treatise description therefore reflects, or helped to generate, a negative reputation of rockets but is not a complete contemporary perspective.

Although contemporary improvements in guns may have caused rockets to pale in comparison, this did not in Britain directly cause rocket experimentation to cease, nor rockets to cease to be requested for deployment. Instead, it is the safety of rockets that prevented their retention alongside guns. This discontinuance, ironically, occurred on the eve of the introduction of new, more powerful propellant powders, quickly adopted for gun ammunition but not for rockets, exacerbating the performance difference between guns and rockets.

1.2 New powders, no rockets

The introduction of new powders in gun ammunition, which were not simultaneously used in rocket propellants, exacerbating the performance gap between guns and rockets, as described below.

Nitrocellulose is a chemical, developed in early the nineteenth century. Where used in ammunition, it was an early "single-base", "smokeless" powder, which had an advantage for aiming or concealment. However, used alone, its burning rate is difficult to control. Gunpowder generally continued to dominate.

Alfred Nobel patented ballistite in 1888, a "double-base" powder created from a mixture of nitrocellulose and nitroglycerine (and other additives). When combined, these produced stability and uniform action requisite for ammunition propellant. They produced much more energy than gunpowder, enhancing range and accuracy. The War Office in Britain tasked two scientists, Abel and Dewar, to investigate their own double-base propellant and their output was patented as cordite in 1889, being adopted across British bullet and shell production in 1890, replacing gunpowder.[23] Equivalents were developed internationally, contributing to a revolution in artillery.

Nobel looked into using the new powder with rockets in partnership with his compatriot, Count Unge, launching a ballistite powder rocket in 1896.[24] Winter suggests that Unge's efforts with double-base powder rockets in the 1890s 'came too late' for rocketry.[25] Nobel's

[23] Cocroft (1999), "Dangerous Energy", 130
[24] New Mexico Museum of Space History, "Wilhelm T. Unge"
[25] Winter (1990), xvii

death in the same year, severely impacted Unge's funding and progress.[26] However, when Unge sold patents (in 1908) of his new "aerial torpedo" to Krupp, this was a gunpowder rocket, rather than one using ballistite,[27] [28] suggesting that he had not found the latter to be practical. Krupp, in any case, did not develop it further after tests in 1909 and 1910, citing poor accuracy.[29] (Interestingly, however, these experiments were cited in 1930 by the German Colonel Becker when proposing further rocket development. He claims that Krupp did not tell the Prussian Army about their tests.[30])

The brief French foray into air-launched anti-zeppelin ("Le Prieur") rockets, first used at the Battle of Verdun (1916), also used gunpowder propelled rockets.[31] Although observation balloons were destroyed, no zeppelins were shot-down by Le Prieur rockets, and it was rather difficult and dangerous to line-up a short-range rocket attack from a moving plane; incendiary bullets were soon found to be superior.[32] The British[33] and French[34] also used ground-launched rockets to defend London and Paris against zeppelins in 1915-1917, said to rise beyond 10,000 feet, although it is not clear whether these were for illumination or impact. However, Ley identifies at least one zeppelin destroyed.[35] Despite those countries' use of modern powders for gun ammunition, they did not choose (or manage) to apply the same to their rockets.

[26] New Mexico Museum
[27] Ley, 164
[28] Neufeld, 165
[29] Ley, 165
[30] Neufeld, 164
[31] Herriott, "Air-to-Surface Rockets", 91
[32] Ibid
[33] Emme (1961), "Aeronautics and Astronautics", 3 and Lehmann (1937), "Zeppelin", 172-3
[34] Ley, 166
[35] Ley, 166

According to Ley, early smokeless powders used in artillery cartridges burned too fast to be a practical rocket propellant.[36] There is no record of other tests of double-base powders for war rockets (other than Unge) until brief experiments by Goddard at the Aberdeen Proving Ground in America in 1918. Winter says Goddard's work ceased due to the Armistice, ending WWI, implying a financial or political decision.[37] However, a seemingly-authoritative document states the work was shelved due to the 'lack of a suitable powder'.[38] Ley claims that it was unlikely that anyone else was experimenting with double-base powder rockets at the time of Goddard.[39] However, he also admits that little was known of historical Russian developments at the time he was writing (in the 1950s).[40] Indeed, he suggests that Britain fielded the first rockets of WWII [41] but in fact the Russians were ahead, as described in the next section.

[36] Ley, 170
[37] Winter (1990), xvii
[38] McLaughlin Green et al (1990), "Planning Munitions for War", 356
[39] Ley, 170
[40] Ley, 171
[41] Ley, 174

1.3 New powders and the rocket renaissance

The Russians had continued to explore the use of new powders for rockets when other nations had substantially ceased efforts. Germany renewed development after 1929 and both nations progressed towards WWII rockets.

Soviet history has become more accessible in the decades since Ley's writing and newer sources show that the Russians never really stopped thinking about rockets. An instructor at the Artillery School, IP Grave, suggested in 1915 a nitrocellulose-based powder rocket propellant as an alternative to gunpowder.[42] The Gas Dynamics Lab developed this further, albeit ruling-out the use of single-base powder. At the same Lab, Filippov and Serikov tested a double-base nitrocellulose-TNT powder in 1924, claiming to have increased rocket ranges by a multiple of 10.[43] A smokeless powder rocket was tested in 1928 by Tikhomirov and Artemiev.[44]

Siddiqi, however, challenges the efficacy of this early work, arguing that Russian historians have accepted unchallenged the descriptions by Artemiev in his memoirs, published in the 1950s. He claims that Tikhomirov and Artemiev 'were not well-versed in the theory of ballistics or chemistry, they made no progress whatsoever'.[45] Their rocket gained its initial energy from a cannon launch (as had Unge's). Tikhomirov died in 1930 and his rocket-cannon was soon deemed a dead-end. Their successor, Tukhachevsky, in 1931 turned to self-

[42] Sokolsky (1967), "Russian Rocket-Fuel Rockets", 155
[43] Ordway (1989), "History of Rocketry", 64
[44] Ibid
[45] Siddiqi (2010), "Red Rockets' Glare", 128

propelled rockets.[46] A new ballistite-like (nitrocellulose-nitroglycerine) rocket powder was developed by a team of scientists under the leadership of Bakaev in 1935.[47] This supported Russian deployment of rockets in WWII.

In contrast, after a lengthy absence, the German miliary rocket renaissance commenced in 1929, looking at a variety of fuels and rocket purposes. (Most famously, the liquid-fuelled V-1 and V-2 rockets evolved from these endeavours.) A private inventor, Reinhold Tiling, attracted worldwide attention for launching a rocket (carrying postcards) some 2,500 feet into the air in 1931 but he was still using gunpowder.[48] One of his later rockets is reported to have reached 36,000 feet.[49]

Elsewhere, all three branches of the German military had been developing rockets in comparative secrecy. The Luftwaffe, experimenting at Tarnewitz, started to develop a solid-propellant air-to-ground rocket from 1936 called the Rauchzylinder 65 (RZ65) but did not put it into production due to concerns of inaccuracy.[50] The Army at Kummersdorf-West, under Dornberger, were working with rockets from 1930, hiring von Braun (of V-1 and V-2 fame) from 1932.[51] As well as liquid-fuelled strategic rockets, this establishment created the RZ73, similar to the RZ65 but intended as an anti-aircraft weapon (and trialled as air-launched) and very few were produced.[52] However, they also developed during the 1930s (and accepted in

[46] Siddiqi, 132
[47] DeLuca et all (2017), "Rocket Propulsion", 49
[48] Ley, 146
[49] Subcommittee "E" (1936), "Memo R1", 3
[50] Chamberlain and Gander (1978), "Weapons of the Third Reich", 321
[51] Ibid
[52] Ibid

1940) what became the 15cm Wurfgranate 41.[53] This was the rocket associated with the Nebelwerfer launcher.

The Nebelwerfer was a multiple-launch rocket system, used on the Eastern Front from 1941. Dornberger claimed that half a million rockets were fired in the first hour of Germany's attack on Russia.[54] Russia deployed its Katyusha system from around the same time and was a mainstay thereafter. Supposedly, 21,000 Katyushas were fielded in the Battle of Berlin (1945).[55] British and US equivalent barrage weapons started to appear from 1944, but were not nearly so widespread, although anti-aircraft and anti-tank rockets preceded these.

Dornberger claimed these German efforts were motivated primarily by restrictions on their military (rockets had not been mentioned in the Treaty of Versailles so were perhaps unrestricted).[56] However, Neufeld goes some way to demonstrate that 'the legality of the rocket had little or no importance in the rocket decision' by reference to early Army Ordnance meeting minutes and argues that Dornberger (writing in 1943) was building on the 'Nazi myth' about Versailles.[57] Germany may have simply had a driver in common with Britain, where rockets were seen as a solution to limitations in producing as many guns as they would want. Rockets required different resources and production processes, so could be supplied as an artillery substitute, as well as being relatively quick and inexpensive.[58]

[53] Ibid
[54] Parry (1961), "Soviets' First Rocket Gun", 58
[55] Boden (2003), "Berlin, 1945", 265
[56] Ley, 155
[57] Neufeld (2000), "The Rocket and Versailles", 170
[58] Military Intelligence Division (1945), "Germany's Rockets", 2

These inter-war German rocket experiments primarily used gunpowder, building on the efforts of Tiling and other civilians in the 1930s, so rockets should not have had their dark age for the prior 50 or so years. Tiling's gunpowder rocket benefited from more modern casings (aluminium),[59] more powerful powder presses and other incremental developments. However, Tiling's death from a gunpowder press explosion in 1933 is perhaps testament to the unavoidable unreliability of that propellant,[60] although this safety issue did not dissuade his successors from attempting to weaponise his gunpowder rockets.

[59] Ley, 146
[60] Ley, 167

1.4 Enablers of new powder rockets - why not sooner?

To apply the new powders to rockets required a more scientific approach to development and multiple iterations of powders to find formulations suitable for rockets. These were not straightforward developments and relied on sponsorship to create the requisite investment.

Double-base powder rockets are materially different in power and complexity to their predecessors. During manufacture, a glue-like substance could be shaped ("extruded") or cut as required to be placed into bullets, shells or rockets. This reduced many of the problems with filling and compacting gunpowder rockets. However, several evolutions of cordite were required before forms were found that had the requisite speed and stability of burning.[61] For example, even minute cracks, acceptable within a shell propellant, could be catastrophic in a rocket where the additional burning surface area could cause peaks of pressure, bursting the case.[62] Therefore, it was not the 1890s powders that were used for rockets in the 1940s. That said, it was a WWI development of an improved extrusion process, to produce 'large one-piece "grains" of slow-burning explosives suitable for rocket propulsion', that became an enabler for the rocket renaissance.[63] Further developments occurred, including a 'method of manufacturing solventless double-base powder by a dry-extrusion process had been developed in the late 1930s by the British [which] produced … longer-burning grains'.[64]

Evidently, the harnessing of double-base powders for rockets required lengthy and considerable development, in significant institutions with considerable resources. However,

[61] McLaughlin Green et al, 353-4
[62] Ibid
[63] Chamberlain and Gander (1978), 321
[64] McLaughlin Green et al, 354

nineteenth century chemistry was also likely to have been inadequate to develop the right formulation and shaping for consistent burning rates required for rockets. The criticisms that Siddiqi levelled at Tikhomirov and Artemiev's 1928 unscientific approach could potentially be extended to global rocket development prior to that, i.e. that it was generally based on trial and error rather than understanding of the underlying physics or chemistry.

Sokolsky writes:

> *'The development of Russian rocketry up to the middle of the 19th century was characterized by the absence of any theoretical principles of rocket design and production. The accumulation of experimental data, without any attempt at serious scientific analysis of the factors governing the performance and quality of rockets, was considered sufficient. The improvements made in the design of military rockets were generally based neither on theoretical nor experimental research, but rather on the intuition and guesswork of individuals.'* [65]

Similarly in Britain, the nineteenth century Ordnance Committee and Director of Artillery Committee minutes report many practical tests of different rocket shapes and features at the Shoeburyness range, but little theoretical discussion. Winter writes that 'it seems that nineteenth-century rocket technicians almost wholly overlooked the chemistry of the propellant in their experimental efforts'.[66] For example, in 1879 it was reported that the Chemist to War Department 'regrets to say that he is not at all sanguine that any radical improvement can be effected [in the issue of deterioration of gunpowder rockets during

[65] Sokolsky, 165
[66] Winter (1990), xvii

storage in hot conditions]'.[67] This is very likely a reference to Sir Frederick Abel, Chemist to the War Office from 1856-1888. He was an expert in explosives and ammunition. After retiring from the War Office, he remained President of the Explosives Committee until his death in 1902. The very man who invented cordite in 1889 and was 'sanguine' about gunpowder rockets apparently did not push for cordite rockets in his influential roles.

Although Abel was succeeded by Dr William Kellner as Chemist to the War Department, an additional new post of Chemist to the Explosives Committee of the War Office was also created at Woolwich in 1901. This was an expression of a general ambition in the Royal Artillery and Government to exploit developments in cordite.[68] However, it was also precipitated by problems with munitions during the Boer War, such as the non-detonation of high explosive shells,[69] which must have taken priority over novel developments, such as revisiting rockets. This role was taken by Dr OJ Silberrad, finding himself at first in a small iron shed with a pair of disaffected subordinates.[70] However, this evolved into the Chemical Research Establishment in 1904 and then Research Department (Woolwich) in 1907. Silberrad solved a problem with lyddite shells by inventing tetryl. He also developed a "New stability test of cordite" in 1911. Crow, who is mentioned again later, became head of Ballistics Research in that Department, from which was born the British rocket renaissance a quarter century later.

[67] Director of Artillery (1878), "Proceedings", 159
[68] Nature (1953), "Armament Research Establishment", 1075
[69] Sharp (2003), "Oswald Silberrad", 302
[70] Sharp, 303

Cocroft notes that 'Waltham Abbey [site of the Royal Gunpowder Mills, closely associated with the Woolwich Arsenal] was at the forefront of explosives development at the end of the nineteenth century' but that 'the poor development of the British organic chemical industry in comparison with that of Germany was one reason for the faltering start Britain made to adapt its peacetime industries to those of war [in 1914]'.[71] If Britain was indeed 'faltering' and Silberrad was so short-staffed, this may indicate why new rocket propellants were not prioritised in this period.

In contrast, Grew, claims that the later, larger Research Department 'was practically the sole inventor of flashless cordite, eliminating gun flash in even the largest guns' as well as that 'the new cordite, was almost uniquely suitable for new types of rocket weapons'.[72] This emphasises that plain cordite was not enough and a large establishment was required to evolve it – he logs many cordite iterations to address shortcomings of the original. He also claims it was 'conceived from fundamental principles, breaking away from old conventions'.[73] This echoes the complaints about Russian rocket development having been more empirical than theoretical. Sources show Abel's expertise, tests and creations but not his theories. In contrast, Silberrad, in his *Stability of Nitrocellulose* treatise develops deductions from theory before checking these experimentally.[74] This is perhaps indicative of the evolution of the new 'fundamental principles' approach identified by Grew.

[71] Cocroft, 152
[72] Grew (1949), "Armament Research", 11
[73] Ibid
[74] Silberrad (1903), "Stability of Nitrocellulose", e.g. 85

Furthermore, a 1944 paper shows a mature, detailed recognition of the desirable qualities of rocket propellants by reference to a number of scientific metrics, as well as the ability to measure them in practice and anticipate them in design. [75] It notes that these qualities are described by 'Young's Modulus, Poisson's ratio, bulk modulus, grid indentation, tensile strength, etc, [which] can be determined directly'.[76] Young's work, for example, was known in Congreve's time but is not mentioned in any nineteenth century primary or secondary sources about war rockets. With the ability to predict the upper temperature limit for cordites, it became possible to predict and avoid bursts on the projector without trials.[77] This led to deliberate attempts to increase the modulus, tensile strength and hardness to increase the limit and diminish chance of burst. In fact, Green argues that until even newer powders became available in 1944, 'premature explosions close to the launcher endangered life and limb of the user and friendly troops in the vicinity', suggesting that cordite had not wholly solved the safety problem of rockets.[78]

The German Army's developments were primarily still using black powder in 1932 for, as Neufeld notes 'for the time being, Becker concluded, black powder remained the only practicable rocket propellant, given the difficulties with liquid fuels and smokeless powders'.[79] Indeed, 'it was not until 1940 that the problems of smokeless powders were resolved sufficiently to stop production of the older types'.[80]

[75] Armament Research Department, "Mechanical Properties of Cordite", 1-2
[76] Ibid
[77] PDE Aberporth (1945), "Development of British Rockets", 4
[78] McLaughlin Green et al, 355
[79] Neufeld, 167
[80] Neufeld, 170

Germany had, by this point, developed an alternative type of cordite, replacing the nitroglycerine with diethylene glycol dinitrate, believing the former could have restricted supply in wartime.[81] Many authors complain of the Nebelwerfer being easy to spot allegedly due to a smoke trail. However, this is inconsistent with the use of a double-base, "smokeless" powder. Ley clarifies that in fact 'the flash of the rocket charge … was some 40 feet long and brilliantly luminous [and] kicked-up large dust clouds'.[82] Evidently, while the British rocket propellant derived from a flashless powder, the German did not, but both were testing cordite rockets by 1940.

Inspired by a 1934 report on the German rocket programs, the British had formed an Advisory Committee on Rocket Investigation in 1935. This 'paper giving particulars of German activities' [83] has not been found although minutes show the War Office had obtained a memo written by Tiling which said 'owing to its low cost and its considerable moral and explosive effects it [the rocket] is particularly adapted to barrage fire – more especially in anti-air defence'.[84] In an Advisory Committee meeting in September 1936, it was declared that 'it is noteworthy that gunpowder forms the basis of most rocket (including the Tiling rocket) propellants … It is, however, by no means thought that it is not possible to improve the gunpowder type of propellant, nor that propellants of the cordite type are excluded [noting advantages of the latter, and that it should be smokeless]'.[85] The British, as late as 1936 are observing the

[81] Ley, 173
[82] Ley, 175
[83] Subcommittee "E", 3
[84] Ibid
[85] Ibid

promise of cordite-powered rockets while offering no guarantees, confirming that the matter was not so obvious that it merely required discovering.

Furthermore, as Ley notes, 'the invention of a better powder charge is not the whole story'.[86] For example, in Britain, it was necessary for the charge to rapidly reach a high rate of burning but then deliver a consistent thrust ("a plateau"). To this end, Dr. Harold Poole of Crow's staff, introduced a star-shaped cross-section grain (and later a cruciform shape) to provide a consistent burning surface while the powder was progressively used-up.[87] He is also credited with suspending the cordite stick on a metal-grid, allowing it to burn on all surfaces, rather than it being pressed against its case.[88] A variety of other innovations were required, in casings, fuses, launching platform and a spin-mechanism in order to deliver an effective rocket system. Similarly, for the German programme, Neufeld also notes a number of developments in stabilisation and guidance, such as through improved nozzles; they also improved the launch racks.[89] The Neberlwerfer rockets included seven suspended sticks, which burned from both ends to produce rapid and smooth burning,[90] achieving similar ends as Poole's innovations.

Ironically, WWII minutes of British scientific meetings complain that solventless cordite was expected to survive only 5 months at 160 degrees, before suffering chemical breakdown or exhaustion of stabiliser.[91] This led to discussions of new coatings and cooler magazines. This

[86] Ley, 178
[87] Winter (2011), "Mr Z", 47
[88] Ibid
[89] Neufeld, 168
[90] Hogg (1976), "Nebelwerfer", 5
[91] Armament Research Department (1944b), "Propellants After Extreme Weather", Para3(a)

is evocative of the storage problems suffered by nineteenth century rockets. Thus, the proximate reason for disadopting those rockets was not wholly rectified. Accuracy concerns also persisted but rockets were pushed-forward nevertheless. Thus, technology cannot be seen to be the sole causes of the "fall" or the "rise" of rockets, as 1930s rocketry innovation did not rely on double-base powders and WWII rockets were sponsored despite their continued shortcomings.

2. Doctrine

The 1871 article in the introduction claimed the British 'use [rockets] with effect', recognising a mobility benefit but aspiring for a future 'true genius' of use. This doctrine section describes how rockets were used in the early and late nineteenth century periods, in contrast with the use in WWII and since. Congreve claimed his rockets were superior to the Indian original, both technologically and due to the 'rocket system' of procedures he developed around their battlefield use.[92] The importance of linking doctrine with technology is consistent with modern views.

Rockets excel in a flexible, mobile role. They can create shock effects in barrage on the offense and can disrupt an enemy's development of shock when used reactively in barrage or individually in defence. Rowland, in his *Stress of Battle*, strongly correlates shock effects with military success, and offers a formula for shock based on intensity, noise, smoke, unpredictability, suddenness and rapidity of approach, all of which fit the profile of war rockets.[93] In contrast, the use of rockets as a simple gun-substitute in a traditional artillery role generally disappointed and led to unfair negative comparisons. In this way, the use and criticisms of rockets have mirrored those of the machine gun, also tied to the artillery in its early evolution.

[92] Werrett (2012), "Trials of the Congreve Rocket", 602
[93] Rowland (2006), 186, 208

2.1 Early nineteenth century

Some of the early successes of British rockets arose from their mobility and from shock effect but that this was not enshrined in training, organisation and doctrine, causing the successes to be few and far between.

Winter opines that rockets were ineffective at Waterloo, citing the low number of rockets fired.[94] Mercer, an eye-witness, also complained of inaccurate rocketry at Quatre Bras (two days before Waterloo) - the first rocket destroyed a French gun but subsequent missiles flew wildly, endangering friendly troops.[95] However, the Siborne papers (quoted below) show that Dunnett's section managed to halt a French division column's advance against La Haye Sainte, at least until ammunition was expended (they having only as many rockets as could be carried on the horses they were riding). [96] In this, he was detached from the main gun line, moving independently ahead and able to engage opportunistically.

> *'Sergeant (Daniel Dunnett), who, on perceiving the advance of the nearest French column towards the farm, dismounted his men as coolly and deliberately as if exercising on Woolwich Common, though without any support whatsoever, laid rockets on the ground, and discharged them in succession into the mass, every one of them appearing to take effect. The advance of the column was checked, and not resumed until Dunnett, having expended all his rockets, retired with his party to rejoin the guns in the rear.'* [97]

[94] Winter (1990), 23
[95] Mercer (1870), "Journal of the Waterloo Campaign", 279-80
[96] Glover (2018), "Letters from the Battle of Waterloo", 158-9
[97] Siborne (1848), "History of the war in France and Belgium in 1815", 305

Similarly, Whinyates, with a different detachment, fired on French cavalry and infantry and 'put the former in great confusion' before retreating to his guns.[98] He reports that he was ordered some hundred yards forward of the guns with the mounted rocket sections, leaving 2 men at each gun, and fired the rockets along the ground.[99] Captain Whinyates commanded the Rocket Troop at Waterloo but had detached 2nd Captain Dansey with part of the Troop, with Sergeant Dunnett (ancestor of this dissertation's author) taking command once Dansey was wounded. (Whinyates and Dansey also appear again later in the rocket story.)

These events are somewhat evocative of the earlier success at Leipzig in 1813 ("the Battle of Nations") where the same Rocket Troop (Britain's only contribution to that battle) similarly stopped a French division, catching the eye of most of the major continental militaries. Operating at his own initiative ahead of the main force, Captain Bogue fired rockets at a column of several French battalions with the result that they 'fell into confusion and began to retreat'.[100] This was more frontal than Dunnett's ambuscade but similarly disruptive to formed infantry. One report suggests that Bogue then charged with some attached dragoons, capturing over 2,000 men, although he died later in the battle and was posthumously decorated by both Tsar Alexander and the Crown Prince of Sweden.[101]

Sadly, however, a common perception was of rockets as a siege weapon, such as used at Boulogne (1806) and Copenhagen (1807). This was partly Congreve's fault, as he attempted to offer rockets of different sizes for every possible circumstance. Indeed, Harris accuses

[98] Glover, 165
[99] Glover, 155
[100] Brett-James (1970), "Europe Against Napoleon", 186
[101] Ibid

Congreve of trying to impress the Prince Regent by showing him larger and larger rockets.[102] It seemed to play to some of the rocket's strengths in range, lack of recoil and a tendency to produce fires (whether due to an incendiary warhead or simply its unspent fuel). That said, Franklin contests the idea that rockets could outrange contemporary smoothbore guns.[103] Furthermore, these cases of static, sustained, strategic bombardment fail to utilise rockets more important strengths, i.e. shock and mobility. For example, Storr identifies that 'short, intense bombardments are much more effective (and efficient) than protracted ones … an example of the shocking effect of sudden violence'.[104]

Franklin and Johnson claim that by 1845 marine artillery was the main British user of rockets, noting that in 1847 the rocket troops of the Army ceased to be a distinct branch.[105] Ostensibly this was to make rockets more widespread and indeed many field regiments in 1850 had a rocket cart, although they retained a reputation for unreliability.[106] This could have helped rockets to become more universal. Indeed, Scoffern says that Congreve himself 'advocated the plan of furnishing rockets to every part of the army … and was opposed to the scheme of organizing an independent body of troops, like the present rocket troops'.[107] Congreve's doctrinal thinking was more than a century ahead of its time, as well as his invention being so. However, in a British Army much diminished in size and evolution in the period after Waterloo, the loss of specialist rocket troops was likely responsible for limited and ineffective adoption of the weapon. It required a degree of training to maintain and use a rocket but,

[102] Harris (1997), "Early War Rocket", 40
[103] Franklin (2005), 15
[104] Storr (2011), "Human Face of War", 88
[105] Franklin and Johnson, 231
[106] Franklin (1998), "Hale Rockets, Part I", 337
[107] Scoffern (1859), "Projectile Weapons", 165

whereas the Navy continued to practise regularly, the Army ceased peacetime training with rockets sometime after 1870.[108]

Furthermore, rockets were not truly spread throughout the army, they continued to be manned by artillerymen and often shackled to the artillery line on the battlefield, thus materially under-utilising the rocketeer's significant advantage in mobility. This was an artillery who were considered to have not evolved tactics at all in the years between Waterloo and Crimea,[109] and continued to present themselves in exposed, neat lines of guns still in 1899.[110] The esteemed Strachan claims that 'ambitions [for future rockets] rested primarily on the rocket's use as an infantry or cavalry support weapon, rather than as an alternative to thoroughgoing ordnance. Its lightness and portability, its minimal frontage, and the rapidity with which it could be brought into action, all pointed to a flexibility which increasing heaviness and concentration were taking from field artillery'.[111] This accurately describes the opportunity but it cannot have been the consistent contemporary view given that rockets remained under the artillery (or marine artillery) branches in most countries, deployed in artillery-like roles, and compared with gun artillery when assessing their merits.

One intriguing, little-documented effective use was that of a rocket barrage in support of an amphibious landing at Taganrog, on the Sea of Azov in 1855. Gunfire and a 'hurrican (sic) of rockets' from boats allowed the raiding party ashore to burn the stores and facilities of this important commercial town, one of many attacked in this campaign to deny resources to the

[108] Callwell and Headlam (1931), "History of the Royal Artillery", 184
[109] Callwell and Headlam, viii
[110] Spiers (1992), "Late Victorian Army", 265
[111] Strachan (1985), "From Waterloo to Balaclava", 135

defence of Sevastopol.[112] This foreshadows a similar usage of rocketry fired in support of the D-Day landings from the Royal Navy "Mattress" launchers, as well as by the US in the Pacific.[113] These cases generated shock from rapid, intense bombardment and benefited from the lightness and mobility of rockets, such as enabling their mounting on landing ships which could not carry large guns. Furthermore, the use in barrage negated any concerns about the accuracy of individual rockets.

[112] Merrill (1956), "Sea of Azov", 24
[113] Winter (2011b), "Mr Z Part 2", 72

2.2 Late nineteenth century

The generally accepted reason for rocket decline was competition from gun artillery. However, other drivers include the doctrinal error of deploying and organising rockets in traditional gun artillery roles.

Winter says that 'the Franco-Prussian War (1870-71) marked the decline of war rockets in other countries, especially since in this war the combatants used rifled, breech-loaded guns as well as hydraulic recoil shocks'.[114] However, the French effective disadoption must have been earlier as the French War Minister declared in 1872 that rockets had not been used in the recent war.[115] That said, their Committee of Artillery did deem that Prussian guns were 'incomparably superior' to war rockets when closing-down rocket production in the same year.[116]

Austria also began disadoption earlier, due to improving rifles, not cannon. The Austrian rocket establishment was one of the largest in Europe by mid-century and their spin-stabilised rockets were supposedly reliable and accurate.[117] Their rocket with shell warhead was described to be used at a 300-400 yards range,[118] implying a different doctrine to the British approach of an artillery-substitute. However, Austrian use was substantially disestablished after facing the Prussian "needle guns" (breech-loading rifles) in the Austro-Prussian War of 1866. The rocketeers (who stood to fire) were undone by the increasing range of accurate

[114] Winter (1990), xvi
[115] Winter (1990), 114
[116] Ibid
[117] Winter (1990), 92
[118] Scoffern, 362

rifle fire from infantry now able to fire from prone position and against whom the rocket was decreasingly effective.[119] However, their rockets had already, by this time, merged with mountain gun units and so ceased to be rocket-specialists,[120] suggesting that they were unlikely to get the best from the weapon.

In British use, rockets were effective in some colonial campaigns, such as against the Ashanti (1873-74).[121] However, the late-century British rocket was suffering from a lack of an effective warhead. For example, in the Transvaal (1880-1) it disappointed because 'lacked the destructive power'.[122] However, the versatility of the rocket continued to be exhibited occasionally, such as shooting from an upper storey of a building in the Crimea War[123] and 'a rocket from the church, well-directed, reduced [the enemy] to comparative silence' in the Ashanti (1874).[124] At Magdala (1868), rockets manned by 'sailors' supported the British infantry against a charge, having unloaded 'in less than a minute'.[125]

In another action on the Benin River (1895), the rocket's versatility was critical to a disembarked action after their 7-pounder gun sank in a muddy river crossing. The only British casualty was killed by a premature rocket explosion, underlining the continuing safety issue that was central to British rocket disadoption.[126] Despite these occasional actions, tellingly,

[119] Winter (1990), 91
[120] Ibid
[121] Konstam (1990), "The War Rocket", 61-2
[122] Konstam, 67
[123] Winter (1990), 107
[124] Boyle (1874), "Diary of the Ashantee Expedition", 75
[125] Franklin (1999), "Hale Rockets, Part 2)", 260
[126] Hickley (1895), "Operations on the Benin River", 191, 198

rockets are not mentioned at all in a chapter entitled The Weapons That Won An Empire in the book *Colonial Small Wars 1837-1901*.[127]

In one of the last cases of British rocket-use, at Tirah in 1897, 'the rockets proved ineffective as well as dangerous, and accomplished nothing', providing a sad epitaph.[128] Winter believes the last British use in action was in 1898 (witnessed by Winston Churchill), or perhaps 1899.[129] The Russian experience somewhat mirrored the British, with rockets being deemed effective at Geok Tepe in 1879,[130] although with rumblings of discontent been heard since at least 1875.[131] The Russians ceased rocket production in 1886, just two years after the British making a similar declaration, and the last Russian use was in 1899, again similar to the British, implying peer-following behaviour.[132]

There is some parallel with the history of the machine gun. At first seen to be fragile and difficult to use, machine guns were typically held in specialist units, often part of the artillery, like rockets. Having a shorter range, machine guns tethered to the artillery were ineffective in the Franco-Prussian War.[133] An 1873 RUSI debate recorded that a Major-General Walker 'sees no place for [mitrailleurs] in European warfare, as he believes them to be inferior to artillery'.[134] This echoes complaints made about rockets.

[127] Featherstone (1973), 25
[128] Winter (1990), 222
[129] Winter (1990), 223
[130] Winter (1990), 105
[131] Sokolsky, 80
[132] Winter (1990), 105
[133] Ellis, 64
[134] Fletcher (1873), "Mitrailleurs", 38

In Britain, they were later consolidated in specialist machine gun battalions and eventually becoming organic to smaller infantry units. This took a long time despite, for example, General Chelmsford arguing in 1879 that machine gun be considered an infantry weapon and bemoaning that Woolwich and the RA kept hold of it (much as they dominated rocketry).[135]

The French mitrailleuse was first used in a major conflict in 1870, just as rockets were declining. However, authors generally do not identify this as cause and effect. Probably both machine guns and rockets were in the shadow of gun artillery. They do now, and could then, co-exist. For example, both Gatling guns and rockets were said (notably, in a report from the Navy) to have been effective in the Zulu War (1879).[136] A modern infantry section is likely to carry both as standard.

[135] Ellis, 63
[136] Director of Artillery (1881), "Proceedings", 43

2.3 World War II

Rocket use matured in barrage and ambush roles as a doctrinal driver for the successful readoption of rockets. These were associated with shock effect. Air-launched and anti-air varieties could also attribute their limited success to shock, while struggling more with accuracy in their early development.

The Germans fielded the Nebelwerfer from 1941 and the Russians fielded the Katyusha from the same year, both barrage weapons. The American Sherman Calliope (a Sherman with 60 rocket tubes mounted inelegantly on top) arrived in small numbers in 1944.[137] The British Land Mattress also appeared in 1944 and both the land and sea Mattress variants was lauded for joint effect at the Battle of Walcheren that year.[138] (Rockets were also effective in the 1809 bombardment of Walcheren – history repeats!)[139] In attack or defence, the intensity of rocket barrage could disrupt enemy concentrations of force, potentially creating a shock effect upon the enemy, or preventing the enemy from creating a shock effect. There is similarity to the employment of nineteenth century Rocket Troops, such as at Leipzig.

A very different type of WWII rocket was of the man-portable variety, typically for anti-armour use. The famous bazooka was the product of a US rocket unit under Leslie Skinner, initially tasked in 1933, but working solo, and 'handicapped by limited funds' until at least 1940.[140] It actually first saw combat in Russian hands in 1942[141] and with US forces in Tunisia soon

[137] Ley, 189
[138] Crow (1947), "Rocket as a Weapon", 20
[139] Headlam, 81
[140] McLaughlin Green et al, 356
[141] Smart et al, 68

after[142]. Due to a lack of training and occasional malfunction (especially in hot environments), the early bazookas were deemed ineffective and deployment was suspended in 1943,[143] somewhat echoing the experience of nineteenth century rockets. However, bazookas did return and half a million were made in all.[144] The Germans also copied the design of captured weapons, soon fielding their own Panzerschreck ("tank terror") and producing some 300,000.[145]

Harris argues that the bazooka is the true successor to the 'misunderstood' Congreve weapon.[146] That simple argument, however, overlooks all the other types of successor rockets, especially those of a barrage type. Furthermore, Congreve rockets were rarely expected to be fired individually so the comparison is strained. However, the bazooka-type rocket shares its effect somewhat with the barrage rocket in being designed to defeat a concentration of force, albeit more commonly in ambush or defence. General Patton stated that 'the purpose of the bazooka is not to hunt tanks offensively, but to be used as a last resort in keeping tanks from overrunning infantry'.[147] This is similar to Dunnett or Whinyates stopping columns of infantry or cavalry, the "tanks" of their day.

The first air-to-ground rockets came in August 1939, used by Russia against Japan, shortly prior to WWII, at Khalkhin Gol.[148] The British also developed air-launched rockets, first for use against ships and submarines. Some successes are recorded, such as hitting U-752 in May

[142] Ibid
[143] Green and Green (2000), "Weapons of Patton's Armies", 38-39
[144] Smart et al, 68
[145] Smart et al, 69
[146] Harris, 1, 60
[147] Green and Green, 38-39
[148] Siddiqi, 178

1943[149]. Winter identifies 8-10 kills of U-boats by June.[150] However, Nesbit argues that air-to-ship accuracy reduced when rockets were adopted, due to being too difficult to aim, and identifies a case of 176 rockets fired at a convoy, damaging only three ships, although also scaring many sailors into precipitously abandoning their ships.[151] Winter also cites enthusiastic media coverage of rockets launched against land targets in Normandy,[152] although that coverage propagates claimed tank kills which in reality exceeded real kills by a factor of more than 10.[153] Price, for example, identifies that rockets were responsible for only 4% of German tank losses at the Battle of Falaise Gap (1944) and only seven tanks were destroyed at the Battle of Mortain (1944) through the use of 2,088 rockets in 458 sorties.[154] However, he also acknowledges that those rockets played a major part in halting a thrust by five Panzer divisions (against the Americans at the base of the Cotentin).[155] A rocket hit, although rare, was usually unsurvivable by the crew and so was feared more than other weapons, in many cases causing tanks to seek cover, or even to be entirely abandoned.[156] Rowland argues that a 'rapid approach threat' was particularly psychological: whether a Hawker Typhoon was strafing with guns or rockets, its approach on a ground attack vector felt personally aimed.[157] He considers these attacks to be analogous to a cavalry charge, which

[149] Herriott, 95
[150] Winter (2011), 58
[151] Nesbit (2014), "The Strike Wings", 61
[152] Winter (2011), 52
[153] Price (2009), "Rocket-Firing Typhoons", 115
[154] Price, 118
[155] Price, 120
[156] Price, 115
[157] Rowland, 200

may create shock when released and not necessarily upon impact. Again, rockets were deployed fast to create shock or defeat shock.

Anti-air use was the primary driver for the British resurgent interest in rockets 1935-1941 because of the air threat and the limited production of anti-air gun artillery. Rockets were cheaper to produce and easier for untrained home defence forces to operate. Rockets were first deployed in late 1940, against the Blitz. Possibly the shooting-down of a V-1 over the Kent Coast by a "Tonsil" Navy rocket battery in 1944 was the first ever case of a cruise missile being defeated by an anti-air rocket.[158]

However, it is not entirely clear that, inclusive of the development cost, rockets were truly cheaper than guns or really enhanced air defence, given their lesser accuracy. It was certainly identified that rockets in this role should be used in a dense barrage, where the accuracy of individual rockets was less important. In this way, anti-air doctrine mirrored the ground barrage rocket doctrine mentioned above. It is interesting to note that although Germany did experiment with anti-air rockets, neither they, nor Russia, materially deployed rockets in this role. Britain could be considered ahead of its time in using anti-air rockets, although it is unclear that this produced any long-term advantage.

[158] Imperial War Museums (2024), "Tonsil"

3. Human drivers: inventors and sponsors

The 1871 article in the introduction identified ‘enthusiasts’ and ‘disrepute’ as key factors in the nineteenth century rise and fall of rockets, while predicting future adaptions to fulfil their potential. Despite inconsistent effectiveness, nineteenth century rockets spread across the world and millions were produced. They had critics but clearly also adherents, perhaps allowing early rocket designs to be more widespread and retained longer than was objectively justified. Successful rocket inventors were typically self-promoters and attracted powerful sponsors. This section argues that the waning of rockets later in that century was for lack of a charismatic proponent and a strong sponsor and that the subsequent readoption correlated with the appearance of new sponsors. It uses the cases of Britain and Russia to illustrate this, they having retained rockets for most of the nineteenth century and being early readopters in the twentieth.

3.1 Britain

The adoption, disadoption and readoption of British rockets demonstrate the importance of the presence and absence of sponsorship.

With establishments such as the Royal Arsenal at Woolwich (and its foreign equivalents), weapon development was clearly somewhat institutionalized well before Congreve. However, even then, many new weapons were named after their inventors, such as with the Congreve, Parlby, Boxer and Hale rockets. Similarly, shrapnel shells were named for the eponymous soldier-inventor and an early machine-gun named for its inventor, Gatling. This indicates a substantially individualistic process, as well as a mix of the state and private sectors being involved.

Anachronistically, Congreve inherited his role as Comptroller of the Royal Laboratories from his father. He was styled with a military rank but never served in the field. He benefited from the powerful sponsorship of Lord Chatham (Master-General of Ordnance and brother to the Prime Minister) and the Prince Regent (who became a friend).[159] Another crucial early supporter of Congreve's rockets was the Marquess of Hastings, the Master General of the Ordnance in 1806-7, when they were first deployed. He also helped Congreve promote them to the East India Company when he became Governor several years later.[160] Although he commenced his rocket developments with his own money, he was able to bring that work into Woolwich soon after. This may have allowed rockets to evolve in Britain despite the influential Duke of Wellington's dislike of the weapon. Wellington, for example, once said 'I do not want

[159] Winter (1990), 6
[160] Werrett, 608-9

to set fire to any town and I do not know of any other use for the rockets'.[161] Wellington was perceived to be uninnovative in general.[162] As such, he may have represented a headwind for rockets throughout his post-Waterloo career, including the relevant posts of Master-General of the Ordnance (1819-27) and Commander-in-Chief of the British Army (1827-8 and 1842-52). Furthermore, Cocroft observes that 'in contrast to other European countries, little research was conducted into armaments technology in Britain during the long period of peace after Waterloo [up to late 1840s at least]'.[163]

Also, Dansey (in the 1840s)[164] and Whinyates (in the 1850s)[165], who together had led the Rocket Troop at Waterloo, were appointed as senior managers at Woolwich. It is possible that Congreve's baton was being passed to other rocket-enthusiasts to carry onward and this may have contributed to rockets surviving in Britain longer than in some countries.

The Hale rocket was the successor to the Congreve, improving accuracy using spin-stabilisation. Hale was a private inventor and entrepreneur, actively selling his product globally to militaries, governments and monarchs. In Britain, Prince George, the Duke of Cambridge (a cousin to Queen Victoria) was instrumental in efforts to replace the Congreve rocket from around 1863, leading to the adoption of the Hale rocket in 1867.[166] Often criticised by history books for being overly conservative,[167] he reportedly opposed the

[161] Johnson (1994), 374
[162] Winter (1990), 24
[163] Cocroft, 65
[164] Askwith (1900), "List of Officers", 241
[165] Callwell and Headlam, 58
[166] Konstam, 52
[167] E.g. Correlli Barnett (1970), 340

adoption of khaki uniforms.[168] However, his record includes innovations such as breech-loading carbines and the Staff College, as well as extending the service lifetime of gunpowder rockets by several decades. Cambridge's influence as Commander-in-Chief of the Forces began to wane once the War Office Act 1870 subordinated that role to the Secretary of State for War.

The further overtures of Hale and (after his death) his son to further evolve his designs after 1870 were repeatedly spurned by Woolwich, although Woolwich continued their own, relatively fruitless iterations for the next decade or so.[169] Hale Junior was told in 1875 that private tests at Shoeburyness were against policy. It is possible that Woolwich itself had become pessimistic about rockets as well as resistant to external, private initiative. This stands in contrast to earlier in the century when private efforts were more commonly adopted and supported by state institutions.

General Wolseley, was also influential in the late nineteenth century and considered to be a reformer. He often disagreed with Cambridge but worked together on the evolution of the British Army for much of the latter decades. He had experienced the utility of rockets in his colonial campaigns, such as 1873-74 in Kumasi against the Ashanti although his 1882 Pocket Book comments only briefly on rocket use.[170] Furthermore, he wrongly refers to explosive warheads,[171] which had been discontinued more than a decade earlier, indicating he had limited familiarity. Conversely, he is said to have been very keen on machine guns in 1885,

[168] Kochanski (1999), "Wolseley", 130
[169] Franklin (2005), 148
[170] Wolseley (1882), "Pocket Book", 400
[171] Ibid

albeit unable to significantly move the establishment at that time.[172] He commenced a campaign against Woolwich in 1886, whom he perceived to be inefficient and dated but rockets are not noted to be a primary motivation for this activity.[173]

Ultimately, the official discontinuance of rockets under the authority of the Ordnance Committee in 1884 occurred under the chairmanship of General Sir Collingwood Dickson, a Royal Artillery officer of considerable repute (a VC winner and veteran of the Crimea) but ageing (he retired that year). Each meeting considered hundreds of weapons and items of equipment, indicating no aversion to new ideas. Furthermore, there is no immediate evidence that Dickson closed-down rockets in favour of guns as part of a Royal Artillery agenda. The only notable disappointment apparently laid within the Royal Navy.

Interestingly, a Colonel Dickson had been in command of the crossing of the Adour in 1814, where rockets were critical in enabling a crossing, causing the French to have 'retreated in the greatest disorder'.[174] This was likely Sir Alexander Dickson, Collingwood's father. Sir Alexander had complained that he did not 'think they [rockets] have ever had a fair trial with this army', ascribing that to Wellington judging rockets based on his pre-Congreve experience in India.[175] Perhaps, however, Collingwood in the 1880s saw rockets as a feature of his father's generation. He certainly would have been aware that peers in France, Austria and Prussia no longer used them.

[172] Ellis (1986), "Social History of the Machine Gun", 57
[173] Kochanski, 179
[174] Headlam (1944), "Rockets in the Artillery", 88
[175] Headlam, 82

When British rockets reappear in the 1930s, it was in response to intelligence of German efforts, which produced an institutional response to investigate the same opportunity. However, following tests and creations in the 1935-39 period, these efforts were substantially shelved due to poor accuracy.[176] Indeed, the leader of that development, Crow, said that all his team offered at first was 'faith and hope'.[177]

An early collaborator in those developments, Professor Frederick Lindemann, became scientific advisor to Prime Minister Winston Churchill, a noted technophile, who became a major supporter of further rocket work.[178] For example, a typically Churchillian memo was issued on 1 August 1940, insisting that Crow be granted 'all facilities' for his work.[179] At the July 1940 Defence Committee meeting, he intervened to direct 'all possible action' towards repurposing the rockets for long-range anti-aircraft use instead of against the fading dive bomber threat.[180] Lindemann was also able to defend Crow when his development work was criticised.[181] Furthermore, Churchill's son-in-law was posted to command the first rocket deployment, defending Cardiff two months later.[182]

This support was despite an early rocket demonstration for Churchill reportedly mis-firing, destroying a house in Carshalton and burning two men in its backblast.[183] It was also despite the accuracy of the deployed rockets remaining relatively poor, with their main virtues being

[176] PDE Aberporth, 5
[177] Crow, 21
[178] Winter (2011), 48
[179] Ibid
[180] Chatwin (2011), " 'Z' Batteries", 96
[181] Chatwin, 93
[182] Chatwin, 97
[183] Absolon (2004), "Z-battery", 8-9

cheapness of production and ease of use by 'personnel with little or no military training'.[184] Rockets, if formed in sufficiently large batteries, could produce a more concentrated barrage than conventional anti-aircraft guns, sometimes producing kills but certainly causing a deterrence effect.[185] For example, Chatwin cites an intelligence report of a Ju88 crew who would take 'great pains to avoid [rocket battery sites], and made a large detour around'.[186] However, it is not obvious that rockets would have received the investment and attention that they did throughout the war without Churchill's sponsorship. Alternatively, Britain may have delivered more effective rockets, sooner, had Churchill's sponsorship been attached earlier.

[184] PDE Aberporth, 6
[185] Winter (2011), 49
[186] Chatwin, 108

3.2 Russia

Similar dynamics arose in Russia as Britain, with rocket development correlating to the degree of sponsorship, which was generally more consistent in Russia, producing WWII rockets sooner.

Russia has a long history of rocketry, fielding rockets right up to the end of the nineteenth century and resurrecting them again in WWII. In 1815, after Congreve had recently repopularised rockets in Britain, Zasiadko is said to have been studying 135 years of development at the Russia Rocket Works.[187] Tsar Nicholas I took a keen interest in developing Russian rockets after seeing Congreve's at Leipzig and further demonstrated in 1814.[188] Zasiadko created a 5-rocket stand, used for example in the 1828-29 Russo-Turkish war, evocative both of the ancient Chinese equivalent and the modern multi-launch rocket systems of WWII and since.[189]

Russia was a big producer of rockets, for example, their production of 33,000 rockets between 1846 and 1854 compares with their leading peers.[190] As in Britain, rockets in Russia declined in the second half of the century but continued to be used in colonial campaigns. The War Council actively questioned their continued use in 1875, with some regional commanders seeking retention.[191] Production was officially discontinued by the Artillery Committee in 1886 although Winter identifies their last use being in 1899.[192] Some experiments were

[187] Parry (1960), "Russia's Rockets", 76
[188] Winter (1990)
[189] Parry (1960), 77
[190] Sokolsky, 40
[191] Sokolsky, 80
[192] Winter (1990), 105

resuscitated in 1907 by Major-General Pomortsev but research was terminated in 1910 and the Nikolaev Rocket Plant was shut down.[193]

However, the ending of the "first golden age" here is seen to overlap with the second. A Russian, Tsiolovsky was the first person to mathematically substantiate space travel using liquid-propellant rockets in key papers in 1898, 1903 and 1911,[194] ahead of similar developments in the West. At the same time, Tikhomirov is said to have been working on war rockets since 1894 and received funding from the Tsar, who witnessed a test in 1912.[195] He managed to bridge the upheaval of the Revolution by writing to Vladimir Bonch-Bruyevich of the People's Commissars in 1919 to gain their support for further research.[196] Funded by Kamenev (the chief of the armed forces), Tikhomirov opened a special rocket lab in 1921,[197] with his assistant Artemiev, later to evolve into the Gas Dynamics Lab ("GDL"), which in turn evolved into a branch of the RNII (Moscow Reactive Research Institute) in 1933.[198] It grew from 10 people in 1921 to 200 people in 1933.[199] It was, however, small and poorly-funded in the 1920s, for example needing to 'borrow' the fuel required for their 1928 test.[200] These establishments became famous as part of the history of the Space Race (as well as war rockets). There is evidence that, like Britain, Russia was partly motivated by international

[193] Sokolsky, 126
[194] Parry (1960), Ch6
[195] Wikipedia; unreferenced
[196] Zak (2018), "GDL", 1
[197] Zak, 2
[198] Zak, 1
[199] Ibid
[200] Siddiqi, 128

competition and were spying on the West. For example, there was a particular secret report in 1931 about the progress of Tiling and others.[201]

This lab experimented with a variety of new powders in the 1920s and 1930s, with Tukhachevsky in charge from 1930, after Tikhomirov's death. Marshall Tukhachevsky was the Red Army Chief of Armaments and first Director of the RNII. Russian rocketry enjoyed the benefit of patronage when Tukhachevsky's influence was on the rise but suffered the worst of the repressions when his fortunes suddenly declined.[202] Key RNII staff members, Kleymenov and Langemak were arrested in 1937 and executed in January 1938.[203] Langemak has been described as the designer of the Katyusha. Glushko and Koroliev were arrested in 1938.[204] Tukhachevsky was also arrested in 1938 and then executed.[205] The GDL was deciminated by the Terrors but priorities had already been defined by prior research.[206] By 1937, two types of rocket were under development.

One was air-launched and was used at Khalkhin Gol in 1939, both in air-ground and air-air use.[207] In November 1941 , General Mason-McFarlane, then head of the British Military Mission to Moscow, reported to the British War Office that the Russians were known to be using airborne rockets, from Stormovik fighters, against German tanks,[208] although one has to suspect that they were no more accurate than the British planes in 1944 Normandy.

[201] Siddiqi, 132
[202] Siddiqi, 193
[203] Nykonev (2003), "Katyusha", 5
[204] Ibid
[205] Zak, 1
[206] Siddiqi, 173-8
[207] Siddiqi, 178
[208] Winter (2011), 57

The other type of rocket was a ground-to-ground barrage weapon. In 1938, a group under Gvai and Shurts evolved a system that could fire a 16 (or perhaps 24) rocket volley from the back of a truck, and which became Katyusha.[209] This was demonstrated to government and military stakeholders in 1941 (having been kept secret from them prior to that) and quickly put into production.[210]

This is a somewhat different pattern of development to the British. Whereas the West substantially ceased rocket development between 1884 and 1929, the Russians never wholly stopped. The British and Russians were equally driven by determined inventors, acting on their own initiative. However, the Russian inventors managed to retain sponsorship from the Tsar and the subsequent regime. Although not always successful, each iteration of experimentation built institutional knowledge. This allowed Russia to be the first to deploy air-launched rockets and to deploy ground-based multi-launch rocket systems around the same time as the Germans. Without the continuity of invention and sponsorship, Russia may have faced German rockets without their own reply. Without the Terrors, the Russians may have stolen a material advantage.

[209] Siddiqi, 179
[210] Nykonev, 5

Conclusion

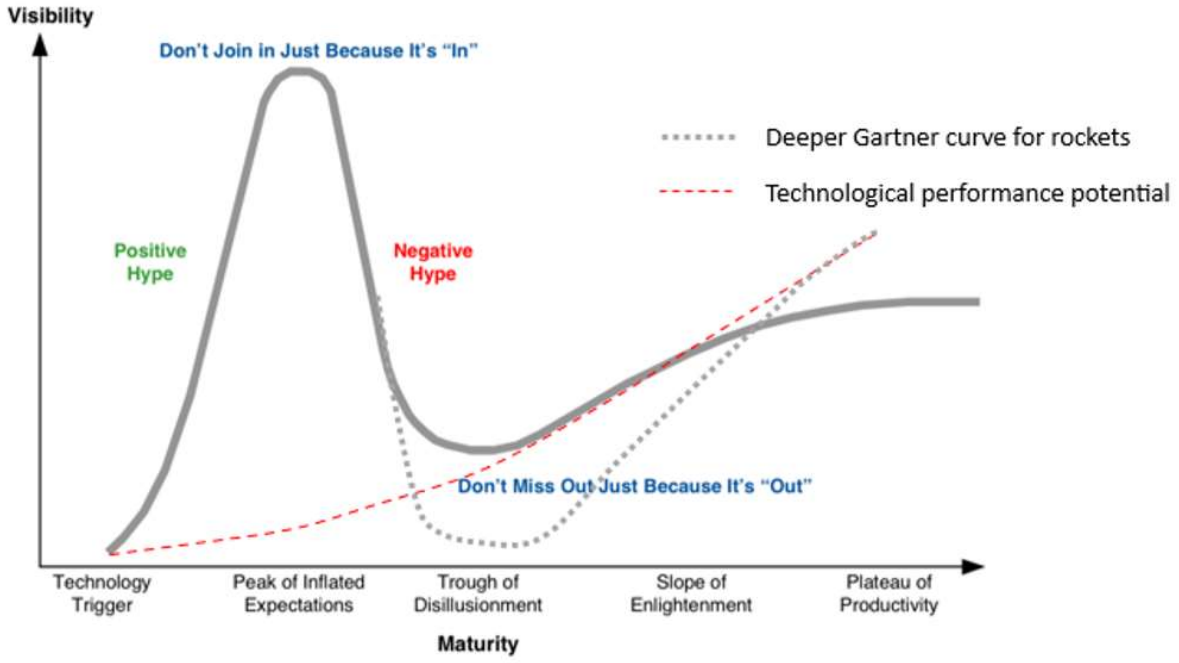
This dissertation has reviewed the (late nineteenth century) “fall” and (early twentieth century) “rise” of rockets. Rocket performance improved throughout these periods but gun artillery improved sooner. This invites historians to posit that competition between the two weapons caused rockets to fall from favour. That conclusion is also consistent with the common, but not universal, nineteenth century doctrinal error of using rockets in traditional gun artillery roles, instead of maximising the advantages of rockets in mobility and shock effect. However, at least in Britain, rockets remained in use right until the end of the nineteenth century, sometimes deployed flexibly alongside (not in competition with) machine guns and gun artillery, much as they are in modern armies. Rockets in Britian were officially phased-out due to the safety risk of premature explosions and had a consequently mixed reputation, coupled with a decline in influence of prior sponsors.

The rocket renaissance coincided with the application of new propellants to rockets, allowing a performance catch-up, as well as improved utilisation in barrage and ambush roles. However, the start of that renaissance in both Britain and Germany continued to use gunpowder propellant. The new propellant ultimately was a big benefit but was not the impetus to readoption. The potential of battlefield rockets had been newly recognised and regained new influencial sponsors supporting investment into the renewed development prior to the harnessing of the new propellants, or perhaps just inspired by international competition.

Winter's "first golden age" (1813 to 1856, say) represents a peak of inflated expectations. The war rocket gained a certain prestige, with Stephenson naming his locomotive after it,[211] and many large rocketry establishments arising across all the major European powers. Rockets were even included in the US national anthem. However, the widespread adoption was not wholly justified by performance. Similarly in the pre-WWII period, the readoption occurred despite continued unreliability and uncertainty of what could be achieved, instead driven by futuristic optimism and peer competition. Conversely, the total absence of war rockets from contemporary armies between those periods under-recognised the continued utility rockets could offer in the right roles. The under-development of rockets in that hiatus meant that they were failing to meet their potential; it delayed some of the technological advantages destined to come.

This divorce between adoption and performance can be attributed to positive and negative "hype" – the reputation of the weapon and the degree to which sponsors backed it, or didn't. The Gartner Hype Curve (see Figure below) is a model for technology adoption, born of late-twentieth century consumer electronics.[212] This dissertation does not seek to justify or analyse this model in general but it offers a good fit for the history of war rocket adoption.

[211] Ley, 71
[212] Linden and Fenn (2003), "Strategic Analysis Report", 5



Source: Gartner Research (May 2003); edits overlaid

Figure The Hype Curve adapted to rockets

Gartner's grey line represents a non-linear path for the degree of visibility of a technology over its lifecycle, initially gaining undeserved excessive exposure, offering a warning to investors not to join in just because of that visibility. The grey line then drops into a "trough of disillusionment" following a period of negative hype, where early investors disinvest severely; an over-reaction. The chart above has been adapted in this dissertation to indicate a deeper trough for rockets, given their total disappearance around the turn of the century. A red line is also overlaid, representing the potential technological performance absent the hype, to better highlight where the grey dotted visibility line lies above or below a more linear path.

Gartner's warning is not to "miss out" during the trough by overly disinvesting or by delaying investing. This aligns to the sentiment of the German, Becker, when in 1930 he bemoaned

Krupp not involving the Prussian Army in tests of the Unge rockets in 1909-10, presumably thinking these could have led to something.

Some nations did better than others in the “Don’t Miss Out” phase in the first half of WWII. The Neberwerfer and Katyusha were clearly impactful and feared since 1941. In contrast, the UK and USA did not have equivalents until 1944. The bazooka was an influential weapon but unimpactful in 1942/3 when first deployed, for lack of training and doctrine. Germany was able to develop an equivalent to the bazooka extremely quickly, inspired by captured bazookas, because they had the establishments and technology, as well as clear perceptions of utility. America was ahead of Japan in the rocket performance curve and therefore able to gain an asymmetric benefit in the Pacific in supporting (or opposing) landings.

Rocket sponsorship was entirely absent in Britian and USA until 1935, military interest absent in Germany until 1929 and funding sparse in Russia until the 1930s. As such, the fall and rise of rockets had some technological performance drivers but ultimately was caused, or at least exacerbated, by human perceptions and social effects, manifesting in a severe negative hype trough that was overcome in some countries quicker than others.

Bibliography

Absolom, John de Mansfield. 2004. "Z-Battery". *SecretScotland* website. Accessed on 4/7/2024 from https://www.secretscotland.org.uk/index.php/Secrets/Z-Battery

Anon. 1871. "The Power and Capabilities of War Rockets", from or by "The Engineer". *Van Nostrand's Eclectic Engineering Magazine,* Vol 4. pp357-9. Accessed on 2/7/2024 from: https://library.si.edu/digital-library/book/vannostrandsecle41871newy

Armament Research Department. 1944. *Significance of Measurements of Mechanical Properties of Cordite for Rocket Performance*. Joint Memorandum, Armament Research Department, Projectile Development Establishment. Viewed at the National Archive in file DEFE 16/57.

Armament Research Department. 1944b. "The Use of Propellants After Exposure to Extreme Weather Conditions" from minutes of meeting 6/10/44. *Minutes of Departmental Meetings, Rocket Propellant Research*. Viewed at the National Archive in file DEFE 16/58.

Askwith, General WH. 1900. *List of Officers of the Royal Regiment of Artillery from the Year 1716 to the Year 1899*. Fourth Edition. Royal Artillery Institution. Viewed on the Internet Archive: https://archive.org/details/listofficersroy01askwgoog/mode/2up

Barnett, Correlli. 1970. *Britain and Her Army 1509-1970: A Military, Political and Social Survey*. Allen Lane

Boden, Mike. 2003. "Berlin, 1945", in John Antal and Bradley Gericke (eds), *City Fights: Selected Histories of Urban Combat from World War II to Vietnam.* Random House.

Boyle, Frederick. 1874. *Through Fanteeland to Coomassie – A Diary of the Ashantee Expedition by a Special Correspondent of the Daily Telegraph*. Chapman & Hall.

Brett-James, Antony. 1970. *Europe against Napoleon, The Leipzig Campaign 1813 from eyewitness accounts*. MacMillan

Callwell, Major-General Sir Charles, and Major-General Sir John Headlam. 1931. *The History of the Royal Artillery from the Indian Mutiny to the Great War (Vol 1)*. Royal Artillery Institute.

Chamberlain, Peter and Terry Gander. 1978. *Small Arms, Artillery and Special Weapons of the Third Reich*. Macdonald and Jane's.

Chatwin, Andrew. 2011. "UP3 Rocket Anti-Aircraft 'Z' Batteries". *Space Chronicle, JBIS*, Vol 64, Supp 2. pp89-111.

Cocroft, Wayne. 1999. *Dangerous Energy: The archaeology of gunpowder and military explosives manufacture*. English Heritage.

Crow, Sir Alwyn. 1947. "The Rocket as a Weapon of War in the British Forces". *Proceedings of the Institution of Mechanical Engineers*, 158 (1), published 1948. pp15-21.

DeLuca, Luigi, Tom Shimada, Valery Sinditskii, Max Calabro. 2017. *Chemical Rocket Propulsion: A Comprehensive Survey of Energetic Materials*. Springer. Accessed on 3/7/2024 from https://archive.org/stream/ChemicalRocketPropulsionAComprehensiveSurveyOfEnergeticMaterialsSpringerInternationa/Chemical+Rocket+Propulsion_+A+Comprehensive+Survey+of+Energetic+Materials-Springer+Internationa_djvu.txt

Director of Artillery. 1875. *Extracts from the Proceedings of the Department of the Director of Artillery*, 1 January - 31 December 1874, Vol XII. Her Majesty's Stationary Office. Viewed at the National Archive in file SUPP 6/34.

Director of Artillery. 1876. *Extracts from the Proceedings of the Department of the Director of Artillery*, 1 January - 31 December 1875, Vol XIII. Her Majesty's Stationary Office. Viewed at the National Archive in file SUPP 6/35.

Director of Artillery. 1879. *Extracts from the Proceedings of the Department of the Director of Artillery*, 1 January - 31 December 1878, Vol XVI. Her Majesty's Stationary Office. Viewed at the National Archive in file SUPP 6/37.

Director of Artillery. 1881. *Extracts from the Proceedings of the Department of the Director of Artillery*, 1 January - 31 December 1880, Vol XVIII. Her Majesty's Stationary Office. Viewed at the National Archive in file SUPP 6/39.

Director of Artillery. 1884. *Extracts from the Proceedings of the Department of the Director of Artillery*, 1 January - 31 December 1883, Vol XXI. Her Majesty's Stationary Office. Viewed at the National Archive in file SUPP 6/42.

Director of Artillery. 1885. *Extracts from the Proceedings of the Department of the Director of Artillery*, 1 January - 31 December 1884, Vol XXII. Her Majesty's Stationary Office. Viewed at the National Archive in file SUPP 6/43.

Director of Artillery. 1886. *Extracts from the Proceedings of the Department of the Director of Artillery*, 1 January - 31 December 1885, Vol XXIII. Her Majesty's Stationary Office. Viewed at the National Archive in file SUPP 6/44.

Ellis, John. 1986. *The Social History of the Machine Gun*. Johns Hopkins University Press.

Emme, E. 1961. *Aeronautics and Astronautics: An American Chronology of Science and Technology in the Exploration of Space, 1915-1960*. NASA.

Featherstone, Donald. 1973. *Colonial Small Wars 1837-1901*. David & Charles.

Fletcher, Lt-Col HC. 1873. "The Employment of Mitrailleurs During The Recent War, and Their Use in Future Wars." *Royal United Services Institution Journal*, 16:66. pp28-57

Franklin, Carl. 1998. “The Hale Rockets in the British Service, Part I”. *Journal of the British Interplanetary Society,* 51. pp337-358.

Franklin, Carl. 1999. “The Hale Rockets in the British Service, Part II”. *Journal of the British Interplanetary Society,* 52. Pp259-266.

Franklin, CE. 2005. *British Rockets of the Napoleonic and Colonial Wars 1805-1901*. Spellmount.

Franklin, CE and Johnson, W. 1995. “William Hale’s “Improvements in Rockets” “. *International Journal of Impact Engineering*, 18 (2). pp231-241. Elsevier Science.

Glover, Gareth. 2018. *Letters from the Battle of Waterloo : Unpublished Correspondence by Allied Officers from the Siborne Papers*. Greenhill Books.

Green, Michael and Gladys Green. 2000. *Weapons of Patton's Armies*. Zenith Imprint Press.

Grew, JS. 1949. “50 Years of Armament Research [Establishment]”. Notes for an article to be published in the ARE Journal. Viewed at the National Archive in file DEFE15/31.

Gruntman, Mike. 2004. *Blazing the Trail: the Early History of Spacecraft and Rocketry*. American Institute of Aeronautics and Astronautics.

Harris, Roger. 1997. *The Early War Rocket, An Enigmatic, Misunderstood and Misused Weapon* (MA Dissertation). De Montfort University. Held by the National Army Museum.

Headlam, Maj-Gen Sir John. 1944. “The Use of Rockets in the Artillery”, *The Journal of the Royal Artillery*, Vol: 71 Issue: 2. pp81-85.

Herriott, Wg Cdr David. 2009. “A History of Air-To-Surface Rocket Systems”. *Royal Air Force Historical Society, Journal 45*. pp90-108. Windrush Group.

Hickley, Lt JD. (1895). “An Account of the Operations on the Benin River in August and September, 1894”. *Journal of the Royal United Service Institution*; 39. pp191-198

Hogg, Ian. 1976. “Nebelwerfer”. *War Monthly*, Issue 30. Marshall Cavendish. pp 1-6.

Imperial War Museums. 2024. “Tonsil, The Royal Navy’s Experimental Anti-Flying Bomb Rocket Battery”. *Admiralty Official Collection*. imw.org.uk. Accessed on 30/6/2024 from: https://www.iwm.org.uk/collections/item/object/205162087

Johnson, W. 1994. “The Rise and Fall of Early War Rockets”. *International Journal of Impact Engineering,* 15 (4). pp365-383.

Kamatham, Ram Ganesh. 2022. “The Battle of Pollilur: Revisiting the Footnotes of History”. *The Wire.* Accessed on 30/6/2024 from: https://thewire.in/history/the-battle-of-pollilur-revisiting-the-footnotes-of-history

Kochanski, Halik. 1999. *Sir Garnet Wolseley*. Hambledon Press.

Konstam, Angus. 1990. "The War Rocket in Late Victorian Military Service". *The Ordnance Society Journal* OSJ 02. pp51-70.

Kranzberg, Melvin. 1995. "Technology and History: 'Kranzberg's Laws.'" *Bulletin of Science, Technology & Society,* 15 (1): pp5–13.

Lehmann, Ernst A. 1937. *Zeppelin: The Story of Lighter-than-air craft*. Longman's, Green and Co.

Linden, A and Fenn, J. 2003. *Strategic Analysis Report*. Gartner Research. Accessed on 3/7/2024 from: http://www.embedded.agh.edu.pl/www/fpga/dydaktyka/MPiMS/Data/Understanding%20Gartner%27s%20Hype%20Cycles.pdf

Ley, Willy. 1957. *Rockets, Missiles, & Space Travel*. 2nd Edition. The Viking Press.

McLaughlin Green, Constance, Harry Thomson and Peter Roots. 1990. *The Ordnance Department: Planning Munitions For War*. Center of Military History, United States Army. First printed 1955. Accessed 2/7/2024 from https://history.army.mil/html/books/010/10-9/CMH_Pub_10-9.pdf

Mercer, General Cavalie. 1870. *Journal of the Waterloo Campaign*. William Blackwood & Sons.

Merrill, James. 1956. "British-French Amphibious Operations in the Sea of Azov, 1855". *Military Affairs*, Vol 20 No 1. US Army. pp16-27.

Military Intelligence Division. 1945. "Germany's Rocket and Recoilless Weapons". *Intelligence Bulletin*, Vol III No 7. US War Department. Accessed on 3/7/24 from https://www.bulletpicker.com/pdf/Intelligence-Bulletin-Vol-3-No-07.pdf.

Nature. 1953. "The Armament Research Establishment". *Nature* 172. pp 1075-1078.

Neufeld, Michael. 2000. "The Reichswehr, the Rocket, and the Versailles Treaty: A Popular Myth Reexamined". *Journal of the British Interplanetary Society*, Vol 53. pp163-172.

Nesbit, Roy Conyers. 2014. *The Strike Wings: Special Anti-Shipping Squadrons 1942-5*. Casemate.

New Mexico Museum of Space History. "Wilhelm T. Unge". *New Mexico Museum of Space History* website. Accessed on 2/7/2024 from: https://www.nmspacemuseum.org/inductee/wilhelm-t-unge/

Nykonov, VP. 2003. "From the History of Katyusha". *Kyiv Polytechnic Institute website*. Accessed on 4/7/2024 from https://kpi.ua/en/ww2-katiusha

Ordnance Committee. 1883. *Proceedings of the Ordnance Committee, 1 January 1882 – 31 December 1882*. Her Majesty's Stationary Office. Viewed at the National Archive in file SUPP 6/117.

Ordway III, Frederick. 1989. *History of Rocketry and Aeronautics*. American Astronautical Society. Accessed on 3/7/2024 from https://epizodsspace.airbase.ru/bibl/inostr-yazyki/iaa/1989/Merkulov_The_First_Scientific_Centers_for_Rocket_Technology_in_the_USSR.pdf

Parry, Albert. 1960. *Russia's Rockets and Missiles*. Macmillan.

Parry, Albert. 1961. "The Soviets' First Rocket Gun". *Quarterly Review of Military Literature*, Vol 41, No 10. US Army. pp56-64.

PDE Aberporth. 1945. *Projectile Development Establishment Report 1945/41 - A History of British Rockets 1935-1941.* Viewed at the National Archive in file AVIA 41/307.

Price, Dr Alfred. 2009. "The Rocket-Firing Typhoons in Normandy". *Royal Air Force Historical Society, Journal 45*. Windrush Group. pp109-120.

Rowland, David. 2006. *The Stress of Battle: Quantifying Human Performance in Combat*. The Stationary Office.

Scoffern, J. 1859. *Projectile Weapons of War*. 4th Ed. Longman, Brown & Co.

Sharp, Robert. 2003. "Oswald Silberrad: the Work of a Forgotten Chemist". *Ambix* 50(3). pp 302-309.

Siborne, Captain W. 1848. *History of the war in France and Belgium, in 1815 : containing minute details of the battles of Quatre-Bras, Ligny, Wavre, and Waterloo*, 3rd Ed. T & W Boone.

Siddiqi, Asif. 2010. *The Red Rockets' Glare – Spaceflight and the Soviet Imagination 1857-1957*. Cambridge University Press.

Silberrad, Dr OJ. 1903. *Investigations on the Stability of Nitro-cellulose, etc*. A treatise. Viewed at the National Archive in file SUPP 6/644.

Smart, Jeffery, Richard Wiltison, Egon Hatfield, Benjamin Sepulveda, Kyle Gallup. 2012. *History of Aberdeen Proving Ground.* 2nd Edition. US Army Research, Development and Engineering Command. https://discoverycentermd.org/wp-content/uploads/2023/2-APG-HistoryBook_Second_Edition.pdf

Sokolsky, VN (or Sokol'skii). 1967. *Russian Solid-Fuel Rockets*. NASA. Accessed on 3/7/2024 from: https://archive.org/details/nasa_techdoc_19680002361

Spiers, Edward. 1992. *The Late Victorian Army 1868-1902*. Manchester University Press.

Storr, Jim. 2011. *The Human Face of War*. A&C Black.

Storr, Jim. 2018. *The Hall of Mirrors*. Helion.

Strachan, Huw. 1985. *From Waterloo to Balaclava: Tactics, Technology, and the British Army 1815-1854*. Cambridge University Press.

Subcommittee "E". 1936. "Meeting at the War Office 3/9/36, Subcommittee "E" Memo R1". *Proceedings of the Advisory Committee on Rocket Investigation, "R" Memos from R1 to R55*. War Office. Viewed at the National Archive in file SUPP 6/510.

War Office of Great Britain. 1877. *Treatise of Ammunition*. Her Majesty's Stationary Office.

War Office of Great Britain. 1902. *Treatise of Ammunition*. His Majesty's Stationary Office.

Werrett, Simon. 2012. "Technology on the Spot: The trials of the Congreve Rocket in India in the early Nineteenth Century". *Technology and Culture*, Vol 53 No 3. pp598-624.

Winter, Frank. 1990. *The First Golden Age of Rocketry*. Smithsonian Institution Press.

Winter, Frank. 2011. " "Mr. Z" - Sir Alwyn Crow, A Little Known British Rocket Pioneer: A New Look at Rocketry in Britain During World War II – Part 1". *Space Chronicle, JBIS*, Vol 64, Supp 1. pp45-54.

Winter, Frank. 2011b. " "Mr. Z" - Sir Alwyn Crow, A Little Known British Rocket Pioneer: A New Look at Rocketry in Britain During World War II – Part 2". *Space Chronicle, JBIS*, Vol 64, Supp 2. pp72-88.

Wolseley, Lt-Gen Sir Garnet. 1882. *Pocket Book for Field Service*. Macmillan.

Zak, Anatoly. 2018. "Gas Dynamics Lab". *RussianSpaceWeb*. Accessed on 23/8/2023 from russianspaceweb.com/gdl.html