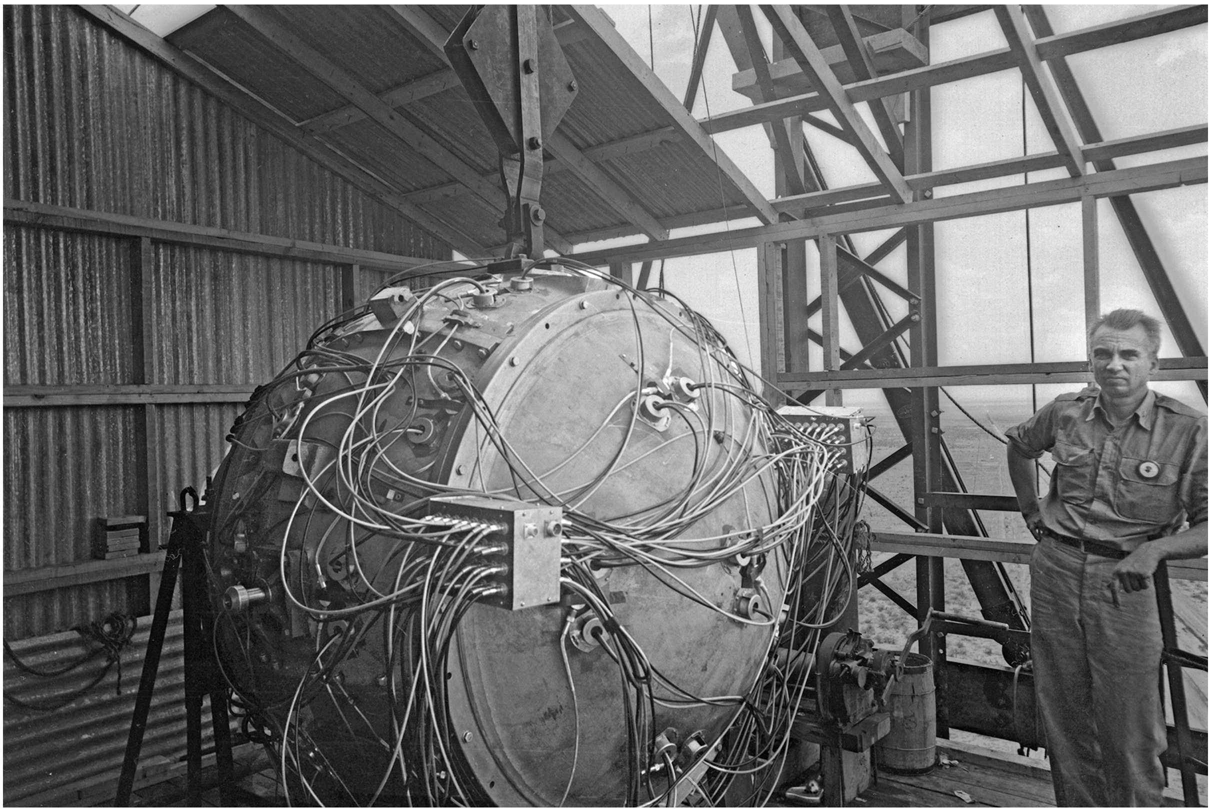

'The Gadget', a spherical bomb developed by the scientists at Los Alamos, at the top of the Trinity test tower. Pictured standing next to it is Norris Bradbury, head of the bomb's assembly team for the test. (Credit: *The Past*)

To what extent did the World War II effort on wartime scientific research lead to long-term, high-quality, and adaptable technological advancements?

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Table of Contents

Investigation

2.1 Introduction

“I am become death, the destroyer of worlds.”[1]

— J. Robert Oppenheimer, father of the atomic bomb[2]

Although World War II is widely recognized for extreme human suffering, including widespread genocide and the rise of extremism (Lim, 2015), paradoxically, it was also a period of great technological advancement. Historically, wars have often accelerated scientific research, driven by the urgent need for innovation (Hill, 1942). Building on this idea, Abraham Schoener’s interpretation of Heraclitus suggests that war acts as a “creative tension that brings into existence”, emphasizing how conflict also stimulates progress. In this light, World War II exemplifies how war, despite its horrors, can drive significant technological and scientific breakthroughs. Consequently, this essay will seek to investigate the question: “To what extent did the World War II effort on wartime scientific research lead to long-term, high-quality, and adaptable technological advancements?”

While World War II is typically viewed for its devastation and as one of the darkest periods in human history, this essay seeks to explore it from a different perspective by focusing on the impact of wartime scientific research. Furthermore, by assessing the long-term effects of these efforts, we can determine if World War II’s impact on scientific research shaped today’s technological landscape.

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[1] J. Robert Oppenheimer Quotes. (n.d.). BrainyQuote.com. Retrieved April 24, 2024, from BrainyQuote.com Web site: https://www.brainyquote.com/quotes/j_robert_oppenheimer_101189

[2] Denver, Mailing Address: Manhattan Project National Historical Park c/o NPS Intermountain Regional Office P. O. Box 25287, and CO 80225-0287 Phone: Hanford: 509 376 1647 Los Alamos: 505 661 6277 Oak Ridge: 865 482 1942 Contact Us. “Scientists - Manhattan Project National Historical Park (U.S. National Park Service).” *Www.nps.gov*, www.nps.gov/mapr/learn/historyculture/scientists.htm#:~:text=Robert%20Oppenheimer&text=Often%20referred%20to%20as%20the%20%22father%20of%20the%20atomic%20bomb.

2.2 Historiography

In terms of the positive or negative impact of World War II on technological advancement, there is scholarly debate on whether the innovations of WWII were of high quality. Some argue that the war brought significant breakthroughs due to the intense need for solutions, while others believe that the rush compromised the quality of these innovations.

The research hypothesis is that the intense need for technology during World War II to be technologically superior to one's enemies positively affected technological advancement and innovations. Thus, World War II catalyzed and impacted short and long-term technological innovations globally.

Three important sources support the aforementioned claim. The first is Gross & Sampat (2020) “Inventing the Endless Frontier: The Effects of the World War II Research Effort on Post-war Innovation”, which explains that the US government launched much effort to centralize scientific research for war and that the newly established Office of Scientific Research and Development (OSRD) created thousands of R&D contracts with industrial and academic entrepreneurs. This argument is highly credible, as the researchers studied at prestigious universities. Gross and Sampat are affiliated with the National Bureau of Economic Research (NBER) (Gross, n.d.; Sampat, n.d.). This affiliation with the NBER enhances their credibility due to the organization's reputation for producing rigorous research. The second paper, Pringle & Peters (1975) ‘Effects of World War II on the Development of Knowledge in the Biological Sciences [and Discussion]”, argues that World War II was beneficial to biological research specifically due to the existence of the Central Scientific Register, a compilation of scientists who might have contributed to the war effort through their knowledge and experience. This document is highly credible as “The Royal Society Publishing” is a peer-reviewed journal (Royal Society, n.d.; About, n.d.). Moreover, The Royal Society Publishing's long-standing reputation and rigorous editorial standards further reinforce the reliability of this paper.

The third paper maintaining my hypothesis is Bullard et al. (1975) “The Effect of World War II on the Development of Knowledge in the Physical Sciences [and Discussion]”, which asserts that World War II heavily reduced work in pure science on short-term to concentrate all efforts to project directly beneficial to World War II. Bullard et al. (1975) claim that World War II was beneficial in the long-term to fundamental science because the facilities and money were available more than ten times that of pre-war. This document is strongly credible as it was published by “The Royal Society Publishing”.

On the other hand, a credible source argues that World War II did not positively significantly impact technological advancements to a large extent. Emphatically, Wu (2016) “The Real Benefits of War: A Closer Look at the Impact on Innovation by World War II” asserts that although there was a major leap in the amount of innovation or invention developed during and shortly after the war, these were not as high-quality or groundbreaking as those developed before the war. This finding challenges the common perception that wars always lead to significant technological leaps, suggesting the quantity might increase, but the quality of wartime innovations could be compromised. (Wu, 2016) also questioned the practicality of these innovations, proposing that many were conducted primarily for military use without clear benefits for civilian life or long-term welfare applications. Furthermore, (Wu, 2016) affirms that the focus on military technologies diverted attention and resources from other essential scientific research, which could have changed the landscape and priorities of postwar research. This source is strongly credible because Queen's University published it as one of Canada’s leading research institutions and a member of the U15 Canada Group (U15 Canada, 2022).

2.3 Methodology

The scope of this essay spans World War II from 1939 to 1945, with a postwar analysis extending into the Cold War to assess the long-term effects of wartime scientific research. By including the postwar period, the analysis evaluates how technologies developed during the war evolved and adapted to peacetime needs, offering a more comprehensive understanding of their quality and adaptability in the long term.

Firstly, the analysis organized the technological developments into multiple distinct categories. This categorization helped structure the research organization despite the consequent quantity of sources. This categorization helped identify which areas were most affected by World War II, which explains the focus on the military nuclear and aerospace sectors. This method enabled an in-depth evaluation of how wartime innovations were transformed from World War II to peacetime applications, mainly focusing on their quality and long-term impacts.

The report by Vannevar Bush, head of the OSRD during the war, to Franklin D. Roosevelt in 1945 provided crucial insight into the aim of the OSRD during the war. Thus, it is a high-quality primary source containing highly credible information about the OSRD. Similarly, Whitfield (2012) contributed significantly to analyzing the aerospace sector segment. It is focused on Metropolitan Vickers, a company that followed the same trend as many other companies in the sector, validating it as a case study of broader industry trends. This allowed for a more generalized understanding of the sector's trajectory.

The military nuclear sector portion (Kelly, 2020) proved indispensable, as it is the most comprehensive collection of primary sources on the atomic bomb I found, along with valuable analyses of these sources, making it a complete reference for the section.

The critical evaluation identified the origin, the content, the purposes of the sources and the different points of view of the authors to maintain the most unbiased perspective possible.

2.4 Effort for Wartime Scientific Research

The United States faced a technological disadvantage relative to the Axis powers, which pressured American researchers and industries to innovate quickly (Wu, 2016). The need for scientific and technological research increased dramatically because of the scale and urgency of the war, which required coordination between the military, scientific and industrial. This forced the establishment of a centralized research body (Gross & Sampat, 2020).

In the need for a centralized research body, the US established the Office of Scientific Research and Development in July 1941 under the leadership of Vannevar Bush (Bush, 1945). The OSRD aimed to concentrate and centralize scientific research for war and allocate resources to critical military projects (Bush, 1945). According to Bush, projects such as the Manhattan Project, which developed the atomic bomb, and others that developed radar technology and vital medical innovations were made possible by the OSRD's centralized approach to resource allocation (Bush, 1945; Delgado, 2011).

Government spending on research and development surged dramatically, with expenditures for the Department of Defense increasing by over 1400% from 1940 to 1945 (Wu, 2016). The total federal budget for scientific research also grew from $83 million to $1.3 billion by 1945 (Wu, 2016).

On the other hand, scientific research effort in National Socialist Germany is regarded by many as a failure as the Third Reich had a robust scientific and technological infrastructure and an organized research effort, but unlike the US and the USSR, not a proper centralized research body (Nigar Neşe KEMİKSİZ, 2022; Elbuzdukaeva et al., 2023). However, Grunden et al. argue that this view is too simplistic and fails to consider the plentiful German technological innovations and scientific advancements made during the war (Grunden et al., 2005). Furthermore, the authors acknowledge that they may not see the Soviet Union's highly-centralized authoritarian structure as inherently better or worse than the decentralized systems of Germany and Japan but view it as a product of the nation's specific context and wartime needs (Grunden et al., 2005).

In addition to scientific research efforts within countries, international scientific collaboration and exchange were crucial to the development of crucial technologies such as the cavity magnetron.

One of the most significant examples of international scientific collaboration during World War II was the Tizard Mission in 1940-1941 during the Blitz in Britain. In 1940, with the Nazi invasion of the UK seemingly inevitable, Henry Tizard, head of the Aeronautical Research Committee, persuaded Churchill to give America the scientific innovation Britain held in exchange for US production lines as the English capacity to mass-produce their technologies was severely limited (Sumida & Zimmerman, 1998; Collar, 1967). The UK shared the design of revolutionary military technologies and one of the most important innovations of World War II, a working magnetron number 12 (Leconte, 2010; Sumida & Zimmerman, 1998). An advancement in radar technology a thousand times more effective than the best American counterparts (Li et al., 2023).
David J. Zimmerman argues that the Tizard Mission is the greatest transfer of technical and scientific information in history as it provided most of Great Britain's military technical secrets to the US and Canada (Zimmerman, 1995). However, some researchers also argue that despite the remarkable joint efforts of Roosevelt, Churchill, and the American and British scientific communities, a failure to institutionalize the relationship underlie challenges in the coming years (Baylis & Eames, 2023). Zimmerman also states that it seems inconceivable that out of 150 meetings, only two were on nuclear research. He insists on the mission's incomprehensibility in the field of atomic research, since, by examining the mission's structure, it had the most expertise in nuclear physics. Out of the four scientists on the mission, three were familiar with the current state of British nuclear research (Zimmerman, 1995).

World War II's wartime scientific research effort reflects its strength under existential pressure. The intense focus on practical scientific research during the war was a double-edged sword. It undeniably accelerated progress in critical fields but came with trade-offs in pure science. Nevertheless, the US centralized approach was a great success in developing technological advances. Furthermore, international scientific collaboration played a crucial role on scientific and military levels despite notable gaps in the military nuclear sector.

2.5 Aerospace Sector

2.5.1 Long-term Impact

Aerospace was one of the most influenced sectors by the effort for wartime scientific research. Nevertheless, the long-term impact of aerospace research remains the subject of significant scholarly debate. This section will explore the debates surrounding innovation versus obsolescence and on the Operation Paperclip.

The debate between innovation and obsolescence regarding World War II aerospace advancements remains contentious. Some argue that much of the innovations made during the war, such as Allied aircraft motorization, were discarded, which became irrelevant with the postwar focus on German-guided weapons such as the V1 and V2 (Mills, 2020). However, others claim these innovations laid the foundation for future progress, as the V2 directly influenced postwar rocket programs in the US and Soviet Union (Perring, 1946). Furthermore, according to Fortun and Schweber, the advances made in radar and sonar were not only of great importance during the war, they transposed into civilian aerospace after the war, shaping modern navigation and communication systems (Fortun & Schweber, 1993).

Specifically, the subject of much scholarly debate and controversy on the postwar impact of World War II aerospace advancements was Operation Paperclip. This American program enabled German scientists, including former SS Wernher von Braun, inventor of the V2 rocket, to work in the US on missiles and, according to Wayne Biddle in his work "Dark Side of the Moon", to become a central figure in the founding and development of NASA. Out of 90 members of the von Braun team, Neufeld found that 42 had been Nazi party members (47%), who had been an integral part of the Holocaust and the war against the US's allies in Europe. (Neufeld, 2012). Von Braun played a crucial role in developing the Saturn V rocket, enabling Apollo's moon missions, one of the most significant milestones of the aerospace sector (Demming, 2021). As Hunt argues, the ethical cost of this decision cannot be ignored. By overlooking the apparent Nazi affiliations of these scientists, the US government made significant moral compromises (Hunt, 1985). This raises important questions about the cost of technological progress and whether the long-term positive impact on the aerospace sector justifies the unethical means employed.

Hence, it can be concluded that the long-term impact of the effort for World War II scientific research was mostly positive on the aerospace sector when considered solely from the point of view of technological advances as it led to the creation of NASA, significant advances in jet engines, radar and sonar, despite that many technologies were discarded in favor of German innovations. On the other hand, as Hunt claims, it's hard to ignore the US's highly unethical means.

2.5.2 Quality and Adaptability

Innovations in the aerospace sector were numerous and important, but the quality and adaptability of these innovations in postwar peacetime were not necessarily assured for reasons such as the urgency of the war or even the obsolescence of certain technologies after the German defeat.

According to Young, companies like Pratt & Whitney and Bristol Aeroplane significantly impacted the aerospace sector during the war thanks to their innovative production techniques and collaboration between the aerospace and automotive industries, further improving engine precision, complexity and quality (Young, 2023).
However, contradictory to Young's statement, Whitefield affirms that the extent of wartime urgency accelerated development processes but ultimately had the opposite effect. For instance, companies like Metrovick, which were involved in gas turbine innovations, were influenced by their heavy engineering practices, prioritizing design over production engineering. This resulted in quality control issues, as their focus was on quickly bringing new products to market rather than ensuring the highest standards (Whitfield, 2012). This pattern of rushing out technological advances extended heavily to Boeing during the parallel production of the B-17 and B-24. As Benitez observes, this haste compromised the aircraft's quality and led to reliability problems and accidents. More broadly, a conclusion can be drawn as the focus on quantity over quality was a common theme as manufacturers struggled to meet the overwhelming demand for aircraft (Benitez, 1997).

The adaptability of wartime aerospace technologies, particularly in civil aviation, is evident in several key examples. According to Whitfield, military advancements in jet propulsion and radar systems were rapidly repurposed for civilian use, helping meet the demand for commercial aviation (Whitfield, 2012). Companies like Metrovick, despite early quality concerns during the war, saw their aero-engine designs adopted by civilian manufacturers, demonstrating their adaptability (Whitfield, 2012). As Lorell notes, competition in the global aerospace industry, especially in the US, drove further innovation, pushing military technologies into peacetime applications, such as commercial aircraft (Lorell, 2003).

However, not all companies adapted successfully. According to Lorell, Curtiss & Brewster, for instance, struggled to transition their wartime innovations to the postwar market, ultimately leading to their decline (Lorell, 2003). Additionally, as Mills points out, certain technologies, particularly Allied aircraft motorization, were quickly rendered obsolete by German innovations such as the V2 rocket (Mills, 2020). On the other hand, although German innovations, such as V2, rendered some Allied technology obsolete, particularly in the realm of rocketry and missile guidance systems, they were adapted and used in postwar research to the benefit of the aerospace industries in the US, Europe and the USSR (Demming, 2021). While many wartime aerospace advancements proved adaptable and transitioned into civilian industries, others faced significant challenges.

In conclusion, while the aerospace sector saw significant technological advances during World War II, wartime urgency often led to compromises in terms of quality in the immediate postwar period but good adaptability to civilian use. This was the case when firms driven by the need to meet overwhelming demand led to reliability problems and the obsolescence of certain technologies after the war. Nevertheless, the successful adaptation of key military innovations played an essential role in the growth of postwar global civil aviation. Demonstrating that, despite the challenges, the sector could leverage military innovations for civilian purposes. Thus, the quality and adaptability of wartime research in the aerospace sector resulted in compromised quality in the short term but an influence on postwar technological growth in the aerospace sector.

2.6 Military Nuclear Sector

"...if the energy released by nuclear fission and radioactivity were used as a weapon, it would mean the end of our planet? [...] No country, no group of civilized people can consciously take on such a responsibility. From strike to counterstrike, humanity would inevitably wipe itself out."

— Adolph Hitler in October 1944 (Skorzeny, 1976, p. 150)

2.6.1 Long-term Impact

Although nuclear fission was not invented during the war, the military atomic industry was. As its long-term impact remains debated, this section will compare and analyze the state of the military nuclear sector before and after World War II. Moreover, it will explore the debate on whether scientific research in the military nuclear sector during World War II was the main factor in the postwar nuclear arms race between the US and the USSR.

Before World War II, the discovery of nuclear fission in 1938 by Hahn, Meitner, and Strassmann, followed by the excitement of physicists worldwide, provided a robust foundation for future military applications. However, as of 1939, nuclear research was primarily theoretical, lacking concrete applications in weaponry, and was the subject of philosophical attacks (Gosling, 1994; Kelly, 2020; Madsen, 2013; Vizgin, 1999).
In contrast, the postwar period marked a transformative shift. Drawing from Delgado's analysis, the wartime emergency atmosphere focused scientific minds on the problem of weaponizing fission. Furthermore, some affirm that this shift led not only to the development of the atomic bomb but also to the establishment of an entire industry around nuclear technology (Delgado, 2011; Bullard et al., 1975). After the war, physicists no longer had to defend their work, as it was widely accepted that atomic research had succeeded (Vizgin, 1999). Without the context of World War II, it is unlikely that atomic weapons would have been deployed as quickly. This analysis may allow a more general conclusion about scientific research in the military sector (Kelly, 2020).

The efforts for wartime nuclear scientific research in the military led to a leap in this sector, transforming nuclear theoretical research into a crucial military sector. This transition, according to some, triggered a global nuclear arms race. However, others argue that the postwar nuclear race between the US and the USSR was mainly due to other national motivations.

The Manhattan Project's scientific efforts ultimately succeeded, bestowing the US with the first atomic bomb in history, leading to a postwar monopoly on nuclear weapons. According to Craig and Jungerman, this led to a brief “atomic diplomacy” period, where the US attempted to use its nuclear monopoly to influence global politics. This approach proved unsustainable and eventually fueled Soviet efforts to develop its nuclear arsenal (Craig & Jungerman, 1990). Outside the impact of wartime scientific research was the rapid postwar progress in nuclear technology, which led to more powerful weaponry. As Rattinger points out, this produced an unattainable stable equilibrium between the USSR and the US, with each advance initiating an action-reaction dynamic (Rattinger, 1975). While tensions between the US and the USSR was a significant factor, it was not the sole cause of the postwar nuclear arms race (Gavin, 2010). Unaffected by wartime scientific research, as Gavin proposes, some states developed nuclear weapons to boost their international standing and showcase their capabilities.

In conclusion, World War II's scientific research efforts ultimately led to long-term advances in the military nuclear sector, which some consider to be the foundation of nuclear technology. However, while it played a role in the postwar nuclear race, it was not as influential as other political and ideological factors.

2.6.2 Quality and Adaptability

The success of the wartime military atomic research in the US is widely recognized, as demonstrated by the devastation of Nagasaki and Hiroshima. Yet, the global quality of atomic research during World War II was uneven, with significant differences between projects like the US’s Manhattan Project and Germany’s Uranverein. This section will explore these differences and examine whether the advances made were solely for the war or if they were adaptable to broader postwar military technologies.

The quality of the scientific research in the military atomic sector significantly differed between the US’s Manhattan Project and the German’s Uranverein. Although the Uranverein project was initially more advanced, particularly in theory and initial experiments, it was affected by factors contributing to its failure (Reed, 2019). On the other hand, the Manhattan Project was behind schedule but was nonetheless successful. This was not due to the quality of the scientists involved since, according to Smyth and Walker, both projects were led by leading scientists in nuclear physics (Smyth, 2019; Walker, 1989). The most significant difference was in the organization of the projects. The Americans' work was highly organized, with detailed objectives, continuous re-evaluation of progress, and meticulous documentation. Each stage of the research was the subject of a detailed plan, and the results were peer-reviewed by expert committees, which led, according to Kelly, to rapid advancements that might have taken longer under ordinary conditions (Smyth, 1945; Kelly, 2020). The German program was fragmented, with work at multiple institutions (Reed, 2019). Furthermore, the persistent lack of crucial materials, compounded by Allied sabotage missions, drastically limited German research capabilities (Walker, 1989). There were also notable scientific errors and misconceptions throughout the Uranverein project, ultimately hindering its progress (Reed, 2019).

The advancements made during the Manhattan Project not only resulted in immediate military applications but also laid the groundwork for ongoing research in nuclear physics and engineering (Hughes, 2016). The creation of the Atomic Energy Commission (AEC) in 1946 in the wake of the Manhattan Project underlines a genuine willingness to adapt the technology of World War II to peacetime and future military technologies (Ochiai, 2013, pp. 43–48).

An example of success of this adaptability is the creation of the naval reactors project, under the responsibility of the AEC, and, as Buck affirms, is the first practical utilization of atomic power for a non-explosive purpose (Buck, 1983). This initiated the first nuclear-powered submarine, the USS Nautilus, which, according to Payne & Foster, represented a major advancement in submarine technology.

However, this transition also faced problems. The AEC's focus on expanding the use of nuclear technology without enough safety contributed to catastrophic accidents like those at Three Mile Island. Moreover, Ochiai and Bucks add that coordinating priorities and managing the interface between military and civilian nuclear programs was an administrative challenge (Buck, 1983; Ochiai, 2013, pp. 43–48).

Upon reflection, the highly systematic work and rapidity of the US resulted in high-quality innovations compared to the German project that, on one hand, included skilled scientists and an initial advantage compared to the US but, on the other hand, failed in its organization, material shortage, and relentless Allied interference. Furthermore, the adaptability of the nuclear research conducted during World War II to other military applications was mainly positive, such as with the advancements in naval propulsion. However, this adaptation also faced some challenges, suggesting that while the effort was innovative, the execution had flaws.

2.7 Conclusion

While World War II led to notable technological advancements in the aerospace and military nuclear sectors, these developments exhibited strengths and limitations, with irregular progress and quality issues emerging between sectors.

In the aerospace sector, wartime urgency facilitated the rapid development of radar, sonar, and jet propulsion, mainly, but others suffered from this haste. Companies like Metrovick eventually adapted to civilian use, whereas many failed to survive beyond the war. Particularly, Allied aircraft motorization from companies like Curtiss & Brewster quickly became obsolete compared to German rocket technologies. Ethical compromises also played a role, notably in programs like Operation Paperclip, where former Nazi scientists were recruited to advance American rocketry technology.

Whereas the Manhattan Project demonstrated unparalleled success in the military nuclear sector, the advancements were not global, as seen in the relative failure of Germany's Uranvereun project. This uneven progress highlights the varied impacts of wartime scientific efforts globally. The adaptability of these innovations also extended to a large extent into postwar applications, such as nuclear-powered submarines.

Ultimately, World War II's effort on wartime scientific research led to long-term, high-quality, and adaptable technological advancements to a large extent, though unevenly distributed in the global scientific space. These developments not only laid the foundation for future progress but also reshaped the postwar technological landscape, with a more limited impact on the geopolitical landscape, underscoring the impact of wartime scientific research.

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