Influences in British Computers, 1935-1950:

How Geopolitical Conflict and Bureaucracy Shaped Progress

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Abstract

In this London HUA Project Center program, I investigated the history and evolution of computers in Britain, focusing on the period from 1935 to 1950. My capstone project examined how World War II, bureaucratic organization, and interpersonal conflict shaped British progress in computing. I compared how these factors influenced Bletchley Park, the National Physical Laboratory (NPL), and the University of Manchester. I discovered that while each institutional setting had commonalities with the others, irreconcilably opposed methodologies and the use of experimental technology influenced the pace and manner by which computers were designed and built in each place. I found that ultimately, supportive and accommodating environments were the most favorable conditions for uninterrupted progress.

Britain was home to a vast array of foundational work in modern computing, carried out mainly between the mid-1930s and 1950. Alan Turing's 1936 paper, "On Computable Numbers, with an Application to the Entscheidungsproblem," marked the start of this period. This publication described an 'automatic machine' to compute real numbers, which is widely considered the theoretical origin for modern computing.[1] Alonzo Church, a contemporary of Turing in mathematics, called the automatic machine "a kind of Turing machine" in his review of the paper.[2] Lance Fortnow, an expert in computing theory, reflected on how the Turing machine "has stood the test of time…capturing digital computation, probabilistic, parallel, and quantum computers."[3] While some scholars note how United States and German computing pioneers were unaware of Turing's work,[4] his paper was the fundamental principle upon which British mathematicians and engineers built the country's first computers. Using Turing's seminal paper as the start of the period of interest and continuing through the creation of the first stored-program computers, historical accounts demonstrate how Britain's groundbreaking work was contingent on the unique attributes of the people involved and the circumstances in which they found themselves. The environment at Britain's premier academic and research institutions flavored engineers' and mathematicians' choices and the pace of computing work, from geopolitical to bureaucratic conflict; and in some cases, these choices were hopelessly tangled with emotion and subjectivity.

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[1] Liesbeth De Mol, "Turing Machines," in *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta and Uri Nodelman, Summer 2025 (Metaphysics Research Lab, Stanford University, 2025), https://plato.stanford.edu/archives/sum2025/entries/turing-machine/

[2] Alonzo Church, *Review of On Computable Numbers, with an Application to the Entscheidungsproblem*, by A. M. Turing, *The Journal of Symbolic Logic* 2, no. 1 (1937): 42–43, https://doi.org/10.2307/2268810.

[3] Lance Fortnow, "The Enduring Legacy of the Turing Machine," *The Computer Journal* 55, no. 7 (July 1, 2012): 830–31, https://doi.org/10.1093/comjnl/bxs073.

[4] Edgar G. Daylight, "Towards a Historical Notion of 'Turing—the Father of Computer Science,'" *History and Philosophy of Logic* 36, no. 3 (July 3, 2015): 205, https://doi.org/10.1080/01445340.2015.1082050.

This paper examines three cases of the instrumental work carried out in Britain. I focus first on Colossus, the all-electronic predecessor to modern British computers, illustrating how its story must be understood even more essentially within the context of a 'cryptography war' between Britain and Germany during the Second World War, rather than a mere influential backdrop. After the war, British computing work branched in two, with Alan Turing leading one major branch and Max Newman leading another. Exploring the uneven success of these two branches shows how varying degrees of bureaucratic involvement significantly impacted the rate of progress in early postwar computing.

After Turing published his 1936 paper, the universal computing machine he described was a mere theory in the eyes of the mathematical community. British engineers had not yet considered using thermionic valves—the hardware building blocks that would undergird the first 'Turing machines'—in computing. Valves were used only for small-scale radio and radar technology. Between 1900 and 1930, though, the customer base of the General Post Office—which provided telecommunications services for Britain—grew rapidly: the number of telephones jumped from 175,300 in 1900 to 1,886,726 in 1930.[5] System-wide infrastructure expansion provided an incentive for the state-funded General Post Office to shift away from fragile mechanical relays and towards all-electronic systems, which could operate much faster.[6]

Experiments to use electronic valves in large systems occurred mainly at the Dollis Hill Post Office Research Station, which was part of the engineering branch of the General Post

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[5] United Kingdom, Parliament, House of Commons, "Telephone Subscribers," *Hansard*, vol. 236, col. 1116, March 11, 1930. https://hansard.parliament.uk/Commons/1930-03-11/debates/e627e4a8-9df0-4814-8fa0-c532c4eac0b9/TelephoneSubscribers.

[6] Brian Jack Copeland, ed., *Colossus: The Secrets of Bletchley Park's Codebreaking Computers*, Oxford Scholarship Online (Oxford: Oxford University Press, 2020), 72.

Office.[7] Tommy Flowers, who worked at Dollis Hill, "pioneered the large-scale use of electronic valves," which had been "regarded with scepticism by many at the time."[8] Notably, Flowers did not shift the prevailing skeptical attitude toward electronic valves, but he did have the novel idea that they could be used as a 'switch' to change between Boolean states far more quickly than the conventional mechanical, electromechanical, and analog switches.[9] He used these switches in "an experimental high-speed electronic data store" for telephone exchanges. Flowers' stress-testing of electronic valves meant he was "possibility the only person in Britain who realized that valves could be used reliably at a large scale for high-speed digital computing."[10]

Always the last choice: Colossus' reactive origins

At Bletchley Park, the center of codebreaking and British intelligence during the Second World War, Flowers' work would become essential for partial automation in cryptanalysis of German ciphers. Nonetheless, Colossus, and its intricately linked predecessor, Heath Robinson, were conceived, designed, and constructed as a response to wartime conditions, rather than as the immediate natural progression of Flowers' success in telephone infrastructure. The most notable of these conditions were changes in German cryptographic techniques that rendered manual codebreaking methods inadequate. Despite Flowers and his research team experimenting with

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[7] "The Post Office Research Station," *Nature* 162, no. 4106 (July 10, 1948): 51, https://doi.org/10.1038/162051a0.

[8] Brian Jack Copeland, ed., 72.

[9] Boolean logic (true/false) has been a cornerstone of computing since George Boole's publication of *The Mathematical Analysis of Logic* in 1847. Gerard O'Regan, *A Brief History of Computing* (London: Springer London, 2012), 38, https://doi.org/10.1007/978-1-4471-2359-0, describes the mechanical nature of computers during the 1930s.

[10] Brian Jack Copeland, ed., 73. Charles Wynn-Williams, a particle physicist who joined the work at Bletchley Park before Flowers, also built electronic counting units using valves, but not to the same scale as Flowers' work, as discussed in Thomas Haigh and Mark Priestley, "Contextualizing Colossus: Codebreaking Technology and Institutional Capabilities," *Technology and Culture* 61, no. 3 (2020): 875, https://doi.org/10.1353/tech.2020.0077.

large-scale thermionic valves well before World War II began, motivation to incorporate electronics specifically in the codebreaking effort did not emerge until the war had been underway for over a year, when "Bletchley Park…enlisted Flowers to create a…device intended to automate [part of the process for finding correct Enigma encryption settings]."[11]

This act of outreach offers a prime example of British reactivity. It defines the inciting event that led to the Colossus as Bletchley Park's response to additional complexity introduced to the Enigma by Germany in January 1941, which left "even [Turing]'s codebreaking factory" unable to "keep Enigma broken."[12] Max Newman, whose Newmanry was responsible for developing cryptanalytic methods at Bletchley Park, began to work alongside Flowers' engineers at Dollis Hill specifically to tackle this new, elusive problem, demonstrating how German cryptographic efforts fundamentally created the conditions for an electronic computer to emerge.[13] While this early blending attempt, an electronic sensing device intended to assist bombe operators,[14] fell apart, collaboration between the two groups (which continued for the duration of the war) was pivotal in the Colossus' development.[15]

A device supplemental to Alan Turing's bombe did not emerge until the British identified messages encoded with a different scheme, generated by Lorenz machines, in 1941.[16] Moreover, serious work on what would become the Colossus did not commence immediately upon

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[11] Haigh and Priestley, 875.
[12] Haigh and Priestley, 874–75.
[13] Wall text at *Museum in Block B*, exhibition at Bletchley Park, Milton Keynes, May 25, 2025, describes how "it was not until [Turing's] wartime days as a Codebreaker…that the dream of building…an all-purpose electronic computer took hold," and that "the code-cracking Colossus computer, designed and built by…Tommy Flowers…was the link between Turing's pre-war work and his post-war project to build an electronic universal machine."
[14] Haigh and Priestley, 875
[15] Flowers, working at Dollis Hill, initially suggested the creation of "an entirely different machine [from Heath Robinson], in which the message, and the wheels to be compared with it, would be set up on [thermionic] valves [an electronic mechanism]," quoted from a 1 March 1973 note written by Max Newman in Haigh and Priestley, 880.
[16] Haigh and Priestley, 876.

discovery. Bletchley Park only began to consider a mechanical solution to breaking the Lorenz cipher after methods with lower opportunity costs proved to be infeasible, mainly because of evolving German cryptography. Haigh and Priestley explain that, specifically, Germany "implement[ed] tighter security procedures"—by removing details Lorenz codebreakers had relied upon from messages—which prompted Bletchley Park to "mechanize parts of the codebreaking process."[17]

Bletchley Park's initial mechanization effort came in the form of mathematical methods, which were "far too laborious to be done routinely by hand" due to the massive number of combinations.[18] Had Germany not provoked Britain into developing counting machines that would automate these methods, a device capable of Colossus-like tasks may not have arrived until years later.[19] Additionally, leadership at Bletchley Park did not automatically decide to approach deciphering Lorenz messages via computational means. Only after Max Newman explicitly proposed the "revolutionary" idea of a computational approach to deciphering Lorenz messages did they consider such an innovation,[20] indicating some level of resistance to applying innovative ideas in the codebreaking space during World War II. Consequently, the first computational approach was mechanical, like the bombe, not electronic as the Colossus would be. Haigh and Priestley, paraphrasing from Tommy Flowers' memoir, write that it was "because

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[17] Haigh and Priestley, 877.
[18] Haigh and Priestley, 877.
[19] Asserted indirectly by Kristen Burton, "The Scientific and Technological Advances of World War II," The National WWII Museum | New Orleans, accessed May 26, 2025, https://www.nationalww2museum.org/war/articles/scientific-and-technological-advances-world-war-ii.
[20] Wall text at *Museum in Block B*, 2025, explains that Max Newman "puts forward the revolutionary idea that some of the considerable work involved [in breaking Lorenz ciphers] might be carried out…much faster by using special machines."

of worries about the reliability and speed of constructing an all-electronic machine" that Heath Robinson, a mechanical device, "should…have first priority."[21]

According to Haigh and Priestley, the time-sensitive nature of war fueled the choice to prioritize Heath Robinson. Hut 8, involved in breaking the less-complex Enigma cipher, "provided crucial day-to-day intelligence during the Battle of the Atlantic…allow[ing] the Admiralty to re-route Allied convoys…around enemy U-boats."[22] The tremendous speed and streamlined operation of Bletchley Park saved lives during the war: for instance, "as a result of [a codebreaker's] quick thinking, the British navy won a significant sea battle."[23] Since Lorenz-encrypted messages "carried information of the highest grade" and "provid[ed] detailed information about…tactical decisions," deciphering these messages quickly and reliably was of the utmost importance.[24] During the war, because of these high stakes, Britain needed to avoid the trap of dedicating resources exclusively to an "ambitious electronic machine."[25] Such a practice may be permissible during times of peace when failure is far more forgiving.

Eventually "the need for a much faster machine [than the Heath Robinson] became clear," and "funds were made available" for the construction of the Colossus.[26] Gordon Radley, the director of Dollis Hill, issued the 'green light' only after engineers noticed deficiencies in the Heath Robinson tied to their use in codebreaking, lending further support to the notion that at every stage in its development, progress on Colossus was tied to wartime necessity. But the fact that Colossus was inextricably tied to the Lorenz machine, even compared to Heath Robinson,

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[21] Haigh and Priestley, 880.
[22] Wall text at *Hut 8*, exhibition at Bletchley Park, Milton Keynes, May 25, 2025
[23] Wall text at *Block A: The Intelligence Factory*, exhibition at Bletchley Park, Milton Keynes, May 25, 2025.
[24] Wall text at *Museum in Block B*, 2025. Also useful to note is the fact that "Lorenz decrypts revealed information that changed the course of the war in Europe, crucially assisting operations before and after D-Day."
[25] Haigh and Priestley, 880.
[26] Haigh and Priestley, 887.

convincingly illustrates its reactive nature. While "the Robinsons could compare any two bitstreams," one of the bitstreams processed by the Colossus "was hardwired to the geometry of the Lorenz machine wheels," with Max Newman "recogniz[ing] that Colossus was too tightly coupled to the specifics of [Lorenz] to be useful for other purposes."[27]

Thus, when the war ended, Colossus was immediately considered obsolete. Engineers dismantled the devices and sent the 'counter' units to the University of Manchester, so Max Newman might use them for his next project: developing a stored-program computer in the spirit of Turing's 1936 paper.[28] However, because of the Official Secrets Act, Newman's team in Manchester were not able to know the original purpose of the units, exemplifying how Colossus was bound by strict rules of secrecy. Colossus had been developed entirely within the confines of Bletchley Park (and Dollis Hill). Only those employed by the British government in the codebreaking effort had any input for the device's composition, and those who did participate had to sign the Official Secrets Act and swear to never discuss their work with anyone outside their unit.[29] Similarly, the ENIAC, the main device to which the Colossus is compared, was also classified and not unveiled until 1946, making collaboration between the two teams impossible.[30]

Institutional collaboration after the war

Examining the design process of the Manchester computers created following the war reveals a sharp departure from these isolated silos that underpinned computer development during World War II. Independent scientific institutions collaborated in the search for a design

[27] Haigh and Priestley, 891.
[28] Haigh and Priestley, 893.
[29] Brian Jack Copeland, ed., 161.
[30] C.D. Martin, "ENIAC: Press Conference That Shook the World," *IEEE Technology and Society Magazine* 14, no. 4 (1995): 3–10, https://doi.org/10.1109/44.476631.

for a reliable, persistent computer memory unit. Jack Copeland describes how Alan Turing, working at the National Physical Laboratory (NPL) in London, sent a copy of "Proposed Electronic Calculator" to F.C. Williams at the University of Manchester, a document which "might…have helped Williams towards an appreciation of" an essential "logical lesson" related to solving the memory problem.[31] Williams' solution, a cathode-ray tube ("Williams-Kilburn tube"), designed and built with Tom Kilburn, "went on to become a mainstay of early computing."[32] Princeton's 1951 computer, for instance, "consisted of 40 Williams-Kilburn tubes."[33] Princeton's computer is just one example of how institutions incorporated knowledge transfer into their computing work during the postwar era.

Varying computer design teams engaged in regular dialogue with each other after the war in the pursuit of an all-purpose stored-program computer, to contrasting levels of extent. Three teams were most relevant: Alan Turing's team, researching at the NPL; John von Neumann's team, based at Princeton; and Max Newman's team, working at the University of Manchester. The work that von Neumann and Newman led represented the most recent developments in two distinct computer evolution trees: the "American tree," rooted in the ENIAC, and the "British tree," rooted in Colossus. While these trees grew in isolation during World War II, with the teams behind Colossus and the ENIAC making design choices independently, after the war, they grew together, with "messages travel[ing] from tree to tree."[34] Turing, on the other hand,

[31] B. Copeland, "The Manchester Computer: A Revised History Part 1: The Memory," *IEEE Annals of the History of Computing* 33, no. 1 (January 2011): 13, https://doi.org/10.1109/MAHC.2010.1.
[32] B. Copeland, 15.
[33] B. Copeland, "The Manchester Computer: A Revised History Part 2: The Baby Computer," *IEEE Annals of the History of Computing* 33, no. 1 (January 2011): 31, https://doi.org/10.1109/MAHC.2010.2.
[34] B. Copeland, 29.

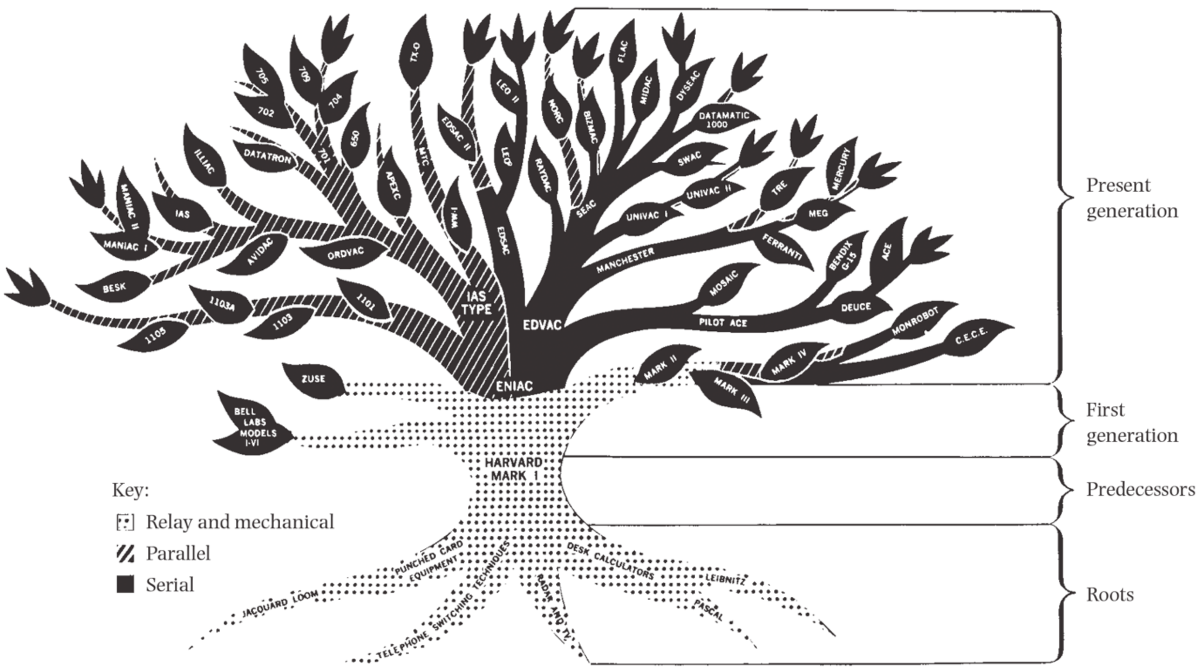

Figure 1. A "tree" representation of the evolution of computers, showing telephone switching technology at the root. It was made before Colossus' influence became known, incorrectly depicting Manchester and ACE originating from the EDVAC.[35]

collaborated more selectively, due to what Copeland called a "predilection for working alone from his own first principles."[36]

At the University of Manchester, Newman made it his mission to "gather all the ideas about computer design he could," exemplifying this collaborative culture unseen in the Colossus history.[37] He visited the Moore School, where von Neumann advocated a 'centralized' approach, and the NPL, where Alan Turing was working on a 'decentralized' device called the Automatic Computing Engine (ACE).[38] After returning to the University of Manchester from his visit, Newman related von Neumann's theory to Kilburn, the main architect of the 'Baby' stored-

[35] B. Jack Copeland, *Alan Turing's Electronic Brain: The Struggle to Build the ACE, the World's Fastest Computer*, 150.
[36] B. Copeland, 30.
[37] B. Copeland, 30.
[38] B. Copeland, 24, explains the difference between centralized and decentralized systems: in a decentralized system, mathematical operations, such as arithmetic, are performed using "a collection of different sources and destinations," while a centralized design has a single shared accumulator.

program computer. Kilburn was already aware of the latter, having previously attended lectures by Turing on the ACE in London.[39]

While Colossus was a special-purpose tool built in reaction to the Lorenz cipher, with limited opportunity for drastically different methodologies to emerge, the opposite was true for the Baby. The former was straightforwardly derived from cryptographic techniques; Newman handed Kilburn, the main architect of the latter, two distinct approaches to work with. At first, Kilburn took substantial inspiration from the ACE, creating "a detailed hypothetical machine in the Turing mold."[40] The ACE's influence was apparent in the machine's decentralized structure and the use of Turing's terminology in describing its components.[41] Kilburn's thorough application of the ACE design gave him an opportunity to closely inspect its strengths and weaknesses, contributing to his pivot to a centralized approach just a year later.[42]

Though Kilburn's reasoning was never made explicit, a significant weakness that may have contributed to his choice was the complexity of the decentralized approach. In Turing's design, "a separate destination implemented each of the machine's elementary and logical operations," while von Neumann's centralized approach employed a "central accumulator" to store results.[43] The Baby was a prototype, with minimalism a key goal. Simplifications in the Baby's design illustrate how Kilburn was pursuing the plainest stored-program computer, including "the adoption of fewer basic instructions," as well as "the use of only one instruction per word instead of two," when compared with von Neumann's theoretical proposal.[44] A central

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[39] B. Copeland, 23.
[40] B. Copeland, "The Manchester Computer: A Revised History Part 2: The Baby Computer," 24.
[41] B. Copeland, 24, explores in detail the similarities between Turing's ACE and Kilburn's first computer design.
[42] B. Copeland, 25.
[43] B. Copeland, 24
[44] B. Copeland, 31.

accumulator would reduce complexity further by requiring fewer physical components. Yet, there was potentially another, less tangible reason for Kilburn's choice. In an interview by Geof Bowker and Richard Giordano, Kilburn recalls how "the only thing I got from [Turing's] lecture was an absolute certainty that my computer wasn't going to look that," suggesting he had some visceral negative reaction to the decentralized approach.[45] Rather than Kilburn shifting towards the centralized mechanism, he may have been only interested in shifting away from the decentralized one.

Influences of personal experience on the Baby and ACE

In any case, Kilburn and Turing's distinctively different backgrounds and attitudes influenced their behavior at their respective institutions. Kilburn's initial lack of theoretical knowledge provided the impetus for immersing himself in von Neumann and Turing's theories. As an electrical engineer, Kilburn possessed none of the prerequisites for conceptualizing a computer, forcing him to seek insight elsewhere.[46] Alan Turing, in contrast to Kilburn, had been working in the domain of computing for over a decade by the time he joined the NPL, and could proceed in solitude to create the first versions of the ACE. Mike Woodger, one of two mathematicians who worked with Turing on the 'ACE Section' at the NPL, wrote in a letter to Copeland that "there is no trace of [early versions of the ACE]" and that he "assume[d] they were sketches in Turing's possession, probably done between March and May 1946."[47] Clearly,

[45] Geof Bowker and Richard Giordano, "Interview with Tom Kilburn," *IEEE Annals of the History of Computing* 15, no. 3 (July 1993): 19, https://doi.org/10.1109/MAHC.1993.10017.
[46] F.C. Williams recollects that "neither Tom Kilburn nor I knew the first thing about computers when we arrived in Manchester University," quoted in B. Copeland, "The Manchester Computer: A Revised History Part 2: The Baby Computer," 22, from an interview of Williams by C. Evans, "The Pioneers of Computing: An Oral History of Computing," Science Museum, 1976.
[47] B. Jack Copeland, *Alan Turing's Electronic Brain: The Struggle to Build the ACE, the World's Fastest Computer*, 59.

Woodger did not collaborate in Turing's early efforts. James Wilkinson, the only other mathematician associated with Turing during that initial period, worked mainly as a numerical analyst and in "pioneer[ing] the science of computer programming," and only arrived at the NPL after the conclusion of foundational work.[48]

Whereas Kilburn was open to input by other engineers, Turing was hostile towards any deviation from his own plans. When Harry Huskey, an engineer from the ENIAC project, arrived at the NPL and initiated construction of a simplified version of Turing's design (called the "Test Assembly"), Turing "tended to ignore [it]…simply standing to one side," when his expertise may have been useful, as the machine's designer.[49] Additionally, when the NPL approached Maurice Wilkes to collaborate with the ACE Section, Turing severely criticized Wilkes' background. In a memo to John Womersley, the director of the mathematics division at the NPL,[50] Turing wrote that what "[Wilkes] suggests is…very contrary to the line of development here, and much more in the American tradition of solving one's difficulties by means of much equipment rather than thought" and that such an approach is "rank folly."[51] Turing's particular word choice implies he was so enamored with his own plans that he thought it foolish to consider anything else. His hostility reflects the broader situation of internal conflict at the NPL, a marked difference from the comparatively frictionless teamwork displayed at the University of Manchester.

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[48] B. Jack Copeland, 59. Additionally, in a short biographical segment, Beresford Parlett, "J. H. Wilkinson - A.M. Turing Award Laureate," A.M. Turing Award (Association for Computing Machinery, 2021), https://amturing.acm.org/award_winners/wilkinson_0671216.cfm, describes how Wilkinson "worked on problems associated with Turing's proposal," rather than the proposal itself.
[49] B. Jack Copeland, 63.
[50] Darwin, C. 'Automatic Computing Engine (ACE)', NPL, 17 April 1946 (Public Record Office), in B. Jack Copeland, *Alan Turing's Electronic Brain: The Struggle to Build the ACE, the World's Fastest Computer*, 1st ed. (Oxford New York: Oxford University Press, 2012).
[51] B. Jack Copeland, 62.

Impact of bureaucratical conditions on the pace of progress

Internal conflict had a substantial influence on the implementation speed of the ACE compared with the Baby. Horace Thomas (who led a group in the 'Electronics Section') was the primary linchpin of this conflict.[52] Wilkinson, in a 1976 interview, explains how Thomas "particularly didn't like…the idea of [the ACE Section]…working independently," and "persuaded [the director at NPL] to have the work done in the Electronics Section" instead, leading to a temporary, near-total cessation of work on the ACE.[53] To claim that Thomas' group resumed progress in the Electronics Section would attribute undeserved credit. In reality, work was suspended until Thomas left the NPL and was replaced by Francis Colebrook as the head of the Electronics Section. Wilkinson recalls that "for a while [Thomas' group] just did basic things and became more familiar with the electronics they needed to build the computer," wasting valuable time.[54] Copeland even laid out a theory that "given better management at the NPL, a minimal computer based on Turing's [ACE] could have run a…program before the middle of 1948," prevailing over the Manchester Baby by several months.[55]

Max Newman's independence in managing the Baby project significantly influenced the aforementioned 'frictionless teamwork' at the University of Manchester. At the NPL, a convoluted and discordant bureaucratic organization was to blame for the internal conflict; Newman's Computing Machine Laboratory, where the Baby development took place, had no centralized governance structure.[56] Obtaining funding for the Computing Machine Laboratory

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[52] B. Jack Copeland, 68.
[53] B. Jack Copeland, 69.
[54] B. Jack Copeland, 69, quoting from Wilkinson in interview with Evans in 1976 (*The Pioneers of Computing: An Oral History of Computing*. London: Science Museum).
[55] B. Jack Copeland, 69–70.
[56] B. Copeland, "The Manchester Computer: A Revised History Part 2: The Baby Computer," 31, states "there was no director" at the Computing Machine Laboratory.

was the sole bureaucratic hurdle in Newman's project. Charles Galton Darwin, the contemporary director of the NPL, criticized Newman's grant application based on his perception that Newman's work would be in too-direct competition with the ACE, which had already been under development for several months.[57] In a rebuttal of Darwin's criticism, Douglas Hartree, a renowned applied mathematician,[58] notes how, in reality, "Newman was embarking on much more fundamental research."[59] His rebuttal, together with other resistance to Darwin, eventually led Darwin to rescind his criticism, over a month after it was first levied.[60]

Once Newman was furnished with funding, he directed his laboratory on his own terms, only communicating with the Royal Society to provide informal progress reports. Letters from November 1947 and April 1948 indicate that Newman solely oversaw the lab, writing that "he was hoping to appoint a senior mathematician in the autumn of 1948," and "Williams…will start on the construction of a miniature prototype…in a few months."[61] Newman spoke with authority in these letters, implying these decisions were of his own design. Moreover, Max Newman directed the lab through the completion of the Baby and into the improved Mark 1 computer, compared to the relatively high turnover at the NPL.

Turnover was a key reason for the disparity in the speed of progress between the NPL and the University of Manchester. Copeland notes four distinct 'eras' of ACE development corresponding to changes in leadership or otherwise essential roles: Flowers, Huskey, Thomas, and Colebrook.[62] Turing designed the ACE, but since NPL possessed no construction facilities of

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[57] Simon H. Lavington, 22.
[58] Charles Galton Darwin, "Douglas Rayner Hartree, 1897-1958," *Biographical Memoirs of Fellows of the Royal Society* 4 (November 1958): 102–16, https://doi.org/10.1098/rsbm.1958.0010.
[59] In a letter by Hartree countering Darwin's objections, summarized by Simon H. Lavington, 22.
[60] Simon H. Lavington, 23.
[61] Simon H. Lavington, 26.
[62] B. Jack Copeland, *Alan Turing's Electronic Brain: The Struggle to Build the ACE, the World's Fastest Computer*, 59–70.

its own, they contracted Flowers (Dollis Hill) to build it.[63] Unfortunately, possibly because of Dollis Hill's focus on Colossus during the war, they had more pressing obligations working on improving telephone infrastructure, leading to Flowers' departure from the project. Work slowed to a near-halt as the NPL worked to find alternative arrangements,[64] illustrating how there was a period of limbo in which no progress could be made on the project.

Turnover also led to vastly differing opinions about how to progress, a major question at the NPL that further slowed ACE development. During the Flowers era, construction of the ACE's memory unit had begun, but this was wasted in later eras.[65] When Huskey, who 'replaced' Flowers, arrived at the NPL, he proposed building a prototypal 'Test Assembly' that incidentally incorporated none of Flowers' work.[66] The arrival of Huskey in early 1947 was ultimately a boon to the project, and Womersley and Edgar Fieller predicted "that the Test Assembly would 'be ready by the end of November [of that year].'"[67] Prior discussion of Thomas (who arrived at the NPL during Huskey's work) reveals how he undermined Womersley and Fieller's hopes by bringing his own disruptive perspective.

Unlike Thomas, Colebrook disrupted the status quo in a positive manner. He was instrumental in enabling collaboration between the Math and Radio divisions. In contrast to his predecessors, Wilkinson described Colebrook as "a great diplomat," and that he had "goodwill so evident to everybody that I do think he played a major part in making it possible for the two groups to [work] together."[68] Under Colebrook's leadership, the Math and Radio divisions

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[63] B. Jack Copeland, 59.
[64] B. Jack Copeland, 63.
[65] 'Status of the Delay Line Computing Machine at the P.O. Research Station', NPL, 7 March 1946 , anon. (Woodger Papers (M 12 / 105), partially reproduced in B. Jack Copeland, 60.
[66] B. Jack Copeland, 63.
[67] B. Jack Copeland, 64, with text from Fieller, E. C. 'Hollerith Equipment for A.C.E. Work – Immediate Requirements', NPL, 16 October 1947 (Public Record Office (document reference DSIR 10 / 385).
[68] B. Jack Copeland, 70, quoting from Wilkinson in interview with Evans in 1976.

together decided to revive the Test Assembly, though with entirely different internals compared to Huskey's model.[69] Colebrook led the Pilot ACE project to completion and oversaw its first program, which ran on 10 May 1950.[70] Turing lost his patience with the NPL in 1948 around the same time Colebrook took over, and because of his frustration, left to pursue new work at the University of Manchester.[71] Bureaucratic conflict pushed Turing away from the NPL, illustrating how these events led to an exodus of expertise from the NPL. Wilkinson, recalling his inheritance of Turing's team, mentions how he believed the team was "in danger of floundering [because] everyone was really a bit demoralized," suggesting that others may have soon followed.[72]

Surprisingly, given the significant slowdowns of the ACE project, Alan Turing and Max Newman's work began on roughly equal footing. And in some respects, such as motivating the development of a stored-program computer, the NPL was 'ahead' of the University of Manchester. Womersley, in his proposal for the ACE project to be approved, wrote at length about problems which a stored-program computer could solve:

> We can attack complicated integral equations, integro-differential equations and partial differential equations by replacing them by large blocks of simultaneous linear equations in 700--1000 unknowns and solve them with ease and speed. We can take T. Smith's theory of the design of optical instruments and use it on practical design problems at a speed which will enable answers to be given to the firms by telephone in a few hours. We

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[69] B. Jack Copeland, 71.
[70] B. Jack Copeland, 71.
[71] B. Copeland, "The Manchester Computer: A Revised History Part 2: The Baby Computer," 31.
[72] Wilkinson in interview with Evans in 1976 (*The Pioneers of Computing: An Oral History of Computing*. London: Science Museum), partially reproduced in B. Jack Copeland, *Alan Turing's Electronic Brain: The Struggle to Build the ACE, the World's Fastest Computer*, 1st ed.

> can revolutionise the study of compressible fluid flow, and of aircraft stability. Problems now slowly attacked piecemeal will be capable of solution as a whole.[73]

Newman, by contrast, described only briefly how his machine would be able to test specific mathematical hypotheses, and concluded with a vague summary of his goal, which was "to investigate electronic machines to deal with mathematical problems of a general type."[74]

Conclusion

Kilburn's reliance on the lectures Turing gave on the ACE is most striking with respect to the question of 'who won' the race to build the first stored-program computer. Even though Newman's team at the Computing Machine Laboratory had a less clear vision of their computer's purpose and spent more time learning about the state of the art (including from Turing himself), they ran a program on the Baby years before the Pilot ACE ran its first program. Assuredly, the National Computing Laboratory would have been able to outpace the University of Manchester with better organization, as Copeland suggests. Differences in the structure of the computers—centralized and decentralized—while relevant, did not impact pace nearly as much as the more influential factors. Kilburn's lack of knowledge, for instance, highlights the severity of the human-centered conflicts at the NPL. Kilburn was able to learn Turing's theory and develop a 'Turingesque' computer in 1947, and he managed to implement his radically different second design in 1948, the same year it materialized in the functional Baby computer.[75]

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[73] Womersley, J. R. '"ACE" Machine Project', National Physical Laboratory, reproduced by B. Jack Copeland, *Alan Turing's Electronic Brain: The Struggle to Build the ACE, the World's Fastest Computer*, 42.
[74] Lavington, 22.
[75] B. Copeland, "The Manchester Computer: A Revised History Part 2: The Baby Computer," 24.

Engineers behind Colossus encountered issues like those faced at the NPL. Thanks to "Churchill's patronage," Flowers did not have to worry about funding; the wartime Prime Minister had provided a "blank cheque…for Dollis Hill's work on [breaking Lorenz]."[76] However, partnership efforts between Bletchley Park and Dollis Hill were marred by delays, like at the NPL, despite the wartime context. Interpersonal conflict also played a role; Flowers sparred with others, such as Wynn-Williams, over the use of electronics in codebreaking computers. However, none of these conflicts turned out to be particularly disruptive or long-lasting.[77]

Despite its similarities to other 1940s-era computing machines, Colossus represents a noteworthy departure from the culture of proactive innovation characteristic of the prewar and postwar eras in computing. And precisely because of this departure, Colossus catalyzed an accelerating pace of progress in British computing. Lorenz-enciphered messages and the changing cryptographic landscape forced designers at Bletchley Park and Dollis Hill to challenge the prevailing opinions on experimental electronic technology, which eventually yielded the Colossus. This codebreaking device forged the path forward for Turing's 1936 theory, thrusting postwar British computing evolution onto a path of implementing and incrementally improving upon Turing's universal machine.

[76] Haigh and Priestley, 878–79.
[77] Haigh and Priestley, 882.

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