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J. Michael Beaver
University of North Alabama

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"Everything faded into mist. The past was erased, the erasure was forgotten, the lie became truth."[1]

Alan Turing's role in the creation of the modern computer is peculiar because his work during the Second World War was shrouded in secrecy and his association with the Hungarian-American computing pioneer John von Neumann muddied his pioneering work immediately after the war. Turing's post-war Automatic Computing Engine (ACE) project at the National Physical Laboratory (NPL) in London was one of his more significant contributions to the development of the modern computer. However, the story of the ACE computer seems to be particularly lost in popular history. For instance, the Encyclopedia Britannica entry for "computer" features an omission of Turing's ACE project, though it discusses Turing's other work.[2] Turing's ACE project did not see a considerable amount of success until after his untimely death. John von Neumann's work on computer design is best known for the eponymous "von Neumann architecture," and he saw

1 George Orwell, *Nineteen Eighty-Four,* Part I, Chapter 7.

2 Paul A. Freiberger, David Hemmendinger, William Morton Pottenger, and Michael R. Swaine, "Computer," in Encyclopedia Britannica, last modified July 5, 2012, http://www.britannica.com/EBchecked/topic/130429/computer.

considerable success in his lifetime. Turing's ACE featured a novel design that rivaled von Neumann's design, but its story has been partially lost in history. If Turing's ACE had the same successful influence as von Neumann's design, there would exist the "Turing architecture" and the "von Neumann architecture"; however, there is only the latter.[3] The commercial and practical failure of Turing's ACE computing project can be attributed to the confluence of several counter-productive influences. Conflicting goals, poor relationships, and exceedingly poor administration ultimately led to the failure of Turing's ACE project.

After the Second World War, Britain needed desperately to reassert its presence on the international stage. The shift to a Labour government in 1945 spawned an interest to exploit the new field of computational research as one method to reassert Britain's dominance. Sir Charles G. Darwin, director of the NPL and grandson of naturalist Charles Darwin, sought to participate in this initiative by establishing a national computer project at the NPL. Darwin charged John R. Womersley, supervisor of the NPL

3 This is not to say that Turing has not had lasting impacts on computer science as a discipline. He contributed the founding theories of artificial intelligence, programming, and architectural design. We are concerned with the development of a practical modern computing machine, not one of his theoretical projects.

Mathematics Division, with the construction of the machine.[4] Womersley's proposed national computer was a machine that could solve all of Britain's computational needs for the future.[5] On the international stage, as David Leavitt reports, the United States was quickly surpassing Britain in the field of computational research, which pressured the NPL to engage in serious computational research.[6] The increase in pressure provided Womersley with initiative to start the research program as soon as possible.

As part of his national computer initiative, Womersley recruited Alan Turing in 1945.[7] Womersley was aware of Turing's 1936 paper "On Computable Numbers, With an Application to the *Entscheidungsproblem*," which would become the genesis of the Turing Machine. Womersley's ingenious idea was to have Turing design and construct the new national computer: the Automatic Computing Engine.[8] However, there was a conflict of interests as Darwin and Womersley were interested in a machine that could service

4 John Hendry, *Innovating for Failure: Government Policy and the Early British Computer Industry* (Cambridge, MA: MIT, 1989), 34. Up until 1945, most computing machines were complex electromechanical contraptions conceived to perform one specialized task exceptionally well. The Electronic Numerical Integrator and Calculator (ENIAC), designed by J. Presper Eckert and John Mauchly, is a notable example. The ENIAC featured a complex, convoluted design, and it was frustrating to operate. After von Neumann joined the ENIAC team as an adviser, he produced the "First Draft of a Report on the EDVAC," which proposed the "von Neumann architecture," as it is known today. For more information, see William Aspray, *John von Neumann and the Origins of Modern Computing* (Cambridge, MA: MIT Press, 1990), 34-9.

5 Andrew Hodges, *Alan Turing: The Enigma* (New York: Simon & Schuster, 1983), 306.

6 David Leavitt, *The Man Who Knew Too Much: Alan Turing and the Invention of the Computer* (London: Weidenfeld & Nicolson, 2006), 199.

7 Simon Lavington, "ACES and DEUCES," in *Alan Turing and His Contemporaries: Building the World's First Computers*, ed. Simon Lavington (Swindon, UK: BCS, 2012), 11-2.

8 Ibid. Turing was fond of remarking that Womersley's greatest contribution to the ACE project was its name. Womersley's idea, the word "engine" was a "deliberate reference to Charles Babbage's unfinished" 1837 Analytical Engine. For more information, see Hodges, 317 and Lavington, "ACES and DEUCES," 13.

the entire country and solve its mathematical problems.[9] Turing, on the other hand, saw the ACE as an opportunity to realize his 1936 concept of a Universal Turing Machine.[10] Nevertheless, Turing drafted a design for the machine, and his proposal was finished at the end of 1945. The NPL's Executive Committee approved the project, and construction officially began on August 18, 1947.[11]

Darwin and Womersley's desire for a glorified calculator to solve the country's numerical problems was not entirely consistent with Turing's view.[12] While Turing understood the importance of national numerical work,[13] he saw the ACE as an opportunity to do so much more. During his wartime codebreaking work at Bletchley Park, Turing worked with non-numerical logic problems, and he understood the significance of such problems.[14] Turing's vision surpassed the short-term goal of number crunching; his ultimate goal was a machine that was universal, or general in purpose. The ACE, Turing hoped, would be able to handle any problem, numerical or non-numerical.[15] What is more,

9 Simon Lavington, *Early British Computers: The Story of Vintage Computers and the People Who Built Them* (Manchester: Manchester University Press, 1980), 23-4.

10 Hodges, 318.

11 It is worth noting that development on the ACE had begun in late 1945 and persisted throughout 1946. The actual ACE—or, rather, the Pilot ACE—began on this date. See also Hendry, 34 and Hodges, 367.

12 Lavington, *Early British Computers*, 23-4.

13 Turing apparently entertained the idea of nationalized computer stations. In fact, in a lecture to the London Mathematical Society on February 20, 1947, he mused that a distant computer could be operated by use of a special telephone line. Perhaps this was Turing's naïve conception of a primitive computer network. He optimistically concluded that the cost would be no more than a few hundred pounds. See also A. M. Turing, "Lecture to L.M.S. Feb. 20 1947." Lecture to the London Mathematical Society, London, UK, February 20, 1947.

14 Hodges, 365.

15 Teresa Numerico, "From Turing machine to 'electronic brain,'" in *Alan Turing's Automatic Computing Engine: The Master Codebreaker's Struggle to Build the Modern Computer*, ed. B. Jack Copeland (Oxford: Oxford University Press, 2005), 181.

Turing saw the ACE as an opportunity to capitalize on his computer-brain metaphor: a computing machine can emulate the human brain.[16] The ACE would embody the philosophy of the Universal Turing Machine: a machine that could be programmed to perform the tasks of any other machine.[17] If the ACE could be programmed to perform any task, then it could theoretically be programmed to mimic a sort of primitive artificial intelligence, which was Turing's goal.

John von Neumann's "First Draft of a Report on the EDVAC"[18] served as the initial inspiration for Turing's ACE proposal. Von Neumann's EDVAC Report was a high-level abstract amalgamation of the various ideas that resulted from various conversations with his colleagues.[19] In principle, the EDVAC Report was a conceptual framework from which a group could consult while building a machine. John Hendry, Fellow of Girton College, University of Cambridge, notes most British researchers were "content to follow the well-disseminated and authoritative work of von Neumann, [which was] encapsulated in the EDVAC report."[20] Womersley obtained a copy of it and gave it to Turing,who accepted the legitimacy of von Neumann's work, but was "keen" to implement his own ideas about computing machines.[21]

While Turing's ACE design drew upon the EDVAC

16 Hodges, 293-4.
17 William Aspray, *John von Neumann and the Origins of Modern Computing* (Cambridge, MA: MIT Press, 1990), 176.
18 Electronic Discrete Variable Automatic Computer, or EDVAC.
19 Jon Agar, *Turing and the Universal Machine: The Making of the Modern Computer* (Cambridge, UK: Icon, 2001),115-6.
20 Hendry, 34.
21 Hodges, 306.

Report, his actual proposal was a much more detailed realization of the abstract EDVAC machine.[22] Turing specified that his ACE proposal should be read in conjunction with von Neumann's EDVAC Report.[23] The proposal had been described as the first complete, detailed description of electronic stored-program digital computer.[24] Indeed, Turing's ACE proposal was the first *detailed* plan for constructing a Universal Turing Machine.[25] However, it is intriguing that Turing's ACE proposal draws more upon von Neumann's work than his own; the ACE proposal is much more heavily influenced by the EDVAC Report than Turing's own 1936 paper.[26] It is worth noting that von Neumann's EDVAC Report makes implicit, indirect use of Turing Machines, though he does not make explicit references to Turing's 1936 paper.[27] Although von Neumann indirectly used Turing's ideas, his EDVAC design differed greatly from Turing's ACE design.

Presumably Womersley wanted Turing to build an EDVAC-type machine but give it a twist to make it distinctly British. Turing's design was a radical departure from von

22 Numerico, 181.

23 Hodges, 318.

24 B. E. Carpenter and R. W. Doran, "The Other Turing Machine," in *The Computer Journal* 20, no. 3 (1977), 269.

25 B. Jack Copeland and Diane Proudfoot, "What Turing Did after He Invented the Universal Turing Machine," *Journal of Logic, Language, and Information* 9, no. 4 (2000): 491.

26 Martin Campbell-Kelly, "The ACE and the shaping of British computing," in *Alan Turing's Automatic Computing Engine: The Master Codebreaker's Struggle to Build the Modern Computer*, ed. B. Jack Copeland (Oxford: Oxford University Press, 2005), 156-7.

27 Leavitt, 201. Von Neumann's EDVAC Report only made explicit reference to a biophysics article by McCulloch and Pitts. In their article, McCulloch and Pitts used Turing Machines to describe neural nets. For further discussion, see B. Jack Copeland and Diane Proudfoot, "Turing and the computer," in *Alan Turing's Automatic Computing Engine: The Master Codebreaker's Struggle to Build the Modern Computer*, ed. B. Jack Copeland (Oxford: Oxford University Press, 2005), 113.

Neumann's original design. As a logician, Turing took great pains to improve on the EDVAC's logical structure. Turing's priorities were a "simple as possible" hardware system and a large, fast memory for storage.[28] For example, in the EDVAC design, arithmetical operations, such as addition and multiplication, were accomplished using adder and multiplier hardware units. In the EDVAC design, the central accumulator performed all arithmetic; however, shoving large amounts of data down one avenue could present a formidable bottleneck for programs. Turing countered this by distributing arithmetical operations across several memory locations in an "ingenious way."[29] The larger adder and multiplier units, while included in the ACE design, were broken into smaller logical units. These improvements allowed Turing to economize on the hardware to allow more program instructions. For Turing, user convenience was not a top priority; in fact, he believed that user convenience could be achieved by thought and planning, not by more machine hardware.[30] The ACE machine was all about speed and efficiency.

As for software execution, the EDVAC and ACE designs were completely opposite. Von Neumann enforced strict serial execution of program instructions, yet Turing allowed for programs to modify their own instructions.[31] Turing's ACE design also incorporated a unique concept:

28 Hodges, 320.
29 Ibid., 323.
30 Ibid., 320.
31 Ibid., 324-6.

optimum coding.[32] Simply put, optimum coding "enabled more computing to the pound-sterling, as it were," but this greater efficiency came at the cost of difficult, complex, and often frustrating programming.[33] However, optimum coding allowed users to achieve up to four times greater speed over conventional contemporary machines.[34] Despite making extensive use of von Neumann's notation and figures,[35] Turing's design distinctly improved upon von Neumann's framework. In fact, Turing completed his ACE proposal in just three months, a much shorter time than that of von Neumann and his colleagues. By the end of 1945, Turing had a complete design from which to work.[36] Enthusiasm aside, Turing's personality and work ethic may have influenced the great speed with which he completed his ACE proposal.

Since his days at Sherborne School, Turing was known for his "self-contained" and "solitary" working style, "chaotic" mind and difficulty expressing himself, and potential for becoming a brilliant mathematician.[37] He carried these traits with him to King's College Cambridge. For instance, Turing worked completely in solitude when developing his 1936 paper. In fact, he was so engrossed in his work he was not aware that an American, Alonzo

32 David M. Yates, *Turing's Legacy: A History of Computing at the National Physical Laboratory 1945-1995* (London: National Museum of Science and Industry, 1997), 33-4. It is worth noting that Turing did not use the term "optimum coding."
33 Campbell-Kelly, 160.
34 Lavington, *Early British Computers*, 115-6.
35 Hodges, 328-9.
36 Lavington, "ACES and DEUCES," 12.
37 Sherborne School, "Grade Report from Sherborne School, Summer Term, 1926."; Sherborne School, "Grade Report from Sherborne School, Lent Term, 1928."; Sherborne School, "Grade Report from Sherborne School, Michaelmas Term, 1927."

Church of Princeton, had published his solution to the *Entscheidungsproblem* just months before Turing finished his paper.[38] Turing also carried his solitary habits into his work at Bletchley Park during the Second World War. For example, Turing managed "to break into five days' worth of Enigma material" completely independently of the main codebreaking efforts; however, the material was mostly trivial pre-war intelligence and of little consequence.[39] Evidence suggests that Turing was driven to solve problems that his colleagues ignored; indeed, he took on new projects so he could have them to himself.[40] This indicates that Turing was strongly self-driven and self-motivated.

Working with Turing could be challenging, particularly due to his personality. His colleagues at Bletchley Park found him to be an incapable administrator because he was more focused on his codebreaking work and private research projects.[41] Turing was quite a disorganized administrator, and he eventually lost his administrative role in Hut 8 at Bletchley Park.[42] He also had a bad habit of micromanaging his colleagues, which often resulted in mutual annoyance.[43] Turing's initial supervisor, the Cambridge classicist and code breaker Dillwyn Knox, found it difficult to manage Turing.[44] Knox remarked that Turing was "very difficult to anchor

38 Yates, 15.

39 Sinclair McKay, *The Secret Life of Bletchley Park: The History of the Wartime Codebreaking Centre and the Men and Women Who Were There* (London: Aurum, 2010), 47.

40 Ibid., 134.

41 Christopher Grey, *Decoding Organization: Bletchley Park, Codebreaking and Organization Studies* (Cambridge: Cambridge University Press, 2012), 210.

42 McKay, 191. See also Grey, 210.

43 Hodges, 376.

44 McKay, 54-5.

down," but his authority was just enough to keep Turing at least partially under control.[45] Turing was notoriously rambunctious, his codebreaking work at Bletchley Park was essential to the Allies' success in the Second World War.

Turing was also well known for his eccentric behavior, such as chaining his coffee mug to a radiator to discourage theft. Also, Turing tended to fall into silences for extended periods and to stare off into the distance, often staring past the people to whom he was engaged in conversation.[46] Conversations with Turing were often hampered by his characteristic "hesitating stammer"[47] and his unusually high voice, which could make his speech difficult to comprehend. Turing also had the bad habit of dressing like a hapless tramp.[48] Indeed, most of Turing's colleagues at Bletchley Park considered him to be a worried "weirdo."[49] What is more, Turing became accustomed to a certain level of wartime priority. He and a few colleagues wrote directly to Winston Churchill to appeal for much-needed supplies and personnel. Surprisingly, Churchill granted the request and gave high priority to the Bletchley Park staff.[50] Ultimately, the idiosyncrasies of Turing's character would contribute to the downfall of his ACE project.

Turing's ACE project stalled and nearly failed due to a combination of inadequate organizational structure, poor

45 Ibid.
46 Marion Hill, *Bletchley Park People: Churchill's Geese That Never Cackled* (Phoenix Mill, UK: Sutton Publishing, 2004): 68-9.
47 McKay, 17.
48 Hill, 68.
49 McKay, 17.
50 Hodges, 376.

administration, and a lack of resources. From the outset, the National Physical Laboratory very much adhered to the bureaucratic standards expected of government institutions. It was composed of a rigid management structure and a strict division of labor; however, the NPL lacked a reputation for innovation.[51] The ACE was a chance to turn that reputation around. Under Darwin, Womersley led and directed the daily research operations of the Mathematics Division and the ACE project. Indeed, Turing would begrudgingly refer to Womersley as "my boss."[52] Turing was accustomed to the managerial structure of Bletchley Park, and Womersley's managerial style was incongruent with that structure. Whereas Turing was interested in solving problems and developing computers, Womersley was concerned with bureaucracy and results.

The NPL's very literal division of labor proved detrimental to the progress of the development of Turing's ACE computer. As part of its organizational structure, the NPL was divided into different Divisions, such as the Mathematics Division or the Radio Division. The construction of a computer was a mathematical and logical task in theory and design, but the actual device had to be constructed by engineers. Turing was allowed his own small team of mathematicians and engineers.[53] However, the NPL's organizational structure "drew a firm line between brain

51 Ibid., 339.
52 Ibid., 317.
53 Yates, 24.

and hand;"[54] hence, ignorance of the developments of each Division would develop.[55] Steady progress would have been difficult to maintain at the NPL without a fluid, cohesive organizational structure. This would become especially evident later when Darwin established the Electronics Section as part of the Radio Division.[56] The Electronics Section became the primary roadblock in the development of the ACE.

Turing originally proposed the establishment of an in-house electronics section in February 1947 to alleviate the pressure on the Mathematics Division.[57] After a trip between 1946 and 1947 to survey the numerous American computer projects, Turing expressed his concern that the NPL's organizational structure was inadequate. As Turing remarked in a letter,

> One point concerning the form of organisation struck me very strongly. The engineering work was in every case being done in the same building with the more mathematical work. I am convinced that this is the right approach. It is not possible for the two parts of the organisation to keep in sufficiently close touch otherwise. They are too deeply interdependent. We are frequently finding that we are held up due to ignorance of some point which could be cleared up by the engineers, and the Post Office find similar difficulty; a telephone conversation is seldom effective because we cannot use diagrams.[58]

54 Hodges, 339.
55 Ibid., 356.
56 Ibid., 366.
57 B. Jack Copeland, "The Origins and Development of the ACE Project," in *Alan Turing's Automatic Computing Engine: The Master Codebreaker's Struggle to Build the Modern Computer,* ed. B. Jack Copeland (Oxford: Oxford University Press, 2005), 69-70.
58 Hodges, 356.

Turing sought to establish a more cohesive work environment. In effect, Turing was betraying his own work ethic; his characteristic style was that of a self-driven loner. However, a more cohesive unit would establish a sense of stability and concentrated effort. In fact, in the same letter, Turing explained that the sheer number of American computer projects was counterproductive because it stretched thin the available resources. In contrast, Turing believed that a concentrated effort on one machine in Britain—namely, the ACE at the NPL—would prove more fruitful than the American efforts. Turing also realized, however, that the British effort was "puny" in comparison to the larger American projects.[59] By 1947, Turing's ACE project entered its second year, and the NPL had little to show for it. Hence, progress needed to be stimulated quickly; a cohesive organizational structure would expedite this process.

Darwin established the Electronics Section of the Radio Division in summer 1947, and Horace A. Thomas was appointed as its supervisor.[60] The new Electronics Section took several months to install due to poor administration, whereas it could have been installed in a matter of weeks. Unlike Turing and the ACE group, Thomas was primarily interested in the industrial applications of electronics, not computing machines.[61] For some reason, however, Darwin decided that all engineers, including the ACE engineers, should fall under the purview of Thomas's Electronics

59 Ibid.
60 Ibid., 366.
61 Copeland, 66.

Section.[62] Turing lost his control of his engineers and Thomas almost singlehandedly stalled all development. Indeed, the ignorant engineers of Thomas's section replaced the capable engineers of the ACE group. Thomas also petitioned Darwin to "curtail the construction work in the ACE Section."[63] Worse yet, after several months of stonewall administration, Thomas left the NPL for Unilever Ltd, which led Womersley to remark that development was "probably as far advanced [as] 18 months ago."[64] While Thomas's Electronics Section was an unfortunate detour on the road to building the ACE, the concept of an Electronics Section was not inherently bad. Turing recognized the potential benefit of and argued for an in-house electronics section,[65] but Darwin's implementation of the section was poorly administered. The establishment of the Electronics Section should have benefited the ACE project, but the relationship between the Mathematics Division and the Electronics Section was not as prosperous as desired.

Evidence suggests that the NPL leadership and Turing were often at odds with one another, especially when Turing's authority began to be undermined. In 1947, American Harry D. Huskey joined the NPL to spend a one-year sabbatical working on the ACE project.[66] By the time of Huskey's arrival, Turing had completed Version VII of his revised ACE design, and progress on the project was at a near

62 Hendry, 35.
63 Ibid., 69-70.
64 Ibid.
65 Ibid.
66 Hendry, 34-5.

standstill.[67] Huskey proposed to construct a miniature, pilot model of the ACE based on Version V of Turing's design; the pilot model was known as the "Test Assembly." Importantly, Huskey revised and made significant changes to Turing's design by stripping Turing's design of its logical components; Huskey believed the machine merely needed to perform numerical calculations.[68] While this view was consistent with Darwin and Womersley's goals, it was totally incongruous with Turing's vision. Interestingly, B. Jack Copeland speculates that a machine such as the Test Assembly, "given better management at the NPL," could have been completed in 1948.[69] However, Thomas's Electronics Section was established shortly after Huskey introduced his Test Assembly. Although Womersley had urged for cooperation between Thomas and the ACE group, Thomas's stonewalling of the ACE project nearly killed Huskey's Test Assembly project.[70] The Test Assembly could not be completed by 1948 due to departmental infighting.

Understandably, Turing did not appreciate Huskey's Test Assembly side project, but he did not actively protest it. Turing simply could not understand why anyone would want to waste time on a pilot model version of the ACE. Indeed, as Teresa Numerico notes, Turing was simply unable "to perceive its urgency and strategic importance."[71] For

67 Copeland, 57.
68 Hodges, 365.
69 Copeland, 69-70.
70 Ibid., 69.
71 Numerico, 187.

Turing, the ultimate goal was the "grand ACE installation";[72] on the other hand, the NPL management wanted a proof-of-concept machine to attract investors and partners.[73] While Turing never publicly expressed his disdain for the "Test Assembly," Huskey's side project was a blatant undermining of his authority. Huskey took control of the ACE group, and all focus was concentrated on the Test Assembly side project.[74] The effort to construct the ACE was further divided as valuable resources were diverted to the Test Assembly project. In fact, the splintering of Huskey's group from the main ACE group ran counter to Turing's wish for a cohesive working unit, as he outlined in his aforementioned letter. Furthermore, Thomas's Electronics Section policies ensured the limited progress of Huskey's Test Assembly machine. In fact, Thomas persuaded Darwin to cease operations on the side project;[75] in response, Huskey remarked, "Morale in the Mathematics Division collapsed."[76] Thomas had effectively demoralized the ACE personnel. After his departure, Huskey's Test Assembly evolved into the Pilot ACE, which also deviated from Turing's original design.

As a sign of the deteriorating social atmosphere at the NPL, Turing and Womersley exhibited rather passive aggressive behavior toward one another. Turing perceived Womersley as the epitome of "bogus,"[77] and Womersley

72 Hodges, 365.
73 Numerico, 187.
74 Ibid.
75 Hodges, 372.
76 Copeland, 64.
77 Hodges, 317.

probably saw Turing as an overly eccentric genius. Womersley and Turing purposely avoided contact with another. Andrew Hodges recounts in his biography of Turing:

> Womersley's gifts of management: a mastery of name-dropping, a genial enthusiasm, a pleasant office manner to important visitors, a diplomatic sense of what to report, were not skills that Alan Turing ranked highly; not just because he lacked them himself, but because he still could not understand why anyone should need weapons other than rational argument. Before long, Alan [Turing] was openly rude to Womersley in the office, saying 'What do *you* want?' and turning his back if Womersley dared to intrude upon some discussion. . . . Conversely, Womersley would show visitors round Cromer House, pointing at the Turing office from afar with exaggerated awe, and saying 'Ah, that's Turing, we mustn't disturb *him*,' as of some rare zoological exhibit.[78]

Turing and Womersley's managerial styles were utterly incompatible. On one hand, Womersley was a stereotypical "yes-man" administrator with hardly a mind of his own.[79] On the other hand, Turing lacked all managerial qualities because he did not desire to be a manager.[80] The mutual juvenility in which Womersley and Turing acted toward one another is of interest; however, juvenility is hardly a professional trait, and it would not be expected from someone of Womersley's status and position. Then again, the same may be said for Turing, though he had a history of disregarding conventional standards and expectations. Furthermore, conflicts between Turing and Womersley could have scarcely benefited morale.

78 Ibid.
79 Ibid.
80 Ibid., 376.

The ACE project lacked the camaraderie to which Turing grew accustomed at Bletchley Park.[81] If Womersley and Turing were at odds with one another on a regular basis, the friction and tension would have negatively impacted morale. Conflicts in management ran counter to Turing's wish for a cohesive working unit, so it is perplexing that he would act compromisingly. Perhaps the frustration of slow progress was putting an end to his resolve. As may be inferred from Hodges's anecdote, visitors may have assumed negative impressions of the NPL based on Womersley and Turing's actions. These negative impressions further complicated the production of the ACE, especially considering these visitors were financiers or potential contractors.

The NPL desperately required financial support, but it would be difficult to obtain. Turing's original ACE proposal featured a rather optimistic projected budget of £11,200,[82] but Womersley recommended increasing the projected cost to about £50,000 or £60,000 to make it more realistic.[83] However, by late 1946, the ACE project was estimated to cost up to £125,000.[84] The NPL needed the help of the Treasury to fund the ACE project.[85] Darwin and Womersley proposed a small "pilot" machine project, the Pilot ACE, to the Treasury and Ministry of Supply. As Hodges reports, the Treasury granted £10,000 for the "small-machine," but this was just an initial

81 Ibid., 343.
82 Lavington, "ACES and DEUCES," 12.
83 Yates, 22-3.
84 "Britain to Make a Radio Brain: 'Ace' Superior to U.S. Model," *The Daily Telegraph*, November 7, 1946.
85 Hodges, 337.

installment. The hope was that a more substantial sum of up to £100,000 would be made available for a larger, full-scale machine. The Treasury made no guarantees of this larger amount.[86] In a sense, the Treasury's small investment was an attempt to insure itself in case Turing's project failed. However, the lack of a guarantee for the full amount put unnecessary strain on the NPL administration.

It is worth noting that Max Newman's Manchester University computer project[87] was able to avoid the financial woes the NPL faced. In 1946, Newman applied to the Royal Society for funding. Interestingly, Darwin was a member of the Royal Society committee that reviewed Newman's application. Naturally, he attempted to reject the application "on the grounds that the ACE was to serve the needs of the country."[88] Darwin was overruled, and Newman was granted £35,000, a much larger grant than the NPL received from the Treasury.[89] Newman's Manchester project would produce the Manchester "Baby," which became the first stored-program computer to run a program on June 21, 1948.[90] By then, the NPL's Pilot ACE had yet to be built; Darwin's dream of a national computer at the NPL was effectively crushed by Newman's Manchester project.[91]

Ultimately, the ACE project was meant to produce a

86 Ibid.

87 Max Newman established a computer laboratory at Manchester in late 1945. Newman was the first reader of Turing's 1936 paper, and he understood its significance. Newman also worked with Turing at Bletchley Park. For more information, see Lavington, *Early British Computers*, 23-4. See also Hodges 341.

88 Hodges, 341-2.

89 Ibid.

90 Yates, 35.

91 Hodges, 366.

real, working machine. The NPL lacked engineers capable of appreciating Turing's design[92] and the space to accommodate the construction of a large computing machine.[93] Thus, outside contractors were needed to supply manpower and materials for construction of the ACE. The NPL made at least three efforts to obtain contracts with outside organizations. The first attempt was a concerted effort to forge a contract with the Post Office Research Station at Dollis Hill. Engineers at the Post Office had made great strides in mercury delay line storage technology during the Second World War. Turing's ACE design called for the use of electroacoustic mercury delay lines as its storage medium.[94] Unfortunately, the Post Office's Dollis Hill facilities were hopelessly inadequate for construction of the ACE.[95] The Post Office also had an extensive backlog of projects of its own to complete, let alone a new project from the NPL.[96] The NPL was unable to secure a contract with the Post Office, but it persisted in trying to farm out contracts to other organizations.[97]

After the Post Office contract foundered, the NPL tried to establish a contract with the Telecommunications Research Establishment (TRE) at Malvern. The TRE was attractive even more so than the Post Office because it had the experienced engineers that the NPL group desperately needed, particularly F. C. Williams. At the TRE, Williams

92 Ibid., 338.
93 Hendry, 34.
94 Ibid.
95 Numerico, 181.
96 Hodges, 340.
97 Copeland, 61.

was experimenting with applications of cathode ray tubes.[98] Turing saw cathode ray tubes as a possible alternative to mercury delay lines for the ACE's storage medium, but this suggestion was not well received.[99] The NPL simply could not afford another major delay. Moreover, most of the able technicians the TRE could spare had been transferred to the Department of Atomic Energy. Also, attempts to recruit Williams soured because he was more interested in building *his* computer, rather than the NPL's computer, Newman recruited Williams to join the Manchester computer project. The TRE could only offer a small staff to be directed under Williams at Manchester;[100] thus, the TRE's attractiveness waned. Unfortunately for Turing and the NPL, the TRE contract foundered.[101]

After the failures with the Post Office and the TRE, Darwin eventually turned to the English Electric Company in late 1948.[102] Sir George Nelson was the Chairman of English Electric; also, he was a member of the NPL Executive Committee.[103] Despite being rather incestuous, the partnership was a much-needed break. English Electric loaned NPL a small staff of engineers, which finally built the Pilot ACE machine from January 1949 until completion in May 1950.[104] Unlike its governmental contemporaries, however, English Electric was only interested in the Pilot ACE for the purpose

98 Yates, 24.
99 Hodges, 340.
100 Ibid., 349-50.
101 Copeland, 61.
102 Ibid., 74-5.
103 Lavington, "ACES and DEUCES," 17.
104 Hendry, 35.

of commercial production.[105]

Even after the NPL's Pilot ACE was completed in 1950, English Electric still did not have a concrete design for a commercial version. Indeed, as John Hendry notes, English Electric was uninterested in "the commercial exploitation of computers."[106] English Electric's attitude is perplexing because the company's sole purpose in aiding the NPL was to commercially exploit the Pilot ACE design. However, for some reason, the company did not want to commercialize computers. Nevertheless, English Electric's efforts to commercialize the Pilot ACE were too late to make a significant difference in the world of commercialized computers.

English Electric waited until the autumn of 1954, a few months after Turing's untimely death, to begin developing a "fully engineered version of the Pilot ACE to be called the DEUCE;" English Electric had no intentions at this point of marketing the DEUCE.[107] Eventually, between 1955 and 1957, English Electric began manufacturing the DEUCE, but the company still made no active efforts to market the machine.[108] By the time the DEUCE was made commercially available in 1955,[109] it was already on the verge of obsolescence. For instance, the British Atomic Weapons Research Establishment (AWRE) ordered a DEUCE machine, but, by early 1956, the

105 Ibid., 43.
106 Ibid., 69.
107 Ibid., 105.
108 Ibid., 119.
109 Lavington, "ACES and DEUCES," 19.

DEUCE was unable to keep up with the AWRE's demands.[110] In the end, English Electric only produced 33 DEUCE units, of which 12 units remained with the company.[111] Although over half of the manufactured DEUCE units were sold, the DEUCE was woefully inadequate for practical operation and research, and was a veritable flop.

The situation at the NPL continued to worsen, culminating in Turing's resignation on May 28, 1948[112] and Darwin's resignation in 1949.[113] Darwin and Womersley grew tired of Turing as progress on the ACE project stagnated. Indeed, conditions were so poor that Darwin and Womersley suggested that Turing should "go off for a spell" to Cambridge, with the understanding that Turing would return to the NPL.[114] Turing agreed to take the sabbatical, but he would return to neither the ACE project nor the NPL. During his sabbatical, Turing came back under the influence of his old colleague Max Newman. At Newman's behest, Turing joined the Manchester computer project,[115] but was too late to make any substantial contributions to the project before the "Baby" ran its first programs in June 1948.[116] Although Turing had no legal obligation to return to the NPL, Darwin was frustrated with him for joining a "rival" computer project.[117] While work on the ACE continued in Turing's absence, it was as

110 Hendry, 120.
111 Lavington, "ACES and DEUCES," 19.
112 Ibid., 17.
113 Hodges, 407.
114 Ibid., 367.
115 Agar, 121.
116 Ibid., 113.
117 There was not necessarily a competitive rivalry between the British computer projects. Rather, the competition was with the American projects. See Hodges, 342.

painfully slow as when Turing was present. In fact, when Jim Wilkinson—an ACE engineer—visited Turing in Cambridge, he brought news of "cuts, crises, and an ever-narrowing vision" at the NPL.[118] Wilkinson's account is strong evidence that Turing may not have been the only reason for the ACE project's slow progress, as Darwin and Womersley may have suspected. Nevertheless, the Pilot ACE machine survived to completion and ran its first program on May 10, 1950.[119]

However, by 1950, the Pilot ACE was no longer Turing's machine.[120] The Pilot ACE was more Huskey's machine since it evolved from the Test Assembly. After its successful 1950 demonstrations, the Pilot ACE was transformed into the English Electric DEUCE, which saw an extremely limited commercial success.[121] Finally, in 1957, a full-scale version of the ACE was completed,[122] and it was a much more complete realization of Turing's dream to build a Universal Turing Machine.[123] Turing's ACE project at the NPL was a veritable disaster; indeed, he would rarely speak of it after he resigned.[124]

Turing had left the NPL for Manchester before the Pilot ACE—or the full ACE, for that matter—reached completion. The Pilot ACE machine of 1950 was derived from Turing's

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118 Hodges, 372.
119 Lavington, *Early British Computers*, 29.
120 Hodges, 368.
121 Lavington, "ACES and DEUCES," 19. The DEUCE was an inferior machine compared to its American counterparts. For example, the IBM 704 was whole orders of magnitude superior to the DEUCE. For a more extensive comparison, see Hendry, 120.
122 Lavington, *Early British Computers*, 46.
123 Ibid., 116.
124 Hodges, 376-7.

designs, but it strayed from his philosophy and goal.[125] The full ACE machine was finally completed in 1957, at which time A. M. Uttley of the NPL remarked, "Today Turing's dream has come true."[126] However, by 1957, it was too little too late. The ACE design, relatively revolutionary in 1945 and 1946, was on the verge of obsolescence in 1957. It could be concluded, perhaps, that the nightmarish process of constructing the ACE had little benefit, except for serving as a step toward Turing's later advances in computer science, particularly in artificial intelligence at Manchester.[127]

While Turing and von Neumann may have been working independently on different computing projects, they were hardly without mutual influence. Indeed, von Neumann's EDVAC Report heavily influenced Turing's ACE proposal, and von Neumann relied heavily upon the theoretical Turing machine. However, von Neumann's abstract EDVAC design has garnered a considerable influence in computer science. Turing was much less fortunate in that his ACE machine fell almost completely into obscurity. While both men may be considered "fathers" of the modern computer, both men did not come about their titles in the same way. Both men took different approaches to the

125 Ibid., 368.

126 Lavington, *Early British Computers*, 116.

127 Although Turing's short time at the NPL was marked by unnecessary frustration, he made great strides in theoretical computer science. For instance, Turing explored the question of artificial intelligence in his NPL report, "Intelligent Machinery." For more on "Intelligent Machinery," see Hodges, 377. In his 1950 article "Computing Machinery and Intelligence" in *Mind*, Turing expounded on his ideas of artificial intelligence and introduced the basic form of what has become known as the Turing Test for machine intelligence. For more on the Turing Test, see Charles Petzold, *The Annotated Turing: A Guided Tour through Alan Turing's Historic Paper on Computability and the Turing Machine* (Indianapolis, IN: Wiley Publishing, 2008), 346.

same problem, encountered different situations, but von Neumann's abstract EDVAC design boasts a much more successful legacy than Turing's real ACE machine.

As per its original initiative, Britain successfully exploited the new field of computing research. However, that successful exploitation came in the form of Newman's Manchester computer project. While Britain again shared the international stage with United States, it was not Turing's doing. Indeed, Turing's ACE was constructed too late to significantly influence computer architecture design. Turing's ACE ultimately failed to meet its original purpose of being the national computer of Britain. Thus, it would appear that Turing and his colleagues wasted much of their time and energy for an impractical and unmarketable computer.