Dorothy K. Stein

LADY LOVELACE'S NOTES: TECHNICAL TEXT AND CULTURAL CONTEXT*

IT IS A TRUTH NOW WIDELY ACKNOWLEDGED THAT THE COMPUTER WAS invented between 1819 and 1834 by the English polymath named Charles Babbage. It is also widely held that the most important description and discussion of this machine was written by Byron's daughter, the Countess of Lovelace, herself a gifted mathematician. But if the character of the inventor and the reasons for the long neglect and ignorance of his invention have been vulnerable to misunderstanding, the doubly poetic figure of Lady Lovelace, and her paper on Babbage's machine, have recently proved particularly susceptible to legendary development, both in popular accounts and in more technical journals.

Several years ago, a high-level computer language, developed by the Department of Defense for military purposes, was rechristened ADA in her honor. Commencing the preface to a monograph describing this language, Henry Ledgard stated:

> If Charles Babbage is to be regarded as the father of modern day computer technology, then surely the Countess Augusta Ada Lovelace, after whom this new language is named, must be remembered as its midwife.
>
> It was she, the daughter of England's poet Lord Byron, who translated the work of the Italian Mathematician L. F. Menabrea, attaching her own scientific commentaries on the dissimilarities between the difference engine and the analytical engine. It was Lady Lovelace, the great lady of computers, who delivered the notes and loosely organized writings of Babbage, with her own invaluable amendments, to a world not quite ready to receive them.[1]

Ledgard may be a computer expert rather than an historian, but even Brian Randell, in a standard reference work on computer history,

* Research for this paper was carried out chiefly while the author was a member of the Institute for Historical Research, London.

[1] Henry Ledgard, *Ada: An Introduction* (New York: Springer-Verlag, 1980), p. iii.

has described Lady Lovelace's paper as the "single most important paper on Babbage's Analytical Engine," and wondered why it was not more influential in Howard Aiken's early designs for the Mark I.[2] Recent research is gradually bringing the account of Babbage's contributions to science and technology into focus, and more continuities between his work and the modern computer have been discovered than were previously suspected.[3] Still, the primary concern of many scholars with present instruments has led to an emphasis on the prescience and anachronism of his plans and ideas, to the neglect of relationships with the society in which he lived. Babbage's own claims for the Lovelace-Menabrea memoir, furthermore, have been unquestioningly accepted: "These two memoirs taken together furnish, to those who are capable of understanding the reasoning, a complete demonstration — *That the whole of the developments and operations of analysis are now capable of being executed by machinery*" (Emphasis in the original).[4]

In this paper, I would like to examine these claims more closely, and to argue that Ada Lovelace's addition — her "Notes" — were more a reflection of the mathematical uncertainty of the author, the political purposes of the inventor, and, above all, of the social and cultural context in which it was written, than a blueprint for a scientific development.

I

Babbage is gradually becoming recognized as one of the most important scientific figures of the nineteenth century. He was born in London, in 1791, the only son of a banker, which made him decidedly a gentleman, though not an aristocrat. He supplemented the instruction of teachers and tutors with a private study of mathematics so broad and deep that when he arrived at Cambridge he found he knew more than most dons. Gathering a group of like-minded fellow students around him, he set out to reform the state of mathematics in England, which was far behind the Continent, particularly France,

[2] Brian Randell, ed., *The Origins of Digital Computers* (New York: Springer-Verlag, 1973), p. 176, 187.

[3] See A. Hyman, *Charles Babbage, Pioneer of the Computer* (London: Oxford University Press, 1981).

[4] Charles Babbage, *Passages from the Life of a Philosopher* (London: Longman, 1864), p. 136.

partly as a result of the high veneration in which Isaac Newton was held. The first campaign of Babbage and his friends was to persuade the University to adopt Gottfried Wilhelm von Leibniz's superior "d" notation for the differential calculus in place of Newton's fluxional "dots."

To accomplish this, they formed a society to translate Sylvestre François Lacroix's abridged work on the differential and integral calculus. It was published in 1816, and, in recognition of the almost sacrilegious step they were proposing, Babbage facetiously suggested that they title their work "The Principles of pure D-ism in opposition to the Dot-age of the University" (*Passages*, p. 29). Then, to encourage the languid dons to adopt it, they published a companion volume of problems with solutions, all in the new notation.

Their campaign was successful, but, having left Cambridge, Babbage was unable to secure an appointment he considered worthy of his talents; one by one they fell to men of lesser acquirements. Cambridge University, he later wrote, finally forgave his irreverence by electing him to the Lucasian Chair of Mathematics, Newton's old post. But the honor came so late (he had been passed over at his first application) that he almost declined it; his father, in whose eyes his refusal to accept lesser positions would have been vindicated by the appointment, was dead. Then, too, he was already deep in work on his first calculating engine. Before that, however, he had produced a series of papers which made highly original and important contributions to the development of modern algebra. A recent assessment of Babbage's work in pure mathematics concluded that it was a thousand pities he had turned his attention to calculators in 1820, aborting this phase of his career.[5]

According to Babbage's accounts, which differ in detail, the impetus behind the invention of his first machine, which he called the Difference Engine, was the need to produce error-free numerical tables of various kinds, a task which seemed beyond the capabilities of fallible human beings. As skillful and inventive in practical matters as in theoretical, by 1822 he had constructed a small model which worked well enough to prompt him to write an open letter to Sir Humphry Davy, then President of the Royal Society, mentioning that he had actually thought of several different machines, suited to different types of mathematical computation.

[5] See J. M. Dubbey, *The Mathematical Work of Charles Babbage* (Cambridge: Cambridge University Press, 1978). Dubbey has pointed out that little of this work was published, but remained in manuscript. Babbage's friend, George Peacock, however, incorporated some of Babbage's ideas into his own text on algebra, which was very influential.

To accumulate and store the numbers, Babbage adopted the device which had been used by Blaise Pascal and Leibniz: tall, vertical shafts or axes on each of which a large number of circular disks were stacked by means of holes through their centers. The disks did not actually touch each other, but each could be independently turned around its axis by means of an attached toothed gear wheel. Each wheel had ten teeth, corresponding to the ten divisions marked on the edges of the disks, one for each digit, 0 through 9. The digits on each disk had a value one decimal place higher than those on the disk below, so that an ordinary decimal number could be read off each column by reading down a vertical line from the top. The number on any level could be changed independently by turning the disk. The number on one column could be added to that on another by connecting the two columns through gear wheels and turning the disks of one until all the digits in the chosen vertical line were zeros. The second column then held the sum of the two original numbers.

A slight complication (in theory, but in practice a considerable stumbling block) was the occasional need to carry from one disk level to the one above when the sum of the two digits on the first level was greater than 9. Babbage worked out several clever mechanical schemes to accomplish this, of which he was very proud. The overall operation of the Difference Engine depended on the fact that many mathematical functions can be approximated by several terms of a power series. The successive values of the powers of any number, and the sums of the power series, can be arrived at by repeated additions of several orders of differences between terms. Thus, the Difference Engine worked by connecting a number of columns of disks together in such a way that the successive numbers on each were added to the column next in line. The column on the starting end of the series of additions, which contained the highest order of difference used, always had the same constant number on it. Unlike previous mechanical calculators, once the Difference Engine was set up for a particular task, it would proceed through the necessary steps without further human intervention; as long as the human operator continued to turn the handle at the top, it continued to churn out successive values of the mathematical function for which it had been adjusted. But almost at once, Babbage began to think of ways to generalize his machine.

After a leisurely delay of a year, he was awarded a gold medal by the recently formed Astronomical Society and a grant from the government of £1,500 to launch him on the construction of a full-sized Difference Engine. In keeping with his principle that a theoretically feasible plan should not be frustrated by mechanical deficiencies, he determined to build his engine of the finest available materials, by the most advanced techniques, in the hands of the most expert workmen. At the recommendation of Marc Brunel, he hired Joseph Clement, who had been trained at the firm of Henry Maudsley, the cradle of the most highly developed mechanical engineering methods of the time. Still, the Difference Engine project required that Babbage himself design many new and ingenious tools for making the parts he needed. These tools, by law, belonged to Clement, the artisan, rather than Babbage, the designer and employer.

The government eventually contributed £17,000 toward the construction, which proved much longer and more involved than the first estimation had anticipated. The support, however, was erratic and uncertain from the first (as government payments often were), and Babbage had frequently to advance money to Clement out of his own pocket. In 1833 Babbage had a portion of the machine put together; it worked perfectly. Shortly thereafter, a dispute over payments broke out between Babbage and Clement, who not only stopped work and laid off his assistants, but appropriated all the drawings and parts of the engine, except for what had been assembled. That portion had been removed to Babbage's house so that he could demonstrate its workings to admiring visitors.

It was almost two years before he regained his plans and parts, and nine years before the changing governments could be brought to a definite decision respecting future support for the project. In the meantime, his restless mind had continued to evolve the possibilities of a calculating engine that could transcend the limitations of the Difference Engine: an Analytical Engine, capable of multiplication and division as well as addition and subtraction, able to perform any numerical calculation and needing no constant order of difference. It was during this period that he made the acquaintance of Ada Byron.

She was Byron's only legitimate offspring; a month after her birth, her mother insisted on a permanent separation which effectively ended the poet's year-long marriage. Shortly thereafter, he left England and never returned. Ada's education was briskly paced and closely supervised by her possessive and domineering, but highly intellectual, mother. She acquired a lifelong taste for learning and displayed an early interest in science, approved by Lady Byron. This was fortunate because, following an attack of measles in early adolescence, she was partially paralysed until she was nearly seventeen;[6] during much of this period, however, she was able to continue some of her studies. At seventeen, the customary age at the time, she was considered sufficiently recovered to "enter the world" by attending her first London season. It was then that she met Babbage, with whom, said her mother, she was delighted. He responded to her delight in his usual fashion, by issuing an invitation to view his Difference Engine.

A careless reading of the inaccurate reminiscences of Sophia De Morgan, a friend of Lady Byron's, furnishes the conventional picture of Ada's response on this occasion: "I well remember accompanying her to see Mr. Babbage's wonderful analytical engine. . . . Miss Byron, young as she was, understood its workings, and saw the great beauty of the invention."[7] The engine that Ada and her mother went to view (with or without Sophia) was not the Analytical Engine, no model or portion of which existed until long after Ada's death. Ada did see the great beauty of the Difference Engine — she later called it the "gem of all mechanism" and borrowed the drawings — but as to understanding it, contemporary correspondence reveals only Lady Byron's:

> We both went to see the *thinking* machine (for such it seems) last Monday. It raised several Nos. to the 2nd & 3rd powers, and extracted the root of a Quadratic Equation. — I had but faint glimpses of the principles by which it worked — Babbage said it had given him notions with respect to general laws which were never before presented to his mind — For instance, the Machine would go on counting regularly, 1, 2, 3, 4, &c — to 10,000 — and then pursue its calculation according to a new ratio, which was, I *think*, 10,002, 10,005, 10,009 — but I am only certain that the numbers were no longer successive ones, and that their differences were neither in arithmetical nor Geometrical ratio, as far as I could apprehend. — If this occult principle of change existed in the law according to which the machine was constructed, (for Babbage discovered it to be latent in the mathematical formula originally applied by him) it may be consistent with the *general* laws of our solar system that the sun shall not rise tomorrow. — He said, indeed, that the *exceptions* which took place in the operation of his Machine, & which were not to be accounted for by any errors or derangement of structure, would follow a greater number of uniform experiences than the world has known of days & nights. — There was a sublimity in the views thus opened of the ultimate results of intellectual power.[8]

Lady Byron's letter reveals that Babbage had already been struck by the cosmological implications of his invention which he later elaborated in *The Ninth Bridgewater Treatise*, his contribution to natural theology. He was very fond of mystifying his guests with the

[6] A discussion of the nature of Ada's illness is outside the scope of this paper. I suspect, however, that she may have been a victim of porphyria, and thus her paraplegia was connected with later episodes of a manic-depressive-like condition.

[7] Sophia E. De Morgan, *Memoir of Augustus De Morgan* (London: Longman, 1882), p. 89.

[8] Lady Byron to Dr. William King, 21 June 1833, L-B no. 336. Lovelace-Byron Papers, Bodleian Library, Oxford. Hereafter cited as L-B. Extracts from the Lovelace Papers appear with the permission of the Earl of Lytton, Viscount Knebworth and the Lovelace Papers.

(1) Ada, Lady King (later Lady Lovelace), 1835. To my knowledge, this has not been previously published, but clearly it was painted at the same time as her portrait by Margaret Carpenter exhibited at the Royal Academy, from which it differs slightly. Her comment on Mrs. Carpenter: "I conclude she is bent on displaying the whole expanse of my capacious jaw bone, upon which I think the word Mathematics should be written." She wished to be painted in her peeress's robes, although her mother felt it indicated an indelicate anticipation of the next coronation (*Murray Collection*).

(2) Babbage painted by S. Lawrence, 1845. His son commented that this portrait looked very like his father (*National Portrait Gallery*).

apparently miraculous behavior of the engine, but it was a simple matter for him to arrange that one or more additional number columns be coupled into the machine's operation after a set number of turns.

Even before this date (1833), he had published his reflections on the connection of his invention with the economics of the industrial revolution. In 1827 Babbage's wife, two children, and his father died. Grief placed a strain on his health so severe that his doctors ordered an extended trip abroad. His form of therapy included visits and surveys of as many factories and scientific establishments as he could take in. One consequence of his industry was the publication in 1832 of *On the Economy of Machinery and Manufactures*, a major and influential work in economics that was later cited with respect by both John Stuart Mill and Karl Marx. It was a hymn to progress through industrial and technological development. Two of its major themes were the division of labor and the processes of replication, and both were to be important in his designs for the Analytical Engine.

II

As delighted as Ada might have been in meeting Babbage, and as interested as she was in science, she knew very little mathematics at the time. It was not until the following year that she appealed to her mother's friend, Dr. William King, for help with "Euclid, Arithmetic and Algebra."[9] From time to time over the next few years she turned to Mary Somerville, another family friend and the celebrated translator of Pierre Simon de Laplace's *Celestial Mechanics*, for help with problems in trigonometry and solid geometry. Then, late in 1839, she looked to Babbage for mathematical instruction. He evaded her somewhat oblique suggestions, but in 1840 a congenial instructor was found in Augustus De Morgan, Sophia's husband.

De Morgan, himself a key figure in the development of modern algebra, and the author of the first textbook in calculus to place the subject on a rigorous basis, was particularly delighted by Ada's fundamental philosophical questions, her "first queries" on new methods and ideas, as he called them. He was so impressed by these that he scarcely noted her slow and erratic progress in acquiring real proficiency and understanding. As for Ada, she had determined to become a scientific writer, and to collaborate with Babbage: "I am very anxious to talk to

[9] Ada Byron to Dr. King, 9 March 1834, LB no. 172.

you. I will give you a hint on *what*. It strikes me that at some future time (it might even be within 3 or 4 years. . .), *my head* may be made by you subservient to some of *your* purposes & plans. If so, *if* ever I could be worthy or capable of being *used* by you, my head will be yours. . . .though I scarcely dare so exalt myself as to hope however humbly, that I can ever be intellectually worthy to attempt serving *you*."[10] But there is no evidence in the surviving correspondence on either side to suggest that he ever encouraged her wish until she laid before him a *fait accompli*.

Babbage was certain that "as soon as an Analytical Engine exists, it will necessarily guide the future course of science" (*Passages*, p. 137), but some of his contemporaries lacked his vision, including some, such as the Astronomer Royal, who were in a position to advise the government. In his strenuous attempts to convert politicians to his faith and obtain the support he needed, if he did not want collaborators he certainly needed friends and promoters to keep the educated public appraised of new developments, and to keep his engines alive in their eyes during the long weary years when he hoped for official backing or at least vindication. Although he himself was energetic in his efforts to publicize, he preferred, whenever possible, to have discussion and praise appear over the names of others, particularly prominent others, even if sometimes he had to do the actual writing himself.

In 1840 Babbage went to Turin to hold forth in a series of lectures and discussions explaining the proposed Analytical Engine to a group of Italian philosophers and men of science. He had hoped to have the most eminent of them, Giovanni Antonio Amadeo, Baron Plana, write a report or article on the subject, but Plana pleaded ill health. In the end he had to content himself with the services of a young military engineer, Captain Luigi Menabrea (who eventually became Prime Minister of Italy). Babbage accepted the substitution with less than consummate grace. From Florence, over a year later, he drafted a letter to Plana: "If you had made a report on the subject to the Academy of Turin during the last year it might have been of special service to me in the discussion of the question with my own government. As it is I must be content with the description drawn up by M. Menabrea with which I am well satisfied because he seems to have penetrated completely the principles in which it rests" (Add. Mss. 37, 191, f. 645).

From this it may be seen that Babbage had reviewed Menabrea's article over a year before it was published. (It appeared, in French, in the *Bibliothèque Universelle de Genève* in October, 1842.) Correspondence from Menabrea indicates that it was rewritten to incorporate Babbage's suggestions before publication (27 January 1842, Add. Mss. 37,192, f. 22). Shortly thereafter, Ada translated it into English, apparently at the suggestion and under the supervision of Charles Wheatstone, the physicist. Wheatstone was yet another family friend who took a great deal of sympathetic interest in Ada's plans, constituting himself a sort of career adviser. He also solicited translations for *Taylor's Scientific Memoirs*, a recently founded journal devoted to making available significant scientific and technical papers from abroad.

Babbage suffered a serious illness in the autumn of 1842, which may partly explain his being unaware of Ada's translation until after it was completed, and why her contribution took the form it did. His role in the publication developed only later in the proceedings. According to his memoirs, when Ada told him what she had been up to, his response was to ask

> why she had not herself written an original paper on a subject with which she was so intimately acquainted? To this Lady Lovelace replied that the thought had not occurred to her. I then suggested that she should add some notes to Menabrea's memoir; an idea which was immediately adopted.
>
> We discussed together the various illustrations that might be introduced: I suggested several, but the selection was entirely her own. So also was the algebraic working out of the different problems, except, indeed, that relating to the numbers of Bernouilli [*sic*], which I had offered to do to save Lady Lovelace the trouble. This she sent back to me for an amendment, having detected a grave mistake which I had made in the process.
>
> (*Passages*, p. 136).

Babbage's references to Ada were always kind, deferential, and flattering. But his autobiography was written twenty years after the events referred to her, and his statements must be checked against other, more contemporary evidence. The autobiography itself was a polemic on behalf of his machines, as he explains there, and he had every inducement to rate highly the most important piece of propaganda concerning his masterpiece. The homage due to Babbage's immense and growing reputation, the awe inspired by his prodigious abilities, has tended to compel acceptance of almost any statement he cared to make about his inventions. However, when these statements are compared with the paper itself, and with the correspondence that accompanied its writing, a very different picture emerges. In particular, Babbage's contribution to Ada's Notes is of interest in examining the ideas they contain.

[10] Ada (Byron) Lovelace to Charles Babbage, 12 January 1841, Add. Mss. 37,191, f.543. British Library Additional Manuscripts, London. Hereafter cited as Add. Mss.

To begin with, how well was she prepared to write on a mathematical subject? And how intimate was her acquaintance with Babbage's as yet immaterial engine? Her mathematical studies with De Morgan appear to have petered out late in 1842. The last surviving letters in that correspondence are dated the 16th and 27th of November of that year — hence shortly before she began work on the translation. They show her wrestling with a simple and straightforward problem in functional equations, still unable to grasp the technique of substituting a new expression back into an equation, even when the correct formula to substitute has been handed to her. It was just such problems which had bedevilled her queries to Mary Somerville seven years previously, and several of her earlier letters to De Morgan. In her letter of 27 November she sighed: "These functional equations are complete Will-o-the Wisps to me. The moment I fancy I have really at last got hold of something tangible & substantial, it all recedes further & further & vanishes again in thin air. . . . I *believe* I have left no method untried."[11]

The evidence of the tenuousness with which she grasped the subject of mathematics would be difficult to credit about one who succeeded in gaining a contemporary and posthumous reputation as a mathematical talent — if there were not so much of it — but perhaps the most telling and consequential piece occurs in her translation of Menabrea's portion of the memoir. In one passage, Menabrea was considering a product which "becomes equal to the ratio of the circumference to the diameter" when *n*, the number of factors, becomes infinite. The translated passage continues: "Nevertheless, when the cos of $n = \infty$ has been foreseen, a card may immediately order the substitution of the value of π."[12] Where did "the cos of $n = \infty$," which makes nonsense out of this passage, come from? In the original paper, the passage reads: "Cependant, lorsque le cos. de $n = \infty$ a été prévu," and Ada made a literal translation of this. But a moment's consideration makes it clear that "cos." is a printer's error, and the expression intended by M. Menabrea was "le cas de $n = \infty$" [the case of $n = \infty$], which makes sense in the context. In other words, Ada translated a printer's error; her mistake, surprisingly enough, has been reprinted several times.[13]

[11] Ada (Byron) Lovelace to Augustus De Morgan, 27 November 1842, L-B no. 170, f.149.

[12] Sketch of the Analytical Engine invented by Charles Babbage Esq. by L. F. Menabrea, of Turin, Officer of the Military Engineers. [Translated and with notes by A. A. L.: Augusta Ada, Countess of Lovelace], Article XXIX, *Taylor's Scientific Memoirs*, 3 (1843), 687. Hereafter cited as *Memoir*. The expression referred to is related to "Wallis' Product."

[13] H. P. Babbage, ed., *Babbage's Calculating Engines* (London: Spon, 1889); and P. Morrison and E. Morrison, *Charles Babbage and his Calculating Engines* (New York: Dover, 1961). B. V. Bowden, ed., in *Faster Than Thought* (London: Pitman, 1953), corrected the error without comment, along with a number of printer's errors in the Notes.

Ada's understanding of the projected mechanical and logical design of the Analytical Engine early in 1843 is at least equally dubious. As fascinated as she had been by the Difference Engine, her letters show that during the early years of marriage and motherhood, which for her began in 1835, she had not kept *au courant* of developments in the Analytical Engine, which in any case would not have been easy. Not only were Babbage's plans continually changing, but the direction of change was not always toward completion. On 29 November 1839, for example, he wrote her, "I have just arrived at an improvement which will throw back all my drawings full six months unless I succeed in carrying out new views which may shorten the labour" (L-B no. 168).

An even more telling instance occurred, once more in the translation of Menabrea, when Ada observed in a footnote that she had altered a sentence "in order to express more exactly the present state of the engine." In the original, the sentence read: "All the parts, all the wheels which constitute that immense mechanism have been put together, their action has been studied, but it has not yet been possible to assemble them."[14] In Ada's translation, we read instead: "The plans have been arranged for all the various parts, and for all the wheel-work, which compose this immense apparatus, and their action studied; but these have not yet been fully combined together in the drawings and mechanical notation" (*Memoir*, p. 690). In the time between the writings of these two statements, the engine seems actually to have dematerialized. In the early 1840s, only Babbage can be said to have been "intimately acquainted" with his engines, and although both of his interpreters were relative novices, completely dependent on him for information and claims about the Analytical Engine, Ada, from friendship and close association during the writing, must have been the more persuadable.

III

An article on Babbage's Difference Engine had been published in 1834. It was written by Dr. Dionysius Lardner, a science popularizer, under Babbage's close supervision. Along with urging the practical need for a machine to produce infallible numerical tables, and

[14] Notions sur la Machine Analytique, par Mr. L.-F Menabrea, capitaine du genie militaire, *Bibliothèque Universelle de Genève*, 41 (1842), 376. The translation of this sentence is my own.

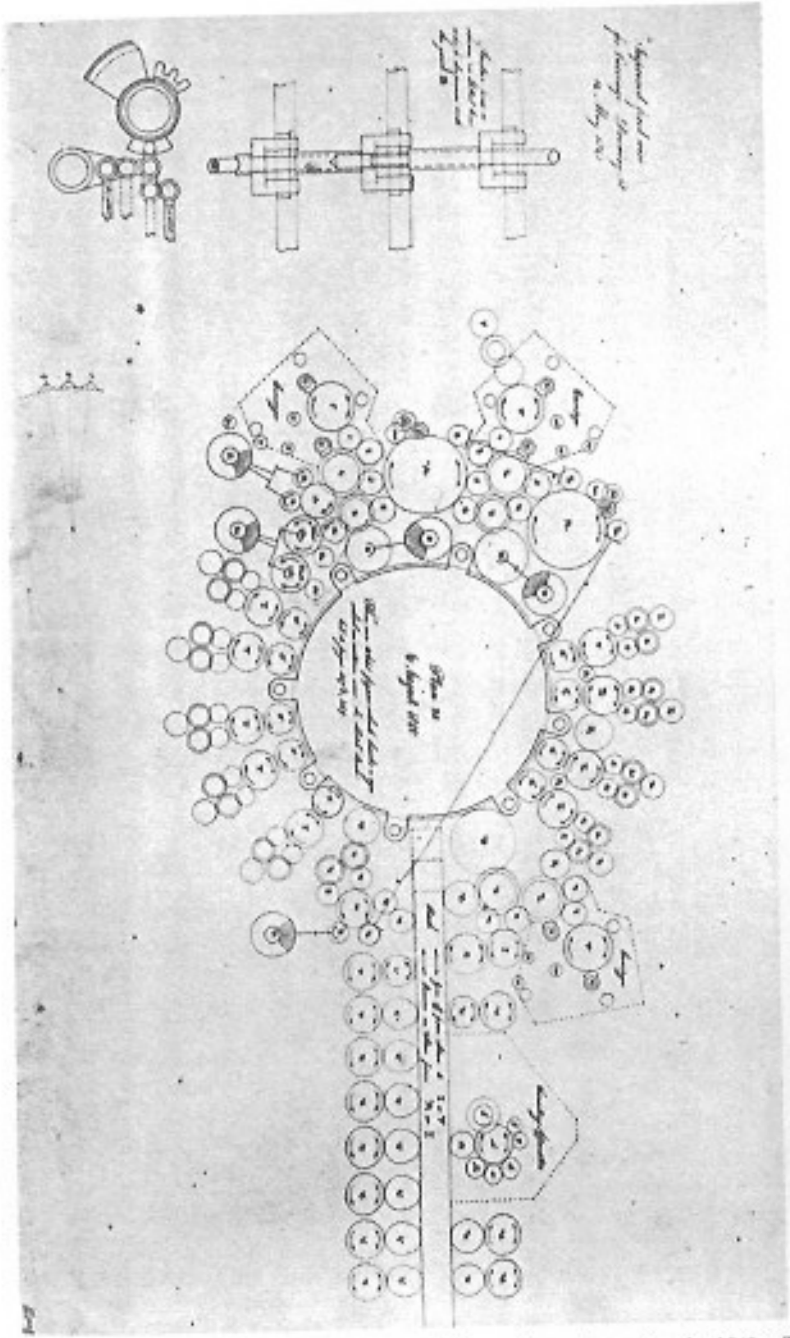
discussing the then current status of Babbage's negotiations with the government, it had included a description of the machine's physical structure and mechanical operation. By contrast, in keeping with the more general nature and immaterial status of the Analytical Engine, Menabrea's account dealt little with physical and mechanical details. Instead he described the functional organization and mathematical operation of this more flexible and powerful invention. To illustrate its capabilities, he presented several charts or "Tables" of the steps through which the machine would be instructed to pass in performing its calculations. These steps were to be punched in coded form on cards to be fed into the engine; hence, the charts constituted the first computer programs. Menabrea's charts were taken from among those brought by Babbage to Turin to illustrate his talks there.[15]

Babbage suggested several more "illustrations" to be included in Ada's Notes, that is, several more of the charts, with attendant discussion of the means of preparing the problems for machine processing. The illustrations she used, except for "that relating to the numbers of Bernoulli," were also among those that Babbage had prepared some years earlier — a circumstance that explains the absence of discussion of these other illustrations in the correspondence which flew between Ada and Babbage while she was writing the Notes.

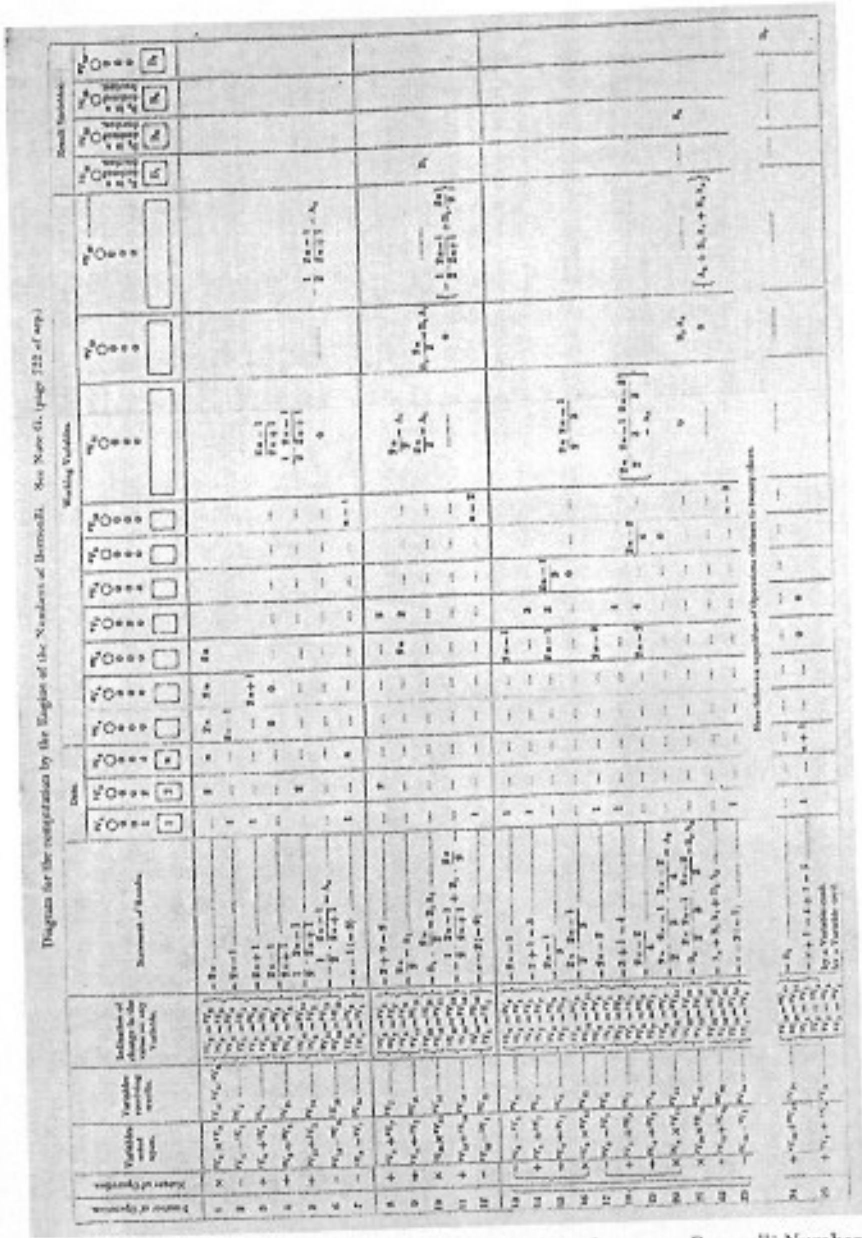
If Menabrea's account of the Analytical Engine was often on a more general and abstract plane than Lardner's description of the Difference Engine, Ada's Notes frequently moved to a level yet more rarefied and detached from the machine's proposed physical embodiment, to expatiate on the metaphysical implications and latent powers of an entire mental industry. Here she seemed to be in her element. With her usual painstaking thoroughness, she had set out to remedy her ignorance by reading all of Babbage's relevant papers. An early letter in the series asks: "I have read your papers over with great attention; but I want you to answer the following question by return of post. The day I called on you, you wrote on a scrap of paper (which I have unluckily lost), that the *Difference* Engine would do (something or other) but that the Analytical Engine would do (something else that is absolutely general) Be kind enough to write this out properly for me; & then I think I can make some *very* good Notes."[16]

[15] I am indebted for information regarding the programs Babbage took to Turin to Dr. Allan Bromley, Basser Department of Computer Science, University of Sydney, Australia, who in addition permitted me to see a prepublication copy of his introduction to a new edition of Babbage's *Calculating Engines*. Lardner's account appeared in the *Edinburgh Review*, 59 (July 1834), 263-327.

[16] Ada (Byron) Lovelace to Charles Babbage, n.d., Add. Mss. 37,192, f.357.



(3) Plan showing the projected arrangement of the number columns in the 1840s. The circular arrangement was abandoned before a model of the arithmetic unit ("mill") was built in the 1870s (*Science Museum, London, Imperial College Library*).



(4) The diagram or "program" for the computation of the first seven Bernoulli Numbers that was included in the Menabrea-Lovelace Memoir (*The British Library*).

As they are presented in the published memoir, Ada's Notes appear to be comments on specific points of Menabrea's paper, clarifying, elaborating, extending, and, occasionally, correcting, the translated portion. However, the Notes are unified and set off from the translation by a set of recurrent themes appearing in a variety of contexts, and on different levels of abstraction. One frequently repeated theme was the contrast between Babbage's two engines. Where Menabrea had remarked that the Difference Engine "gave rise to the idea" of the Analytical Engine (which was both chronologically and logically true), Ada denied the relationship, insisting that there was no necessary temporal or conceptual relationship between the two inventions. She stressed instead the metaphysical differences. The Difference Engine, she said, could do nothing but add and tabulate; hence, its entire significance rested in the numerical data it processed. The Analytical Engine, on the other hand, maintained a strict separation between data and operations, which could be manipulated independently; hence, it transcended mere number. Possibly, the Government's final decision in the previous year to abandon the Difference Engine made Babbage wish to focus public attention on his newer, superior, and still hopeful project.

For the modern reader the important difference between the two machines is that the Difference Engine followed an unvarying computational path (except for the parlor games Babbage played for the benefit of visitors such as Lady Byron), while the Analytical Engine was to be truly programmable, and capable of changing its course contingent upon the results of intermediate stages in the calculation. (This was a feature mentioned by Ada only in passing.) Thus, modern interest in Ada's Notes has centered on the prototype programs they contained — a century before the actual construction of a programmable computer.

The ideas expressed, the themes stressed, however, show that the Notes were inspired by views that were more characteristic of the period in which they were written. For Ada (and Babbage) the calculating engine was a metaphor as well as a harbinger of economic and scientific progress. The theme stressed in presenting the "illustrations" or programs was that they demonstrate how certain lengthy, laborious, and complex calculations can be most efficiently executed — from the point of view of the human programmer or operator — by organizing the operations to be performed by the machine into repeated cyclical groups. The same set of operations can then be repeated over and over by the engine, with only the starting and stopping places indicated by the instructions. To describe this efficiency Ada used an interesting analogy taken from economic theory: "In the case of the Analytical Engine we have undoubtedly to lay out a certain capital of analytical labour in one particular line; but this is in order that the engine may bring us in a much larger return in another line" (*Memoir*, p. 698).

Where did this idea come from? Ada had referred to knowledge as capital early in 1841, when discussing her career plans with Sophia De Morgan: "Now the philosophy, the training, the instruments in short, I am as you know gaining. . . . I shall be years before I have the necessary quantity of what I call *capital*. . . . I am enterprising; & the greater & harder the work, the greater my spirit of enterprise."[17] But the full development of the calculating engine as a metaphor in economics had appeared in 1832 in Babbage's analysis of the industrial system, *The Economy of Machinery and Manufactures*. There Babbage had reflected to the full his laissez-faire and utilitarian views. He elaborated and extended the principles of the division of labor which had been illustrated by Adam Smith in *The Wealth of Nations*.

The benefits derived from the division of labor, he explained, included not only the time saved and skill attained by each worker when restricted to the repetition of a small set of simple operations, but, most important, the money saved in the hiring of less skilled labor, such as that of women and children, for jobs requiring little strength or training. A plentiful supply of cheap and available labor is also assured by this means: "Again, the facility of acquiring skill in a single process, and the early period of life at which it can be made a source of profit, will induce a greater number of parents to bring up their children to it; and from this circumstance also, the number of workmen being increased, the wages would soon fall."[18] Babbage's language is so matter-of-fact and complacent as to leave no doubt of his approval. But the example of the division of labor which intrigued him most was one of the division of mental labor, also, as it happens, inspired by Adam Smith's pin factory. It had been devised by Baron Gaspard de Prony, and was adverted to (presumably with Babbage's approval) by Menabrea as a preliminary to his discussion of the Analytical Engine. M. de Prony had been commissioned by the French government to supervise the preparation of the new mathematical tables needed by a newly decimalized nation. While considering how such a prodigious

[17] Ada (Byron) Lovelace to Sophia De Morgan, 1 March 1841, L-B no. 171.

[18] Charles Babbage, *On the Economy of Machinery and Manufactures* (London: C. Knight, 1832), p. 132. Hereafter cited as *Economy*.

task could be organized, he chanced upon a copy of Smith's book. At once he determined to manufacture logarithms like pins.

He set up two workshops which would perform the same calculations, serving as a mutual check on accuracy. Above them were two other sections of mental operatives. The higher consisted of five or six of the most eminent mathematicians in France, charged with deciding which formulae would be best for use in the step-by-step calculation of the functions to be tabulated. (They performed the programmer's task.) These formulae were then passed to the second section, consisting of seven or eight competent mathematicians, who would substitute numbers into the formulae and then pass them to the third section. (In other words, they performed the operator's task.)

The third section consisted of sixty to eighty persons who performed most of the numerical work, using only addition and subtraction. Babbage, in *Economy*, went on immediately to make the connection between this third section and his Difference Engine, and between the organization of calculations and that of a factory, now in terms of class (in both senses) as well as task:

> From that part executed by the third class [i.e., section], which may almost be termed mechanical, requiring the least knowledge and by far the greatest labour, the first class were entirely exempt. Such labour can always be purchased at an easy rate. The duties of the second class. . . were yet in some measure relieved by the higher interest naturally felt in these more difficult operations. . .; but when the completion of a calculating engine shall have produced a substitute for the whole of the third section of computers, the attention of analysts will naturally be directed to. . . a new discussion of the methods.
> (*Economy*, p. 157).

While it replaced the laboring class, the calculating engine would produce fresh and more challenging work for the best trained and most gifted men. That class in both senses is intended is clear, for Babbage went directly on to state: "The proceeding of M. Prony. . . much resembles that of a skilful person about to construct a cotton or silk-mill, or any similar establishment. Having, by his own genius, or through the aid of his friends, found that some improved machinery may be successfully applied to his pursuit, he makes drawings. . . and may himself be considered as constituting the first section. He next requires the assistance of operative engineers. . . and these constitute his second section" (*Economy*, p. 157). And once more an easily replaceable third section would actually perform most of the work, at least at first. Like Leibniz, Babbage deplored the waste of brilliant, educated men in routine, boring drudgery, for which he claimed the uneducated were better suited: "It is remarkable that nine-tenths of this class had no knowledge of arithmetic beyond its first two rules which they were thus called upon to exercise, and that these persons were usually found more correct in their calculations, than those who possessed a more extensive knowledge of the subject" (*Economy*, p. 157).

When convenient, however, he saw no obstacle to replacing them by yet more accurate or efficient machinery (he disapproved of unions). He did not at first consider the displacement of the second section in this fashion, but once his work on the Analytical Engine began, he saw it could be assigned far more sophisticated tasks than the third section, and that the work of the second could be greatly simplified if not superseded. Ada went further than Menabrea in suggesting what the Analytical Engine could be made to accomplish, but she rephrased Babbage's words of assurance for the men of Prony's first section, characteristically making a metaphysical virtue out of computational necessity: "The Analytical Engine has no pretensions whatever to *originate* anything. It can do whatever we *know how to order it* to perform. It can *follow* analysis; but it has no power of *anticipating* any analytical relations or truths. . . . but it is likely to exert an *indirect* and reciprocal influence on science itself in another manner. For, in so distributing and combining the truths and the formulae of analysis, that they may become most easily and rapidly amenable to the mechanical combinations of the engines, the relations and the nature of many subjects in that science are necessarily thrown into new lights, and more profoundly investigated. This is a decidedly indirect, and a somewhat *speculative*, consequence of such an invention" (*Memoir*, p. 722).

IV

In what might be the earliest of the letters written by Ada to Babbage concerning her preparation of the Notes, she said: "I want to know also something about how you manage the *imaginary* quantities; because as they are *nonsense* when supposed to be numbers; & as your results are wholly *numerical*, & your engine is a strictly *numerical* engine, I do not see my way there. Likewise *what* is the nature of the views you allude to (page 96, 97 of your Bridgewater), '& I was well aware that the mechanical generalisations &c, &c — which would lead &c&c' I particularly want to know to *what* that is wholly new, & valuable, you can allude, as being likely to be developed by the engine."[19] Ada's dependence on Babbage as sole authority on his machine clearly did not prevent her from making her usual challenging "first queries" on unfamiliar subjects, but it must have contributed to her susceptibility to being fobbed off with inadequate answers. Babbage's answer to this letter has unfortunately not survived.

The question about imaginary numbers is a curious one. Although mathematicians had for long been reluctant to accept them as inherently as "real" as the more conventional kind, it was well recognized that they could be used in computations as pairs of numbers, and hence were quite amenable to numerical methods, though a bit more complicated to manipulate. During her studies with De Morgan, a good deal of attention had been devoted to this topic, which was of special interest to him. But what is really interesting about this query, in the light of the comments she subsequently made in her Notes, is that, having been struck by the "strictly numerical" nature of the planned engine, she was somehow induced to change her mind.

The statement in *The Ninth Bridgewater Treatise* to which Ada referred ran: "and I was well aware that the mechanical generalisations I had organised contained within them much more than I had leisure to study, and some things which will probably remain unproductive to a far distant day."[20] Ada devoted much space in her Notes to suggesting the implications of the "mechanical generalisations" of the Analytical Engine. Many of these derived, actually or metaphorically, from the physical separation between the operating part of the engine and the numerical storage, on one hand, and between the punched card instructions for operations, on one hand, and the orders for numerical storage and transfer on the other. These separations had both cognitive and cosmological significance. About the first, she said: "It were much to be desired that when mathematical processes pass through the human brain instead of through the medium of inanimate mechanism, it were equally a necessity of things that the reasonings connected with *operations* should hold the same just place as a clear and well-defined branch of the subject of analysis, a fundamental but yet independent ingredient in the science, which they must do in studying the engine" (*Memoir*, p. 692).

Although Ada defined "operation" with great generality, in fact the "operations" of the engine were planned to be the four arithmetic operations. What is being alluded to in the passage above, however, is that the development of the infinitesimal calculus, the core of

[19] Ada (Byron) Lovelace to Charles Babbage, Add. Mss. 37,192, f.370.

[20] Charles Babbage, *The Ninth Bridgewater Treatise* (London: Murray, 1838), pp. 96,97, i.e., 98,99. Hereafter cited as *Bridgewater*.

"analysis" (which took place before, and independently of, its estab- lishment on a rigorous basis) arose from the analogy between the rule of summation of exponents and the effects of the repeated iteration of other types of functional operation, such as differentiation. The method of separation of symbols permitted the symbols of function or operation to be detached from the symbols or numbers on which they operated, and separately manipulated, applying this analogy.[21] Babbage's work on the theory of functions was heavily dependent on such analogies (see Dubbey). Thus, it is interesting (and significant) to find Ada continuing her polemic on the superiority of the Analytical Engine in these terms:

> The calculus of operations [or theory of functions] is likewise in itself a topic of so much in- terest, and has of late years been so much more written on and thought on than formerly, that any bearing which that engine, from its mode of constitution, may possess upon the illustration of this branch of mathematical science should not be overlooked. Whether the inventor of this engine had any such views in his mind while working out the invention, or whether he may subsequently have regarded it under this phase, we do not know; but it is one that forcibly occurred to ourselves. . . . We cannot forbear suggesting one practical result . . . ; we allude to the attainment of those combinations into which *imaginary quantities* enter. This is a branch of its processes into which we have not had the oppor- tunity of inquiring.
>
> (*Memoir*, p. 694).

But Ada had had, as we have seen, every opportunity of inquiring into these points, and had done so. We will return to the significance of her falsehood.

She herself, meanwhile, passed from the practical to the specu- lative to the cosmological: the same "just" separation was reflected in the design of the universe: "When it is remembered that this science [mathematics] constitutes the language through which alone we can adequately express the great facts of the natural world, . . . those who thus think on mathematical truth as the instrument through which the weak mind of man can most effectively read his Creator's works, will regard with especial interest all that can tend to facilitate the translation of its principles into explicit practical forms" (*Memoir*, p. 696).

The view that mathematical truths were a direct revelation of God's way of thinking had been on the wane for well over a century, but in the rapid technological and social changes that were taking place in the nineteenth century, almost any scientific discovery could be scrutinized for its implications for religious belief. There was much

[21] See E. Koppelman, "The Calculus of Operations and the Rise of Abstract Algebra," *Archive for History of Exact Sciences*, 8 (1971), 155-242.

interest in demonstrating that scientific activity could lead to a strengthening rather than a weakening of faith. The Bridgewater Treatises were commissioned with this aim in mind. In 1829 the Earl of Bridgewater died leaving £8,000 to be distributed by the President of the Royal Society to authors nominated by him to produce works "On the Power, Wisdom and Goodness of God as manifested in the Crea- tion." Babbage, a sharp critic of the Royal Society, was not among the eight authors so chosen. Undeterred as usual, whenever he had a con- tribution to make, he wrote and published *The Ninth Bridgewater Treatise* as his and his engines' statement on natural theology.

While the officially selected authors focused on some aspect of the physical or biological universe as a miracle of God's design, Bab- bage chose to consider the design of miracles. Among his illustrations of the ways in which a really clever God could perform miracles, he pointed to the possibility of adjusting his Difference Engine in the manner which had so impressed Lady Byron: it could calculate a million terms of some regular progression, then produce an aberrant term on the million and first. After that it could return to the original series, continue with the new one, or proceed to some other. In like manner the Analytical Engine could change its operations in accord with a previously planned set of punched cards. How much more esti- mable, he asked, must we consider a God who programmed the uni- verse to behave in this manner, with miracles preplanned from the beginning, than One who must be continually adjusting and inter- vening in the workings of His mechanism? He recommended his Trea- tise to the attention of Queen (then Princess) Victoria as a work favor- able to religion.

Was he serious? Despite his scorn of piety, it seems he was. Ada and Mary Somerville considered him so from the beginning. Even before Ada had read it, she wrote to Mrs. Somerville:

> I am longing to see Mr. B's book. From Mama's accounts of it . . . it is a pity it was written in such haste & is so fragmentary & undeveloped in its character. It seems to resemble one of those curious *multum in parvo* algebraical expressions of which you know infinitely more than I do, which under a few symbols involve & indicate to the initiated quantities endless in their complication & variety of mutual relations. But *what* a pity that such a mind has not in some degree filled up the crude outlines for the benefit of those who could not! I fear the work will be underrated, and the circumstances you mention of the extreme haste fully accounts for this, though it in *fact* enhances its merit & indicates the more what it might be. — However, I am criticising what I have not read. I think when I *have* read it . . . I shall probably give my opinion to Mr. B. himself. Would this be presumptuous do you think?[22]

[22] Ada (Byron) King to Mary Somerville, 22 June 1837, Somerville Papers, Bodleian Library, Oxford, Dep. c. 367. The collection of Somerville Papers is owned by the Fairfax-Lucys and has been arranged and catalogued by Professor Elizabeth C. Patterson.

Babbage himself later presented a copy to her. Perhaps she saw in her work on the Notes an opportunity to fill in the outlines. Much of her comment on the significance of the Engine is on such an exalted metaphysical plane as to make hers actually the more mystical of the two accounts.

V

Most of the time Babbage devoted to his engines was necessarily taken up in working out to the minutest details his plans for the arrangement and construction of the physical realization of his grand visions. These were so complex that he had invented a system of mechanical notation or symbols to keep track of and coordinate all the moving and stationary parts at every moment during the cycles of calculation. In the area of physical mechanism, his ideas were so concrete and practical that he plausibly argued that the by-products of his industry, in the form of improved tools, engineering practices, and training given to the machinists and draftsmen he employed, more than justified the investment of the government all by themselves.

In contrast to this daily involvement, the Menabrea-Lovelace memoir dealt little with physical and mechanical details, and his discussions with its authors gave him scope to expand upon his visions. With authors so young and impressed by his genius, the temptation to suggest functions or capabilities of the engine which were not quite worked out must have been great. Alone on an entirely new frontier, Babbage was ever an optimist, and ever underestimating the time necessary to complete his plans. He had, for example, assured both writers that the process of division, like the other arithmetic operations, could be executed by the machine on command. Yet, in a letter to Ada dated 30 June 1843 (while she was nearing the end of the Notes), he revealed he was still having difficulties with some of the details: "I am still working at some most entangled notations of Division but see my way through them at the expense of heavy labour, from which I shall not shrink as long as my head can bear it" (L-B no. 168).

In addition to their relative freedom from consideration of the limitations imposed by mechanism, and Babbage's own tendency to enthusiasm and optimism, another circumstance must have contributed to the exuberance of the claims made for the engine by both authors, but especially by Ada. This is the curious disingenuousness by which both claimed not to have consulted the inventor about certain of the conjectures they made. In both cases the disclaimers were made for specific points, but seem, by implication, to cover the entire memoir. And while these claims may have been technically true when written, they need not, as we have seen, have been true by the time of publication. Babbage seems to have encouraged their claims and disclaimers, which had the effect of freeing both author and inventor from responsibility for the statements made. Concerning Ada's first Note, in which her disclaimers and unfathered conjectures first appear, for example, Babbage wrote her, "I am very reluctant to return the admirable and philosophic view of the Anal. Engine contained in Note A. Pray do not alter it."[23] That Babbage did not hesitate to correct even small misrepresentations of his ideas is demonstrated in the same letter, for he goes on to say, "There is still one trifling misapprehension about the variable cards."

The conjecture which Menabrea attached to his disclaimer of consultation was on the manner of handling the signs of the numbers in the process of multiplication. It turned out to be correct. Ada, characteristically, took her conjectures farther. Why, she speculated, if the machine could automatically combine the plus and minus signs of pairs of numbers when they are multiplied together, could it not be arranged to deal appropriately with any other algebraic symbols that might accompany numerical multipliers? Why could not symbols themselves be multiplied or divided, added or subtracted? Why could not the machine do algebra? The suggestion was a plausible though imaginative extension, not only of the sign feature, but of the metaphysical hierarchy between the Difference and the Analytical Engines. The development of modern algebra, as Ada must have known from her work with De Morgan and talks with Babbage (who were both among its founders), was based on the freeing of algebraic symbols from the presumption that they could represent only numbers, and on the subsequent elaboration of rules for the manipulation of symbols in the abstract. The idea of a machine to transcend number had been in Babbage's thoughts for some years. It was the next step in making a machine "think."

In a letter to Mary Somerville, dated 8 March 1836, he had spoken of having "a kind of vision of a possible developing machine."[24] This was even before he had decided to adopt punched cards. Then, in

[23] L-B no. 168. The punched cards were inspired by those used in the Jacquard loom.

[24] Charles Babbage to Mary Somerville, 8 March 1836, Somerville Papers, Dep. c. 369.

July of that year, ten days after that momentous decision was taken, he mused in his notebook:

> This day I had for the first time a general but very indistinct conception of the possibility of making an engine work out *algebraic* developments — I mean without *any* reference to the *value* of the letters. My notion is that as the cards (Jacquards) of the calc. engine direct a series of operations and then recommence with the first so it might be possible to cause the same cards to punch others equivalent to any given number of repetitions. But these hole[s] might perhaps be small pieces of formulae previously made by the first cards and possibly some mode might be found for arranging such detached parts according to the powers of nine numbers and of collecting similar ones [the entry breaks off here].[25]

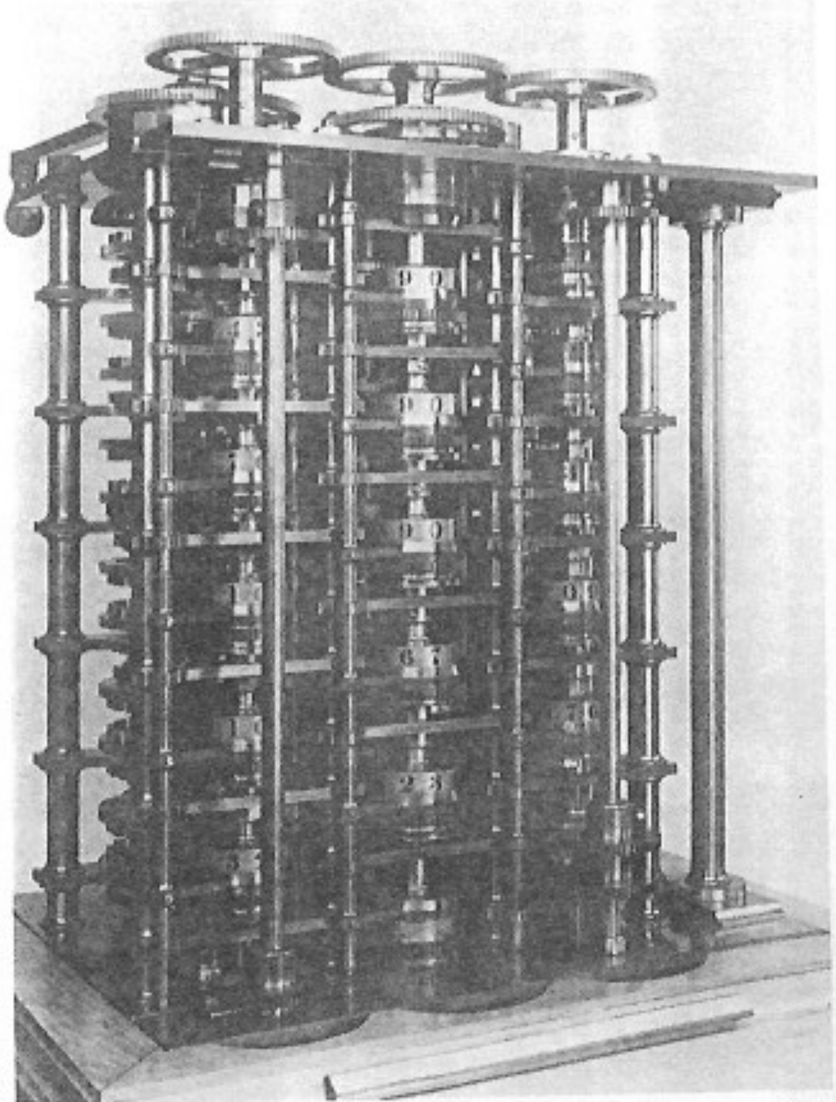
What he was groping for here was some means of bypassing or replacing the columns of stored numbers which were ordinarily the objects to be operated on so that he could operate on symbols instead.

The crux of the difficulty lay in the very separation between operation and number over which the Notes expressed such pride. In generalizing from the Difference Engine to the Analytical, Babbage had added a control system with a very different physical and conceptual basis from the number columns, which he retained. The control was essentially a yes-no affair, that is, binary, while the columns were decimal. Now he seemed to wish to operate on the binary-coded cards, on which could be punched codes for numbers, symbols, instructions, and locations; but, as Ada's account conceded, results could not be produced unless the system operated on the columns of decimally divided disks, with a seemingly intractable fixed interval between successive divisions. It was this fixed relationship, not the inscription of digits on the edges of the disks (which were placed there only for the benefit of observers) that made the Analytical Engine "numerical."

There was also another sense in which the engine was "numerical." Babbage sometimes applied his knowledge of number theory (as well as algebra) to simplify the mechanism or shorten the projected time required to execute certain operations. The representation of the plus or minus signs of the numbers as odd or even digits was actually one such "arithmetical artifice."[26] To have generalized beyond a few such specific instances would have required a recognition of a correspondence between number and symbol which Babbage's plans and the argument of the memoir show he was then moving away from. In his notebook, in December 1837, Babbage returned to the problem, but

[25] Babbage's "Scribbling Books," Science Museum (Imperial College) Library, Kensington, London, vol. 2, on Microfiche D3, 3/5, 10 July 1836.

[26] Babbage, "On the Mathematical Powers of the Calculating Engine," in Randell, p. 36.



(5) Model of the Difference Engine put together in 1832 (*Science Museum, London*).

with less clarity than in the passage quoted above, and he concluded
that it would "be better to construct a new engine for such purposes."[27]
But though he continued to evolve new plans and modify old ones for
the remaining thirty-five years of his life, he never produced plans for a
"development engine."

In 1843 the solutions to his difficulties lay in mathematical (if
not technical) developments between five and ninety-five years in the
future, between George Boole's symbolic logic and Kurt Gödel's
symbolic arithmetic.[28] He nevertheless continued to return to the prob-
lem from time to time. In *The Exposition of 1851* he wrote:

> I had frequently discussed with Mrs. Somerville and my highly gifted friend the late Pro-
> fessor M'Cullagh of Dublin, the question whether it was possible that we should be able to
> treat algebraic formulae by means of machinery. The result of many inquiries led to the
> conclusion that, if not really impossible, it was almost hopeless. The first difficulty was
> that of representing an indefinite number in a machine of finite size. . . . This is not a fit
> place to enter into the detail of the means employed, further than to observe, that it was
> found possible to evade the difficulty by connecting *indefinite* number with the *infinite in*
> *time* instead of with the *infinite in space*. The solution of this difficulty being found, and
> the discovery of another principle being made, namely — that *the nature of a function*
> *might be indicated by its position* — algebra, in all its most abstract forms, was placed
> completely within the reach of mechanism.[29]

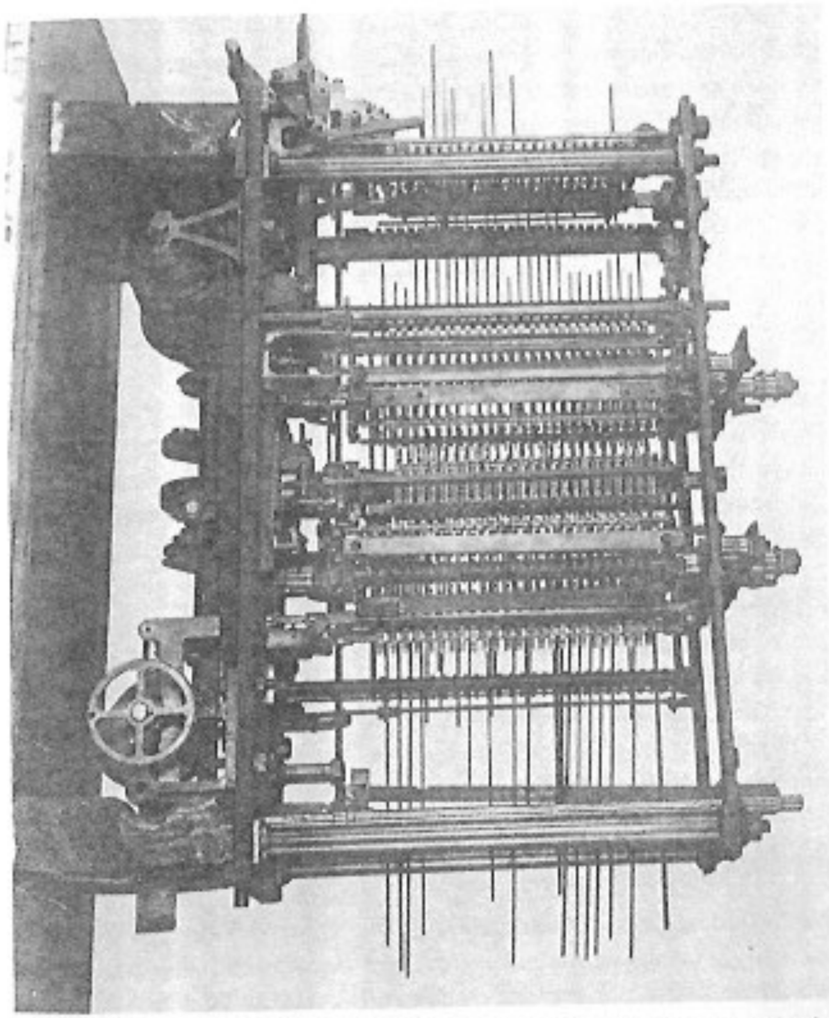
In this passage (whose "detail" is entered into in his autobiography)
Babbage seems to believe that to be able to express an "indefinite"
number, that is, a symbol standing for any number, one had to have
the capacity to express an infinite number of significant figures. This is
not the case, and, anyway, neither his "solution" nor the other "prin-
ciple" really deals with the problem posed by the numerical columns.
Since the creation of an "algebra machine" would have been so impor-
tant a step in Babbage's approach to intellectual invention, it is dif-
ficult to avoid the conclusion that he never really succeeded in solving
this problem.

It is interesting (and significant) that Babbage mentioned dis-
cussing his difficulty with Mary Somerville, but not with Lady Love-
lace. Ada was not even aware of the nature of the problem, over which
she repeatedly waved her hands (or wand, for she had taken to calling
herself a fairy, despite Babbage's protests). While Menabrea more cau-

[27] Babbage's "Scribbling Books," vol. 3, Microfiche D4, 3/9, 13 December 1837.

[28] For illuminating discussions of machine coding, I am indebted to Garry J. Tee, Department of Computer Science, University of Auckland, New Zealand. However, I am responsible for any errors in the conclusions I have drawn. Babbage did consider other number bases than the decimal, among them the binary, but he rejected them as too cumbersome or slow for his mechanism. Electrical circuitry was not well enough developed until a number of years after this period, and even then he does not appear to have considered using it.

[29] Charles Babbage, *The Exposition of 1851* (London: Murray, 1851), p. 184.



(6) Model of the "mill" of the Analytical Engine, on which Babbage was working when he died (*Science Museum, London*).

tiously interpreted the machine's algebraic capacity as the calculation of the (numerical) coefficients of power or functional series, Ada makes more general claims in several of her Notes, unrestrained by Babbage. In Note A she observes airily: "It seems to us obvious, however, that where operations are so independent in their mode of acting it must be easy by means of a few simple provisions and additions in arranging the mechanism, to bring out a *double* set of results, vis. — 1st, the *numerical magnitudes* which are the results of operations performed on *numerical data*. . . . 2ndly, the *symbolical results* to be attached to those numerical results, which symbolical results are not less the necessary and logical consequences of operations performed upon *symbolical data*, than are numerical results when the data are numerical" (*Memoir*, p. 694).

It might be supposed that the method of "attaching" the symbolic results might be for some human programmer to have worked them out and arranged for them to be printed with the corresponding numerical results, but in Note E the claim is repeated with a variation that makes it clear that she had symbolic processing by machine in mind: "The engine can arrange and combine its numerical quantities exactly as if they were *letters* or any other *general* symbols; and in fact it might bring out its results in algebraical *notation*, were provisions made accordingly. It might develop three sets of results simultaneously, viz. *symbolic* results (as already alluded to in Notes A. and B.); *numerical* results (its chief and primary object); and *algebraical* results in *literal* notation. This latter, however, has not been deemed a necessary or desirable addition to its powers" (*Memoir*, p. 713).

The distinction made here between "symbolic results" and "algebraical results in literal notation" implies that the former referred simply to the printing of formulae worked out by human "analysts" and "attached" to the numerical results. When we turn to Note B to confirm this supposition, however, we find instead another type of confusion reigns. Here Ada makes the claim for the algebraic capability of the engine with the aid of a diagram in which circles appear at the tops of the representations of the columns of stored numbers. (In the actual plans, an extra disk at the top of each column would carry the sign of the number below, in the form of an even or odd digit.) She says: "Each circle at the top is intended to contain the algebraic sign plus or minus, . . . according as the number represented on the column below is positive or negative. In a similar manner any other purely *symbolical* results of algebraic processes might be made to

appear in these circles. In Note A. the practicability of developing *symbolical* with no less ease than *numerical* results has been touched on" (*Memoir*, p. 702). Touched on but not explained. In the extract above, moreover, Ada seems to be succumbing to a curious confusion between the engine as planned and its representation in her diagram. Although anything at all may be written with equal ease in circles on a diagram, it is more difficult to produce some things by mechanical means than others. This kind of confusion is particularly tempting when the mechanism exists in the form of drawings only, and one the Menabrea, too, occasionally fell victim to.

It was a trap that proved particularly difficult for Ada to avoid. Her turn of mind, revealed in so much of her correspondence and other writing, was essentially intuitive and mystical. Against these propensities, encouraged by her mother, Babbage fitfully fought hard. It was the formal beauty and surprising, seemingly magical results of mathematical processes and reasoning which entranced her; yet it was actually a subject for which she had little natural talent, and one whose techniques, despite periods of hard work, continued to elude her. Thus, she was never able to turn her probing questions and picturesque conceits into ingenious and fruitful solutions.

It is one thing to speculate that some wonderful accomplishment might be possible, but, without a firm grasp of the subject matter, she was not only unable to suggest how it might be achieved, but unable to see that such an explanation was necessary. The same prophetic vagueness with which she claimed that the Analytical Engine could easily be arranged to do algebra is equally evident in her notion that it could be programmed to compose music (*Memoir*, p. 694).

VI

Ada was well aware of her technical deficiencies and was invariably timid and tentative with Babbage in these matters. A paragraph in a letter of 14 August reveals this clearly, as well as the fact that Babbage's supervision of the Notes was so close that only one trivial footnote in the published version had been inserted without his previous approval: "I have ventured inserting into one passage of Note G a small Foot-Note, which I am not sure is *quite tenable*. I say in it that the engine is remarkably well adapted to include the whole *Calculus of Finite Differences* & I allude to the computation of the *Bernoullian*

Numbers by means of the Differences of Nothing, as a beautiful example of its processes. I hope it *is* correctly the case."[30]

Her letters also effectively refute Babbage's autobiographical statement that he had worked out the example of the Bernoulli numbers "to save Lady Lovelace the trouble" — an unlikely assertion since a number of them proclaim the time and trouble she was taking over this "illustration." Her decision to include it was announced in the following fashion: "It appears to me that I am working up the Notes with much success; & that even if the book be delayed in its publication, a week or two in consequence, it will be worth Mr. Taylor's while to wait. I will have it *well* & *fully* done; or not at all. I want to put in something about Bernoulli's numbers, in one of my Notes, as an example of how an implicit function may be worked out by the engine, without having been worked out by human head & hands first. Give me the necessary data & formulae."[31]

There is no sign at all in the surviving correspondence on either side that she ever sent his calculations back to him for correction. Her labor over this example seems to have been expended in preparing the chart (which she called a "Table & diagram") that accompanied her discussion of it, and constituted the nearest approach to a computer program for a hundred years. The general form of this was similar to Babbage's other programs, but Ada added embellishments and improvements: "Think of my horror then at just discovering that the Table & diagram (over which I have been spending infinite patience & pains) are seriously *wrong*, in one or two points. I have done them however in a beautiful manner, much improved upon our *first* edition of the Table & diagram" (Add. Mss. 37,192, f. 401).

The experience of working with a man of Babbage's calibre, on terms which friendship, and her rank and sex, made appear almost like equality, was heady to the point of intoxication. It was also exhausting and nerve-wracking, pursued in the face of nagging illnesses. It fed both a belief in her own abilities and an irritation with her colleague's more casual attitude. She went from a humble desire to serve him to a view of the division of labor between them in which she was executive and supervisor, he technician and informant: "I hope another year will

[30] Ada (Byron) Lovelace to Charles Babbage, 14 August 1843, Add. Mss. 37,192, f.422. The "Differences of Nothing" refers to the successive differences of the first terms of the series 0^n, 1^n, 2^n, etc., where n is a positive whole number. In her footnote, and in this letter, Ada is vague about how she proposed to use these numbers.

[31] Ada (Byron) Lovelace to Charles Babbage, Add. Mss. 37,192, f.362. This letter is incorrectly dated 10 July in Babbage's hand. Several letters written earlier show she was already at work on this example.

make me *really* something of an *Analyst*. The more I study, the more irresistible do I feel my genius for it to be. I do *not* believe that my father was (or ever could have been) such a *Poet* as *I shall* be an *Analyst* (& Metaphysician); for with me the two go together indissolubly" (Add. Mss. 37,197, f. 407). Her writing ability and her transcendent mind, she wrote her mother, must make him value her services; her position, and her superior habits of organization qualified her to be his "Whipper-in."[32] She scolded him for altering her sentences and mislaying her papers: "I wish you were as accurate, & as much to be relied on, as I am myself. You might often *save* me much trouble, if you were; whereas you in reality *add* to my trouble not unfrequently.... By the way, I hope you do not take upon yourself to alter my corrections.... you have made a pretty mess & confusion in one or two places (which I will show you sometime), where you have ventured... to *insert* or *alter* a phrase or word; & have utterly muddled the sense" (1 August 1843, Add. Mss. 37,192, f. 414). A clash between Ada and Babbage was bound to come, but, when it did, it was not over her imperiousness but his.

There was one point on which Babbage must have found Ada's use of the disingenuous disclaimer less pleasing and less useful than her exaggerated claims for his engine's powers. The "philosophy" of Note A had also included the following: "Respecting the circumstances which have interfered with the actual completion of either invention, we offer no opinion; and in fact are not possessed of the data for doing so, had we the inclination" (*Memoir*, p. 699). This declaration was Ada's way of distancing herself from Babbage's dispute with the government, and establishing a separate and disinterested position for herself and her future writing. To her mother she explained: "I declared at once to Babbage that no power should induce me to lend myself to any of his quarrels, or to become in any way his *organ*."[33] She was no longer "subservient to some of *your* purposes & plans."

Babbage immediately set about to remedy any absence of opinion among readers by composing his own statement on the point, to be included (anonymously) with Ada's publication. He was anxious that it should not seem to emanate from himself. When the editor of *Taylor's Scientific Memoirs* considered it too polemical to be included, rather than have it published separately, Babbage urged Ada to

[32] Ada (Byron) Lovelace to Lady Byron, 15 August 1843, L-B no. 42, f.85. A "Whipper-in" was a person charged with controlling the dog-pack during a hunt.

[33] Ada (Byron) Lovelace to Lady Byron, 8 August 1843, L-B no. 42, f.73.

withdraw her paper at the last minute.[34] He was astonished and dismayed to receive an indignant refusal.

Although Babbage had not initiated the translation, the preceding weeks and months had taken a heavy toll of his time and attention, diverted from work on his drawings. He had been willing enough to comply with her stream of requests, however high-handedly made, for papers, books, meetings, explanations. Yet, despite the commands to supply her with materials, the summonses to her town house, the orders to take charge of this or that detail, to run errands to the printers, to stop meddling in her sentences, it had not occurred to him that she considered the paper her own property. Now she sent him a demanding list of conditions that she wished to govern their future work together; she asked him to place himself and his invention in her hands:

> Firstly: I want to know whether if I continue to work *on* & *about* your own great subject, you will undertake to abide wholly by the judgment of myself (or of any persons whom you may *now* please to name as referees, whenever we may differ), on all *practical* matters relating to *whatever can involve relations with any fellow-creature or fellow creatures.*
>
> Secondly: Can you undertake to give your mind *wholly* & *indiciduully* [*sic*], as a primary object that no engagement is to interfere with, to the consideration of all those matters in which I shall at times require your intellectual *assistance* & *supervision* & can you promise not to *slur* & *hurry* things over; or to mislay, & allow confusion & mistakes to enter into documents, &c?
>
> Thirdly: If I am able to lay before you in the course of a year or two, explicit & honorable propositions for *executing your engine* (such as are approved by persons whom you may *now* name to be referred to for their approbation), could there be any chance of your allowing myself & such parties to conduct the business for you; your own *undivided* energies being devoted to the execution of the work; & all other matters being arranged for you on terms which your *own* friends should approve.[35]

At last he understood. He refused all her conditions in such flattering terms that she was at first under the impression that he had accepted. The quarrel was patched up, but never again did he risk collaboration with his "dear and much admired Interpreter."[36]

It has often been deplored that Babbage's work had little or no influence on the development of the modern computer, and, in particular, that Lady Lovelace's "clear description" was not used or referred to in the process. The immense reverence for Babbage's awesome abilities has seemed to require acceptance of his assessment of her Notes. An examination of the document itself, of the context in which it was written, and of contemporary correspondence, indicates that the Notes actually presented a picture of the Analytical Engine both misleading and inconsistent. The description was distorted by the inventor's ideology in economics, theology, and mathematics, by his political purposes, by the author's aspirations, by the inadequacies of her training and understanding, and by the social relation between them. Such influences were bound to lessen the paper's usefulness as a blueprint for a twentieth-century, war-motivated technological development. Strangely enough, it was the inventor's vision of the engine's capacity to displace labor, and the author's mystical fervor which have proved truly prophetic of the computer's position and prestige in our own society.

London

[34] Charles Babbage to Ada (Byron) Lovelace, L-B no. 168, f.42; Ada (Byron) Lovelace to Charles Babbage, Add. Mss. 37,192, f.422.

[35] Ada (Byron) Lovelace to Charles Babbage, 14 August 1843, Add. Mss. 37,192, f.422.

[36] Charles Babbage to Ada (Byron) Lovelace, 9 September 1843, L-B no. 168.