



The Little Engines that Could've: The Calculating Machines of Charles Babbage

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by
Bruce Collier

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Preface

Charles Babbage's invention of the computer is something like the weather. Everyone working with computers for the last two decades has been talking about it, but nothing has been done. Every historical introduction to a computer text contains a section on Babbage, often extensive; but they are all based on the quite scanty information about the Analytical Engine published during the nineteenth century. The immense amount of manuscript material concerning Babbage extant in England has remained essentially untouched.

The one hoped for exception was Mabeth Moseley's *Irascible Genius* (London, 1964), a full length biography of Babbage. Moseley consulted the Babbage correspondence at the British Museum and the unpublished biography of Babbage written by his friend Harry Wilmot Buxton; yet despite the fact that Moseley was the editor of a computer journal, she did not examine Babbage's notebooks and drawings, now in the Science Museum in South Kensington, and her book contains virtually nothing of interest on the Analytical Engine. On the whole, *Irascible Genius* is a good deal less interesting than Babbage's own volume of memoirs, *Passages from the Life of a Philosopher* (London, 1864), and it is no more balanced, and not very much more accurate.

Unfortunately, the publication of Buxton's biography would not solve the problem, for it is basically an unorganized collection of extensive extracts from some of Babbage's books, papers, and letters; and while many of these are quite interesting, they are badly in need of more coherent treatment, and there are many gaps in their coverage.

Consequently, the student of Babbage's work must return directly to the original sources. The manuscript material is in three primary collections, on which this study is based. Twenty volumes of Babbage's correspondence are deposited in the British Museum; a similar quantity of technical material is held by the Science Museum in South Kensington; and the Museum of the History of Science at Oxford University has Buxton's manuscript biography, and, more important, the Babbage papers upon which it was based.

Although Babbage's life and accomplishments encompassed far more that was important than the invention of his two calculating machines, the Difference and Analytical Engines, it is on them that new research has most been needed; consequently, the present study is limited to material relevant to them. Babbage's early mathematical work, his role in founding or reforming several important scientific societies, and his many other activities will scarcely be touched upon. But the first chapter, by way of introduction, will provide a brief sketch of Babbage's life, as it is the context into which the calculating machines must be fitted. Likewise, this study will not deal with the development of calculating machines before or after Babbage. His work was completely out of the mainstream of invention and construction which led from the primitive desk calculators of the seventeenth century to their widespread commercial success by the beginning of the twentieth century, and later to what we know as computers; Babbage was neither influenced by what had gone before nor influential upon what followed him.

The invention, development, attempted construction, and eventual abandonment of the first Difference Engine will be considered in the second chapter. The third chapter deals with the invention of the Analytical Engine and its period of primary development, from 1834 to 1847. The fourth chapter deals with three later concerns of Babbage: a project to interest the government in what he called his Difference Engine No. 2; support for the Scheutz Difference Engine, a simplified version of his own earlier machine; and his resumption of work on the Analytical Engine late in life, with the intention of attempting its construction. The final chapter will provide some observations on the general character of Babbage's work on the Analytical Engine. My own interest in Babbage was first aroused through a research project on the history of calculating machines and computers directed by Professor I.B. Cohen and Professor Owen Gingerich on behalf of the International Business Machines company for the purpose of developing an IBM museum on computers and their history; this project still continues. IBM has also provided generous financial and logistical support for my own work. A trip to England to study the manuscripts was supported by a grant from the National Science Foundation. Assistance and access to the sources has been provided by the staffs of the Manuscripts Division of the British Museum, the Museum of the History of Science at Oxford University, and especially the Science Museum in South Kensington, London, where Dr. H.B. Calvert has long had a special interest in Babbage. Professor Gingerich has read this thesis and made valuable suggestions, as has Kenneth Manning.

To all these and other individuals and institutions who have helped me in ways large and small, I express my gratitude.

Note on Sources and Quotations

The following abbreviations are used in the notes for sources frequently cited. Further information will be found in the Bibliography.

- B.M. The twenty volumes of Babbage correspondence in the British Museum manuscript collections.
- S.Kens. The Babbage manuscripts held by the Science Museum in South Kensington, London.
- S.B. The volumes called Scribbling Books, part of the South Kensington collection.
- G.S.B. The Great Scribbling Book at South Kensington.
- Buxton The collection of Babbage manuscripts, together with a manuscript biography of Babbage by H. Wilmot Buxton, deposited in the Museum of the History of Science at Oxford University.
- B.C.E. [Babbage's Calculating Engines](#), edited by Henry P. Babbage, London 1889; a volume reprinting the important published material concerning Babbage's calculating machines, begun by Charles Babbage and completed and published after his death by his son Henry P. Babbage.

P.L.Y. Passages from the Life of a Philosopher, by Charles Babbage, London, 1864; a volume of memoirs.

Many of the quotations given in this thesis are from manuscript sources, often from rough notes or drafts. For the sake of increased intelligibility, punctuation has been altered to a certain extent (principally by the addition of commas), and spelling has been standardized; capitalization and italics have not been altered. Quotations from published sources are of course left unchanged.

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CHAPTER ONE

Introduction

We may entertain some fear that the style of scientific writing in the present day is becoming bald, careless, and even defective in philosophical accuracy. If so, the study of Mr. Babbage's writings would be the best antidote. ¹

= Babbage is remembered today primarily for his invention of the computer, and that invention is the subject of this thesis. However, Babbage's interests and labors in fact covered a very wide range of subjects, and to picture his life as predominantly devoted to the invention and unsuccessful construction of calculating machines would be misleading. It is therefore intended to provide here, by way of introduction, a general biographical sketch, although it must be both superficial and highly selective. ²

Charles Babbage was born on December 26, 1791. His father, Benjamin Babbage, was a partner in a London bank. After private tutoring and two private schools. Charles entered Cambridge University in 1810, attending first Trinity College and then Peterhouse, from which he graduated in 1814.

In June, 1814, Babbage married Georgiana Whitmore, and they went to live at his father's house, at 5 Devonshire Street, London. The marriage produced = eight children, but only three sons survived to adulthood. In early 1827, Babbage's father died, leaving him an estate of about 100,000 pounds; in the fall, Georgiana died. Considerably distraught, Babbage spent most of 1828 on a European tour, recovering his spirits. When he returned, he moved to a new house at 1 Dorset Street, Manchester Square, London, where he was to remain the rest of his life; the children were left in the care of his mother, in Devonshire Street.

Although Babbage spent the rest of his life with his family around him only occasionally, he was by no means a solitary man. For many years he gave evening parties every Saturday during the season which were attended by some two to three hundred people, and to which invitations were in great demand. He was himself in great demand as a dinner guest, and he was acquainted with practically every prominent scientific, literary and social figure of the era.

Only in old age did he become somewhat crotchety. During the last ten years of his life a considerable part of his energy went into attempting to prevent organ grinders and other musicians from playing in the streets and soliciting money, as they interrupted his work and destroyed his concentration. His efforts were basically futile and became quite a preoccupation, yet they were not fundamentally eccentric, as many of Babbage's contemporaries agreed = with him that street musicians were a genuine public nuisance. Babbage's campaign ended with his death on October 18, 1871.

Babbage's first major scientific interest was in mathematics. Having largely taught it to himself, he soon found that he knew more than his tutor at Cambridge. Finding that they could not fruitfully study mathematics as part of their formal education, Babbage and a number of friends, most notably John Herschel and George Peacock, formed themselves into the Analytical Society. As one of the main aims of this Society was to promote the notation for the calculus devised by Leibniz and in use on the Continent, as opposed to the Newtonian notation which was holding back British mathematics, Babbage suggested that they call their first volume of *Memoirs*: "The Principles of Pure D-ism in opposition to the Dot-age of the University."

They intended to alter the teaching of mathematics, and this required a textbook from which the new material could be learned; but as Babbage, Herschel and Peacock were not established figures, a work of their own would not be accepted; therefore they produced a translation of the *Differential and Integral Calculus* by Lacroix, which was published in 1816; a few years later two volumes of *Examples* to accompany the text were issued. Although there were some individuals and groups apart from the Analytical Society working toward the same ends, and although the important works published by the Society = were mostly joint productions, Babbage, as the principal organizer of the Society, played a key role in the reform and revitalization of British mathematics in the first half of the nineteenth century.

By 1820, Babbage had published seventeen mathematical papers, and had established his name in scientific circles. In March, 1816, he had been elected to Fellowship in the Royal Society. That same month he first applied for a teaching position, one of a long series of jobs which he sought without success, despite the fact that he was often better qualified than the candidate who got the post. He concluded, probably correctly, that the positions were being handed out on the basis of social connection, not scientific merit.

Fortunately for Babbage, his father's wealth meant that this failure to get a job did not force him out of science. This failure did, however, strengthen his belief in the importance of the reform of scientific institutions, and gave to his efforts in this regard a fervor, sometimes even a bitterness, that was to win him many enemies. ³

In 1820, Babbage played an important role in the foundation of the Astronomical Society of London (later the Royal Astronomical Society). He was not the = dominant social or scientific figure among the founders - unlike his good friend John Herschel he did no significant original work in astronomy; but Babbage was largely responsible for the initial organization of the Society, and he served as its first Secretary.

It was while proofreading some tables being prepared for the Astronomical Society that Babbage developed an interest in calculating machines which led to his invention of the Difference Engine in 1822. His efforts to construct this machine, with massive if rather uneven government support, were his major preoccupation for over a decade. This will be described in detail in Chapter Two, but it is important to keep in mind at this point that it served to further divert him from a more conventional scientific career, as he was reluctant to take on any responsibilities which he felt would interfere with his completion of the Difference Engine.

However, Babbage's universal interests and boundless energy could not be channeled into a single project. In 1824, he was retained for a time as an advisor to a group of men intending to form a new life insurance company, but the firm was dissolved before it actually got launched. Another company offered to hire him as its manager, but he declined in order to devote his time to the Difference Engine. However, he wrote up what he had found out = about the operation of existing insurance companies into a popular treatise on the subject, which appeared in English in 1826 and in German in 1827. Another 1826 publication was a laboriously prepared volume of logarithmic tables, which set a new standard for freedom from error; this volume appeared in several English and foreign editions.

While Babbage was on his European tour in 1828, following his wife's death, he attended the meeting in Berlin of the Gesellschaft Deutscher Naturforscher and Artze, organized by Alexander von Humboldt. Babbage was impressed by this organization, and on his return to England, he published an account of the meeting. At this time a considerable struggle was going on within the Royal Society over the question of its reform. Babbage became the leader of the group pushing for change by his publication, in 1834, of *Reflections of the Decline of Science in England and on Some of its Causes*. This book became the focus of a widespread and often bitter argument over whether English science, and particularly the Royal Society, deserved to be the pride or the disgrace of the nation. Eventually, the foundation in 1831 of the British Association for the Advancement of Science largely resolved this conflict, the Association being modeled on the German Gesellschaft, which was much admired by the reformers. Although Babbage was a leading figure = in the group that launched the Association, he did not play a vital role in the Association itself. He served as one of the three permanent Trustees of the Association from its beginning until August, 1838, but at that point a dispute over a supposed promise of the Presidency of the Association to Babbage caused him to resign, and he had little to do with the Association for the rest of his life. He was, however, responsible for forming the Statistical Section of the Association, and then, in 1834, for transforming it into the Statistical Society of London.

During this period Babbage also sought more general social reform as a candidate for a seat in Parliament in the elections of January, 1833. However, he did very badly, in part because of rumors that he had misappropriated funds given to him by the government for construction of the Difference Engine.

= When Babbage undertook the construction of the Difference Engine, he had to become knowledgeable about machinery and manufacturing processes; to this end, he visited a large number of factories in various parts of England, and others during his tour of the Continent. His interest became more general,

and his various findings and speculations appeared in 1832 in the book *On the Economy of Machinery and Manufactures*. This work, combining economics and operational research in a pioneering way, was immensely successful, being published in many England and American editions, and translated into most European languages. ⁴

In 1834, Babbage invented the Analytical Engine, and work on it was to absorb most of his energy for the rest of his life, although there were periods during which he laid it aside. This Engine and related matters will be discussed in Chapters Three and Four.

Throughout his life, Babbage advocated the application of scientific methods to practical problems. A good example of this was a long series of experiments he conducted in 1839 in connection with the disputes over the proper gauge for railway tracks. He obtained the loan of a railway car, and filled it with equipment which would automatically record on long rolls of paper the various forces to which the carriage was subjected, its speed, sway, and so on. He called for the installation on all engines of devices to record certain information on all trips, so that the causes of accidents could be studied after they occurred, in much the same way that airplanes now have black boxes to record pertinent flight data.

An accomplishment of which Babbage was particularly proud, but which did not prove to be influential, was his invention of a special mechanical notation, by means of which the character, function and motion of the different pieces of a machines could be symbolically represented on a drawing or schematic diagram. Babbage used this mechanical notation extensively while working on his own calculating machines, and he thought it would be most valuable if used generally by engineers and mechanics, even serving as an aid to invention itself. Although he tried to get publicity and acceptance for it, this notation was generally ignored, perhaps because it was too complex and arbitrary to be learned easily, and so geared to his own peculiar modes of thought that its personal value could not become a general one.

Babbage did make valuable contributions to almost every principal field of human endeavor, with the exception of music. He wrote on mathematics, physics, astronomy, geology, theology, economics, statistics and government. He wrote a satirical play; he invented the ophthalmoscope and the method of distinguishing different lighthouses by coded occultations; he was a master at undoing locks and ciphers; he was a pioneer of central heating and theatrical lighting. In all, he published some eighty books and papers during his life.

Many of Babbage's writings were brief and incomplete, often because they were intended as temporary diversions from his other work. Yet it is not true, as is sometimes charged, that little of his work was important. Nothing that he did had all the polish or perfection that could be desired, and no single achievement can be said to have been wholly worthy of him; but in several vital areas - mathematics, scientific organization, the application of science to technology, machining capabilities, and the application of mathematics to the study of society - his cumulative actions had a substantial impact on the development of British society.

Towards its end, Babbage's life appears rather sad, for he became somewhat bitter about his failure to gain the honor he felt he deserved, and he felt deeply the lack of any single monument to his abilities. Yet in the last analysis, Babbage's life cannot be judged by the sum of his accomplishments; quite apart from the truly prophetic quality of his invention of the Analytical Engine, we must say with one of his contemporaries:

Let it be granted that in his life there was much to cause disappointment, and that the results of his labours, however great, are below his powers. Can we withhold our tribute of admiration to one who throughout his long life inflexibly devoted his exertions to the most lofty subjects? . . . He nobly upheld the character of a discoverer and inventor, despising any less reward than to carry out the highest conception which his mind brought forth. His very failures arose from no want of industry or ability, but from excess of resolution that his aims should be at the very highest. ⁵

Footnotes:

¹. From obituary of Babbage in *Nature*, Vol. V (1871-72) p. 29.

². As this biographical sketch is not intended to be definitive, no documentation will be provided. The sources of information on Babbage's life are discussed at length in the bibliographical appendix.

³. Ironically, the only distinguished scientific post that Babbage ever held was the Lucasian Professorship at Cambridge University, and it was not offered to him until after he no longer really wanted it. He accepted with reluctance, and served without distinction from 1829 to 1839, when he resigned to devote all his energy to the Analytical Engine.

⁴. But it is not true that Babbage suggested uniform postage in this book, nor is there any evidence that he was instrumental in its adoption by the Post Office.

⁵. From the obituary of Babbage in *Nature*, Vol. V (1871-72), p. 28-29.

CHAPTER TWO

The Difference Engine

There once was a man who said, "Damn!
It is borne in upon me that I am
An engine that moves
In determinate grooves,
I'm not even a bus, but a tram." ¹

- In order to understand the attention Babbage devoted to the invention and construction of the Difference Engine, beginning at the end of 1821, it is important to understand that prior to that time, he had not become committed to any particular vocation or area of scientific research. Since his graduation from Cambridge in 1814, Babbage had been publishing mathematical papers, and he had gained a substantial reputation for this work; but his attention was being drawn increasingly in other directions. As early as May 8, 1818, Edward F. Bromhead, a close friend of Babbage, wrote him, asking his opinion on a plan for reforming the poor laws. Bromhead said:

If you continued in the dignified Situation of a Mathematician. I should feel some Conscience against distracting you thus, but as you are a dissenter from the true faith, and turned naturalist, I am hardened. You are wrong. This is not the way to a great Name in England. You must do something strikingly useful, and then everything you do afterwards will be properly valued. Better to be one of the House of Peers in Analysis (as you are) than be mixed up with the 10¹⁰ Geologists etc. etc. Your Genius is mechanical. Try to invent some plan for propelling wagons by the steam engine. This might perhaps be effected by two feat beating the ground at an angle alternatively. Perhaps the cylinder of the Engine might work with pistons at both ends. At all events it will be effected in some manner in a few years, and why should not you do what will get great credit and perhaps profit. ²

- By 1820, Babbage's attention was also being directed toward the organization of science. He had been interested in the reform of the Royal Society as early as 1816, and this interest emerged again in 1820, in connection with the struggle over the election of a new President to replace Sir Joseph Banks: ³ Further, Babbage was one of the individuals chiefly responsible for the founding of the Astronomical Society in 1820, although he did not think of himself primarily as an astronomer. ⁴ Bromhead again chided Babbage for allowing this activity to distract him from his own investigations, saying: "I fear you are so busy managing the machinery of the scientific mill, that you may forget that you are one of the principal husbandmen to supply the corn." ⁵

Yet the problem was precisely that neither in science itself nor in its organization had Babbage found a problem of sufficient interest and magnitude and of the right character to be made peculiarly his own. As one who liked to commit himself to his activities with almost missionary zeal, Babbage was a man in search of a goal. The goal he was to choose came into being at the end of 1821, with the invention of the Difference Engine.

- The genesis of Babbage's interest in the Difference Engine is not reflected in his correspondence or other extant documents exactly contemporaneous with it. However, that the idea first arose at the end of 1821, and the way in which it developed, are fairly clear, for the three major accounts written by Babbage (one less than a year after the event) are in substantial agreement. ⁶

Babbage's first extensive description of the early development of the Difference Engine was written in November, 1822. He gave the following account of the origin of the invention:

Being engaged in conjunction with my friend Mr. Herschel about the conclusion of the last year in arranging and superintending some calculations of considerable extent which were distributed amongst several computers, the delays and errors which are inseparable from the nature of such undertakings soon became sufficiently sensible. . . .

- In the course of our conversation on this subject it was suggested by one of us, in a manner which certainly at the time was not altogether serious, that it would be extremely convenient if a steam-engine could be contrived to execute calculations for us, to which it was replied that such a thing was quite possible, a sentiment in which we both entirely concurred; and here the conversation terminated.

During the next two days the possibility of calculating by machinery (which I should never for a moment have doubted had I ever proposed it to myself as a question) recurred several times to my imagination; the idea appeared to possess that species of novelty which gives so much pleasure and makes so strong an impression on the mind when for the first time we express in words some principle of or precept to which we have long tacitly assented. When we have clothed it with language, we appear to have given permanent existence to that which was transient, and we admire what was frequently only a step in the process of generalization as the creation of our own intellect.

Finding myself a leisure the next evening, and feeling confident not only that it was possible to contrive such a machine but that it would not be attended with any extraordinary difficulty, I commenced the task. The first point in the inquiry was to be fully aware of the power of the machine I wished to construct. In order to produce printed tables free from error I proposed the engine should be able to calculate any tables whatever and that it should produce a stereotype plate of the computed results, or at least that it should deliver a copper plate from which they could be printed. . . .

In order to satisfy the condition that the calculating part should be capable of computing every species of tables, it was necessary to found it on some great and comprehensive mathematical principle; the method of differences is the only one that possesses this extensive range. ⁷

Babbage's second major account of the invention of the Difference Engine was written on September 6, 1834, almost 13 years after the event. It reads as follows:

- The first idea which I remember of the possibility of calculating tables by machinery occurred either in the year 1820 or 1821; it arose out of the following circumstance. The Astronomical Society had appointed a Committee consisting of Sir J. Herschel and myself to prepare certain tables; we had decided on the proper formulae and had put them into the hands of two computers for the purpose of calculation. We met one evening for the purpose of comparing the calculated results, and finding many discordances, I expressed to my friend the wish, that we could calculate by steam, to which he assented as to a thing within the limits of possibility.

In reflecting upon the nature of the greater part of the operations employed in table-making and on the extreme difficulty as well as on the importance of succeeding in having correct tables, it appeared to me to be exactly the circumstance in which machinery ought to be applied. For although its application to the manufacture of numbers was novel, yet machinery is always valuable wherever extreme accuracy is required, and also wherever the same process is to be repeated in almost endless succession. ⁸

This account of the occasion of the first idea of Babbage's machine is somewhat more specific than the earlier one. The only discrepancy is that in the second account Babbage asserted that it was he who first suggested the idea of a steam engine to compute tables, whereas in the first account he could not remember which of them brought up the idea. The final account of this occasion was written in November, 1839. It reads as follows:

The earliest thought which I recollect of reducing any part of the science of number of pure mechanism arose on the following occasion.

- Mr. Herschel and myself having been appointed by the Astronomical Society on a Committee for the purpose of procuring certain calculations, we first agreed on the proper formulae, and then employing two independent computers to reduce them to numbers, ourselves compared the manuscript results. On the first of these occasions my friend brought with him the calculations of both computers, and we commenced the tedious process of verification. After a time many discrepancies occurred, and at one point these discordances were so numerous that I exclaimed, "I wish to God these calculations had been executed by steam," to which he replied, "It is quite possible."

The idea continually presented itself during the few succeeding days, and soon after, having a leisure evening, I resolved in devoting it to the preliminary enquiry. In a few hours I satisfied myself that it is possible to make machinery compute tables by differences, and even to print them when computed. This however was but a general view, and was very far indeed from the subsequent realization of the conclusion. ⁹

The exact course by which the design of the Difference Engine developed from the general view to the subsequent realization cannot be traced in detail, and, indeed, one cannot say just when Babbage began to make specific plans, for most of his notes and drawings from the time have not survived. However, a certain amount can be reconstructed from the paper written in November, 1822, referred to above, and another manuscript from the spring of 1822.

In the first stage, evidently in early 1822, Babbage was concerned simply with establishing the theoretical possibility of constructing calculating machinery. He was concerned with three types of machines. One, a machine to calculate tables by the method of differences where some order of difference is constant. Two, a machine to calculate tables by the method of differences where there is no constant order of differences. Three, a machine to multiply two numbers together.

The last of these machines is described in some notes entitled "Of an Engine to Multiply N Figures by M Figures," written in early 1822. ¹⁰ This machine has no significance. Babbage said that if one has two wheels connected by a mechanism (not described and evidently not contrived) which will make the second wheel turn through an angle which is an integral multiple from one to nine of the angle through which the first wheel is turned, then one can multiply two digits. If this is repeated with different increments set into the first wheel, corresponding to the digits of the multiplicand, and the whole set of operations is repeated with different ratios between the wheels, corresponding to the digits of the multiplier, and the entire collection of partial products is added together in the appropriate positions, then the machine will multiply. The entire idea is rather preposterous, and Babbage never pursued it.

The machine to construct tables where no order of difference was constant was of considerable theoretical interest to Babbage in the latter part of 1822, but he did not attempt to design an actual mechanism to accomplish this for more than a decade; since its significance lies really in the transition from the Difference Engine to the Analytical Engine, discussion of the subject will be postponed until the following chapter. We need, then, consider here only the machine to calculate tables using a constant difference.

First, a brief explanation of the method of finite differences itself must be provided. This branch of mathematics, analogous to the more familiar calculus of infinitesimals, considers the variation in the value of a function as the independent variable is increased through equal, finite increments. In mathematical terms, for a function $u(x)$ and an increment of w the basic operator of finite differences, Δ , is defined by the relation:

$$\Delta u(x) = u(x+w) - u(x)$$

In other words, given a series of tabular values of a function, we can generate a series of first differences, corresponding to the arithmetic difference between the values of the function.

The series of first differences is of course itself a function of the variable, and it is a series from which we can form another series of differences, namely second differences. Mathematically:

$$\Delta^2 u(x) = \Delta u(x+w) - \Delta u(x)$$

We can further generate a series of third differences, and so on, as long as we please.

As an example, we may take the function $u(x) = x^2$; when we set the increment, w , equal to 1, and apply the above definitions, we find that:

$$\begin{aligned} \Delta^1 x^2 &= (x+1)^2 - x^2 = 2x + 1 \\ \text{and } \Delta^2 x^2 &= 2(x+1)+1 - 2x+1 = 2 \end{aligned}$$

This can be clearly seen when the different values are set out in tabular form as follows:

x	u(x)	Δ^1	Δ^2
0	0		
1	1	1	2
2	4	3	2
3	9	5	2
4	16	7	2
5	25	9	2
6	36	11	2
7	49	13	2
.	.	.	.
.	.	.	.
.	.	.	.

Here the first difference is the series of odd integers, the second difference is a constant, namely two, and all higher orders of difference are naturally all equal to zero.

It is a happy fact that any algebraic function of order n will have its n th order difference constant. This makes it easy to generate a table of such a function by simple addition. Take the following as an example.

Set:	$A_1=2; B_1=2; C_1=41.$
Then set:	$C_2=C_1+B_1; B_2=B_1+A_1; A_2=A_1.$
Generally:	$C_{n+1}=C_n+B_n; B_{n+1}=B_n+A_n; A_{n+1}=A_n.$

Then the series of values $C_1, C_2, C_3, \dots, C_n$ will give us a table of the function $u(x) = x^2 + x + 41$, a function which Babbage liked to use as an example, since it generates a large quantity of prime numbers. ¹¹

As has been said, any algebraic function will have some order of difference constant, and is thus subject to generation in tabular form by this method without limit. Transcendental functions are another matter, however, for they do not have any order of difference constant. As a rule, they can be handled by selecting an algebraic function which approximates the desired transcendental function to a desired degree over a given domain, then switching to a slightly different algebraic function to tabulate another section of the function, and so on. As suggested above, Babbage also had a quite different method for tabulating transcendental functions without manually altering the differences, but this subject will be discussed in the next chapter.

It is not difficult to imagine how a machine could be constructed to carry out the above mathematical process mechanically. Basically, if a column of wheels is provided to hold the digits of each order of difference, if a mechanism is provided to add each digit to the corresponding digit in the next lower order of difference (naturally carriage of tens must be provided for), and if the machine is so organized that the different operations will take place in the proper order, then the machine can tabulate any function without limit, simply by turning the crank that drives it.

Naturally, the physical design of a difference engine is a vastly more complex problem than its theoretical organization. An account of the elegant form which Babbage's machine eventually took is provided as an Appendix to this thesis. What will be considered here is the early development of the design, in so far as it can be reconstructed.

As mentioned above, Babbage was initially concerned only with establishing the theoretical possibility of building a Difference Engine. It was evident to him from the first that the problem of the design of the entire machine could be reduced to the problem of adding one digit to another, since the machine would consist of this mechanism repeated many times over.

The first approach Babbage proposed was admirable for its indifference to mechanical details or problems. As he described it in November, 1822, the plan was that: "a rod sliding in a groove and divided into ten parts numbered from 0 to 9 might be set so that a fixed mark or pointer should indicate one of the numbers, 5 for instance; and the moving power being set in action might urge on the slider until it was released from it by a stud or pin previously fixed at a point indicated by another set of numbers, and which we will in the present case call three; the slide would now have moved over 3 spaces, and consequently the number under the fixed pointer would be 8." [12](#)

Evidently Babbage developed this notion of a machine based on sliding rods to the point where he was satisfied that a difference engine was possible, and wrote describing his idea to Edward Bromhead, for in a letter to Babbage, Bromhead said: "I have turned your scheme of Rod Tables over and over, and can make nothing of it, scarcely even in the simplest cases; I think I might by a machine like a 74 gun ship construct a table of squares." [13](#) Unfortunately, because this letter was not dated, it does not indicate when Babbage had reached this stage.

It is not surprising that Bromhead was perplexed by Babbage's "scheme of Rod Tables," for clearly the idea was simply a passing phase in Babbage's thought which satisfied him that a difference engine should be possible, rather than a proposal for an actual design. Babbage said that on considering the grave difficulties that would result in this plan from the discontinuity arising when a digit passed from nine to zero (carriage to the next higher digit being assumed): "I was induced to lay down the following maxim to which I have made but few exceptions in the variety of machinery I have contrived: Always to prefer a circular motion to any other when its immediate object relates to number." [14](#)

Taking the principle that the digits from zero to nine should be represented in the machine by divisions around the circumference of a wheel, Babbage drew up a rough sketch of a possible adding mechanism entitled "Engine for Table of Differences." [15](#) Again Babbage was concerned only to establish the possibility of adding a single digit from one difference to the next, forming the basic module out of which a complete engine could be constructed; and again, he did not attempt to describe the details of the mechanism that would do the adding or perform the carries; but the description did begin to bear some resemblance to the Difference Engine as constructed.

In this same paper, Babbage provided the first notes on a printing mechanism for the machine. As his orientation was almost entirely toward building a machine to calculate accurate, mathematical and astronomical tables, he naturally considered it very important that the possibility of the introduction of errors in typesetting and proofreading be eliminated. In this paper, Babbage considered only the problem of printing single digits, since he again assumed that by repeating the same mechanism, multiple digits could be printed. He proposed that connected with the wheel whose number was to be printed there be a series of dies for the different digits. When printing was to be done, a hammer would fall and strike the die in the appropriate position, thus stamping the corresponding digit in a sheet of pewter or "music-plate-composition metal," from which "the figures could be printed in the same manner as music." [16](#) He also suggested that the digits might be stamped deeper into some other material from which stereotype plates could be cast.

The point reached when Babbage had written up the first rough notes on the Difference Engine may be described as the first stage of its development. In this stage, Babbage had satisfied himself that a Difference Engine was constructible in principle, and formed a vague idea of how the individual digits ought to be added.

In the second stage of development, he considered how the individual sections for adding single digits could be organized together to form a coherent difference machine. Exactly when this second stage was reached is not clear. In his November, 1822 paper, where it is described, Babbage said that it occurred while he "was visiting Mr. Herschel in the country." [17](#) In the Babbage correspondence, there is a letter to him from Bromhead, addressed in care of Sir William Herschel at Slough, and dated January 12, 1822. [18](#) Quite possibly this was the visit to which Babbage referred, but it could also have been a separate visit, up to a few months later.

Babbage described the progress made during this visit as follows. [19](#) Taking the "rough outlines of the first idea" he had already sketched out, he "proceeded to enquire into the duties of the several parts, to curtail those which were unnecessary and to unite those which were similar." The progress made was most gratifying. "Wheel after wheel gradually disappeared, and the axes on which they were supported becoming unnecessary, individuals became substitutes for classes, actions intended to operate simultaneously were effected by the same agent, and the connections of the several parts with the moving power becoming apparent, gave to the design a unity in which it had appeared deficient." The simplification was such that a machine for constant second differences which in the original arrangement would have required 96 wheels and 24 axes, would in the new design require only 18 wheels and 3 axes. The details of this new design are nowhere described, but presumably the organization was fairly close to that of the section of the Difference Engine that was eventually constructed.

On his return to London from this visit to Herschel, Babbage again turned his attention to the design of a printing mechanism. Inspection of a variety of printing presses driven by steam engines suggested to him a method of automatic inking which would allow the machine to print single copies of its results directly, when this was all that was needed. But he was still primarily concerned with the problem of preparing tables for publication.

Experiments with stamping the machine's results in metal to form stereotype plates were not satisfactory. Babbage decided to explore the possibility of having the machine set conventional type, and he was encouraged in this by hearing, from "an American gentleman, Mr. Church," of a machine he had invented for setting type which was controlled "by means of keys similar to those of a piano."

Babbage was concerned with two possible sources of error that could arise if the machine were to set movable type. First, the machine would have to select the pieces of type from hoppers corresponding to the ten digits; Babbage wished to assure that the type would never get into the wrong hopper. Second, pieces of type could fall or be drawn out of the frame either before or during printing, and then be wrongly replaced; Babbage wished to guard against this danger.

Babbage said that he remembered hearing a few years earlier from Sir William Herschel of a technique tried out at a printing concern in Glasgow, whereby a hole would be drilled through the center of each pica of type, and after composition was complete, a wire would be placed through the holes in each line of type, assuring that no letter could fall out. In the Glasgow experiments, it was decided that the expense of drilling was too great to justify the technique.

Babbage decided to modify this method in two ways. First, instead of drilling a hole through the center of each piece of type, he decided to plane a semicircular groove in one edge of the type, as this would be cheaper and easier than drilling; then, when two lines of type were placed together, they could be secured by a single wire placed through the single hole formed by the two semi-circular grooves. Second, in addition to this groove common to all pieces of type, he decided to add a second special groove whose position was peculiar to each different digit separately. Then when the type was divided among the ten hoppers, each one could be checked for wrong type by passing a wire down this special groove.

However, design of a printing mechanism did not progress any further. In the spring of 1822, Babbage assembled a small working model of the Difference Engine, but it did not include any printing mechanism; [20](#) indeed, Babbage never did assemble a printing mechanism the whole time he was working on the Difference Engine. In July, 1822, Babbage was still thinking in terms of a machine to set movable type, [21](#) but by November, he was again considering the idea of stamping the results in a matrix from which stereotype plates could be cast. [22](#) In July, 1823, Babbage was still undecided between these two methods of printing, [23](#) but by the spring of 1824, Babbage had decided in favor of stereotype plates. [24](#)

Little can be said about the working model of the Difference Engine referred to above. In a letter dated June 2, 1822, Babbage spoke of this model as

being "just finished," and as having two orders of differences. ²⁵ At the beginning of July, Babbage described having tabulated thirty values from the formula $x^2 + x + 41$ in two and one half minutes, the net speed being thirty three digits per minute. The number of figures that could be handled by the model is not clear; writing in 1864, Babbage said that the model "consisted of from six to eight figures"; ²⁷ this could mean the number of figures in the result column, but more probably it also included the difference columns. It is plausible that the machine had three figures for the result, two for the first difference, and one for the second difference (six in all), for this would allow tabulation of exactly the thirty values of $x^2 + x + 41$ referred to above; but this is by no means conclusive. In any case, the model constructed at this early date is nowhere described, and evidently has not survived. It is not possible to say exactly how similar in design it was to the larger section later put together for the government.

Having considered the early development of the Babbage Difference Engine on paper and in metal, we must now consider the process by which the government came to decide that it should provide support for the construction of a full scale machine.

Evidently Babbage did not feel ready to make public his invention of the Difference Engine until after he completed the working model, near the end of May, 1822. But in June, Babbage sent to the Astronomical Society a "Note on the Application of Machinery to the Computation of Astronomical and Mathematical Tables." This brief paper, dated June 2, 1822, and read to the Society on June 14, simply announced that he had completed a working model of the calculating mechanism, and was engaged in designing the printing mechanism. ²⁸

Francis Baily, in a letter to Babbage dated June 8, 1822, remarked: "I trust you are making rapid progress with your new machine: I long to see some practical results." ²⁹ Again on June 29, Baily wrote: "I trust you are getting along with your expose of the valuable properties of your machine; and I sincerely wish you success through every stage of your progress." ³⁰

The "expose" refereed to was that which emerged as Babbage's "Letter to Sir Humphrey Davy, Bart., President of the Royal Society," dated July 3, 1822, bearing also the, title: "On the Application of Machinery to the Purpose of Calculating and Printing Mathematical Tables." ³¹ In this letter, Babbage reviewed the success of the working model of the Difference Engine and the possibility of having the machine set type. He described at some length the methods used and the difficulties and expense involved in calculating complicated mathematical tables by hand, and suggested how a difference engine would alleviate the problems. Babbage concluded this letter with the following observations:

Whether I shall construct a larger engine of this kind . . . will in a great measure depend on the nature of the encouragement I may receive. . . . I, have now arrived at a point where success is no longer doubtful. It must, however, be attained at a very considerable expense, which would not probably be replaced, by the works it might produce, for a long period of time, and which is an undertaking I should feel unwilling to commence, as altogether foreign to my habits and pursuits. ³²

This "Letter to Sir Humphrey Davy" Babbage had privately printed and distributed to his friends and others whom he thought might be interested, and their reactions began to come in. Writing to Babbage on July 16, 1822, Olinthus Gregory thanked Babbage for a copy of the letter, and remarked:

The application of machinery to the purposes of computation, in the way you have so happily struck out, is highly interesting, and cannot fail, I should think, to be exceedingly beneficial. I trust that our valued friend Mr. D [avies] Gilbert, and some other friends to science who possess influence in high quarters, will exert it cordially on this occasion, and obtain an adequate grant from the Government to complete and render extensively effectual the whole of your curious invention. ³³

Edward Bromhead, writing to Babbage on August 20, 1822, said that he had distributed "where I thought the effect would be greatest" the copies of the letter which Babbage had sent him. He continued:

It is my impression that you are much to blame if you put yourself to any trouble or expense in forming one of the larger Engines; it ought to be done at the charge of the Literary World, and I need not say how anxious I am that something of the kind be set on foot. A Memoir in the Phil[osophical] Trans[actions] containing the particulars of your method will give all the fame you can procure by it. Napier and Newton did not increase their Glory by making Rods and Reflectors. ³⁴

It is not clear whether at this time Babbage agreed with Gregory's suggestion that he should seek financial support for constructing a full scale machine, or with Bromhead's belief that he should not himself construct it, but rather make the plans available to any group that wished to. It is clear that at this point Babbage ceased working on the practical problems of building a Difference Engine.

This can be seen in a letter to David Brewster, dated November 6, 1822, in which Babbage said that he had, "during the last two or three months, laid aside the further construction of machinery for calculating tables." ³⁵ This letter, together with a paper read to the Astronomical Society on December 13, 1822, ³⁶ developed at some length the idea Babbage had first formed much earlier in the year, suggesting that the mathematical powers of the Difference Engine could be greatly extended if it could automatically alter the highest order difference depending on its own results. This subject will be discussed in the next chapter.

The closing passage of the letter to Brewster, however, must be quoted here, for It provides insight into Babbage's deep conviction in the ultimate significance of the work he was doing; indeed, it seems almost prophetic. Babbage said:

If the absence of all encouragement to proceed with the mechanism I have contrived, shall prove that I have anticipated too far the period at which it shall become necessary, I will yet venture to predict that a time will arrive when the accumulating labour which arises from the arithmetical applications of mathematical formulae, acting as a constantly retarding force, shall ultimately impede the useful progress of the science, unless this or some equivalent method is devised for relieving it from the overwhelming incumbrance of numerical detail. ³⁷

A more poetic side to this version of the importance of the calculating machine was expressed in a letter to Babbage from W.W. Lamb, dated December 29, 1822, saying: "I hope your new machine is growing strong and active like a new giant. I suppose it must begin to feel its powers about this time and to think about moving the whole solar system." ³⁸

Babbage's "Letter to Sir Humphrey Davy," discussed above, had been distributed to him not only among fellow scientists, but also among those who might have influence in winning financial support for construction of a full scale Difference Engine. By the spring of 1823, interest in the machine on the part of people in various sections of the government was beginning to emerge.

On March 21, 1823, John Croker, secretary of the Admiralty, wrote to Sir Robert Peel, secretary of the House of Commons (and later Prime Minister). This letter read as follows:

Mr. Babbage's invention is at first sight incredible, but if you will recollect those little numerical locks which one has seen in France in which a series of numbers are written on a succession of wheels, you will have some idea of the first principle of the Machine, which is very curious and ingenious and which not only will calculate all regular series but also arranges the types for printing all the figures. At present indeed it is more a matter of curiosity than use, and I believe some good judges doubt whether it ever can be of any. But when I consider what has been already done by what are called Napiers bones and Gunters Scale and the infinite and undiscovered variety of what may be called the mechanical powers of numbers, I cannot but admit the possibility, may be probability, that important consequences may be ultimately derived from Mr. Babbage's principle. As to Mr. Gilbert's proposition of having a new machine constructed, I am rather inclined (with deference to his very superior judgment in such matters) to doubt whether that would be the most useful application of further money towards the object at present.

I apprehend that Mr. Babbage's machine, which however I have not seen, answers the purposes which it is intended for sufficiently well, and I rather think that a sum of money given to Mr. B. to reward his ingenuity, encourage his zeal and repay his expenses would tend eventually to the perfection of his machine. It was proposed at the Board of Longitude to give him £500 out of the sum placed at our disposal for the reward of inventions tending to facilitate the ascertaining the Longitude, but the Board doubted that the invention was likely to be practically useful to a degree to justify a grant of this nature.

I think you can have no difficulty in referring the matter to the Committee of the Royal Society (of which although unworthy I have the honor to

be one), which by the assistance of its scientific members will give you the best opinion as to the value of the invention; and when that is obtained it may be considered whether another machine should be made at the public expense, or whether Mr. Babbage should receive a reward either from Parliament or the Board of Longitude. [39](#)

Exactly what the "proposition" of Davies Gilbert referred to here was, and to whom it was made, is not clear. But as early as July, 1822, he had been suggested by Olinthus Gregory as the obvious person to plead Babbage's cause with the government. [40](#)

On April 1, 1823, George Harrison of the Treasury wrote to Sir Humphrey Davy, as President of the Royal Society; he enclosed a copy of Babbage's "Letter to Sir Humphrey Davy," saying that it had been sent to the Treasury by Babbage, and stating that the Lords Commissioners of the Treasury "request to be favored with the opinion of the Royal Society on the merits and utility of this invention." [41](#)

In response to this enquiry, the Royal Society formed a committee to consider the matter; it consisted of the President, Treasurer, and the two Secretaries of the Society, and eight other distinguished men. On May 1, 1823 William Thomas Brande, Secretary of the Society, wrote to Harrison, reporting their opinion. They had concluded: "That it appears that Mr. Babbage has displayed great talents and ingenuity in the construction of his machine for computation, which the Committee think fully adequate to the attainment of the objects proposed by the inventor, and that they consider Mr. Babbage as highly deserving of public encouragement in the prosecution of his arduous undertaking." [42](#) This correspondence between the Royal Society and the Treasury was mentioned in the House of Commons on May 6 and May 22, 1823, and was directed to be printed in the Parliamentary Papers; but no formal action was taken, and the question was turned back to the Treasury. [43](#)

Advice and information continued to flow in to Babbage from his various friends. Edward Bromhead wrote him, saying:

I have always objected to your undertaking your machine yourself; it would have been more just, and would have had a better effect, that you should have thrown out the Principle, and a Committee of scientific Men taken it up. You should have two courses in view on the Parliamentary inquiry; 1st, a remunerative Grant, such as was granted to Dr. Jenner and many others, 2ndly an annual Grant of 5 or 10 thousand a year to the Board of Longitude, for scientific purposes. Either of these would be carried, but you will find it hard to Persuade Parliament to address the Crown for the manufacture of a Machine. The addresses for printing the National Records and Chronicles are almost the only cases in point. I shall mention the Business among my friends who may be in Parliament. [44](#)

On May 26, 1823, Francis Baily wrote Babbage, suggesting that he would be better prepared to answer such questions as might be raised if he would look into the earlier history of calculating machines. In a postscript he added this: "A celebrated mathematician, who has seen your machine, says that it would take as much time to make calculations [as] with the pen!!! You see how difficult it is to lead the public." [45](#)

On May 28, 1823, Davies Gilbert wrote Babbage, saying:

I have some very unpleasant news to communicate. To my great astonishment . . . the Administration have . . . declared an extreme unwillingness to consent to encourage or assist any invention whatsoever, partly arising I believe by the large demands of London Bridge.

I believe it would be in my power to persuade them to reimburse any actual expense incurred since the matter has been in actual agitation; but this for the present I have declined doing.

I have mentioned the affair to the Solicitor General, who has promised to look at your machine tomorrow. [46](#)

Shortly after this, Babbage received his first formal public honor for the invention of the Difference Engine, in the form of the Gold Medal of the Astronomical Society. Communication of this award was sent to Babbage on June 13, 1823, by John Millington, Secretary to the Society (Babbage had resigned from this same position a short time earlier). The resolution passed by the Council stated that the Medal was being presented to Babbage by the Society "as a token of the high estimation in which it holds his Invention of an engine for calculating and printing Mathematical and Astronomical Tables." [47](#)

The actual award of the Medal took place on July 13, 1823, and its presentation was accompanied by a speech by Henry Thomas Colebrooke, President of the Astronomical Society. In this speech, Colebrooke stressed the importance of the machine to astronomy; not only would it alleviate "the most irksome portion of the astronomer's task," but he hoped it would make applicable by the astronomer mathematical equations "which involve operations too tedious and intricate for use, and which must remain without efficacy, unless some mode be devised of abridging the labour or facilitating the means" of their application. [48](#)

There is no evidence that this award had any effect on the Government's decision, but this did follow shortly after. At some point in July, Babbage had an interview with F.J. Robinson (afterward Lord Goderich, later Earl of Ripon), Chancellor of the Exchequer. [49](#) At this interview, Babbage was told of the government's intention to support the Difference Engine, but unfortunately there was no written record of any details of what was agreed upon; as we shall see, this lack became rather important later on. Apparently the interview took place about July 11, for on that day there was a Treasury Minute authorizing the first payment to Babbage. [50](#)

The Committee of the Royal Society which had reported to the Treasury on the merits of Babbage's machine was informed of the government's decision in a letter from the Treasury to Davies Gilbert, dated July 21, 1823. The letter stated that the Lords Commissioners of the Treasury had "directed a Warrent to be prepared for the issuing the sum of one Thousand Five hundred Pounds to Mr. Babbage to enable him to bring his invention to perfection in the manner recommended." [51](#)

Unfortunately, there was no indication of what "the manner recommended" meant; the Royal Society committee had recommended nothing about how the Difference Engine should be built. Further, the letter did not make clear whether the Treasury expected that £1500 would be enough to complete the machine, or what they would do if it was not. It is even possible that they intended the money simply as a reward for Babbage's invention, with the expectation that this would encourage him to construct it, rather than as direct support for construction. As we shall see, all these ambiguities were to cause considerable trouble in later years.

Babbage started work on construction of the Difference Engine shortly after this grant of £1500 was announced, and he hired Joseph Clement (1779-1844) as his chief engineer and draftsman. Clement, who was largely self-taught in machining and drawing, had come to London in 1813 to become a professional mechanic. He had worked in the shops of two of the foremost engineers of the time, Joseph Brahmah and Henry Maudslay, and himself later employed Joseph Whitworth, the leading machine-tool maker of the 19th century. Clement was himself responsible for several important improvements in lathes and other tools. [52](#)

Due to the lack of the appropriate documents, it is unfortunately not possible to reconstruct a detailed account of the progress of the Difference Engine during the early years of its development. The first surviving Babbage letter with any substantial comment on the work was written on November 21, 1826, to Christopher Wordsworth, Master of Trinity College and Vice Chancellor of Cambridge University. Babbage had applied for the post of Lucasian Professor at Cambridge, and in this letter he argued that the requirement, generally not enforced, that the Lucasian Professor reside at the University not be applied in his case, if he were elected. In regard to the Difference Engine, Babbage said:

During the last four years I have been occupied in the construction of an engine for calculating and printing mathematical tables. I am executing this work at the desire of the government, and although in my first interview with the Chancellor of the Exchequer I did not pledge myself to devote my whole time exclusively to this object, yet I feel that the liberal and very handsome manner in which I was received at the Treasury would be but ill returned if I were to allow any other agreements to impede its progress. I have hitherto given up everything for this object, situations far more lucrative although not at all more honorable have been sacrificed, and I should not wish to change these sentiments now that it is approaching, I hope, to a successful termination.

The thought and time which this has cost me will never be known. Severe illness in my Draftsman has delayed me much beyond my original expectation, but my machinery and arrangements are now arrived at such a point as to admit of occasional absences of some duration without detriment to the progress of the work. [53](#)

However, this determination to proceed rapidly to the completion of the Difference Engine was not to last, despite the fact Babbage was not elected to the Lucasian chair. Early in 1827, Babbage's father died, leaving to Charles a fortune of about £100,000. Whether it was due to grief over his father's death, the time required to look after his affairs and care for his mother, or other matters, Babbage was soon led to suspend work on the Difference Engine temporarily.

About the end of March, 1827, Babbage wrote to Thomas W. Hill, in response to a complaint from Hill that Babbage had not sent him any news of progress on the machine. Babbage's response was simply: "As the machine is out of order and condemned to the lumber room I did not think it worth while troubling you about it." ⁵⁴ Hill replied, on April 10, 1827, suggesting to Babbage the same feelings that had been advanced by Edward Bromhead several years earlier:

For your sake I rejoice that your machine cannot at present be brought from its retirement. Your justly high reputation, like many other things good in prospect, must by this time, like a chain of Gold, have hung heavy upon you and impeded your escape from many an impertinent hunter after some new thing, who might stare at your Promethean machine without the ability to see its excellence or at all appreciate its value or its uses.

Time like yours ought not to be thus preyed upon, and until the period shall arrive when the engine can work in other hands than your own, I wish it may rest in peace. ⁵⁵

No doubt Babbage's remark had arisen from the press of other affairs and momentary annoyance at the slow progress of the work, for it was clearly not his intention to abandon it for good. However, there was soon another set-back, for in October, Babbage's wife died; ⁵⁶ this loss, added on to the deaths of Babbage's father and two of his children, caused something approaching a nervous breakdown. It was decided that for the sake of his health, Babbage should go on an extended tour of the Continent. Even in these circumstances, however, Babbage considered himself to be under an obligation to work on the Difference Engine; he thus applied to the government for permission to leave the country; this permission was granted on October 24, 1827. ⁵⁷

During his European tour, Babbage paid little direct attention to the continuation of the construction of his machine. He had, however, left behind drawings from which the work could be continued, as well as £1000 of his own money to advance toward the expenses. By this time, the money expended or owing from the project amounted to some £3500. ⁵⁸ Babbage thus naturally became concerned with the status of his understanding with the government about the support of its construction.

Early in 1828, Babbage wrote to his brother-in-law, Wolryche W. Whitmore, M.P., asking him to obtain from F.J. Robinson, now Lord Goderich (who had been Prime Minister for the last few months of 1827), acknowledgement that at his interview with Babbage in July, 1823, he had promised that the government would reimburse Babbage for all expenses incurred in constructing the Difference Engine. Whitmore obtained an interview with Lord Goderich, and on February 29, 1828, he wrote the following pessimistic account of the results:

It was under disadvantageous circumstances that I entered upon this subject with him, as I was ignorant of the precise nature of the promise to you at the time, and all I could do was to take it for granted and argue accordingly. I did not find him very candid about it; he did not like to admit that there was any understanding at the time the 1500 was advanced that more would be given by government, and all I could prevail upon him to do was to state if referred to by the Treasury that the subject had been mentioned to him and that he had sanctioned an advance of money to begin it. . . .

Economy is now so much the order of the day that I should despair of obtaining any pecuniary aid from Government at present. But I should hope that when money is more plentiful and the machine is completed, we might be more successful. ⁵⁹

Apparently Babbage decided that no clarification of the mutual obligations between himself and the government could be reached in his absence; the matter was not pursued until he returned to England near the end of 1828. At this time he talked directly to Lord Goderich; seemingly what they agreed was that no definite arrangements had been settled on in 1823. ⁶⁰

In January, 1828, the Duke of Wellington had replaced Lord Goderich as Prime Minister, and Babbage decided that the matter could be resolved only by direct appeal to him. Consequently, on December 6, 1828, he addressed to the Duke a lengthy statement of the circumstances surrounding the construction of the Difference Engine. With respect to the crucial interview with Robinson, as Chancellor of the Exchequer, in July, 1823, Babbage said that he had gone to this interview:

with the view of ascertaining whether it was the wish of the government whether he should construct a larger machine, and one which could also print the results it calculated. Mr. Babbage apprehended that such was their wish, and in the course of the interview with which he was honored, the Right Honorable the Chancellor of the Exchequer stated this principle:

That the government were unwilling to make grants of money to inventions however meritorious, because if they really possessed the merit claimed for them, the sale of the article produced would always be the best reward to the inventor.

That the present case was an exception, and that it was apparent that the construction of such a machine could not be undertaken with a view to pecuniary profit arising from the sale of its produce, and that as the tables it was intended to produce were peculiarly valuable for nautical purposes, it was deemed a fit object of encouragement by the Government.

It was proposed in the present instance to make a grant to Mr. Babbage of £1500, which was taken from a certain fund in the Civil List.

The impression which remained in Mr. Babbage's mind from this interview was that whatever might be the labor and difficulties of his undertaking, he should not suffer any pecuniary loss from it, and it was on the firm conviction of this that he has relied during the many difficulties he has encountered. ⁶¹

This statement went on to say that much progress had been made toward the completion of the machine, although it had taken longer and cost more than had been anticipated. Babbage said that about £6000 had been spent, all but £1500 having come from Babbage's own resources, and that he would find it difficult to advance any more money; further, if the uncertainty as to his position continued, "the additional anxiety thus created would be highly unfavorable to that state of mind most fitted for the performance of this and his other scientific duties." ⁶²

In response to this statement by Babbage to the Duke of Wellington, the Treasury wrote to the Royal Society, in December, 1828, asking them "whether the progress made by Mr. Babbage in the construction of his Machine confirms them in their former opinion, that it will ultimately prove adequate to the important objects which it was intended to attain." The response of the Royal Society, predictably, was to appoint a committee to consider the question; it consisted of ten distinguished scientists and engineers, with Babbage's good friend John Herschel serving as chairman. ⁶³

The committee decided to consider neither the mathematical principles of Babbage's engine, nor its usefulness when complete, for these matters had been settled in the Royal Society report of 1823. They confined themselves rather to the actual progress in execution of the machine. They submitted their report to the Council of the Royal Society in early February, 1829. The key findings of this report were as follows:

In the actual execution of the work they find that Mr. Babbage has made a progress, which, considering the very great difficulties to be overcome in an undertaking so novel, they regard as fully equaling any expectations that could reasonably have been formed; and that although several years have now elapsed since the first commencement, yet that when the necessity of constructing plans, sections, elevations, and working drawings of every part; that of constructing, and in many cases inventing, tools and machinery of great expense and complexity (and in many instances of ingenious contrivances, and likely to prove useful for other purposes hereafter), for forming with the requisite precision parts of the apparatus dissimilar to any used in ordinary mechanical works; that of making many previous trials to ascertain the validity of proposed movements; and that of altering, improving, and simplifying those already contrived and reduced to drawings; your Committee are so far from being surprised at the time it has occupied to bring it to its present state, that they feel more disposed to wonder it has been possible to accomplish so much. . . .

The actual work of the calculating part is in great measure constructed, although not put together, a portion only having been temporarily fitted

up for the inspection of the Committee; and from its admirable workmanship they have been able to form a confident opinion that it will execute the work expected from it. At the same time, the Committee cannot but observe that, had inferior workmanship been resorted to, such is the number and complexity of the parts, and such the manner in which they are fitted together, the success of the undertaking would have been hazarded; and they regard as extremely judicious, although, of course, very expensive, Mr. Babbage's determination to admit of nothing but the very best and most finished work in every part; a contrary course would have been false economy, and might have led to the loss of the whole capital expended on it. . . .

Finally, taking into consideration all that has already been said, and relying not less on the talent and skill displayed by Mr. Babbage as a mechanic, in the prosecution of this arduous undertaking, for what remains, -- than on the matured and digested plan and admirable execution of what is accomplished -- your Committee have no hesitation in giving it as their opinion, that "in the present state of Mr. Babbage's engine, they do regard it as likely to fulfill the expectations entertained of it by its inventor." ⁶⁴

The Council of the Royal Society considered this report on February 12, 1829, and resolved to report to the Treasury their conclusion that Babbage's machine indeed would "ultimately prove adequate to the important objects which it was intended to attain." They further expressed "a hope that while Mr. Babbage's mind is intently occupied on an undertaking likely to do so much honour to his country, he may be relieved, as much as possible, from all other sources of anxiety." ⁶⁵

Babbage's own state of mind and health at this time, and the degree of his recovery from his wife's death, can be judged from the following passage in a letter to the Reverend Edward Smedley, dated March 1, 1829:

I have suffered so severely in health that however much I desire to be active, all my friends, and more especially my medical ones, urge me to lay aside my pursuits and to set my mind at rest or asleep. The alternative in case of refusal seems to be the long sleep. The intensive occupation I have used as a remedy has had its effect. I have lived through two years and I may live two or twenty more, but the medicine has produced a disorder, and if I am to finish the machine I must cure the new complaint. I have therefore decided on giving up everything but that. ⁶⁶

Babbage had been reassured by the response from the Treasury to his statement to the Duke of Wellington, and also by the report of the special committee of the Royal Society. Although by early April, the Treasury had not responded to this report, Babbage thought that his relations with the government were on their way to being put on a proper footing, since it seemed that they were going to accept his view that he had undertaken construction of the Difference Engine on their behalf and at their request.

This led Babbage to turn his attention to another area, namely his relations with Joseph Clement. He believed that if the government was to pay Clement's bills, they ought to get appropriate assurance that the amounts of the bills were reasonable. Therefore, on April 11, 1829, Babbage wrote to Bryan Donkin and George Rennie, both distinguished civil engineers who had served on the special committee of the Royal Society to consider Babbage's progress, asking them to undertake an examination of Clement's bills for work done to date. ⁶⁷

There were also certain more general matters that Babbage wanted to have settled, and he asked Donkin and Rennie to discuss them with Clement. These included the questions of ownership of the drawings and special tools made for the calculating machine, liability for damage to them or to parts of the machine itself, and procedures for examining future bills. Babbage also desired assurance from Clement that he would not make further copies of the Difference Engine without written permission from Babbage; he gave the following reason:

The machine when completed may perhaps have cost 12,000 and many years of my own labor. When it is completed it would be possible in twelve months to make another such at an expense of perhaps two thousand pounds. It would be manifestly a great injustice for the contriver of such a machine at whose sole risk it was made that any other should be made by the same workman with the same tools. ⁶⁸

The character of Babbage's request to Donkin and Rennie, especially in light of the open break between Babbage and Clement that was about to erupt, might give the impression that Babbage already felt some apprehensions about Clement's work, and wished to have Clement's bills examined to prevent him from cheating Babbage and the government. But this seems not to have been the case; Babbage simply wanted to have matters put on as business-like a basis as possible, in order to guard against later problems. Indeed, in Babbage's letter to Donkin, he said: "I believe you are perfectly aware of my feelings toward Mr. Clement; he is a most excellent workman and draftsman, and ought to be well paid." ⁶⁹

On April 22, 1829, Donkin wrote Babbage, reporting the results of the interview he and Rennie had conducted with Clement. Clement had maintained that the tools belonged to him, as they had been made at his own expense; the patterns, drawings and machinery belonged to Babbage, and should be insured against damage by him. Clement would not promise to refrain from making a copy of the machine without written permission. As to Clement's bill, Donkin said that Clement was preparing a detailed itemization of it for examination. ⁷⁰

In the meantime, the Treasury was slowly acting on the report to it from the Royal Society. On April 16, 1829, Edward Walpole wrote Babbage from the Treasury, saying that Henry Goulburn, Chancellor of the Exchequer, had agreed to another grant of £1500 from the Civil Contingencies funds. ⁷¹ On April 28, 1829, there was a formal Treasury minute: it reviewed the reports submitted to it, and concluded that the Treasury was "fully justified in directing a further payment of £1500 to Mr. Babbage to enable him to complete the machine by which such important benefit to science may be expected to result." ⁷²

On the surface, things appeared to be going fairly smoothly at this point, but difficulties and misunderstandings in two different directions very shortly brought work on the Difference Engine to a halt -- one that was to last more than a year. The initial problem involved disputes with Clement over payment of his bills; the second and longer lasting involved the lack of any clear-cut understanding with the government. Although these problems were inter-related, their course will here be traced separately.

As mentioned above, Rennie and Donkin had thought that Clement's bill was not sufficiently detailed for a thorough examination, but Clement had agreed to supply the particulars of the charges. At this point, both parties seemed to have confidence in the good faith of the other; but near the end of April, something occurred between Babbage and Clement which caused them to become suspicious of one another's motives. The first indication of this is in a letter from Richard Penn to Babbage, dated May 5, 1829. Penn wrote:

I am truly sorry to hear of the annoyances to which you are exposed by the conduct of Mr. Clement. . . . I feel scarcely qualified to advise on such a subject, but it appears to me at first sight that (as Mr. Clement has chosen by his offensive conduct to forfeit all claim to that liberality on your part which disposed you at first not to question the amount of his charges, but merely to require the particulars of them) your best course would now be to force the matter to a more hostile Arbitration. I cannot but think that if you should do so, Mr. Clement's low cunning will be defeated, because I conceive that under such an Arbitration he would not be allowed to charge both for his own time and also a Tradesman's profit on the articles; and I am sure that an investigation made in this spirit would greatly reduce the amount of his charges, and show that you have purchased and paid for everything which is now done. A conclusive settlement made now seems to be absolutely necessary for your future Comfort in the business. ⁷³

Exactly what had occurred is not clarified by the other correspondence at this time, but the basis of the trouble was monetary. The financial transactions surrounding the the machine can be seen from a summary financial statement prepared by Babbage on May 13, 1829; ⁷⁴ the amounts are somewhat rounded off here:

Clement's total bills through Jan. 1, 1829:	£4775
Other expenses paid by Babbage:	1120
Estimate of Clement's bill, Jan. to May, 1829:	800
Paid to Clement by Babbage, through May, 1829:	3260
Owing to Clement by Babbage, May, 1829:	2315

Total paid by or due from Babbage:	6695
Paid to Babbage by the Treasury:	3000
Expenses not Covered by the Treasury:	3695

The bill with which Rennie and Donkin had been dissatisfied was the one for the period through January 1, 1829. The work had continued after that, but on May 9, it was halted, for reasons that are complex and obscure, and will emerge as this account proceeds. On May 25, 1829, Babbage wrote Clement a note of very frosty tone, requesting that Clement inform him of the amount of his bill through the time when the work stopped. This Clement did on May 29, 1829. The amount of the new bill was about £680; for some reason, his figure for the previous bill was lower than that given by Babbage (above), amounting to only £4630. Thus in Clement's reckoning, Babbage owed him a balance of just over £2050. ⁷⁵

Although some further contact between Babbage and Clement was carried on through intermediaries, including the leading engineer Mark Isambard Brunel, ⁷⁶ there was apparently no more direct correspondence between the two until November 18. On this date, Clement wrote Babbage, saying:

It is now upwards of Six months since you informed me that you should be prepared to settle my account in about ten days or fortnight; Since that time I have scarce had the pleasure of seeing you.

You now impose on me the unpleasant task of demanding the money on you. I therefore request that you will not exceed Ten days . . . in settling my account with you. ⁷⁷

On the back of this letter, Babbage wrote his own account of the course of events:

The true state was this. Clement asked for payment about 6 months since. I said that I must submit the bill to Mess. Rennie and Donkin previous to payment. Mess. Rennie and Donkin said the bill was not properly made out and ought to be more detailed. They communicated this to Clement, who promised to give it in detail, and he told me (this day 18 November, 1829) that he had begun it at that time.

After about 2 months I wrote to request to know the expense incurred from 1 January 1829 to the time the work ceased. Clement in about 2 weeks called on me and said he had discontinued to make out detailed bills because he thought from my letter that I did not want it. I told him that my letter implied nothing of the kind and I desired him to continue it and communicate with Mess. Rennie and Donkin.

The day after the letter of 18 November, 1829, I saw him, and he then for the first time told me he declined making such bill because it is not the custom of engineers to do so. I requested him to communicate this to me through Mess. Rennie and Donkin. ⁷⁸

Despite Clement's demand for prompt action, matters proceeded very slowly. The next letter preserved from Babbage to Clement was dated December 18, 1829, and simply stated that "all communications between us relative to accounts" would take place through Rennie and Donkin, and not directly. Babbage said that Rennie would see Clement at his convenience to discuss the general situation. ⁷⁹

Apparently this discussion, if it took place, was not fruitful, for on January 23, 1830, Babbage wrote a letter to Clement including the following passage:

Your refusal to furnish me with any of the particulars of your bill renders it necessary that I should adopt some mode of satisfying myself of its correctness. Arbitration or a suit in one of the courts seems to be the only means of deciding the question. Having myself little reason for preferring one more than the other of those courses, I request you will choose that which you think most advantageous to yourself. ⁸⁰

In response to this letter, J.B. DeMole wrote to Babbage on February 16, 1830, on behalf of Clement. He said that Clement accepted the proposal of arbitration of the bill, and wished the matter "to be referred in the usual way . . . to 3 Engineers of eminence, one to be chosen by each party, and the third by the two so first chosen." As his own representative, Clement chose Henry Maudsley, another eminent engineer. ⁸¹

Babbage chose Brian Donkin as his representative; evidently Donkin and Maudsley did not find it necessary to select a third party to settle disputes. They examined the bills in April, 1830, and found them to be correct and reasonable; on May 6, 1830, the account was settled by a new payment from Babbage to Clement which brought the total of payments through that date to just under £5420. ⁸²

We must now return to early May, 1829, to the point where the Treasury had granted Babbage £1500, the first money he had received from them since 1823, and trace through this same period his interactions with the government with respect to the machine.

No doubt Babbage was relieved that the government was willing to grant him more money, but he was rather disturbed that they saw fit to limit the payment to £1500, since they had been informed in the report from the Committee of the Royal Society that expenses had already amounted to £6000. Further, there was still no progress toward an understanding as to the mutual obligations between Babbage and the government.

This anxiety led to two actions. First, as mentioned above, work on the engine was halted on May 9. The difficulties with Clement discussed above undoubtedly contributed to this stoppage, but it seems clear that the principal cause was Babbage's anxiety about the government's intentions. On the one hand, Babbage was reluctant to continue laying out funds at the rate of about forty pounds per week with no assurance of being reimbursed; on the other hand, he felt that he could use the halt in construction as a lever with which to pry some attention out of the government.

This attention was to be gained through the second action taken, apparently at the suggestion of Wolryche Whitmore. This consisted of a report and appeal to the government drawn up on May 12, 1829, by seven distinguished personal friends of Babbage, namely Lord Ashley, the Duke of Somerset, Sir John Franklin, Wolryche Whitmore, Henry Fitton, Francis Baily and John Herschel. This report advanced the following main points: that Babbage had begun construction of a full scale Difference Engine at the desire of the government; that it had been understood that the government would pay for the work as it progressed; that although Babbage "had devoted the most assiduous and anxious attention to the progress of the Engine," he was not being reimbursed, and could not afford to go on making large advances from his personal funds; and that if the government did not respond appropriately, Babbage would be under no obligation to continue the work. ⁸³

These conclusions were presented by Whitmore and Herschel in an interview with the Duke of Wellington, the Prime Minister. For once the government did not respond by asking for the opinion of the Royal Society; presumably the opinion expressed four months earlier still held. Rather the government did not respond at all. After some weeks, Whitmore inquired of the Chancellor of the Exchequer as to what had happened; he was informed that the Duke of Wellington wished to personally inspect the progress made on the machine. ⁸⁴

This clearly pleased Babbage, for he felt that the Engine was finally getting the attention it deserved from the only man who could really decide the government's policy toward it. The Duke of Somerset considered it necessary to warn Babbage against excessive optimism; writing to him on June 8, 1829, the Duke said:

I am very glad that the Duke of Wellington will see the machine. If he should understand it, he must be a much greater Mechanician than I imagine him to be, and if he should comprehend its uses, he must have much more science than what usually falls to the lot either of a soldier or a statesman. So that I apprehend he must take a great deal upon trust, or else your end will not be answered. You seem to think your wishes very moderate, when you wish for nothing more than that it may be completely understood. Now I consider this as altogether hopeless. ⁸⁵

As it turned out, it was optimistic even to expect a prompt visit from the Prime Minister. After more than two months of waiting, Babbage wrote again to the Duke of Wellington on August 13, 1829. He once again reviewed the circumstances of the construction of the Difference Engine, and urged that a rapid resolution of the problems surrounding it was important, because, among other reasons, as long as the work was halted, Clement would be free to sell the tools made especially for the Engine, since they were legally his property. ⁸⁶

Once again, there was no response. On October 7, 1829, almost another two months later, Babbage wrote to Edward Drummond, secretary to the Duke of Wellington, complaining that he had received no reply to his letter of August 13, and saying that he had been waiting in London since June in daily expectation of a visit from the Duke. Babbage stated that he had some business away from London, and needed to know if the visit would occur within

three weeks, so that he should delay his departure. ⁸⁷ On October 13, Babbage wrote again to Drummond, saying that since he had received no reply to his last letter, he was leaving for Worcester, but would return at once if they wrote him there. ⁸⁸

Babbage returned to London on November 16, and wrote to Drummond again, informing him that he awaited a visit at the Duke's convenience. ⁸⁹ Finally, after nearly six months of silence, he received a reply, setting up an appointment a few days later. ⁹⁰ The Prime Minister and Henry Goulburn, Chancellor of the Exchequer, were shown the model of the difference engine that was built in 1822 and the drawings and parts that had been completed since then.

The results of this interview were expressed in a letter from Goulburn dated November 20. He said that he and Wellington had, as a result of their visit, recommended to the Treasury that it give Babbage another 3000 pounds, as "a further payment towards the completion of the Machine." He also expressed their belief that since the printing mechanism would have to be quite complicated, "the Machine should be so arranged that in the event of any failure in the printing department of it the calculating part should be nevertheless perfect and available." ⁹¹ Babbage replied to Goulburn on November 24, describing at length the relation and relative independence of the calculating and printing sections of the Engine, although no detailed plans for the printing mechanism had been made at this point. ⁹²

The fact that the government was now ready to pay Babbage another £3000, though gratifying, did not really reassure him. This emerges very clearly in a letter from Babbage to Lord Ashley, dated November 25, 1829, in which Babbage expressed his anxieties about his relations with both Clement and the government in great detail. ⁹³ With respect to Clement, Babbage said that he was quite satisfied with the work he had done, and that it was "clearly of the greatest advantage to the progress of the machine that he should continue under my direction to execute it." However, Babbage continued, he was "much displeased" with Clement's conduct with respect to his bills. Babbage considered it most important that the need for discussion between him and Clement of financial arrangements, being a source of considerable irritation, should be removed.

With respect to the government, Babbage admitted that the difficulties he had had, arose in part "from my own fault in not requesting at the outset [July, 1823] from the then Chancellor of the Exchequer [F.J. Robinson, later Lord Goderich] some more distinct understanding and some written document which would place me in a similar relation to his successor." Despite the additional grants the government had made or proposed, there was still no definite commitment or understanding.

Babbage called these two sources of anxiety "the moral difficulties of the machine," and said that they were "difficulties which perhaps the very constitution of my mind rendered me as incompetent to contend with as it seems to have rendered it fatally susceptible of them as a source of disgust."

Babbage proposed that these moral difficulties could be removed if the government would agree to consider the Difference Engine to be their own property, and if they would pay Clement directly, appointing some engineers to examine the propriety of his bills. This course, he said, "would relieve my mind from all causes calculated to distract its attention, and I should be enabled to devote all my energies to complete the machine." Babbage requested that Lord Ashley propose this arrangement to the government, along with the reasons for it.

On December 3, 1829, Babbage received a minute from the Treasury confirming their intention to grant him a further £3000 to enable him "to complete the Machine." It repeated the suggestion about the printing mechanism earlier made by Goulburn, but proposed no basis for a future understanding. ⁹⁴

On December 13, 1829, Goulburn wrote to Lord Ashley in response to the proposals he had forwarded on behalf of Babbage. Goulburn said that accepting the suggested arrangements would be inconsistent with the principle on which the earlier support had been granted:

The view of the Government was to assist an able and ingenious man of science whose zeal had induced him to exceed the limits of prudence in the construction of a work which would if successful redound to his honor and be of great public advantage. It was no part of our intention to divest Mr. Babbage of the machine or by transferring the property in it to Government to place him in the situation of a Government Agent acting under the instructions of the Treasury. ⁹⁵

Goulburn claimed that such a course would be to nobody's advantage, and would set an unfortunate precedent. "We feel ourselves, therefore, under the necessity of adhering to our original intention, as expressed in the minute of the Treasury, which granted Mr. Babbage the last £3000, and in the letter in which I informed him of that grant." Unfortunately for the cogency of Goulburn's reply, nothing concerning the government's "original intention" had been expressed in either of those documents.

Babbage found Goulburn's letter, forwarded to him by Lord Ashley, rather astonishing. As he said in a letter to Lord Ashley on December 16, 1829, Goulburn seemed to feel "that I commenced the machine on my own account, that pursuing it zealously I expended more than was prudent, and then applied to government for aid." Babbage flatly contradicted Goulburn's view. He pointed out that the small model of the Difference Engine had been completed long before he had had any contact with the government, and that in his letter to Sir Humphrey Davy he had expressed his disinclination to undertake a full scale machine, which, indeed, he had started on only after he had received the first £1500 from the government. ⁹⁶

A thought that Babbage expressed in some private notes on Goulburn's letter to Ashley, but did not include in his own letter to Ashley, was as follows: "Having already suffered so much from the want of a sufficiently clear understanding, I hope I shall be excused in not advancing further until I perfectly understand the nature of the position in which I am placed." ⁹⁷ In the letter to Ashley, Babbage put the matter in terms of a list of questions he wanted to have Ashley put to the government. Among them were the followings

Supposing I receive the £3000 last given. What are the claims which Government have in the machine, or on myself?

Does Mr. Babbage owe the £6000 or any part of that sum to Government? . . . Is it expected by government that Mr. Babbage should continue to construct the machine at his own expense, and if so, to what extent in money?

Suppose Mr. Babbage should decline resuming the machine, to whom do the drawings and parts already made belong? ⁹⁸

The pessimistic view Babbage had of the future of the project at this point, and some further insight on his relations with Clement, is revealed in a letter he wrote to Rennie three days later, on December 19. He said:

I have had since I saw you some discussion with government which it appears to me will not be speedily terminated, and I am inclined to believe that the result must be my giving up the machine.

However, Mr. Clement has worked well, and notwithstanding that I am dissatisfied with some parts of the engine, he ought to be paid liberally. I have not yet accepted the sum last proposed, and shall probably him from my own means. ⁹⁹

Exactly what happened in the following few weeks is not clear, but evidently Lord Ashley had some fruitful discussions with Goulburn, for on January 10, 1830, Babbage wrote to Lord Goderich, who (as F.J. Robinson) had been Chancellor of the Exchequer in 1823, and said: "The communications I have had with the Government relative to the calculating machine are I hope about to be terminated in a way which will enable me to continue its construction." ¹⁰⁰

Babbage went on to say that Goulburn would probably ask Goderich for his account of the 1823 interview, and consequently Babbage wished to refresh his memory as to what had been said. Babbage's version was summarized in the following passage:

The matter was, as you have justly observed on another occasion, left in a certain measure indefinite, and I have never contended that any promise was made to me. My subsequent conduct was founded in the impression left in my mind by that interview. I always considered that whatever difficulties I might encounter, it could never happen that I should ultimately suffer any pecuniary loss. ¹⁰¹

This series of negotiations was finally terminated at an interview between Lord Ashley and Goulburn on February 24, 1830. Babbage made the following notes on the government's decision, as described to him by Lord Ashley:

Government would not pledge themselves to complete the machine.

Government were willing to declare the machine their property.

Government were willing to advance 3000 more than that already granted [apparently this refers to the £3000 authorized on December 3, 1829].

At the end when it is completed they were most willing to attend to my claim for remuneration. ¹⁰²

Although this understanding was still somewhat vague, it was enough to satisfy Babbage, and he forgot his thoughts of abandoning the project. One point of considerable concern to him which had not been resolved, was his desire not to be involved in the payment of Clement's bills. Although Babbage could not get the government to pay Clement directly, he did manage to bring about another aspect of his plan, namely that the bills would be examined on behalf of the government by engineers whom they appointed. In a letter to Goulburn dated March 19, 1830, Babbage suggested that the government name Bryan Donkin and Henry Maudsley to do this; he did not mention that these were the two men whom he and Clement had already agreed upon to arbitrate their disputes. On March 29, Babbage was informed that Goulburn had agreed to this. ¹⁰³

That Babbage was not quite optimistic about the prospects of finishing his machine is revealed in a letter to Nathaniel Bowditch, dated March 20, 1830. Babbage first referred to his finally "inducing the government to place my Calculating machine on a proper footing." He then said. "The construction of a large machine is now going on under my direction for the government and will probably be completed in three years." ¹⁰⁴

Exactly when Clement resumed work on the machine is not clear; the statement last quoted implies he had done so by March 20; but there is also a note from Babbage to Clement, dated July 5, 1830, which reads: "I request you will continue to execute the drawings and machinery for the Calculating machine under my supervision." ¹⁰⁵ But it is possible that this note was meant not to get Clement to start the work again, but rather to give him formal assurance that he was still responsible directly to Babbage, rather than to the government. In any case, work on the machine began again on the order of one year after it had been halted.

It is to be noted and marveled at that although both Babbage and the government felt that the project had been put on a satisfactory basis, there was once again no written statement describing their agreement; indeed, this agreement had been arrived at through an interview with a third party.

With construction under way again, and with his earlier disputes with Clement and with the government out of the way, Babbage turned his attention to the acquisition of a site where the Difference Engine could be assembled and operated. On July 13, 1830, Babbage sent a report on this matter to the Chancellor of the Exchequer. In it, Babbage stated that nothing could "render doubtful the full success" of the machine, provided that both he and Clement lived a few more years. The time was nearly at hand when the parts of the machine which had been made would have to be assembled, and this could not be done in Clement's workshop. Since after its completion Babbage would need to superintend the operation of the engine, he argued that new workshops and space for assembly should be acquired near his own house (Clement's shop was about four miles away). He also argued that such a course would tend to preserve Clement's rather frail health. ¹⁰⁶ On August 6, 1830, Edward Walpole wrote Babbage from the Treasury, saying that Goulburn did not accept Babbage's proposal. ¹⁰⁷

The matter rested until December 21, 1830. On this date, Babbage wrote Lord Althorp, who had replaced Goulburn as Chancellor of the Exchequer, pointing out that at the last settlement of accounts there had still been £600 owing to Babbage, and that since then an additional £600 had become due to Clement. Clement had told Babbage that he was running short of funds, and would have to lay off some of the workmen if he was not paid soon. In this letter, Babbage also repeated his suggestion that work on the Difference Engine should be carried on near his house. ¹⁰⁸

In reply, James Stewart wrote Babbage from the Treasury on December 24, 1830, saying that the Treasury would pay Babbage an additional £600 if he would declare the machine to be the property of the government. ¹⁰⁹ Evidently the government simply wanted a written statement to this effect from Babbage, for the same day Stewart also wrote to the Royal Society, informing them "that the machine is the property of Government and consequently my Lords [Commissioners of the Treasury] propose to defray the further expense necessary to its completion." ¹¹⁰ Stewart also told them that Babbage was to be paid an additional £600, and requested the Royal Society to report again on the progress on the Difference Engine and estimate the additional money it would cost.

In Babbage's reply to Stewart's letter to him, he stated that it had been understood at the interview between Lord Ashley and Lord Goulburn in February, 1830, that the machine belonged to the government, and that they would pay all expenses incurred in its construction, this being in remarkable agreement with the points made in Stewart's letter to the Royal Society. ¹¹¹ Stewart replied again on December 31, informing Babbage that the payment of another 600 pounds had been authorized. ¹¹²

Babbage, meanwhile, had continued to explore the possibility of new workshops on his own. In December, 1830, he had Charles Jearrad, surveyor, inspect several possible sites near Babbage's house; in early January, 1831, they decided that the only one suitable was some space in Babbage's own garden. ¹¹³ On January 19, Babbage wrote Lord Althorp (Chancellor of the Exchequer) arguing again the desirability of the move, reporting his findings, and estimating the cost of construction and other expenses at £2250. ¹¹⁴

Early in February new difficulties arose involving Clement, this time involving a quarrel between him and a drafting assistant, C.G. Jarvis. Jarvis (who Babbage later hired as his chief assistant on the Analytical Engine) wrote Babbage in early February, 1831, saying:

It should be borne in mind that the inventor of a machine and the maker of it have two distinct ends to attain. The object of the first is to make the machine as complete as possible. The object of the second - and we have no right to expect he will be influenced by any other feeling - is profit; to gain as much as possible by making the machine; and it is his interest to make it as complicated as he is permitted to make it. I am fully aware how far these observations may do me injury. But they are made, Sir, whether well or ill judged, for your good. ¹¹⁵

Jarvis had resigned from Clement's employment by February 19, but in a letter to Babbage on that day, he stated that the only major cause was a disagreement over his salary; a compromise salary was proposed for Babbage's approval. In another letter a short time later, Jarvis stated that the fault in the salary dispute lay with Donkin and Field (the latter had become co-inspector of Clement's bills upon Maudsley's death earlier in the month), since they had refused to let Clement pay a salary higher than that for an ordinary draftsman. Eventually Jarvis was rehired. ¹¹⁶

On March 26, 1831, the Royal Society issued the new report on the progress of the Difference Engine that had been requested by Stewart on December 24, 1830; the Council of the Society had again appointed a special Committee. They stated that "the various parts of the Machine appear to them to have been executed with the greatest possible degree of perfection as to workmanship," and that the bills had been carefully checked. In regard to the question of building a new workshop for the engine, they considered the reasons advanced for the move by Babbage to be valid, and the plans he had suggested to be sound. As to the probable future expense of the Difference Engine, they forwarded an estimate by Brunel, who said that the new arrangements would cost about £2000 initially, and then about £2000 to 2500 per year; £8000 total additional funds would probably be ample, but the government should allow for as much as £12,000. ¹¹⁷

For the next two years, work on the Difference Engine proceeded fairly routinely. Babbage received another £1000 to pay Clement in July, 1831, ¹¹⁸ and almost £2000 in September, 1831. ¹¹⁹ In August, 1831, Babbage urged that the new workshops be in a large permanent building, as space would be needed for the staff necessary to produce such things as the Nautical Almanac. ¹²⁰ In March, 1832, Jarvis wrote Babbage criticising Clement's plan for a glass case for the machine from which the printing mechanism would stick out, since this would result in an appearance "as grotesque as that of a stuffed tiger, the body of which was encased in glass, and the tail left dangling outside through a hole made for that purpose." ¹²¹

As the new fire-proof building to hold the workshops progressed, Babbage began to plan its use. It was intended that Clement and his family actually live on the premises. On July 6, 1832, Clement, responding to a request from Babbage, sent him an estimate of what it would cost him to move. He wanted £350 for moving his tools to the new workshop and back when the work was finished, £130 for furniture, and an extra £660 per year "as compensation for having a divided business, keeping up an extra Establishment," and extra travel expenses. Clement also wanted some alterations made in the living quarters of the new building. ¹²²

Babbage forwarded Clement's memorandum to the Treasury. On September 14, James Stewart replied, saying that Clement's demands were "unreasonable and inadmissible." ¹²³ The Treasury would pay the actual expenses of moving the engine and tools; as for the other items, perhaps it would be cheaper to have Clement live at his own house; in this case the government would pay him two pounds per week for extra travel expenses; the other items were disallowed. Babbage forwarded a copy of this letter to Clement, who replied on October 12, suggesting that the matter be arbitrated by Donkin

and Field. [124](#)

Exactly what happened between October, 1832, and March, 1833, is difficult to reconstruct from the partial and somewhat conflicting accounts given by the various parties, but the following seems to be true.

After Clement's letter of October 12, Babbage several times tried to get Clement to make some alternate proposal on moving himself and the Engine to the East Street building, but Clement did not respond. [125](#) Early in 1833, Clement drew up his bill for work done between July 1 and December 31, 1832. On February 8, 1833, Donkin and Field examined the relevant parts of the machine in Clement's shop, and then proceeded with Clement to Babbage's house, where they examined a section of the Engine which had been assembled and could be operated (doubtless corresponding to the extant section); they found the material to be satisfactory. [126](#)

On February 26, Donkin and Field approved Clement's bill, and on February 27, he submitted it to Babbage. According to Clement, Babbage said that "he would not present my account to Government unless I would give him some other proposition for my removal to East Street; I told him the very great inconvenience that I should be put to made me decline going there altogether." [127](#)

According to Babbage, Clement not only did not give such a definite answer on the question of removal, but "ultimately he had refused even to write a letter to me to state that he declines giving me any answer." [128](#)

Babbage evidently once again found that he "moral difficulties" of the project were an onerous burden, and that disagreements over financial transactions with Clement interfered with his supervision of its actual construction, and he returned to his earlier conviction that satisfactory progress would be made only if the government paid Clement directly. Accordingly, when Clement again demanded payment on March 20, Babbage told him that he would forward the latest bill to the Treasury, and that as soon as he received payment, he would transfer it to Clement, but that he would no longer make advances from his own money. [129](#)

Clement replied, quite correctly, that he had had no dealings with the Treasury, and that as Babbage had given him all instructions and orders, he was personally responsible for paying the bill. Clement declared that he could not proceed with the machine unless someone took responsibility. Accordingly, the following day, Clement laid off the workmen employed in his shop and halted all construction. [130](#)

Babbage must have expected this result. Apparently he had decided that he could no longer serve as a financial middle man between Clement and the government, and decided that the government would agree to other arrangements if it was necessary in order for the work to continue. This is exactly what happened. Donkin, acting as intermediary, soon got Clement and the government to agree in principle that the latter would take direct responsibility for the cost of the machine, and the former would proceed with its construction. [131](#) In practice, the matter was not worked out so swiftly. Not until May 29 did the Treasury make an explicit commitment to pay Clement's old bill and give him direct authorization to proceed, as soon as the finished parts of the machine were deposited in the new building. [132](#) Clement on the other hand responded to this proposal by insisting that he be paid in full before any parts of the engine were moved. [133](#)

The matter rested without progress for some time, [134](#) but on July 22, 1833, Clement wrote a long letter to the Treasury, giving his own version of everything that had happened to date, and proposing what future course should be followed. He argued that his bill for the period ending December 31, 1832 had been approved and due several months earlier, and should be paid right away; further, it would be more convenient for the engineers to examine the work done between January 1, 1833, and March, when the work stopped, before it was moved to the new building; after the bill for that period was approved, the finished parts and unnecessary drawings could be moved, and then the Treasury could pay the bill. Clement also said that he would proceed with construction of the Difference Engine under Babbage's direction if the Treasury instructed him to, but he stressed the need for new procedures that would assure the prompt payment of his bills. [135](#)

The Treasury responded on August 13 with a minute directing that the £1782/11/4 due to Clement for work done up to December 31, 1832, should be paid to him forthwith, and that when the completed parts and drawings not needed in Clement's shop were deposited in East Street, they would pay his bill for January through March, 1833, the implication being that the work would be inspected after it was moved. [136](#)

On August 25, C.G. Jarvis, who had formerly worked on the Difference Engine as an assistant to Clement, wrote Babbage, suggesting that, if the machine was to be finished within any reasonable time it would be necessary to adopt a new procedure whereby the plans and working drawings would be executed in the new workshop under Babbage's immediate supervision, and then manufacture of the various parts could be contracted out to a variety of people, so that work on various sections could proceed simultaneously. Jarvis then continued with the following passage, highly revealing of his feelings toward Clement:

I am aware there will be great opposition to any such plan as this, and that every thing will be said and every thing will be done by more than one person to prevent its adoptions this I do not wonder at. To a man who although inactive and unenterprising loves money, it must be very agreeable to construct a newly invented machine, the cost of the parts of which cannot be taxed; and still more agreeable to be able to charge for time expended upon arranging the parts of that machine without the possibility of the useful employment of that time being disputed, and to doze over the construction year after year for the purpose of making one thing after another, and thus without any inconvenient exertion to gain the profit upon all; but it is not to the interest of the inventor that this should be suffered. His credit requires his invention to be completed with as small an outlay of time and money as possible; and his interest is any thing but promoted when his invention is placed at the disposal of persons who do not even know the names or purposes of the several parts without appealing to better heads than their own. [137](#)

Exactly how Babbage responded to this proposal is not clear, but it is clear that he valued Jarvis' abilities, and tried to persuade him to return to working on the Difference Engine under Clement when construction was continued. In a letter to Babbage on September 11, Jarvis expressed his disinclination to do so, despite his gratitude to and respect for Babbage, in even stronger terms:

Now let me consider what my situation would be if I returned. I must devote all my attention and care to this machine because, if any thing was made to a drawing which did not answer its purpose, I should incur the principal share of the blame as being necessarily most familiar with the details, whereas all the praise which perfection would secure would attach to Mr. Clement, who would come over now and then an sanction my plan only when he could not substitute any of his own, either better or worse; and I should have the indescribable satisfaction of knowing that I was labouring to increase the credit of a man who was envious of my talents and jealous of my influence, whose interest and inclination it would be to use every method in his power, however mean and mortifying, to guard against the suspicion of my possessing ability, and who would be paid about four times as much as myself for generously condescending to reap the fruits of my exertions. No! Whatever situation circumstances may force me into I will bear as best I may; but I will never, if I know it, become a party to my own degradation. [138](#)

In the meantime, the process of moving the appropriate material to East Street proceeded with incredible slowness, for reasons that cannot be determined. On December 4, 1833, Babbage wrote Clement, saying that he understood that preparations for the move were nearly complete, and asking that a day be agreed upon for the move itself. [139](#) On January 10, 1834, Clement wrote to James Stewart, at the Treasury, to say that preparations for the move were complete, but that it would be much more convenient for the engineers to make their examination before the parts were packed up. [140](#) This information was forwarded by Stewart to Babbage, who wrote Donkin and Field on February 4, requesting that they make the examination. [141](#)

What happened during the next six months is not clear, but on July 6, 1834, Babbage wrote to Donkin, saying that the parts and drawings were now in the new building, but that they needed to be examined before he could officially take charge of them. [142](#)

Finally, on July 16, 1834, Babbage wrote Stewart to inform the Treasury that the material had been examined and delivered into his charge the day before; he pointed out that no progress had been made since March, 1833, and asked for further instructions. In a private cover note to Stewart, Babbage said "The drawings and parts of the Engine are at length in a place of safety. I am almost worn out with annoyance and disgust at the whole affair. [143](#)

Before turning to the final phase of the Difference Engine project, we must consider two other matters from earlier in the year which shed some light on the public view of the Difference Engine.

In an undated letter evidently written in the later part of 1833, Dionysius Lardner (the immensely prolific popularizer of science) informed Babbage that he

wished to consult him "respecting some steps to get up an contrivance for explaining the Machine at popular lectures." ¹⁴⁴ In about December, 1833, Babbage wrote to Alexander von Humbolt in Berlin, saying that he and Lardner had been cooperating on preparing lectures on the Difference Engine and the mechanical notation which Lardner was to deliver in Manchester, Leeds, "and several other large manufacturing towns" through Easter; but after that Lardner could deliver them in Berlin, if Humbolt cared to invite him. ¹⁴⁵

On February 16, 1834, Lardner reported to Babbage from Manchester that the first lecture had been a great success, but that he feared he could not complete the exposition in three lectures. ¹⁴⁶ At the end of March, Lardner wrote Babbage that more than 5000 people had thus far heard the lectures, and that he would present them again at the Royal Institution in London in April and May. ¹⁴⁷ By this time, it had also been arranged for Lardner to write an article on the Difference Engine for the *Edinburgh Review*, but he complained that he had had no time to work on it. In April and May, Lardner and Babbage corresponded about the article, and Babbage took a large hand in preparing it. ¹⁴⁸ The article finally appeared in the July, 1834, issue of the *Edinburgh Review*, ¹⁴⁹ and it formed much the most competent and extensive description of both the background and the actual operation of the Difference Engine published up to the present day.

As far as one can tell, Lardner took no direct part in mediating between Babbage, Clement and the government, although he was highly interested in seeing the Difference Engine completed. But in this regard, there is a most interesting passage at the end of his *Edinburgh Review* article, one which clearly was not submitted for Babbage's approval, and, indeed, was directed more toward Babbage himself than toward other readers. Lardner mentioned that construction had been halted for a considerable period and showed no signs of being soon resumed. He said that Babbage ought to have suggested to the government exactly what arrangements would be most conducive to the completion of the machine, but he had not done so:

On the contrary, it is said that he has of late almost withdrawn from all interference on the subject, either with the Government or the engineer. Does not Mr. Babbage perceive the inference which the world will draw from this course of conduct? Does he not see that they will impute to it a distrust of his own power, or even to a consciousness of his own inability to complete what he has begun? We feel assured that such is not the case; and we are anxious, equally for the sake of science, and for Mr. Babbage's own reputation, that the mystery - for such it must be regarded - should be cleared up; and that all obstructions to the progress of the undertaking should immediately be removed. Does this supineness and apparent indifference, so incompatible with the known character of Mr. Babbage, arise from any feeling of dissatisfaction at the existing arrangements between himself and the Government? If such be the actual cause of the delay (and we believe that, in some degree, it is so), we cannot remain from expressing our surprise that he does not adopt the candid and straightforward course of declaring the grounds of his discontent, and explaining the arrangement which he desire to be adopted. ¹⁵⁰

Some further interesting light is shed on the Difference Engine and its reputation by a letter to Babbage from Richard Wright, dated June 18, 1834. Wright had formerly worked on the machine under Clement, and he wrote to tell Babbage that he had subsequently gotten a job in a Manchester factory through Joseph Whitworth; Whitworth, later Sir Joseph Whitworth, had himself worked in Clement's shop during 1831 to 1833, ¹⁵¹ and had subsequently become a partner in the Manchester firm where Wright was employed. Wright said that the fact that he had worked on the Difference Engine had been a great help to him, since there "is much talk about the Machine here, so much so that a Man who has worked at it has a greater chance of the best work, and I am proud to say I am getting more wages than any other workman in the factory." ¹⁵²

Another interesting fact revealed in this letter is that Babbage had been considering hiring someone to replace Clement in charge of construction, one candidate being Wright. Wright said that he was confident that he could finish the machine "with workmanship equal to that which is done, and I think I shall not exaggerate in saying with one half the trouble to yourself, one third the time, and one fourth-the Expense." ¹⁵³

Returning to the fate of the construction of the Difference Engine itself, as stated above, Babbage reported on July 16, 1834, that the finished parts were back in his possession, and asked the Treasury for instructions; one reason he felt the need for new authorization was that in July, a new government was formed, although it lasted only until December, and Babbage felt the need for a new sanction to proceed.

On August 16, James Stewart replied, telling Babbage that the payment of an additional £1200 to Clement had been authorized, to bring the accounts up to date, and giving Babbage authority to proceed with construction. ¹⁵⁴

This did not happen. The reasons were many and complicated, and no fully accurate explanation can be reconstructed, but some of the reasons can be given here.

Babbage no longer felt it possible to work effectively with Clement, yet he was reluctant to try and teach a new man what was wanted. Babbage had already spent many more years on the project than he had originally intended, and he had had to forego many other activities, some directed toward science and some toward profit. He was fed up with having to deal from a position of weakness with a series of governments which often seemed to have neither understanding nor enthusiasm for the project. Despite the fact that Babbage had lost money because of the Difference Engine, he was thought by many people to have been paid for his work. Further, despite all of these sacrifices and annoyances, Babbage had received neither reward nor honor for his time and energy, indeed not even an expression of gratitude.

However, all of these factors had been present to a greater or lesser degree in previous years, and the crucial factor was a new development which undermined Babbage's deep interest in the Difference Engine, an interest which previously had brought him to overcome such obstacles; this development was the invention of the Analytical Engine. The way in which the Analytical Engine. (which was not in fact called this until many years later) emerged out of Babbage's work on the Difference Engine and then developed on its own is the subject of the next chapter. What is crucial at this point is that in September, 1834, Babbage began working in a new direction, though without yet knowing just where he was going, and his interest in the Difference Engine steadily waned.

At first, Babbage simply wished to inform the government of the invention of the new machine so that they could decide whether they wished him to continue building the old one. Babbage wrote twice in September and again in October, 1834, to Lord Melbourne, the Prime Minister, requesting an interview and suggesting that Melbourne ought to personally inspect the machine. Melbourne showed some interest, but his government was thrown into crisis, and he was out of office by December with no interview having taken place. ¹⁵⁵

The Whig government of Melbourne was replaced by the Tory government of Sir Robert Peel, who also served as his own Chancellor of the Exchequer. The Duke of Wellington served as Foreign Secretary, and on December 17, 1834, Babbage wrote to him, saying:

Sir Robert Peel's known opinions upon science render me unwilling to apply to him in the first instance, and my object in applying to your Grace is to entreat you to procure for me a decision; after the delay and neglect I have experienced, the nature of that decision is of comparatively minor importance. ¹⁵⁶

On December 18, Wellington replied, asking Babbage just what it was he wished him to do. Babbage responded by preparing an important paper dated December 23, entitled "Statement addressed to the Duke of Wellington respecting the Calculating Engine." ¹⁵⁷

Babbage began by summarizing the first ten years of the project, and the personal and financial sacrifices he had had to make. He then stated that the successful operation of the section of the machine assembled in 1832 had shown the soundness of his plans and of the work done. Whereas it would have been reasonable to expect that the government would recognize and honor this "first conversion of mental into mechanical processes," they chose instead to ignore it.

Babbage then laid out the four different courses that could be followed. First, the government could request that Babbage continue to supervise Clement in the construction of the machine; Babbage said that this would be virtually impossible, implying that present relations with Clement make it so. Second, the government might suggest that Clement be replaced by another engineer; Babbage commented that this would be much more successful, but that it would call for sacrifices from him which he was not willing to make; he hinted, however, that he might agree to this plan if the government would in some way reward him. Third, the government might find someone other than Babbage to supervise construction; Babbage said that this would be a course of "doubtful expediency," but that if they wished to follow it, he would fully cooperate. Finally, it might be decided to abandon the project; Babbage predicted that if this were done there would probably be a Parliamentary inquiry which would end up unjustly blaming Babbage for squandering large sums of public moneys but, Babbage said, "I have experienced the injustice of my countrymen, and if need be I shall not quail before a greater exercise of it."

Babbage then announced his recent invention of "a totally new engine possessing much more extensive powers, and capable of calculations of a nature far more complicated." But, he hastened to add, although much more powerful than the old machine, "it is not intended to supersede it, on the contrary, it will greatly extend its range and usefulness." He declared his intention to complete the design of the new machine so that it could be constructed from the drawings "at any future period."

Babbage expressed doubt that he could ever afford to build the new machine himself, and clearly he did not expect that the English government would support it. Curiously, however, he warned that some foreign government might decide to sponsor the construction of the new machine in their own country, and that foreign workmen would learn about the best of English machining tools and techniques the result would be "that a school of mechanical engineers might arise whose influence would give a lasting impulse to the whole of the manufactures of that country, and that the secondary consequences of the acquisition of that Calculating Engine might become more valuable than the primary object for which it was sought."

Despite this suggestion that the construction of the Analytical Engine might easily pay for itself in the value of its technological spin-off alone, Babbage did not in fact request or even suggest that the English government should underwrite it. Indeed, the thrust of the whole Statement to Wellington is rather perplexing; although Babbage requested as rapid a decision on the Difference Engine as possible, the effect of the letter was to argue that any of the decisions he enumerated would be wrong.

Evidently Wellington also found Babbage's statement perplexing, for there was no response. On April 7, 1835, Babbage sent to Sir Robert Peel, Prime Minister, a copy of the statement to Wellington, again appealing for a prompt decision; [158](#) but Peel's government soon fell, and Viscount Melbourne (William Lamb) returned to head a new one. Babbage sent him another copy of his statement with the same appeal on May 4, 1835. [159](#)

On May 15, 1835 there was a Parliamentary debate on the Civil Contingencies funds, out of which Babbage had been paid. It was charged that a number of projects that had been supported had constituted "unprincipled waste and squandering public money," and Babbage's machine was mentioned among these. In reply, Spring Rice, the new Chancellor of the Exchequer, said that the Difference Engine was "a most distinguished scientific discovery," and stated that the money had been used only to pay the expenses of construction, not "a single farthing" going to Babbage himself. In response, another Member (Mr. Warburton) expressed his apprehensions "lest the Gentleman, who had produced the invention, greatly desirous to bring his machine to as great a degree of accuracy as possible, and successive improvements occurring to himself, should go on, step by step, and be led on to greater expense than would be proper." He suggested that the Treasury call for a report on the present state of the machine. [160](#)

On April 20, Spring Rice wrote to Babbage, inquiring whether he wanted his statement to the Duke of Wellington to be made a public document. Rice also mentioned the questions on the machine in the House of Commons, and suggested that in order to answer them the government could refer again to the Royal Society for the report on progress. [161](#) In his reply, dated May 22, and in an interview on May 26, Babbage argued that nothing would be gained by referring the question to the Royal Society. Babbage said that the most progress on construction would be made if the work were done in the new East Street workshop under the control of Jarvis, and under an agreement which gave incentive to the workmen to finish the machine rapidly. [162](#)

Apparently Jarvis had been working for Babbage on the drawings of the new engine since the fall of 1834; in November, 1835, Jarvis was offered another job at higher wages which would have required him to move abroad; the result was a new one year renewable contract between Jarvis and Babbage, wages being paid by Babbage personally at the rate of £11/8 per day. [163](#)

On January 14, 1836, after more than a year's delay, Babbage finally received from Spring Rice a letter responding to Babbage's statement to the Duke of Wellington. In this letter Rice said the following:

The conclusion to be drawn from the statement alluded to is that you have invented a machine of much more extensive powers and capable of calculations of a nature far more complicated than those to be performed by the machine at present in progress; and you request to be informed whether Government would undertake to defray the expense of this new machine. [164](#)

At this point Babbage wrote in the margin of the letter: "I never did make this request nor ever thought of doing so."

Rice further stated that the government would not feel justified in considering support for the construction of the new machine until the old one was finished. Rice anticipated that there would be further questions raised in Parliament, and again suggested that in order to be able to answer them the government should ask for a report from the Royal Society.

Babbage replied on February 2, 1836. He said that the state of the new engine at the time he had written to Wellington had been such that it would have increased the usefulness of a Difference Engine, but that subsequently the new machine had progressed to a point where it not only can do many things that the old machine couldn't, but "it also performs all those calculations which were peculiar to the old engine both in less time and to a greater extent," and, in fact, "it completely supersedes the old Engine." Further, Babbage said, the new machine had become so mechanically simple that if it were desired only to have a machine with the powers of the Difference Engine, still "it would be more economical to construct such an engine on the new principles than to finish the one already partly constructed." Babbage pointed out that it was fairly common for machines to become obsolete very rapidly, sometimes even before they were completed. Babbage concluded his letter by saying that his report was merely for the information of the government, and that "I wish distinctly to state that I do not entertain the slightest doubt of the success of the first Engine, nor do I intend it as an application to finish the one or to construct the other." [165](#)

From Rice's letter to Babbage of January 14, it had appeared that the government fully intended to support the completion of the Difference Engine, despite the delays and difficulties which had beset it. But Babbage's reply seems, understandably, to have thrown them into some confusion, and they neither replied to Babbage nor asked the Royal Society for a report. The next move came, after a long delay, from Babbage, who wrote to Lord Melbourne, still the Prime Minister, on July 26, 1838. Babbage appealed "for the last time to ask for no favor, but to ask for that which it is an injustice to withhold from me: a decision." He said that he had been asking for a definite decision for five years, and "if the question has now become more difficult because I have invented superior mechanism which supersedes that already partly erected, this consequence has arisen from that very delay against which I have repeatedly remonstrated." [166](#)

An assistant to Lord Melbourne (whose name cannot be deciphered) replied to Babbage on August 16, 1838, saying that the government did not understand what Babbage wanted them to decide. Did he wish to finish the old machine or to start the new one? What did he think either of these courses would cost? [167](#)

Babbage replied on October 21, 1838 (he had not received the August 16 letter until he returned "from a tour of the Highlands"). He said that he had never applied for support for the new engine; not being a Professional engineer, he declined to estimate the cost of either machine. The only question he wished to have decided was: "whether the government require me to superintend the completion" of the Difference Engine "or whether they intend to discontinue it altogether." [168](#)

For unknown reasons, the government made no further response, and Babbage apparently gave up hope of extracting from them the decision that he wanted. He made no further advances for well over three years, until Sir Robert Peel had again become Prime Minister. Then, on January 22, 1842, Babbage wrote to Peel and asked if the understanding implied by his early relationship with the government (that he would work on the machine until it was finished) could be considered as ended. [169](#)

On January 29, 1842, Sir George Clerk replied to Babbage from the Treasury, saying that Peel was at the time too busy to make any decision in the matter, but that he would attend to it as soon as he could. As expressed by Clerk, the choice was between completing the Difference Engine on the old principles or building a new difference machine on the new simpler principles. He said that the Treasury understood that the cost would be about £8000, and suggested once again that the matter be referred to the Royal Society. [170](#)

Babbage responded on February 4, 1842, writing to Clerk that he had "never either asked or offered to make any other Machine for the Government" than the original Difference Engine; all that was to be decided was whether it should be abandoned. Further, the estimate of £8000 was probably much too low. There was no reply to this letter; Babbage tried again to get some response from Peel on July 9, August 12, and October 8, but with no success. [171](#)

Although not yet responding to Babbage's letters, the government had by this point begun to consider the matter. On September 15 Henry Goulburn, who was once again Chancellor of the Exchequer, asked the opinion of Sir George Airy, the Astronomer Royal, as to the probable utility of the Difference

Engine, and the propriety of spending more money on it; Airy's reply was "that it was worthless."¹⁷² Curiously, in 1822, while an undergraduate at Cambridge, Airy had heard of Babbage's recent invention of the Difference Engine, and had himself sketched out some ideas for calculating machines.¹⁷³ However, by 1837, Airy's opinion of the Difference Engine was that "the thing is a humbug,"¹⁷⁴

Finally on November 3, Goulburn wrote to Babbage, saying that he and Peel felt that they could not justify the additional estimated expense to complete the Difference Engine, although they greatly regretted abandoning a machine "on which so much scientific ingenuity and labour has been bestowed." But they hoped "that by withdrawing all claim on the part of the Government to the machine as at present constructed and by placing it at your entire disposal, we may to a degree assist your future exertions in the cause of science."¹⁷⁵

On November 6, Babbage replied to Goulburn, refusing the offer of the government to give him the parts of the Difference Engine.¹⁷⁶ The same day he wrote also to Peel; he said that he inferred that the government might be more interested in supporting the construction of the Analytical Engine, and that they might be prepared to consider Babbage's claim for remuneration. He requested an interview with Peel to discuss these matters.¹⁷⁷

This interview took place on November 11. The only record of it is several pages of "Recollections" recorded shortly afterwards by Babbage.¹⁷⁸ It appears that Babbage focused on the statement reported to him by Lord Ashley on the basis of his interview with Goulburn when he was Chancellor of the Exchequer in February, 1830, to the effect that "at the end when it is completed they were most willing to attend to my claim for remuneration."¹⁷⁹ Babbage had written to Lord Ashley on January 17, 1842, asking him to confirm that this had been said; in the same letter he remarked that the proposal had been totally unexpected by him.¹⁸⁰

From the meager record of the 1830 understanding, it is not possible to determine if the government was undertaking to simply repay the expenses of the Difference Engine when it was finished, or whether they were agreeing to reward Babbage himself for the work he had done.

Clearly, in 1842, Babbage thought both these things were implied.

Thus it seems that his intentions in the interview with Peel in November were to determine if the government intended to reward him, since, as he saw it, the Difference Engine had been abandoned as the result of the government's decision, and through no fault of his own. He was then going to make some proposal for building either the Analytical Engine or a new type of Difference Engine.¹⁸¹

In fact, although Babbage summarized at length the many sacrifices he had made, and described how many other men of science had been rewarded with either money or honor, Peel denied that Babbage had any claim to such reward himself. At this, Babbage "merely remarked that I considered myself to have been treated with great injustice, but that as he was of a different opinion, I could not help myself, on which I got up and wished him good morning." Babbage made no proposal for future arrangements.¹⁸²

Thus ended the construction of the Difference Engine finally and officially. Babbage refused to accept the completed section from the government as a gift; he recommended instead "that the finished part of the original Difference Engine and all the drawings in as complete a state as possible ought to be carefully preserved for the history of science; and that the partially manufactured materials are of comparatively insignificant value."¹⁸³

The assembled portion was placed in the Museum of King's College, London, along with the drawings. The unassembled parts were sold to Babbage for their value as scrap metal; he also bought one tool and several drawing boards. The extent of the parts of the engine which were completed but not assembled is difficult to judge, as there is nowhere any detailed description of them. However, in November, 1834, Babbage had stated that there were "above ten thousand pieces of the Engine" stored in the new workshop.¹⁸⁴ This number seems implausibly high, even though it doubtless included every screw. But the indirect evidence suggests that it comprised all or nearly all of the parts of the calculating section of the full scale engine, some ten times the magnitude of the section actually assembled, but included nothing from the printing mechanism.¹⁸⁵ The great majority of these pieces were eventually cut up or melted down as scrap.¹⁸⁶

No doubt Babbage felt considerable relief at finally having the matter settled, although also considerable distress at the ingratitude of the government and the failure of his many years of work to bear tangible fruit. The ambivalence felt by Babbage and his friends found expression in the judgment rendered on the entire Difference Engine project in a letter to Babbage from his brother-in-law and supporter, Wolryche Whitmore, dated November 21, 1842, one which could equally well have been a judgment of most of Babbage's life:

Had I not long been convinced that the decision the Government have come to, e.g. abandoning the old machine, was the only one to which, under the circumstances, they could come, I should have been sadly disappointed by your letter. That you should have occupied so much time and expended so large an amount of talent and ingenuity on a machine now superseded and rendered comparatively of smaller moment is much to be lamented but you are your own rival, and exercise too much ingenuity for the age in which you live and your own pecuniary or temporary interests. That posterity will render justice to your talents I do not doubt, but unfortunately such considerations do not add either to ones wealth or consideration in the present age. I scarcely know what to say on this perplexing subject; that you should continue all your life to expend so much talent and money on an undertaking which however ingenious is never in your lifetime likely to be brought practically to a conclusion seems unfortunate, but you are and must be as well the best as in truth the only judge in the matter.¹⁸⁷

FOOTNOTES

^{#1} Limerick by Maurice Evan Hare, quoted in *The Modern Dictionary of Quotations*. ed. Robin Hyman, London, 1962, p.128.

^{#2} B.M., Vol. I, ff. 95-96.

^{#3} See B.M., Vol. I, ff. 52-53. 270-271.

^{#4} On Babbage's role in founding the Astronomical Society, see B.M., Vol. I, ff. 217. 227-28. 237-38, 241-42.

^{#5} B.M., Vol. I, ff. 241-42.

^{#6} The account given in P.L.P., p. 42, the only one ever published, may be regarded as apocryphal, having been written over forty years after the fact, and presented as second hand. Yet it may simply have been set ten years too early, and in the wrong Society. In any case, the event described was not the invention of a calculating machine, but the recognition that one might be invented.

^{#7} Buxton, Vol. VII.

^{#8} Buxton, Vol. VII. This passage is from the introduction to a paper Babbage intended to write, entitled "History of the Invention of the Calculating Engine," but he never continued it.

^{#9} Buxton, Vol. IX. This is from the introduction to an unwritten paper to be called "The science of Number reduced to Mechanism." The existing introductory section is not dated, but elsewhere in the Buxton papers there is a loose sheet, dated November 26, 1839, outlining a paper of the same name; it is clear that the two belong together.

^{#10} Buxton, Vol. IX.

^{#11} See B.C.E., p. 211.

^{#12} Buxton, Vol. VII.

^{#13} B.M., Vol. I, ff. 415-416.

^{#14} Again, from the November, 1822 paper; Buxton, Vol. III.

^{#15} Buxton, Vol. VIII. In a note added to the first page of this manuscript sketch, and dated 1840, Babbage referred to it as "the first idea and earliest

sketch of the Calculating Engine." The original paper is not dated.

[#16](#) Ibid.

[#17](#) Buxton, Vol. III.

[#18](#) B.M., Vol. I, ff. 398-99.

[#19](#) The next six paragraphs are all based on the November, 1822. manuscript: Buxton, Vol. III.

[#20](#) See below.

[#21](#) B.C.E., pp. 212-13.

[#22](#) Buxton, Vol. III.

[#23](#) B.C.E., p. 224.

[#24](#) B.C.E., p. 225.

[#25](#) H.C.E., p. 211.

[#26](#) B.C.E., p. 213.

[#27](#) P.L.P., p. 47.

[#28](#) The "Note" was published in the *Memoirs of the Astronomical Society, of London*, Vol. I, Pt. II (1825), p. 309, and reprinted in B.C.E., p. 211.

[#29](#) B.M., Vol. I, ff. 419-20.

[#30](#) B.M., Vol. I, f. 423.

[#31](#) Reprinted in B.C.E., pp. 212-15.

[#32](#) Ibid.

[#33](#) B.M., Vol. I, f. 425.

[#34](#) B.M., Vol. I, ff. 431-432.

[#35](#) The letter was reprinted in B.C.E., pp. 216-19.

[#36](#) "Observations on the Application of Machinery to the Computation of Mathematical Tables," *Memoirs of the Astronomical Society of London*, Vol. I, Pt. II (1825), pp. 311-14; reprinted in B.C.E., p. 220-22.

[#37](#) B.C.E., pp. 218-19.

[#38](#) B.M., Vol. II, f. 144. The year is not given in the date on this letter, and the cataloguer of the correspondence has placed it in 1824. This may be correct, but the postmark looks more like 1822, and it is so dated here.

[#39](#) B.M., Vol. II, ff. 8-9. Babbage marked his copy of the original letter; "given me by J.O. Martin."

[#40](#) See above; B.M., Vol. I, f. 425. Gilbert was both Treasurer of the Royal Society and a Member of Commons.

[#41](#) *Parliamentary Papers*, 1823 (370) VX, 9.

[#42](#) Ibid.

[#43](#) Ibid.

[#44](#) B.M., Vol. I, ff. 433-34. The letter is not dated; the cataloguer has marked it as possibly written about August 20, 1822, but the reference to the "Parliamentary inquiry" make it more plausible that it is from about May, 1823.

[#45](#) B.M., Vol. II, ff. 30-31.

[#46](#) B.M., Vol. II, f. 32.

[#47](#) B.M., Vol. II, f. 39.

[#48](#) *Memoirs of the Astronomical Society of London*, Vol. I, Pt. II (1825), pp. 509-12; reprinted in B.C.E., pp. 223-24.

[#49](#) *Statement of the Circumstances Respecting Mr. Babbage's Calculating Machine*, privately printed pamphlet, 1843, p. 5; a copy of the pamphlet is in the Buxton material. The "Statement" was reprinted in P.L.P. as Chapter VI; it was there said to have been "drawn up by the late Sir. H. Nicolas" from Babbage's papers (p. 68).

[#50](#) B.M., Vol. III, f. 285.

[#51](#) B.M., Vol. II, f. 55; Davies Gilbert sent Babbage this copy of the letter.

[#52](#) On Clement, see Samuel Smiles, *Industrial Biography: Iron Workers and Tool-Makers*, Boston, 1864, pp. 289-313. See also Chapter Four of this thesis.

[#53](#) B.M., Vol. II, ff. 371-72.

[#54](#) B.M., Vol. II, ff. 444-45. The draft of Babbage's letter is not dated, but internal evidence and its relation to other letters place it in late March or early April, 1827.

[#55](#) B.M., Vol. III, f. 3.

[#56](#) *Memoirs and Correspondence of Major-General H.P. Babbage*, London, 1910, p. 1. Mabeth Moseley, in *Irascible Genus* (London, 1964), p. 83. has evidently misread H.P. Babbage's remarks on his mother's death, and places it in September.

[#57](#) B.M., Vol. III, ff. 92-93.

[#58](#) P.L.P., p. 72.

[#59](#) B.M., Vol. III, ff. 114-15.

[#60](#) P.L.P., p. 73.

[#61](#) B.M., Vol. III, ff. 156-57, 163-65.

[#62](#) Ibid.

[#63](#) . B. C. S., p. 232.

[#64](#) Taken from the full report, reprinted in B.C.E., pp. 233-35.

[#65](#) B.C.E., p. 232.

[#66](#) B.M., Vol. III, ff. 233-34.

[#67](#) B.M., Vol. III, ff. 252-53.

[#68](#) B.M., Vol. III, ff. 254-55.

[#69](#) B.M., Vol. III, ff. 252-53.

[#70](#) B.M., Vol. III, ff. 266-67.

[#71](#) B.M., Vol. III, ff. 264-65.

[#72](#) B.M., Vol. III, f. 285.

[#73](#) B.M., Vol. III, ff. 281-82.

[#74](#) B.M., Vol. III, f. 310.

[#75](#) These notes are: B.M., Vol. III, ff. 291-92, 310.

[#76](#) B.M., Vol. III, ff. 337-38.

[#77](#) B.M., Vol. III, f. 419.

[#78](#) Ibid.

[#79](#) B.M., Vol. III, f. 463

[#80](#) B.M., Vol. IV, f. 21.

[#81](#) B.M., Vol. IV, ff. 57-58.

[#82](#) B.M., Vol. V, ff. 25-26.

[#83](#) B.M., Vol. III, ff. 301-5; P.L.P., pp. 73-74.

[#84](#) P.L.P., pp. 74-75.

[#85](#) B.M., Vol. III, ff. 337-38.

[#86](#) B.M., Vol. III, ff. 369-72.

[#87](#) B.M., Vol. III, f. 404.

[#88](#) B.M., Vol. III, f. 405.

[#89](#) B.M., Vol. III, f. 413.

[#90](#) B.M., Vol. III, f. 412.

[#91](#) B.M., Vol. III, ff. 421-22.

[#92](#) B.M., Vol. III, ff. 426-29.

[#93](#) B.M., Vol. III, ff. 432-35.

[#94](#) B.M., Vol. III, f. 445.

[#95](#) B.M., Vol. III, ff. 451-52.

[#96](#) B.M., Vol. III, ff. 459-60.

[#97](#) B.M., Vol. III, ff. 455-56.

[#98](#) B.M., Vol. III, ff. 459-60.

[#99](#) B.M., Vol. III, f. 464.

[#100](#) B.M., Vol. IV, ff. 10-11.

[#101](#) Ibid.

[#102](#) B.M., Vol. IV, ff. 69-70.

[#103](#) B.M., Vol. IV, ff. 96, 105.

[#104](#) B.M., Vol. IV, ff. 98-99.

[#105](#) B.M., Vol. IV, f. 258.

[#107](#) B.M., Vol. IV, f. 286.

[#108](#) B.M., Vol. IV, f. 380.

[#109](#) B.M., Vol. IV, f. 394.

- [#110](#) B.M.. Vol. IV. f. 524.
- [#111](#) B.M.. Vol. IV, f. 387. The letter is dated December 23, but this must be a mistake for the 24th or 25th.
- [#112](#) B.M., Vol. IV, f. 396.
- [#113](#) B.M., Vol. IV, ff. 384, 428, 431, 433.
- [#114](#) B.M., Vol. IV, ff. 447, 455-48.
- [#115](#) B.M., Vol. IV, ff. 419-20. The letter is undated, but its relation to other letters places it in early February, 1831.
- [#116](#) B.M., Vol. IV, ff. 474-79, Vol. V, ff. 295-96.
- [#117](#) B.M., Vol. IV, ff. 513-15.
- [#118](#) B.M., Vol. V, ff. 25-266.
- [#119](#) B.M., Vol. VI, f. 125.
- [#120](#) B.M., Vol. V, ff. 63-65.
- [#121](#) B.M., Vol. V, f. 345.
- [#122](#) B.M., Vol. VI, ff. 6-8.
- [#123](#) B.M., Vol. VI, ff. 134-36.
- [#124](#) B.M.. Vol. VI, f. 168.
- [#125](#) B.M., Vol. VI, ff. 458-59.
- [#126](#) B.M., Vol. VII, ff. 16-17.
- [#127](#) Ibid.
- [#128](#) B.M., Vol. VI, ff. 458-59.
- [#129](#) B.M., Vol. VII, ff. 16-17.
- [#130](#) B.M., Vol. VI, f. 453.
- [#131](#) B.M., Vol. VI, ff. 465, 480.
- [#132](#) B.M., Vol. VI, f. 549.
- [#133](#) B.M., Vol. VI, f. 557.
- [#134](#) According to Babbage, this was because Clement would not make any constructive proposals B.M., Vol. VII, f. 22.
- [#135](#) B.M., Vol. VII, ff. 16-17.
- [#136](#) B.M., Vol. VII, f. 28.
- [#137](#) B.M., Vol. VII, ff. 39-40.
- [#138](#) B.M., Vol. VII, ff. 58-59.
- [#139](#) B.M., Vol. VII, f. 96.
- [#140](#) B.M., Vol. VII, f. 186.
- [#141](#) B.M.. Vol. VII, f. 191.
- [#142](#) B.M., Vol. VII, f. 435. Replying on July 7 (f. 437), Donkin blamed three months of delay on "the obstinacy of Clement."
- [#143](#) B.M.. Vol. VII, ff. 449-50.
- [#144](#) B.M., Vol. VII, f. 203.
- [#145](#) B.M., Vol. VII, ff. 123-124.
- [#146](#) B.M., Vol. VII, ff. 208-09.
- [#147](#) B.M., Vol. VII, ff. 288-89.
- [#148](#) B.M., Vol. VII, ff. 335-36. 350.
- [#149](#) No. CXX, The article "Babbage's Calculating Engine," was reprinted in B.C.E., pp. 51-82.
- [#150](#) B.C.E., pp. 81-82.
- [#151](#) B.M., Vol. XV, ff. 264-65.
- [#152](#) B.M., Vol. VII, ff. 390-91.
- [#153](#) Ibid.
- [#154](#) B.M., Vol. VII, f. 451.
- [#155](#) B.M., Vol. VII, ff. 480-81, 484, 488.
- [#156](#) B.M., Vol. VII, ff. 520-21.
- [#157](#) B.M., Vol. VII, ff. 525-29.
- [#158](#) B.M., Vol. VIII, f. 74.

[#159](#) B.M., Vol. VIII, f. 89.

[#160](#) *Eansard's Parliament Debates*; Third Series, Vol. XXVII, 1154-55.

[#161](#) B.M., Vol. VIII, f. 100.

[#162](#) B.M., Vol. VIII, ff. 101, 110, 112.

[#163](#) B.M., Vol. VIII, ff. 203-4.

[#164](#) B.M., Vol. VIII, ff. 273-76.

[#165](#) B.M., Vol. VIII, ff. 292-93.

[#166](#) B.M., Vol. IX, f. 496.

[#167](#) B.M., Vol. IX, ff. 518-19.

[#168](#) B.M., Vol. X, f. 14.

[#169](#) B.M., Vol. XI, f. 19.

[#170](#) B.M., Vol. XI, ff. 29-30.

[#171](#) B.M., Vol. XI, ff. 37, 128, 147.

[#172](#) *Autobiography of Sir George Biddell Airy*, ed. Wilfrid Airy, Cambridge, England, 1896, p.152.

[#173](#) *Ibid.*, p. 37.

[#174](#) *The Diaries of William Charles Macready*, ed. William Toynbee, New York, 1912, p. 410

[#175](#) B.M., Vol. XI, ff. 172-73.

[#176](#) B.M., Vol. XI, f. 178.

[#177](#) B.M., Vol. XI, ff. 176-77.

[#178](#) B.M., Vol. XI, ff. 189-94.

[#179](#) B.M., Vol. IV, ff. 69-70.

[#180](#) B.M., Vol. XI, f. 13.

[#181](#) B.M., Vol. XI, ff. 180-84.

[#182](#) B.M., Vol. XI, ff. 189-94.

[#183](#) B.M., Vol. XI, ff. 224-26.

[#184](#) B.M., Vol. VII, f. 514.

[#185](#) See, e.g. B.M., Vol. VII, ff. 39-40.

[#186](#) *Memoirs and Correspondence of Major-General H.P. Babbage*, London, 1910, pp 224-25.

[#187](#) B.M., Vol. VII, ff. 506-7. The year is not supplied on the letter, but is clear from the context, although the cataloguer has placed it in a much earlier volume.

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CHAPTER THREE

The Analytical Engine through 1846

"The Calculating Engine is a Locomotive that lays down its own railway." ¹

= In order to understand the genesis of the Analytical Engine, one must trace it back to 1822, to the first stages of Babbage's work on the Difference Engine. As mentioned in Chapter Two, Babbage had from the beginning the idea of a machine to calculate tables by difference methods for functions without a constant difference, and he announced this idea in his "Letter to Sir Humphrey Davy" in July, 1822. ² It was out of this seed, which lay dormant until 1834, that the Analytical Engine grew.

Before exploring just what that idea was, it will be necessary to explain in an elementary way another aspect of the method of finite differences. First, it will be remembered from Chapter Two that the fundamental definition of finite differences is:

$$\Delta u_x = u_{x+w} - u_x$$

and that Δu_x is itself a function of x . For convenience, it will be assumed for the rest of this discussion that w is equal to one, that is, that we are tabulating various functions always using an increment of unity. It will be further remembered that for any algebraic equation of order n , the n -th order difference is a constant, which is the same as saying that the differences of higher order than n are all zero, and are not needed in a difference machine. Babbage decided that for the full scale Difference Engine the appropriate compromise between a small machine and wide applicability would be to set n equal to six.

Again, it will be remembered that transcendental functions (in this discussion the sine function will be used as the example) do not have any order of difference constant; that is, to tabulate a sine function precisely would take an infinite number of columns in a difference engine. In practice, this is not necessary, since the higher order differences do become smaller; one can substitute for the transcendental function an algebraic function which approximates it over a given domain, then manually alter the differences to proceed through another domain, and so on. As the number of orders of difference available becomes larger, the width of the domain that can be tabulated without intervention increases also; but as the number of significant figures to be retained goes up, the possible domain shrinks. In practice, it is possible to tabulate a sine function through a whole quadrant only by breaking it up into many small domains. To calculate a sine table at intervals of one minute with eight significant digits, a machine which had a constant fourth difference and fifteen digit capacity would have to be reset about every two degrees ³

This approach Babbage found to be objectionable, for two reasons. First, the necessity of manually altering the setting of the machine several times in an operation greatly increased the possibility of introducing errors into the tables it produced, and this he wanted to avoid at all costs; it also became more difficult to verify the accuracy of a produced table, since it was no longer true that if the first and last values were correct, the whole table was correct. Second, Babbage found this approach to transcendental functions to be theoretically impure and inelegant; it did not satisfy his image of the intimate relation that should be possible between the machine and the mathematics on which it was based.

As it turned out, Babbage found that transcendental functions could often be handled quite simply and elegantly by a somewhat different approach to dealing with the fact that they had no order of difference constant. This can be seen in the following simple development.

Taking again the fundamental definition of the method of finite differences, and assuming we want to tabulate the function $\sin(x)$ from zero to ninety degrees for increments of one degree, it follows immediately that:

$$\Delta \sin(x) = \sin(x+1) - \sin(x)$$

then taking the elementary trigonometric identity:

$$\sin(a) - \sin(b) = 2\cos\frac{1}{2}(a+b)\sin\frac{1}{2}(a-b)$$

= we get, combining all the constant factors into Z :

$$\Delta \sin(x) - Z\cos(x+\frac{1}{2})$$

It then follows that;

$$\Delta^2 \sin(x) = Z [\cos(x + 3/2) - \cos(x + 1/2)]$$

Using the identity:

$$\cos(a) - \cos(b) = -2\sin\frac{1}{2}(a+b)\sin\frac{1}{2}(a-b)$$

and combining all the constant factors, we get:

$$\Delta^2 \sin(x) = K\sin(x+1)$$

This equation is, then, an expression of the way in which the value of the second difference of our function varies, one which turns out to have a very simple relation to the function itself.

One's immediate impression is apt to be that this relation is circular, since in order to generate new values of the function by it, a difference engine would have to predict those same values. But this is not in fact the case. In order to generate $\sin(x+1)$ from $\sin(x)$, one need know only a $\Delta \sin(x)$. $\Delta^2 \sin(x)$ is needed only to calculate $\sin(x+2)$, by way of calculating $\Delta \sin(x+1)$.

In fact, even though this difference equation applies to the second difference of the function, no second difference column is needed to use it. Instead, as soon as $\sin(x+n)$ has been calculated from $\Delta \sin(x+n-1)$ by adding it to $\sin(x+n-1)$, we can simply add $K\sin(x+n)$ to $\Delta \sin(x+n-1)$ to form $\Delta \sin(x+n)$, from which $\sin(x+n+1)$ follows, and so on.

= Although it is thus possible to tabulate $\sin(x)$ with only one difference column (plus, of course, a result column - what Babbage called a table column), it unfortunately is not mechanically simple, since in the above account $\sin(x+n)$ must be multiplied by the constant K (which is in fact negative), which must have several digits to preserve accuracy. This negates the great advantage of the difference engine, that it reduces the problem of tabulating any kind of function to the mechanically simple problem of repeated addition; however, functions tractable to simple difference equations could still be handled that way; this new approach was to be used only for tables which the basic difference engine cannot handle well anyway.

But clearly, due to its theoretical priority and its mechanical simplicity, a machine to calculate only from equations of constant differences ought to be built first. This was the course that Babbage adopted.

The first working model of the Difference Engine, completed about the end of May, 1822, as well as the full scale version whose construction was undertaken for the government, were both of the simpler kind. However, the section of the full scale machine which was put together in 1832 had added on to it a special provision for demonstrating the sort of technique by which transcendental functions could be handled. It will clarify Babbage's thinking in 1822 and after if we first consider this later device.

In the 1832 section, there were essentially three vertical columns arranged parallel to one another across the front of the machine to hold the table, first difference and second difference. What Babbage did was to add extra axes in front of the table column and the second difference column; each of these axes had a wheel on it which could be set to engage with any one of the wheels on the column to which it was adjacent; further, the two special axes were also geared together in such a way that they always rotated together. In this way, a single digit of the tabulated result, say the units digit, could be fed back onto the second difference column, and from there be added on to the first difference columns if the special digits in the table and second difference column were initially set equal, they would remain equal throughout the calculation, since the second difference digit would be continuously reset to equal the table digit.

Thus Babbage demonstrated in a primitive way the technique for tabulating transcendental functions. However, this device was of no practical use, for two reasons: it could handle only a single digit from the table column, and even so, it could not multiply it by a special constant before adding it back in, as would be required in a useful computation. Returning now to 1822, it has already been stated that the machine of which Babbage made a first working model was one for computing functions with a constant second difference and very few digits.⁴ It was clear to Babbage from the first that by using the same general design the machine could be extended to employ greater numbers of differences and digits, but this did not satisfy him. He expressed his dissatisfaction with the limitations of constant differences most clearly in the paper he read to the Astronomical Society on December 13, 1822, in the following terms:

I have already stated to the society, in my former communication, that the first engine I had constructed was solely destined to compute tables having constant differences. From this circumstance it will be apparent that after a certain number of terms of a table are computed, unless, as rarely happens, it has a constant order of differences, we must stop the engine and place in it other numbers, in order to produce the next portion of the table. This operation must be repeated more or less frequently according to the nature of the table. The more numerous the order of differences, the less frequently will this operation become requisite. The chance of error in such computations arises from incorrect numbers being placed in the engine; it therefore becomes desirable to limit this chance as much as possible. In examining the analytical theory of the various differences of the sine of an arc, I noticed the property which it possesses of having any of its even orders of differences equal to the sine of the same arc increased by some multiple of its increment multiplied by a constant quantity. With the aid of this principle an engine might be formed which would require but little attendance, and I believe that it might in some cases compute a table of the form $A \sin \theta$ from the 1st value of $\theta = 0$ up to $\theta = 90^\circ$ with only one set of figures being placed in it. It is scarcely necessary to observe what an immense number of astronomical tables are comprised under this form, nor the great accuracy which must result from having reduced to so few a number the preliminary computations which are requisite.⁵

Although this passage was written in December, 1822, Babbage had been considering the problem from early in the year. In none of the papers in which Babbage discussed a machine to operate without a constant difference did he give any mechanical or mathematical details of what he was planning, but it is clear from the train of thought into which he was led that he had imagined just such a modification of the working model he had built as he was later to add on to the section of the full scale machine assembled in 1832, discussed above.

This emerges in Babbage's Letter to Dr. Brewster, dated November 6, 1822,⁶ and in the paper delivered to the Astronomical Society on December 13, already quoted. In these papers Babbage wished to discuss - because of its purely theoretical interest - a new kind of mathematical series he had found while thinking about the Difference Engine, a series "whose analytical laws were unknown."⁷ The example Babbage gave was the following:

Table	1st Dif.	Sec. Dif.
2	0	2
2	2	4
4	6	0
10	6	6
16	12	8
28	20	8
48	28	6
76	34	0
110	34	4
144	38	.
.	.	.
.	.	.
.	.	.

The principle of generation of this table was that the second difference for any terms was equal to the units figure of the table value of the next succeeding term, or:

$$\Delta^2 x_n = \text{units figure of } x_{n+1}$$

It is very clear that this is just the direction in which Babbage would have been led while thinking about a method of generating sine tables if he had devised only a method for transferring single digits from the table to the second difference, and without multiplication; and this is exactly the kind of special mechanism which he later added on to the 1832 machine. It is clear, however, that in 1822 he did not actually build the special mechanism, for he spoke of having computed by hand the above table "such as would have been formed by the engine had it existed in this new shape."⁸

The period during which Babbage was thinking along these lines was that between the completion of the first working model of a simple difference engine and the start of construction of a machine for the government. After that point, Babbage pursued the matter very little. He wrote one paper, "On the Determination of the General Term of a New Class of Infinite Series," read to the Cambridge Philosophical Society on May 3, 1824, exploring the mathematical aspects of the new kind of series.⁹ Also, the possibility of using the new technique in a machine to calculate astronomical tables was discussed in a paper in the *Philosophical Magazine* for May, 1824, written by Francis Bailey, but based on conversation with Babbage.¹⁰ But aside from this, Babbage let the subject drop while he worked on the full scale machine without these special capabilities.

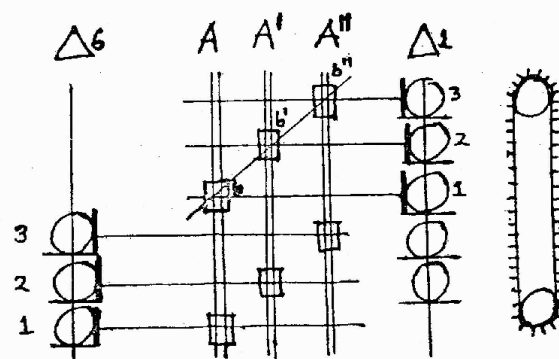
As has been discussed in Chapter Two, Clement suspended work on the Difference Engine in March, 1833. From then until July, 1834, the drawings and parts of the machine (with the exception of the section which had been assembled in 1832) sat in his workshop idle, with Babbage essentially not having access to them. But on July 15, 1834, the parts and drawings were delivered in Babbage's custody. However, as we have seen, he was reluctant to proceed with construction until some new understanding was reached with the government on mutual rights and responsibilities with respect to future work. While Babbage waited for the Prime Minister, the machine waited as well.

Though Babbage did not proceed with any direct work on the Engine, and felt quite disgusted with the circumstances surrounding the project, he had by no means lost interest in the basic idea of the machine. He therefore occupied himself, while waiting, with re-examining the basic plans. In particular, he tried to design a mechanism which would allow the machine to handle difference equations of the sort discussed in the first section of this chapter.

This work is recorded in a volume entitled the "Great Scribbling Book;"¹¹ unfortunately the relevant pages are generally not dated. One can only say that this re-examination began in July or August, 1834, and the first stage of it was complete by the middle of September, 1834.

This first stage consisted of attempts to develop the method used in the 1832 section for demonstrating the transfer of single digits from the table column to the second difference column. The first item to be found is a group of obscure sketches entitled "Plan for adding from one axis to another a number multiplied by 10^n ."¹² But it is not at all clear from the sketches what Babbage had in mind.

On the next page, under the title "Plan for multiplying any numbers on any Δ axis and adding them to any other" is the following sketch: [13](#)



This plan is clear, and is a modification of the device used in the 1832 machine. On the right and left are, as examples, the first and sixth difference columns. The object is to shift the top three digits from $\Delta 1$ to $\Delta 6$, in this case dividing them by 100. Miter gears collect the digits off $\Delta 1$ as its wheels are turned and put them onto the vertical racks in the center marked A, A', and A''. Similarly, these racks turn the horizontal axes at the bottom, which put the digits onto the lower wheels of $\Delta 6$. Since the pinions called b, b' and b'' can be slid back and forth on their axes, they can connect the wheels of $\Delta 1$ with whatever set of vertical racks is desired, effecting multiplication by different powers of ten as the transfer is made.

During the succeeding days or weeks, Babbage sketched several variations on methods of effecting this transfer from one end of the machine to the other, the process which he called "the engine eating its own tail," to describe its recursive character. [14](#) By a series of steps which are not recorded, Babbage was led, shortly before September 18, to the very important step of arranging the columns in a circle around large central wheels. [15](#)

In an account of this period written much later, in November, 1869, Babbage said that he had come to adopt an arrangement of horizontal racks connecting the axes, but then realized that if the columns were circularly arranged, the highest and lowest order columns could communicate directly, since they would be adjacent, and no racks would be needed. He then realized that the advantages of the racks could be retained in the new design if they were replaced by large geared wheels in the center. This account of the development is plausible, but doubtless also somewhat of a simplification. [16](#)

Exactly what this new arrangement was is not clear from the 1834 sketch mentioned above, and there was no written description of it. Apparently the difference columns, soon to be called adding axes, were put around one side of the circle; they were divided vertically into a certain number of "cages," corresponding to their separate digits. Special pinions could engage their wheels with the central wheels as desired; the central wheels were simply very large gears rotating freely on a central axis; there were in fact two central wheels per cage. On the other side of the central wheels were the "multiplying pinions," used to step up numbers on the central wheels, that is, to multiply them by powers of ten by moving their digits up a certain number of cages. A particular digit would be transferred from, say, the lower central wheel in one cage to the higher central wheel in another cage higher or lower by a number corresponding to the power of ten by which it was being multiplied; the number of cages stepped would be determined by the way in which the connecting gears on the multiplying pinions were set. The multiplied number could then be taken off by a desired adding axis from the higher central wheels. [17](#)

This arrangement formed what might be described as the final stage of the Difference Engine design, for in filling in the details and making it workable, Babbage was led to realize that there were much greater possibilities lurking in the plan, ones which eventually led him to the fully elaborated plan of the Analytical Engine.

What may be called the second stage of the transformation from the Difference Engine to the Analytical Engine began at this point, and continued until the summer of 1836, by which time all the main principles had been laid down, although many details remained to be filled in. The course of development during this period was so complex that only the main outlines can be given here. Further, it will be much easier to understand some aspects of the design when they are explained in the context of the operation of the machine as a whole, so such explanations will be at times postponed. [18](#)

The first subject to which Babbage turned was a method for multiplication and division. Working on multiplication was no real departure from the previous phase, for it was necessary in order to use the kind of recursive difference equations in which Babbage was interested. But the fact that the multiplication pinions could step numbers down as well as up, and the fact that division was the inverse of multiplication, led Babbage to try to make the machine capable of both.

Given the ability to step numbers up, multiplication was fairly simple; the problem was to decide how many times at each level of stepping the multiplicand should be added to a result column. The method first devised was as follows. The multiplier was on one adding column, say A^1 ; the multiplicand was on A^2 ; and the product was to be produced on A^3 . Attached to each figure wheel on the adding columns was a snail; this was a notched spiral wheel with the steps on it corresponding to the ten digits. When an arm from another column fell on this snail, it could sense the digit at which the figure wheel was set. In multiplication, an arm would first sense the lowest cage on A^1 , and would set a special wheel to the same digit; then this wheel would be gradually "reduced to zero" by another wheel with a single tooth, which would "gather up" the units of the selected digit, one per revolution. With each revolution of the gathering up wheel, all the digits on A^2 would be added to the central wheels; the cages of A^3 being connected in the same way to the central wheels, the multiplier would be successively added onto A^3 . When the special wheel was reduced to zero (i.e. when the multiplicand had been multiplied by the first digit of the multiplier) the following would happen. The snail opposite the second cage of A^1 would set the special wheel to equal the second digit of the multiplier; also the multiplying pinions would be set so that as the digits from A^2 were put onto the central wheels, they would be stepped up one cage before being added to A^3 . The multiplicand would then be multiplied by the second digit of the multiplier by the same gathering up process, the snails and multiplying pinions would be reset for another cage, and so on, until the digits of the multiplier were exhausted. [19](#)

No irony was intended above in saying that multiplication was simple; compared to division it was. Thus even with a one digit divisor, that digit had to be compared with the first digit of the dividend (requiring two sets of snails and feeler arms and other apparatus); if the latter was equal or larger, the former was subtracted from it, and the fact of subtraction was entered as a unit at the top of the result column; then the comparison was repeated, and so on. If the divisor digit was larger, then apparatus had to be shifted to compare it with the next cage, and the successive subtractions had to be registered on a different cage, and so on. Dividing by a multi-digit number was far more complicated, for if the initial comparison of the top two digits of the divisor and dividend showed that they were equal, the second digit of each had to be compared to the other, and perhaps even the third and subsequent ones, before the machine would know which of the two numbers was larger.

At this point, Babbage's new machine was fearsomely complex, even though its powers were still very limited, and so far only the outlines of the parts needed had been considered. Further, it would have been incredibly slow, for the time required for multiplication and division would have been considerably longer than the sum of all the digits in the multiplier or divisor times the basic addition time. But Babbage considered that this simply meant that he had to shorten the basic cycle time and make the complex processes more efficient.

To shorten the cycle time, the fundamental operations had to be improved; these were: basic addition, that is, transferring digits from one wheel to another, and carriage of tens between the wheels in a given column. In the Difference Engine, addition had been made by bolting the two wheels so that they would gear together, then giving the first wheel a full revolution, unbolting the second wheel from it after the proper number of digits had been passed. In the Analytical Engine, Babbage thought through a number of other possibilities. One involved direct gearing between the two wheels, having a projection in one be pushed up by an inclined plane after the proper part of the revolution had been passed so that they were lifted out of gear. [20](#) Another

method was to have snails and feelers to set extra wheels equal to the figure wheels, and then add onto the receiving wheels by a gathering up wheel as in multiplication, but this took more time. ²¹

The method ultimately adopted was taken from the approach used as early as the beginning of October, 1834, ²² for the purpose of clearing a number off a column, or as Babbage called it, reducing it to zero. This worked by having the wheels turn freely on an axis which could be moved up and down relative to them by a small amount; fixed to this axis was a series of projecting arms, one for each cage; on each figure wheel was a stud which would be contacted by the projecting arm when the axis was in its lower position. The number on the column would be reduced to zero when it was disconnected from the rest of the machine and the axis was lowered and rotated through a full turn so that it pushed the studs and thus the wheels around until they all were set to zero. It was only some months later, apparently in January, 1835, ²³ that Babbage realized that the same technique could be used for transferring numbers from one wheel or column to another (and thus also for addition) if they were simply left connected while the reduction to zero was performed. Naturally this entered the number on the second wheel in an opposite sense of rotation, but since most connections were made through a series of wheels and pinions which could be made odd or even in number at will, ²⁴ this did not matter.

The second area of basic operation which required improve went was the carriage mechanism. In the Difference Engine, the carriage had been delayed and sequential; that is, carriage could not be performed as a wheel passed from nine to zero in addition, since this would interfere with the separate addition proceeding simultaneously on the next higher digit; therefore carriage was delayed until addition was complete. Further, in performing a series of carriages onto a column of numbers, it is quite possible that a unit will be carried onto a wheel already standing at nine, thus making necessary a second order carriage, and so on; this problem is solved if the carriages are performed sequentially, that is, first on the lowest wheel, then on the next, and so on. This solution gives rise to its own problem, however, since if a large number of digits are used (and Babbage had in mind thirty or forty for the new machine from quite early on) sequential carriage can take a great deal of time, even considerably more than the basic addition itself.

The first approach Babbage used to speed up carriage was what he called hoarding carriage. ²⁵ In this method, carriage was delayed not until a single addition was complete, but until a series of nine additions had been made. In the mean time, the carriages required by each addition had been stored on a special set of wheels; when carriage was to be made the numbers on these wheels were transferred to the result wheels as in an ordinary addition. This technique had two disadvantages, however; these carriages could still require second order carriages, so they would require either an additional mechanism to take care of these, or else to be added separately for each digit; both approaches would require extra time and mechanism. Further, hoarding carriage would be effective only in those cases where a whole string of numbers were being summed together; if the machine were performing isolated or separate additions, it would be no improvement over the old method of carriage.

The second new approach Babbage tried, and the one he eventually adopted (although perfecting it to his satisfaction took more time than any other part of the machine), was what he called anticipating carriage, since it allowed the machine to anticipate that a second order carriage would arise from a first order carriage, and perform then at the same time. This operated by having a special mechanism brought into play when the wheel onto which a first order carry was being made already stood at nine; then the special mechanism would cause a carry to be made onto the next higher wheel at the same time, and so on. Thus all carries could be performed in one step immediately after addition in a time independent of the number of digits in the column. The details of the many different ways Babbage tried to accomplish this need not be considered here, but the first attempts seem to have been made about the end of October, 1834. ²⁶

Although it was clear to Babbage that anticipating carriage would save a large amount of time, it was equally clear that whatever the details of the version finally worked out, the mechanism for carriage would be immensely complicated in relation to that required for addition by itself. This apparent drawback led Babbage to an important step, namely that of separating the carriage mechanism from the columns on which it was intended to act. Thus given one or two carriage mechanisms which could be connected at will with the central wheels or with any adding column in use, a large amount of mechanism could be saved.

This was a most important step in the evolution of the Analytical Engine, for as the same approach was applied to other aspects of the engine, there gradually emerged the notion of a central processing section in which the various arithmetical functions were to be carried out, distinct from the area where the numbers were stored when not being manipulated. The central processing unit Babbage later came to call the "Mill," and the other number columns he called collectively the "Store," this fundamental distinction of course still exists in current computers.

It is not clear exactly when Babbage devised this way of organizing the machine, along with the specialization of the carriage mechanism from which it flowed, but apparently they developed gradually between November, 1834 and the early spring of 1835. During this time Babbage continued to develop the process of division, with respect to which he made a very important breakthrough in principle, though again the exact dates of the different steps are not clear. We can, however, say that the following had been thought through by early in March, 1835. ²⁷

The problem with division was still that of deciding whether the divisor was smaller than the remainder at any given point in the operation, so that subtraction should occur. Babbage's first approach, that of comparing as many digits as necessary by using snails (discussed above), required too complicated a mechanism. His next approach was to eliminate most of this mechanism by having the machine assume that the divisor was larger than the remainder if the two numbers had the same first digit; thus the divisor would be stepped down a cage and also the successive subtractions would be registered on a lower cage, and subtraction would proceed. The difficulty with this approach was that on those occasions when the first digits of divisor and remainder were equal but yet the remainder was larger, the machine would perform ten subtractions where it could have performed one, although it would still produce the right answer; thus this method was too time consuming.

The neat approach Babbage used was most ingenious. The numbers on the divisor and remainder axes were copied onto two subsidiary axes, and the first was subtracted from the second; if the result was negative, that is, if the highest wheel changed from zero to nine and tried to carry down from the (non-existent) wheel above it, then the divisor (back on its regular axis) had to be stepped down a cage; if the result was positive; that is if the top wheel did not change, then the subtraction could proceed back on the main axes without stepping. Thus all the snails and feelers and comparisons of digit to digit were eliminated.

The final step was to reverse the roles of operation and test in this last method. That is, the machine was to assume that the remainder was larger than the divisor and proceed with subtraction; if this assumption were false, it would show up in that the remainder would turn negative in the way indicated above; this would put the machine into a special sequence where it would add the divisor back to the remainder, subtract one from the quotient, and then step down the divisor and the cage in which digits were registered in the quotient before again making a subtraction. This improvement saved time, since in general the total number of subtractions that had to be made was considerably larger than the number of steppings that had to be made.

Again, Babbage had been led for practical reasons to a change in the machine which was to be of far reaching importance; as the Analytical Engine evolved from this point, Babbage applied this method of controlling divisions to other internal decisions the machine had to make, and eventually to general program branching itself.

By early 1835, the number of different kinds of axes which had to be interconnected in different ways depending upon what operation was to be performed had grown so much that a new approach to controlling the machine was required. ²⁸ The basic technique was to have connections between different axes made through a series of pinions and possibly the central wheels; the axes on which the pinions were held could be moved up and down a small amount, and the particular position they were in determined what connections were made. The problem of control was thus the problem of governing the position of the pinions. This was to be done by what Babbage called "traveling platforms," which moved up and down repeatedly in the basic cycle of the machine; when a pinion axis was to be raised, it was temporarily locked to a traveling platform; when this reached the proper height, the axis was unlocked from it and locked to some stationary support, so that it would stay in the proper position.

The connections between the pinion axes and the traveling platforms were controlled by the barrels. These were cylinders embedded with many studs arranged in rows; the studs in a particular row would activate levers which made the connections necessary for a particular step. ²⁹ Successive steps would be controlled by successive rows of studs, the active row being determined by rotating the barrel.

As this control system had evolved by July, 1835, ³⁰ each different variable had its own barrel, which had studs set for the sequences of steps necessary for the different operations. These barrels were all controlled by a central drum, a similar cylinder with studs which could be set by hand for the particular sequence of operations desired. A given row of studs on the drum would specify what operation was to be performed and what variables it was to be performed on; it would turn the barrels so that they would bring about the sequence of steps necessary for that operation; when the operation was complete, control would be returned to the central drum, which would advance a row and call for a new operation. ³¹

In March and April, 1835, Babbage developed two important improvements in the processes of multiplication and division. First, on March 22, Babbage realized that he could adapt the machine for double precision operation. ³² In particular, Babbage realized that if he made it possible for the top of one column to carry and step to and from the bottom of another column, then he could take two numbers of, say, forty digits each (the number of digits he seemed to be planning on at this time), and multiply them together, retaining eighty digits in the product; then when this product was divided by a forty digit divisor, the quotient would still have forty significant digits. On the other hand, it would also be possible to convert the machine generally; thus a machine with sixty variables of twenty digits each could be made into a machine of thirty variables with forty digits each with no real mechanical change. ³³

The second change in the way multiplication was to be done was devised on March 30, and was called multiplication by table. ³⁴ In this scheme, the machine would start a multiplication by forming a table of the multiplicand multiplied by each of the digits from one to nine: this would be placed on nine special axes, and could be formed quite easily by simple addition. Then a snail wheel would sense the first figure of the multiplier, and supply it to a selecting mechanism, which would cause the corresponding multiple in the table to be added to the result axis. Then the result and the multiplier would each be stepped up one place, and the operation would be repeated for the second digit of the multiplier, and so on. In this way, every digit of the multiplier could be taken care of in one step, rather than requiring a number of additions equal to the digit's value. Division could be handled in a similar manner, although the problem of selecting which particular multiple ought to be subtracted from the dividend was considerably more complex. Babbage did not develop the details of division by table as early as those of multiplication.

It is interesting to note that it was at about this same time that Babbage made the first public statement of his invention of the new machine; this was in the form of a letter to the great Belgian statistician L.A.J. Quetelet, who read it to the meeting of the Royal Academy of Sciences at Brussels on May 7-8, 1835. ³⁵ Without going into details of the machine or its capabilities, Babbage said "I am myself astonished at the power I have been enabled to give this machine; a year ago I should not have believed this result possible." Babbage also announced, with characteristic optimism, "that the greatest difficulties of the invention have already been surmounted, and that the plans will be finished in a few months."

During these next few months and many more, Babbage did indeed continue developing the machine, and he turned his attention increasingly to less critical parts of the Engine, ones which will not be discussed here in any detail. For example, in the late spring of 1835, Babbage began to reconsider his original basic plan of a circular arrangement of the machines he sketched possible arrangements using straight racks, and also combinations of racks and central wheels. ³⁶ He also devoted some attention to the forms of output for the new machines as early as July, 1835, he made some notes about a "curve drawing apparatus" which would turn numerical output from the engine into graphic form. ³⁷ In December, 1835, Babbage was making plans for having the printing mechanism completely separate from the rest of the engine, perhaps in another room, with only one rack to convey the data to it, ³⁸ he also wished to be able to turn out single copies of results by having the type print through carbon paper, rather than making an impression in a stereotype mold. ³⁹

What must be realized at this point, though, is that while the engine as a whole was becoming more and more complex in some respects, some of its individual parts were getting much simpler, due to the specialization that had been made necessary by the very complexity introduced into the particular processes. Most especially, the separation of the Store from the Mill had made it possible for the Store axes which held individual variables to be very simple indeed, much simpler, for example, than one of the columns in the Difference Engine. This of course made it possible and practicable to have the machine able to handle a very large number of variables; Babbage at one time considered as many as one thousand. ⁴⁰

But although Babbage could imagine problems which would take advantage of this large capacity and also of the rapidity and sophistication of processing of which the Mill was now capable, the machine would not have been able to solve these problems, because the control mechanism was not able to handle the necessary instructions; the process of placing studs for the different operations in the drums by hand was far too limited, too cumbersome and too inflexible to take advantage of the rest of the engine.

This led Babbage, on June 30, 1836, to adopt punched cards for the control of the engine. ⁴¹ These he adopted quite directly from the system of control of automatic looms by punched cards which had been perfected at the beginning of the century by J.M. Jacquard of Lyons. ⁴² In principle, these cards were identical to the Hollerith punched cards used in twentieth century computers, in that they consisted of cardboard rectangles with rows and columns of spaces which could be punched out or left solid, conveying information through some kind of sensing mechanism to the machine which they were to control. In practice, Babbage's cards were to be sensed by mechanical levers rather than by electrical brushes, so that they had to be made of thicker cardboard, and their area was also to be larger.

The introduction of punched cards into the new engine was important not only as a more convenient form of control than the drums, or because programs could now be of unlimited extent, and could be stored and repeated without the danger of introducing errors in setting the machine by hand; it was important also because it served to crystallize Babbage's feeling that he had invented something really new, something much more than a sophisticated calculating machine. The first indication of Babbage's vision came in a memorandum in his notebook dated July 10, 1836, sayings "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" (that is, the value of the letters in the formulae with which the machine was dealing). ⁴³ Unfortunately, the rest of this note is very obscure and sheds no light on what Babbage had in mind, but from some of the notes in the vicinity of the above quotation it appears that one of the things Babbage had in mind was eliminating between variables in high order simultaneous equations.

In any case, by this time, midsummer of 1836, all the main principles of the Analytical Engine had been laid down; if one were obliged to name a single point at which it was "invented," this would be it. From this point on, Babbage's task was essentially to fill in the details, although this phrase cannot do justice to the magnitude of what he did. The character and complexity of those details, and indeed what it was that Babbage had by this time invented, can only be understood in terms of the general structure and operation of the machine as a whole.

No description of the mechanical operation of the Analytical Engine has ever been published, and it is doubtful that anyone other than Babbage has ever understood it fully, and very few have understood it at all. Fortunately, in December, 1837 Babbage wrote a paper "On the Mathematical Powers of the Calculating Engine," of fifty three manuscript pages, which provides a rather full, if sometimes less than lucid, account of the operation of the machine. ⁴⁴

The following description of the Analytical Engine is drawn largely from this 1837 paper, being quoted directly when appropriate, although the original material has been rearranged and condensed, with some explanations rewritten or added as necessary. ⁴⁵ . The Analytical Engine consisted of two sections, the Store and the Mill. [Figure 1](#) is a plan of the Engine drawn in August, 1840, but basically the same as what Babbage described in 1837. The Mill was the collection of circles and devices surrounding the large central wheels in the middle of the drawing. The Store was the section extending off toward the right from the Mill; not all of it is shown. It can be seen from the scale provided, in the drawing that the length of the part of the Engine shown was about ten feet.

Running down the middle of the Store was a series of long racks, one for each cage; any column in the Store could be engaged with these racks. At their left end, the racks connected with the central wheels of the Mill. The section of the Store beyond the edge of the drawing was simply a continuation of the part shown.

The Store may be considered as the place of deposit in which the numbers and quantities given by the conditions of the question are originally placed, in which all the intermediate results are provisionally preserved and in which at the termination all the required results are found. . . .

A number of axes each having forty figure wheels placed in different cages one above another are connected with the rack of the Store. These figure wheels are

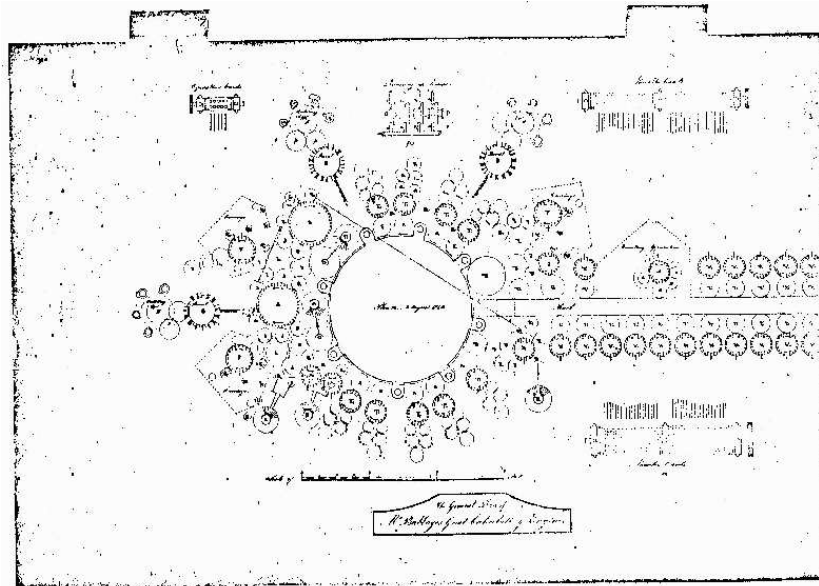


FIGURE 1: General Plan 25, August 6, 1840. S.K., Drawing II, 89°

each numbered from 0 to 9; they may be turned by hand so that any digit may stand opposite a fixed index. Thus any number of not more than forty places of figures may be put upon the figure wheel of each axis.

Above the fortieth cage is another cage containing a wheel similar to a figure wheel and also having its circumference divided into ten parts. These parts have the signs (+) plus and (-) minus alternately engraved upon them. Above this wheel is a fixed character to distinguish each particular axis, or rather the variable number which may be found upon its wheels. These fixed marks are $v_1, v_2, \dots, v_{32}, \dots$ as far as the number of quantities which can be contained in the store. . . .

The number of variable cards which can be contained within the store will depend on the length of the rack and number of figure axes which can be placed round it, and although a large number of variables might with perfect safety be employed yet there is obviously a practical limit arising from the weight of the rack to be moved.

One hundred variables would not give an inconveniently large rack, but still the calculations of such an engine would be limited. The limitation can be entirely removed by another set of cards called Number Cards which will presently be described.

If any of the coefficients contain decimals, or if the result is required with decimals, then all the coefficients must be considered as having the same number of decimals. If an imaginary line is drawn between any two cages - the third end fourth for example - then all below it may be considered as decimals. In order to convey to the Engine this information there exists a wheel with the numbers from 1 to 40 engraved on its edge; this wheel being set at any number the Engine will treat all the numbers put into the Store as having that number of decimals. . . . ⁴⁶

In deciding on the content of the numbers with which the engine should compute, the first consideration was to look at the number of figures which in the present state of mathematical enquiry are required in the most extensive calculations. It then became desirable to look forward to the probable increase which improved observations might require. Finally the mechanical structure of the engine or its necessary arrangement might put limits to this extent or render the time employed in given calculations longer at certain definite intervals.

But even if it were thus possible to satisfy all practical wants, there would still remain a desideratum to render the mechanism philosophically perfect as to its power of converting algebraic expressions into numbers without any limit as to their magnitude or extent.

The result of my reflections has been that numbers containing more than thirty places of figures will not be required for a long time to come. I have however made the drawings of the Engine for forty places of figures. All additions and subtractions may be made with such numbers, and the products amounting to eighty places may be preserved in the Store and brought back into the mill to be divided by numbers of forty places of figures, thus retaining forty places in the quotient. ⁴⁷

At the beginning of a computation, the numerical data could be fed into the Store by manually setting each wheel of the columns being used. However, it was also possible, and obviously preferable, to feed the data in by a special set of punched cards, called the "Number Cards." These cards had another function which Babbage considered even more important. It might happen that in some very complex computation, more variables would be needed than there were columns in the Store; in this case the Store could be directed to punch certain cards to hold the overflow data, which could later be recalled and read back into the machine as needed. ⁴⁸

The Store also contained various output provisions. Single copies could be printed through carbon paper; copper plates were punched when the results were to be published. Most interesting was the Curve Drawing Apparatus:

The discovery of laws from the examination of a multitude of tabulated and reduced observations is greatly assisted by the representation of such tables in the form of curves.

As one of the employments of a calculating engine would be to reduce collections of facts by some common formula, I thought that at the time it impressed the computed results it would be desirable that it should mark the point of a corresponding curve upon paper or copper if preferred. The three or four first figures of the table will be expressed by the curve. The contrivances for this purpose are not difficult, and their employment does not lengthen the time of the calculation. ⁴⁹

However, Babbage considered that it would probably be best to have all output from the Store in the form of punched cards. These would then be fed into a totally separate (off-line) printing mechanism which would produce whatever form of output was desired.

The functioning of the Store was controlled by a set of Variable Cards, whose action was co-ordinated with the Operation Cards which controlled the Mill. The Variable Cards could order a number to be given off from a particular store axis to the ingress axis of the Mill, or for a number to be received from the Mill and put on a particular store axis; the Variable Cards also could order that numbers be read and stored from the Number Cards, or that particular variables be punched on cards. ⁵⁰

The actual operations were performed in the Mill. It was made up of the following principal components: Figure Axes, Carriage Axes, Table Axes, Digit Counting Apparatus, Selecting Apparatus, Barrels, Reducing Apparatus, Operation Cards, and Combinatorial Cards. These components were described

by Babbage as follows (and see [Figure 1](#)).

1. Of the Figure Axes

The Figure Axes A and 'A are connected with each other without the intervention of the central wheels so that a number on the figure wheels of one axis may be transferred to those of the other. These figure wheels are considerably larger than any others in order to allow of sufficient space on their circumference for placing the pinions by which communications are made with other parts of the mill.

By means of some of these pinions a process called Stepping down and another called Stepping up may be performed. It consists in shifting each digit of a number one cage lower or one cage higher, which processes are equivalent to the arithmetical operations of dividing or multiplying the number by ten. Other pinions are fixed on register axes R and Ri and convey the two highest figures of the dividend to the Selecting apparatus.

The third figure axis, "A, is placed near the Store and constitutes the egress axis. It is adjacent to the digit counting apparatus, with which it communicates.

2. Carriage Axes.

These Axes F, 'F, "F with their peculiar apparatus are employed to execute the carriage of the tens when numbers are added to or subtracted from each other. The carriages F and 'F can be both connected with the Figure axis A, or one of them with the Figure axis A and the other with 'A, or they may by means of the central wheels be connected with any other part of the Mill. The third carriage, "F, is connected with both the Mill and the store and may be used with either.

Whenever the number subtracted is greater than that from which it is taken the resulting carriages would, if effected, and if the mechanism admitted, produce a carriage in the forty first cage. This fact is taken advantage of for many purposes: it is one of very great importance and when it happens a Running up, is said to occur. Connected with this part is a lever on which the running up warning acts, and this lever governs many parts of the engine according as the circumstances demand.

3. Table Figure Axes.

These axes are ten in number; nine of them contain the table of nine multiples of one factor in Multiplication and of the Divisor in Division. The tenth contains the complement of the Divisor in the latter operation. They are all connected with the central wheels and the number on each figure wheel can be stepped up or down upon the other figure wheel of the same cage. The figure which at each stepping goes off from the bottom wheel is transferred to the top wheel.

4. Of the Digit Counting Apparatus.

This is a mechanism by which the digits of any number brought into the mill may be counted; and certain calculations made as to the position of the decimal point in the result of multiplication and Division. It is also used to limit the number of figures employed when the engine is making successive approximations either to the root of equations or to the values of certain functions. It consists of three distinct systems nearly similar to each other.

5. Of the Selecting Apparatus.

When a table of the nine multiples of a multiplicand has been made it becomes necessary in order to effect multiplication to select successively those multiples indicated by the successive digits of the multiplier.

This mechanically is not difficult. But when in the process of division it becomes requisite to select that multiple which is next less than the dividend from which it is to be subtracted, the mechanical difficulty is of quite a different order, and hitherto nothing but the most refined artifices have been found for accomplishing it. . . .

[6.] Of the Barrels.

The barrels are upright cylinders divided into about seventy rings, the circumference of each ring being divided into about eighty parts. A stud may be fixed on any one or more of these portions of each ring. Thus each barrel presents about eighty vertical columns every one of which contains a different combination of fixed studs. These barrels have two movements. 1st They can advance horizontally by a parallel motion of their axis. 2nd They can turn in either direction and to any extent on their axis.

When the barrels advance horizontally these studs act on levers which cause various movements in the mill: the stud belonging to each ring giving a different order.

Amongst these movements or rather these orders for movements the following may be more particularly noticed.

The advanced of a barrel may order:

1. A number with its sign to be received into the mill from the ingress axis;
2. A number with its sign to be given off from the mill. This number may thus be altogether obliterated from the mill: or it may at the same time be received on the egress wheels or the number may be given off from the mill to the egress wheel and at the same time be itself retained in the mill.
3. A variable card to be turned.
4. An operation card to be turned.
5. The circular movement of the Barrel itself or of any other barrel to another vertical. This always occurs at every step from the beginning to the end of what are called operations. The barrels when once ordered by the operation cards from their zero point to any given vertical always direct themselves to be turned to another vertical preparatory to their next advance. This circular motion is however occasionally changed by an action arising from another source.

7. Of the Reducing Apparatus.

Behind each barrel is placed a reducing apparatus.

It consists of six or eight sectors which can be made to act upon the barrel and give it a rotatory movement so as to make it pass over 1, 2, 3, or any required number of verticals previously to its next advance. The levers which put these sectors into action are acted upon by

1. The studs on their own barrel..
2. The studs on any other barrel.
3. The Operation Cards.
4. The Running up levers.

The first and third of these sources of action occur most frequently. ⁵¹

8. Of the Operation Cards.

Those who are acquainted with the cards of a Jacards [sic] loom will readily understand the functions performed by these cards. To those who are unacquainted with that beautiful contrivance it may be necessary to state that the Cards consist of pieces of thick paste board, tin plate, or sheet zinc, pierced with a number of holes. These cards, being strung together by wire or tape hinges, pass

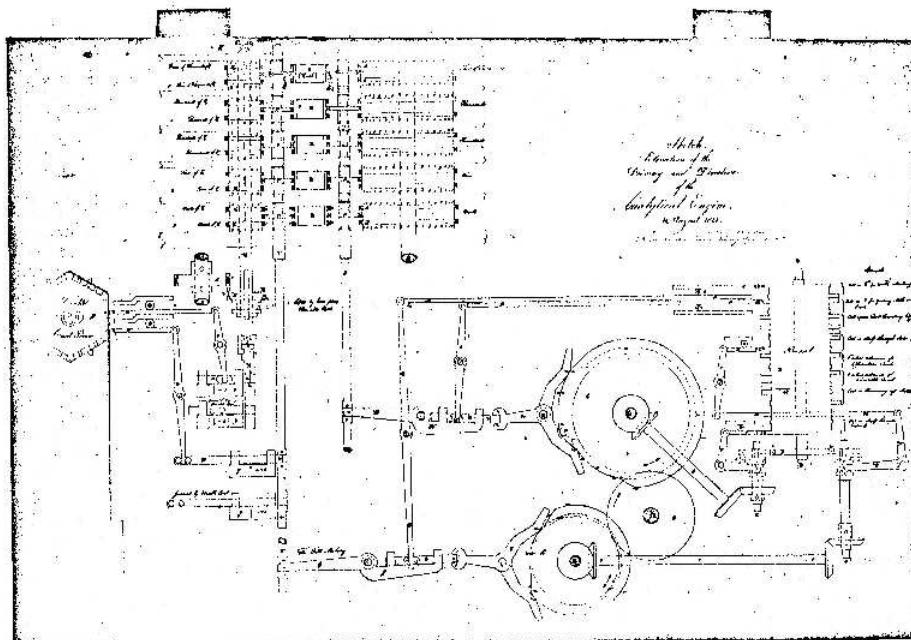


FIGURE 2: Driving and Directive of the Analytical Engine, August 14, 1841. S.K., Drawing II, 94.

over a square prism. The prism is situated in front of a number of levers placed in rows which govern the Reducing Apparatus and consequently the barrels. The faces of the prism are perforated so as to present an opening opposite every lever. If the prism alone is made to advance horizontally against these levers then the levers themselves will enter into the holes of the prism and be partly covered by it; but they will not be moved out of their places.

Again if a card having as many holes as the prism has, or as there are levers opposite to it, is placed upon the advancing face of the prism, no effect can be produced on the levers by this advance of the prism. But if a card having one hole less than the prism is placed on its face, then when the prism advances the lever opposite that hole will be pushed away and any order given for which that lever was appointed.

Suppose after every order the levers to be replaced, and let the prism be turned one quarter round, then a new card will be presented to the levers, and if one or more holes of this second card are stopped up, a different order will be transmitted through the levers to the Reducing Apparatus and thence to the barrels.

Thus by arranging a string of cards with properly prepared holes any series of orders however arbitrary and however extensive may be given through the intervention of these levers.

The number of the levers acted upon by the operation card is small: they respectively direct the barrels to commence the following operations:

1. The Addition of two numbers.
2. The Subtraction of one number from another.
3. The Multiplication of two numbers.
4. The same Multiplication limited to a given number of the first figures.
5. The Division of one number by another.
6. The same Division limited to a given number of figures in the quotient.

The levers numbered 4 and 6 are rarely used; the extraction of roots being the only case in which they are required.

These cards are called into action by orders from the barrels. What they shall do when acting depends on the nature of each individual card. What repetitions they shall be subject to depends on the orders communicated to them from the Combinatorial Cards and their Counting Apparatus. Many calculations are much simplified by having two sets of Variable Cards.

9. Of the Combinatorial Cards.

One or more peculiar cards may be inserted among the operation cards of certain formulae. They are called Combinatorial Cards.

The object of these cards is:

To govern the Repeating Apparatus of the Operation and of the Variable Cards and thus to direct at certain intervals the return of those Cards to given places; and to direct the number and nature of the repetitions which are to be made by those cards.

Whenever Combinatorial Cards are used other cards called index cards must occur amongst those of the formulae. The use of these cards is to compute the numbers which are to serve successively for the indices of the combinatorial cards. At what time the Combinatorial Cards shall act depends on the number of repetitions the last of those cards appointed. What orders each Combinatorial Card shall give depends on the nature of each individual Card. ⁵²

Thus the detailed steps within an arithmetical operation were controlled by the Barrels, while the sequence of operations was determined by the operation cards. The interaction between the two occurred as follows:

In any operation it is only necessary that the operation card ordering its commencement should be advanced. This sets the barrels in action and provides through the variable cards if necessary the first quantity to be operated upon; the barrels there call in the other quantities required at the proper times, until the operation is completed, the Mill cleared of all numbers, and the computed result placed in its intended situation in the Store. The last vertical on the barrels belonging to each operation directs them to move to its zero point.

Such being the arrangement, the calculation of numerical quantities resulting from two or more successive operations may be readily performed by placing the operation cards, strung together in their proper order on their revolving prism, and the variable cards marking the numbers in the Store on [sic] which are to be the subjects of those operations and also in the order in which they are required on their own revolving prism, and then putting on the final verticals of one of the barrels a stud which orders the operation cards to advance. ⁵³

The actual operation of addition as controlled by the Barrels was performed by the method of reduction to zero already discussed; that is, the Store axis off which a number was to be read was connected to the Mill axis which was to receive the number, and then the wheels of the

former were set mechanically to zero, transferring the number to the Mill. Similarly, carriage was performed by the method of anticipation already discussed, although Babbage never finally settled on the details of the carriage mechanism.

The only new or complex element in the process of addition was the treatment of signs, since addition and subtraction were to be performed alike, and since the machine could now contain both positive and negative numbers in the Store. This was to be done in the following way. Suppose two numbers were to be combined; each would have two signs, one corresponding to addition and subtraction, as specified by the operation cards (Babbage called this the algebraic sign), the other corresponding to whether the number actually in the Store as determined by previous operations was positive or negative (called the accidental sign). As a number came onto the ingress axis of the Mill from the Store, the two signs would be compared, simply by adding the pseudo-numbers on their topmost wheel, or sign wheels as a positive sign corresponded to an even number on this wheel, and a negative sign corresponded to an odd number, the result of the addition of the two digits would correctly indicate the combination of the algebraic and accidental signs. If this combined sign was positive, the number was added to the figure axis where addition was to take place; if it was negative, the number was subtracted, that is, an extra pinion was introduced into the train of gears to reverse the direction of rotation.

The same process was applied to the second number as it came into the Mill, and it would be added or subtracted from the Figure Axis as determined by its combined sign (and the same could be done with a third or subsequent number in the same way). The effect of this addition or subtraction might be to change the sign of the number on the Figure Axis by making it pass through zero; the number on the Figure Axis would then appear as the complement of its arithmetic value; but the engine would know this because a running up would have taken place, so that before the result was used or returned to the Store it would be changed back to its proper form, along with the finally correct sign. ⁵⁴

Multiplication

The process of multiplication is thus performed by the Engine:

The two factors P and Q with their respective accidental signs being placed on the two sets of Figure wheels No. 1 and No. 2 of the Ingress axis, an operation card is turned. This directs the barrels through the reducing apparatus to move circularly to the vertical which commences multiplication.

At the next turn the barrels advance and order the reception of one of the factors, Q. They also direct themselves to move on their axes to the second vertical belonging to multiplication. At the third turn the barrels advance and order the reception of the other factor, P, from the second set of Ingress wheels. At this turn the factor P is subtracted from the factor Q, which had at the preceding turn been placed upon the figure wheels of 'F.

The result of this subtraction determines which of the two factors is largest, and consequently which factor is to be tabulated. Much time is saved by this decision, for supposing one factor to contain only four places of figures and the other to contain thirty five figures, then if a table of the first nine multiples of the first factor were made, its multiplication by the other factor would require thirty five additions, whilst if the larger factor had been tabulated, only four additions would have been necessary. The mechanical mode by which this knowledge is conveyed to the barrels is thus. The barrels, after ordering the subtraction of P from Q in the axis 'F, direct themselves to move on to another vertical; if P is less than Q no Running up takes place, and the order thus given by the barrels is obeyed; but if P is larger than Q then a Running up takes place, and the order given by the barrels to move to a certain vertical is enlarged, and they are directed by the running up lever to move on to a different vertical. This new vertical directs the tabulation of the second factor, whilst the former vertical appointed that of the first factor..

At the next turn the number which the Mill has decided on tabulating is added to each of the nine table axes and to the carriage F.

At the next turn the same number is added to eight of the Table axes and the carriage axis, then to seven, and so on, until the nine multiples have all been formed on the nine Table axes.

During these turns the number of the digits in the multiplier has been ascertained and placed in the Counting Apparatus No. 1.

The Multiplier having been prepared is now stepped down and acts upon the Selecting Apparatus. Whatever digit exists in the lowest figure of the multiplier, by means of the Selecting Apparatus the corresponding Multiple is added over to the product axis 'A. During this addition each multiple is stepped up one cage higher on its own figure wheels; also the multiplier being stepped down, its next figure is conveyed to the Selecting Apparatus preparatory to the next addition to the product.

The product is thus formed beginning with its lowest figure on the figure wheels of the axis ['A]; but in the process of stepping up, the highest figure on the tables axes may at length reach the top or 40th cage of their axes. At the next stepping the highest figure would of course be stepped off the machine and lost, but this is prevented by a communication with the lowest figure wheel on the same axis to which the number stepped off from the highest is transferred. These figures which are so transferred to the lower cages are not added to the same axis but are by a particular mechanism added over to a set of figure wheels on the axis A and the carriage F on which the head of the product is formed.

If a number of twenty figures only is multiplied by another factor containing an equal number of digits, as the product will not exceed forty digits it will be contained on the first axis. But if both factors contain forty digits then the head or first forty digits of the product will be formed on the axis A and the tail or second forty digits of the product will be formed upon 'A.

The signs which entered with the original factors, having been added together on the sign wheels, will give the resulting sign of the product. For if they were both positive, then each sign being equivalent to an even number, the sum of the two signs would give an even number or its equivalent the positive sign. If on the other hand both signs were negative, then a negative sign being equivalent to an odd number, the sum of two odd [numbers] produces an even number, which is also equivalent to the positive sign which the product ought in this case to possess. Lastly, if the sign of one factor be positive and that of the other negative, then the sum of an even and of an odd number being odd, the negative sign results.

The termination of Multiplication arises from the action of the Counting Apparatus, which at a certain time directs the barrels to order the product thus obtained to be stepped down so that the decimal point may be in its proper place, and then to turn to another vertical the consequence of which is the transfer of the product with its proper sign to the wheels on the egress axis from whence they may be removed by Variable cards and the barrels to any axis in the Store. ⁵⁵

Division

Of the numerous difficulties which the contrivance of an engine to perform arithmetical operations presented, none certainly offered more reasonable grounds of difficulty than that structure of it by which it should be enabled to perform the operation of division. . . .

It has already been stated that when any number which happens to be greater than another is subtracted from that other number, an event which has been termed a Running up takes place, and that in consequence of this event any order which may be desired can be given to any part of the engine. Bearing this fact in mind, the division of one number by another may be conceived to take place in the following manner. . . .

The first direction given by the barrels is to subtract the divisor from the dividend. This order is repeated until . . . it is found that a Running up has taken place, a fact which of course indicates that the divisor has been subtracted once too often. The number of times the divisor has been subtracted is marked by a register axis. Now it is in consequence of this fact of a Running up that the engine knows it has subtracted the divisor once too often, and that knowledge is conveyed by the running up levers to the barrels in the form of an order to move to such verticals that at the succeeding turns they shall direct the erroneous subtraction and registration to be corrected, and the remainder of the dividers, to be stepped up, in order to undergo a similar process for the

Discovery of the next digit in the quotient. . . .

The first figure in the quotient being thus obtained, a repetition of the same process will of course produce the succeeding figures.

The complete understanding of this principle is of some importance, for it not merely relates to the process of division, but it is capable of being applied to any tentative arithmetical process. I had applied it to the extraction of roots, but other improvements induced me to dispense with it in this instance. Its application is not limited to existing rules, but I believe I may venture to state that whenever new methods are contrived for overcoming arithmetical difficulties by tentative processes, it will be found available for these new purposes; and that even in cases where the tentative processes relate to algebraic expressions it may yet be useful.

I have given a simple case in order to explain the nature of this principle. Division however is not executed by this tedious process, which would be required for its performance a number of turns more than equal to the sum of the digits in the quotient. The process really used may be thus described.

The operation card ordering division having advanced directs the barrels to the proper verticals.

The divisor P is first received from the ingress wheel upon several parts of the mill.

The Dividend B next enters. Several processes are gone through in order to ascertain whether it will be necessary to step the dividend up or down, and how many steppings there ought to be of either kind. This depends upon the number of digits of the quantities operated upon, and is principally executed by the counting apparatus, which also computes the number of figures which must occur in the Quotient.

At about the eighth turn the formation of the table commences, and also the selecting apparatus is prepared.

If the Stepping down is completed, the actual division may commence about the eighteenth [?] turn.

By means of the selecting apparatus the two first figures of the dividend are compared with the first two figures of each of the nine multiples of the divisor, and that multiple which has its two first figures either equal to or nearest less than the first two figures of the dividend is selected and subtracted from the dividend.

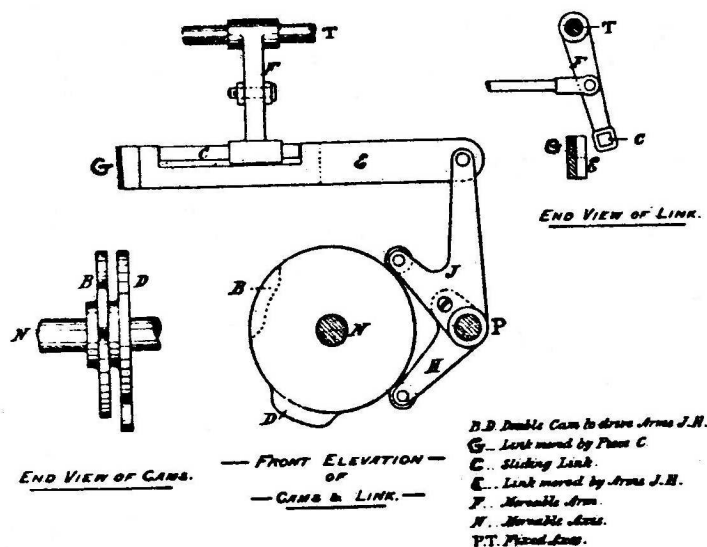
The remainder is then stepped up, and the process repeated until the counting apparatus interferes to finish the process.

In case the two first figures of the dividend are exactly the same as the two first figures of one of the multiples of the divisor, there may arise a doubt whether that multiple or the proceeding one should be subtracted: this will depend on the third figure of each quantity. But in this case the mill always takes for granted that the multiple selected is the true one. If however the contrary happens to be the case, then the subtraction of the multiple which is really too large will cause a running up in the dividend, and in consequence of this, orders will be transmitted to the barrels to direct the addition of the first multiple and the subtraction of unity from the multiple registered in the quotient, by which means, the quotient being set right, the first process is then continued.

After the end of the actual division, the quotient and the remainder, if required, are given off to the egress wheels.

As the result of the multiplication of a number containing forty digits by another of equal extent is a product containing eighty digits, and as this product can be conveyed into the store on two sets of figure wheels, a provision has been made for bringing such numbers back into the mill when they are to become dividends, so that the results of the division of a number eighty by one of forty digits shall have the forty figures of its quotient true to the last figure. [56](#)

This completes the explanation of the outlines of the four basic arithmetical operations. But it will be well to provide, as Babbage did not, a brief account of the mechanical approach of a lower level by which the various connections referred to were controlled. The fundamental notion necessary for understanding this is one that Babbage called Chain. This can be understood from the following sketch: [57](#)



Here the power input is on the shaft N; this turns a wheel holding the cams B and D, which act through a rocker-arm to move the piece E back and forth. E slides along a similar piece, called G; G and E will be connected together if the link C is in position in the slot cut away in them, and in this case the rotation of N will cause G to oscillate. The position of C, which pivots around the axis T, is controlled by the small arm F. The principle involved is that the transmission of power from N to G is controlled through a link which acts rather like a switch, and can be operated with much less power than it is controlling. Thus F might in fact be a feeler which senses whether a hole is punched in a certain position in a card.

The way the principle of Chain was applied in practice in the Analytical Engine can be seen in two crucial cases in [Figure 2](#). In it, a variable card can be seen on the left and a Barrel on the right, with the columns they control near the top. One chain can be seen from the large cam wheel, C, next to the Barrel; the rocker arm H will rock the arm K, which will move the pinion axis that can connect the Rack to the figure axis up or down; but this chain will only be complete if the link B is in the proper position, as determined through a couple of arms by a stud near the top of the Barrel. Other arms forming Chains from the Barrel to other axes or to effect the rotation of the Barrel itself are activated by different studs, but only a few are shown in this drawing.

The Variable Cards form Chains of a slightly different kind. Again, their function is to raise a column with pinions so that a certain Store axis will be connected to the Store Rack. They act through what were called Travelling Platforms, which were shafts below the main machinery which

move up and down a small amount at regular intervals; they are shown to the right of the variable cards in the drawing in cross-sections marked P. Arms activated by the variable cards would connect or disconnect the Travelling Platforms from the pinion axes through special sliding links.

One final and slightly different example of a Chain is the technique used for anticipating carriage. The examples of Chains given above are ones where a power train would be completed if one certain contingency were fulfilled. In the Chain involved in anticipating carriage, there were multiple contingencies of different kinds. Thus the beginning of the chain would be moved if there was a first order carriage at a certain point in the number column; the link would be activated if the wheel next above stood at nine (in the case of addition); the chain could be as long as the series of adjacent wheels standing at nine, or there could be several, separate partial chains set up in a column at the same time.

One final aspect of the operation of the Analytical Engine must be considered here, both because an understanding of it is important in any assessment of the Engine, and because Babbage himself considered it very important; this is the question of the speed of the Engine.

In his 1837 paper, Babbage proposed several principles which had guided the design of the machine, one of them being "that the several operations shall be executed in the shortest possible time." ⁵⁸ Babbage described the great difficulty this principle had caused him, and why he considered it to be extremely important, in the following remarks, which indeed, serve also to express in a way the fundamental paradox of Babbage's project, and also some of the motivation which drove him on.

In fact the whole history of the invention has been a struggle against time. As soon as any contrivance has been made which was unexceptionable as to the mechanism, the question has always arisen: Can it not be executed in less time by some other contrivance? Thus every advance has but raised up a new object of rivalry, itself to be superceded by some more rapid means; nor can I hope that I have nearly reached the limit. If I have approached it, it is more than I have a right to expect as the pioneer in this difficult career. Another age must be the judge of that as well as of the other questions relating to the Engine. . . .

The reader who only looks at the mechanical difficulties in contriving such an engine will doubtless be surprised, when he examines the history of the contrivances, . . . at the lavish rejection of inventions which has taken place in order to achieve rapidity in execution. But the Analyst, who is aware that the last resource in all our difficulties is the conversion of the most intractable expressions into infinite series, will more readily appreciate the importance of even a small abbreviation of the time, when he is informed that it is one of the objects of this engine to arrive at the numerical values of the coefficients of such series, however complicated the laws by which they are formed; and proceeding again from these results as established data, it is proposed to assign the values of such expressions for any magnitudes of the variables. ⁵⁹

As to the actual time taken, Babbage first defined the unit of time in which to describe the length of operations as that required for a figure wheel to pass over one unit of number, as to go from zero to one. Then the minimum cycle for adding one number would be ten units, nine for units which might be added, and one for another digit which might be carried; this cycle of ten, he thought, was the theoretical minimum which any decimal machine could ever attain. In practice, the cycle had to be longer, for time had to be allowed for moving the connecting pinions into place and for making the lockings and unlockings which prevented the machine from making any mistakes; the extra time required brought the cycle up to fifteen units in the case of plain addition, and twenty units in the case of addition with carriage. ⁶⁰

Beyond this, there were certain other operations which would take extra time; operation and variable cards had to be read, the Barrels had to be set, and so on. In order to accommodate these operations, it in fact took six cycles to add two numbers. However, the machine was so arranged that in certain circumstances it could perform different operations simultaneously in different sections; in a series of additions, it was possible to add each additional number after the first two in a single extra cycle. In other words, adding (or subtracting) n numbers together in succession, each of forty digits, would require $n + 4$ cycles of twenty units.

As to the length of the unit of time, wishing to give a conservative estimate of the speed of the Engine, Babbage estimated the maximum practicable velocity of the circumference of the figure wheels as ten feet per minute, or two inches per second; this would give a unit of time about 0.157 seconds long. Thus a cycle of twenty units would be about 3.14 seconds. This would mean that adding two numbers together would take about 18.8 seconds, but that each additional number would require only another 3.14 seconds. ⁶¹

In the case of multiplication and division, the time required depended on the number of digits in the numbers being operated on, and Babbage's own calculations of the time needed were incomplete; but seemingly for two numbers of about forty and twenty digits respectively, for example, multiplication would have required a little less than two minutes, with division taking somewhat longer. ⁶²

It will be readily apparent that the above mentioned ten unit cycle is a theoretical minimum for addition only in the case of decimal operation, and that there would be a different cycle length for different numerical bases; this was also apparent to Babbage. His initial concern was that the performance of carriage was - even after all the work on it - still taking a large fraction of the total time. Babbage calculated that carriage would take only about one ninth as long if the Mill were operated on a numerical base of one hundreds but he decided not to adopt this base. ⁶³ In general, the length of the basic cycle would vary directly with the magnitude of the base, but the number of cycles needed for multiplication or division would vary inversely with the magnitude of the base used. This general problem led Babbage to consider the question of "whether an arithmetic whose basis were 12, 16 or any other number being adopted, the operations might not be performed in a shorter time, notwithstanding the time consumed in converting the numbers out of the decimal scale and in reconverting the results into that scale." ⁶⁴ Babbage did not record the reasoning which he went through, but he decided to continue his planning on a decimal basis.

The modern reader, concerned with the relation of what Babbage did to modern computers, would be interested primarily in evidence that Babbage considered using the binary system. It must be borne in mind, however, that the binary system is used in modern machines primarily not because of any inherent superiority or logical purity it has in comparison to other bases, but because the components of which modern machines are constructed, being electronic or magnetic, are themselves inherently binary, and in this respect less flexible than Babbage's wheels. In any case there is some evidence that Babbage was considering some use of the binary system in the Engine. While discussing Number and Variable Cards in his December, 1837 paper, he remarked that "fourteen levers and their equivalent fourteen holes will be all that is required . . . for eight thousand variables." ⁶⁵ Unfortunately the context does not make very clear what Babbage was talking about, but the fact that 2^{13} equals 8192 strongly suggests that Babbage was pointing out that fourteen binary bits - represented by fourteen possible holes in a card - could convey numbers up to eight thousand to the machine, with the fourteenth hole serving to convey the sign. Later, however, Babbage planned simply to have a different hole punched out for each of the digits from one to nine. ⁶⁶

We have thus seen the picture of the internal development and operation of the Analytical Engine that emerges from an examination of Babbage's working notebooks and drawings, and from his December, 1837 paper. By this point Babbage had completed the invention of what we now know as the general purpose digital computer, and thus the changes which he worked on in later years were - by definition - not changes in principle, but rather changes to speed up the operation of the machine, or make it easier to construct, or some other such practical matter. Before proceeding with any further mechanical details, it will be well to consider the Engine in a more general context, in terms both of Babbage's own attitude toward it, and the communication concerning it he had with the outside world, in which that attitude is sometimes clearly revealed.

One aspect of this has already been covered in Chapter Two, namely the communication respecting the Analytical Engine which Babbage had with the government in connection with their support for the construction of the Difference Engine. It will be remembered that in his statement to the Duke of Wellington dated December 23, 1834, Babbage had announced the invention of a new machine with far greater powers than the Difference Engine, but one which did not supersede it, ⁶⁷ 1836 Babbage was saying that the old machine had been rendered wholly obsolete. ⁶⁸

In the first few years of Babbage's work on the Analytical Engine, he carried on almost no correspondence concerning it with his friends and colleagues, or at least almost none is preserved. One notable exception is a letter written to an unnamed friend (apparently an American), dated August 2, 1835. ⁶⁹ In this letter, Babbage described how, on gaining access to his drawings of the Difference Engine the previous

September, a re-examination of them had led him to the invention of a new machine at the same time more powerful and less complex than the old one. He continued:

I have had a draftsman constantly at work since September and I have given up all other pursuits for the sake of this, and the progress I have already made surpasses my expectation, it is indeed more than I ever before made in several years. This arises partly from a more enlarged experience, partly by having a better tempered draftsman, partly by having all my drawings in my own house instead of at a distance of four miles. My intention is to finish a complete set of mechanical drawings of the new engine and a variety of Mechanical Notations to explain its operation. I have already got over all the difficulties of the first order and most of those of the second and feel very confident that in twelve months more, if I can carry it on as I have done, that I shall have completed the drawings so that the invention can not ever be lost. [70](#)

Babbage then gave a brief outline of the function of the new machine, mentioning that among other things it could extract the roots of numbers by successive approximations, calculate logarithms and Bernoulli numbers, sum converging series, and reduce large numbers of observations.

Babbage concluded this letter as follows:

You will be able to appreciate the influence of such an engine on the future progress of science. I live in a country which is incapable of estimating it and I am much displeased with the treatment I have experienced . . . I have made large sacrifices and am prepared to make still larger. There is however, a limit at which my duty to my children demands my forbearance and I place that at the completion of my drawings, which is in fact the completion of the invention. These will remain when I am gone, and when some more enlightened country than my own shall at some future period become sensible of the value of the engine or ambitious of the fame of calling it into real existence, those drawings will undoubtedly be sought and from them a machine will be made which shall give to all nations and to all after time, tables at once perfect and enduring, and which shall execute calculations from which all human agents would shrink in hopeless despair. I have thus given you an outline of the work I am employed in; the views that it has opened and which it continually suggests are amongst the most interesting and important I have met with. [71](#)

It is notable in this passage that Babbage was still thinking at this time, August 1835, in terms of the production of tables as the primary function of the new machine. This idea was one that Babbage was to continue to hold and express for many years, and this was true also of several other themes laid out in the same passage, for example that the machine could not be properly appreciated in England, and that he himself would not build it, but that it would be built after his death, and have a profound influence upon science.

This last point particularly was amplified and powerfully expressed in the passage with which Babbage concluded his paper of December 26, 1837, from which extensive quotation has already been made; the final paragraph read: [72](#)

Whenever engines of this kind exist in the capitals and universities of the world, it is obvious that all those enquirers who wish to put their theories to the test of number will apply their efforts so to shape the analytical results at which they have arrived that they shall be susceptible of calculation by machinery in the shortest possible time, and the whole course of their analysis will be directed towards this object. Those who neglect the indication will find few who avail themselves of formulae whose computation requires the expense and the error attendant on human aid.

In the same paper, Babbage felt for the first time the need to express the opposite idea, namely that the machine had limitations; the form in which this was expressed is particularly interesting, for it came close to speaking directly to the modern worry over whether or not a machine can "think." In the passage in question, Babbage was apologizing in a footnote for the use of expressions like "the engine knows" or "the engine forsees" something. He said:

In Substituting mechanism for the performance of operations hitherto executed by intellectual labor it is continually necessary to speak of contrivances by which certain alterations in parts of the machine enable it to execute or refrain from executing particular functions. The analogy between these acts and operations of mind almost forced upon me the figurative employment of the same terms. They were found at once convenient and expressive, and I prefer continuing their use rather than substituting lengthened circumlocutions. For instance, the expression "the engine knows etc." means that one out of many possible results of its calculations has happened and that a certain change. has taken place by which it is compelled to carry on the next computation in a certain appointed way. [73](#)

Despite the large amount of time Babbage was putting into the planning of the new calculating machine in the next couple of years, [74](#) his correspondence still did not discuss the Engine. Yet apparently this was despite a growing commitment to it, for on December 26, 1838, Babbage wrote to the Vice Chancellor of Cambridge University, communicating his desire to resign from the Lucasian Professorship, this sacrifice being necessary for the sake of "the completion of the designs and description of the Calculating engine." [75](#)

Not until December, 1839, can one find another letter of interest concerning the machine; on that date, Babbage wrote to the noted French scientist D.F.J. Arago in Paris, asking Arago to get for him a copy of the portrait of Jacquard woven on the Jacquard loom, an example of which Babbage had recently seen in London. He gave the following account of why he was anxious to get the portrait:

You are aware that the system of Cards which Jacquard invented are the means by which we can communicate to a very ordinary loom orders to weave any pattern that may be desired. Availing myself of the same beautiful invention, I have by similar means communicated to my Calculating engine orders to calculate any formula however complicated. But I have also advanced one stage farther, and without making all the cards, I have communicated through the same means orders to follow certain laws in the use of those cards, and thus the Calculating Engine can solve any equations, eliminate between any number of variables, and perform the highest operations of analysis. Imagine then that I am anxious to possess so singular a portrait of your distinguished countrymen. [76](#)

Babbage concluded this letter with the following account of this progress:

I am continuing unintermittedly the Drawings of the machine on which I was engaged when you last visited London. I hope at my own expense and by my own efforts to leave behind me the drawing and full descriptions of an engine which has the power of solving by mere mechanical means most of the great problems of analysis.

In the original draft, this last sentence continued with the following words, subsequently struck out:

But it is very improbable that I shall ever possess the pecuniary means to undertake its execution. I have spent many thousands of my private fortune on this pursuit, and when the drawings are completed, the invention can never be lost. [77](#)

In 1840, Babbage received an invitation from the Italian mathematician Giovanni Plana to attend the second Riunione degli Scienziati Italiani, to be held in Turin in September, where all the leading Italian scientists would meet. The year before, Babbage had declined an invitation to attend the first meeting, on the grounds that it would hinder the progress of the Analytical Engine. [78](#) In 1840, however, Babbage changed his mind, doubtless in part because of the interest Plana had expressed in his invitation:

M. Plana stated that he had inquired anxiously of many of my countrymen about the power and mechanism of the Analytical Engine. He remarked that from all the information he could collect the case seemed to stand thus:

"Hitherto the legislative department of our analysis has been all-powerful - the executive all feeble.

"Your engine seems to give us the same control over the executive which we have hitherto only possessed over the legislative department." [79](#)

Babbage was very taken with this expression of the possibility that the Analytical Engine could make aspects of analysis which had previously

been of purely theoretical interest become practical and useful. He decided to go to Turin, for the following reasons:

The great object of my visit to Turin was to convey to Plana and to some of the Analysts of Italy the principles on which I had contrived an engine to perform as he has beautifully expressed it "the whole Executive of Analysis." The discovery is so much in advance of my own country and I fear even of the age, that it is very important for its success that the fact should not rest on my own unsupported authority. I therefore selected the meeting at Turin as the time of publication, partly from the celebrity of its Academy and partly from my high estimation of Plana. ⁸⁰

Babbage took with him to Italy "such of my models, drawings and notations as I conceived to be best adapted to give an insight into the principles and modes of operating of the Analytical Engine." At Turin, while the regular scientific meetings were in recess, Babbage met privately with Plana "and others of the most eminent geometers and engineers of Italy." Among these "others" was Luigi Federico Menabrea. Babbage later described these meetings as follows: ⁸²

These discussions were of great value to me in several ways. I was thus obliged to put into language the various views I had taken, and I observed the effect of my explanations on different minds. My own ideas became clearer, and I profited by many of the remarks made by my highly-gifted friends.

Babbage hoped that as a result of his visit to Turin, Plana would give a report on the Analytical Engine to the Academy of Turin, so that its importance would not rest on his own unsupported authority. However, Plana became ill, and the paper did not get written. In March, 1841, Babbage wrote to Angelo Sismonda, suggesting that one of the other people, including Menabrea, who had heard his exposition could assist in drawing up the report. ⁸³

In about July, 1841, Babbage wrote to Alexander von Humbolt, whom he had known for many years:

I am very desirous to make you acquainted with the object that I have proposed to accomplish and to convince you that the means exist of constructing an engine which as Plana has described it gives us as complete a power over the executive of analysis as we have hitherto possessed over the legislative portion. The greater part of the drawings exist by which an engine might be made which shall reduce to numbers any explicit function whose laws of formation can be assigned. For instance, the equation of finite differences expressing the law of formation of the numbers of Bernoulli being given to it, it will work out and print the successive numbers.

This engine is unfortunately far too much in advance of my own country to meet with the least support. I have at an expense of many thousand pounds caused the drawings to be executed, and I have carried on experiments for its perfection. Unless however some country more enlightened than my own should take up the subject, there is no chance of that machine ever being executed during my own life, and I am even doubtful how to dispose of these drawings after its termination. ⁸⁴

Babbage went on to say that he was most anxious to explain the machine to Humbolt and to get his advice, but that as the material needed for the explanation could not readily be taken abroad, he would have to invite Humbolt to visit London to see it.

One other point about this letter must be mentioned; it is apparently the first place in which Babbage used the term "analytical engine" although in this instance it does not seem to have taken on the role of a proper name for the machine, it did so shortly after. ⁸⁵ Although there is no direct evidence, it seems likely that Babbage came to use this name because of the phrase from Plana's letter to him of 1840, which he quoted quite frequently, to the effect that the machine would allow man's "legislative" power over analysis to be extended to include "executive" power: this relation was then summarized in the term Analytical Engine.

Nothing came of this attempt to gain Humbolt's backing for the Analytical Engine, but apparently Babbage desired it for two main reasons. First, he felt he was unlikely to get understanding and support for the machine from his own countrymen. Second, he wanted support for his ideas at this time because he was about to re-open negotiations with the government over the Difference Engine, and try to persuade them to underwrite the Analytical Engine. ⁸⁶ This is further revealed in a letter from Babbage to Plana, dated October 3, 1841, in which he discussed the description of the Analytical Engine which had finally been drawn up by Menabrea. Babbage said:

If you had made a report on the subject (of the Analytical engine) to the Academy of Turin during the last year it might have been of essential 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 on which it rests. ⁸⁷

Menabrea's paper was published in October, 1842 in French, and later in English, and will be discussed below. Evidently, however, Babbage was not as "well satisfied" as he might have been, for on October 7, 1841, having finally succeeded in getting an account of the Analytical Engine written by someone else, he set about writing another of his own.

This 1841 paper, called "Of the Analytical Engine," ⁸⁸ was a fairly straightforward introduction to the Analytical Engine on an elementary level, rather similar to the 1837 paper discussed and quoted extensively earlier in this chapter, though not as polished or complete. It did not, for example, go any further into the principles of the Combinatorial Cards or their mode of action, the cards which would have controlled in detail the flow of instructions into the Mill.

What was valuable about the 1841 paper was its introduction, where Babbage set out in a much clearer and more coherent way his conception of the general character of the Analytical Engine. This introduction began as follows:

The object of this engine is twofold. 1st To convert into numbers and to print the results of any formulae which may be required. 2nd To develop any analytical formulae the laws of whose formation are given.

In order to accomplish these objects it is necessary that it should be possible; 1st To express in the engine any functions whatever of any number of quantities and their numerical magnitude, together with their numerical coefficients, their indices of operation and their algebraic signs. 2ndly That it should be capable of performing with those numbers the four operations of arithmetic. 3rdly That it should be capable of all those combinations of symbols which the laws of analysis may require.

After stating what the Analytical Engine will do it may perhaps be necessary to state what it cannot accomplish. It cannot invent. It must derive from human intellect those laws which it puts in force in the developments it performs. It cannot in fact do anything more than perform with absolute precision and in much shorter time those series of operations which the hand of man might itself much more imperfectly accomplish. It must however be observed on the other hand that this great abridgement of time does in a certain sense render possible calculations which otherwise might be practically although not physically impossible from their tediousness as well as expense.

Another and an important fact is that it will perform calculations which the hand of man has never yet attempted, such as the elimination of one variable between two equations of the 6th dimension, and that in communicating to it our commands to execute such operations, it is quite unnecessary that we should ourselves go through them even in the first instance. This is accomplished by communicating to it the laws according to which the system of operations is performed. ⁸⁹

In the rest of the introduction to his 1841 paper, Babbage discussed the possibility of actually constructing a machine with the powers described. Without making any remarks as to his own plans or intentions about building a working machine, he set out three prerequisites for the construction of an analytical engine.

First, it must "be possible to carry on the whole of the executive department of analysis by means of the combination of a few simple arithmetical and algebraical processes." Second, it must be the case that "those elementary principles can be fully effected by means purely

mechanical." Babbage said that the fulfillment of these pre-conditions was a matter of demonstration, not of opinion; and although he did not set out to prove them, he clearly did not consider them to be in doubt.

The third condition was of a different sort. "Whether that system of contrivances which has been drawn can in the present state of mechanical art be executed so as to work regularly and exactly is an important point, a point on which opinions may fluctuate until experiment has decided the question." But Babbage expressed his confidence that "no man thoroughly acquainted with the present state of machinery in England and having complete drawings and notations of the engine can or will fail in making it work perfectly." ⁹⁰

As mentioned above, L.F. Menabrea had, by October, 1841 written up a description of the Analytical Engine as described by Babbage in Turin in September, 1840, and this description was shown to Babbage. For reasons that are not clear, it was not published until an additional year had passed; it is possible that some changes or additions suggested by Babbage delayed the matter. In any case, it appeared under the title "Notions sur la machine analytique de M. Charles Babbage" in the *Bibliothèque Universelle de Geneve* in October, 1842, ⁹¹ and constituted the first published description of the Analytical Engine.

In the summer of 1843, Menabrea's paper was translated by Ada Augusta, Countess of Lovelace, and only legitimate daughter of Lord Byron; she composed, in extensive consultation with Babbage, a series of long notes to the paper, which together comprised about three times the length of Menabrea's original version. The whole was published in Richard Taylor's *Scientific Memoirs* for 1843, ⁹² under the title "Sketch of the Analytical Engine invented by Charles Babbage, Esq.;" this was the only extensive paper on the Analytical Engine published in English during Babbage's life, or, indeed, up to the present. Although it is clear that Lady Lovelace was a woman of considerable interest and talent, and it is clear that she understood to a very considerable degree Babbage's ideas about the general character and significance of the Analytical Engine, and expressed them well in her notes to Menabrea's paper, it is equally clear that the ideas were indeed Babbage's and not hers; indeed, she never made any claim to the contrary. She made a considerable contribution to publicizing the Analytical Engine, but there is no evidence that she advanced the design or theory of it in anyway. And she did not even express an interest in learning about the machine until January 5, 1841, ⁹³ even as late as June 30, 1843, she apparently knew quite little about the mechanical details of the Engine. ⁹⁴

All of this is said not to belittle Lady Lovelace, but because a very exaggerated view has been formed by some recent writers of the significance of her contribution to the Engine or of her role in Babbage's life. ⁹⁵

From the present perspective, the Menabrea paper and the Lovelace notes are more interesting as an actual publication on the Analytical Engine than as a source of additional information. Very little was said of the operation or mechanical details of the Engine, far less than in the earlier Babbage manuscript papers. However, the extent of the powers of the machine, and, its limitations, and thus the question of its significance, were developed more clearly and elegantly than in the earlier works. Menabrea said the following:

Considered under the most general point of view, the essential object of the machine being to calculate, according to the laws dictated to it, the values of numerical coefficients which it is then to distribute appropriately on the columns which represent the variables, it follows that the interpretation of formulae and of results is beyond its province, unless indeed this very interpretation be itself susceptible of expression by means of the symbols which the machine employs. Thus, although it is not itself the being that reflects, it may yet be considered as the being which executes the conception of intelligences. . . .Who can foresee the consequences of such an invention? In truth, how many precious observations remain practically barren for the progress of the sciences, because they are not powers sufficient for computing the results! And what discouragement does the perspective of a long and arid computation cast into the mind of a man of genius, who demands time exclusively for meditation, and who beholds it snatched from him by the material routine of operations! Yet it is by the laborious route of analysis that he must reach truth; but he cannot pursue this unless guided by numbers; for without numbers it is not given us to raise the veil which envelops the mysteries of nature. Thus the idea of constructing an apparatus capable of aiding human weakness in such researches, is a conception which, being realized, would mark a glorious epoch in the history of the sciences. ⁹⁶

In the notes, these ideas were developed further and cast in more general terms:

The bounds of arithmetic were. . . .outstepped the moment the idea of applying the cards had occurred; and the Analytical Engine does not occupy common ground with mere "calculating machines." It holds a position wholly its own; and the considerations it suggests are most interesting in their nature. In enabling mechanism to combine together general symbols in successions of unlimited variety and extent, a uniting link is established between the operations of matter and the abstract mental processes of the most abstract branch of mathematical science. A new, a vast, and a powerful language is developed for the future use of analysis, in which to wield its truths so that these may become of more speedy and accurate practical application for the purposes of mankind than the means hitherto in our possession have rendered possible. Thus not only the mental and the material, but the theoretical and the practical in the mathematical world, are brought into more intimate and effective connexion with each other. We are not aware of its being on record that anything partaking in the nature of what is so well designated the Analytical Engine has been hitherto proposed, or even thought of, as a practical possibility, any more than the idea of a thinking or of a reasoning machine. ⁹⁷

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. Its province is to assist us in making available what we are already acquainted with. This it is calculated to effect primarily and chiefly of course, through its executive faculties; 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 engine, the relations and the nature of many subjects in that science are necessarily thrown into new lights, and more profoundly investigated. ⁹⁸

The publication of the Menabrea paper and of the much expanded Lovelace translation and notes was quite pleasing to Babbage. The former (which Babbage had gone to Turin in order to bring into being) he considered to be a "lucid and admirable description" of the Analytical Engine; the notes Babbage considered to have "entered fully into almost all the very difficult and abstract questions connected with the subject." The paper and notes taken together, said Babbage, "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." ⁹⁹

Also highly pleased by the translation and notes was Lady Lovelace, and she was even more pleased with herself for having produced them, despite what she considered to have been the inaccuracy and unreliability of Babbage's revision and suggestions. ¹⁰⁰ On July 30, 1843 she wrote to Babbage, among other things, "The more I study the more irresistible do I feel my genius to be. I do not believe that my father [Lord Byron] was (or ever could have been) such a Poet as I shall be an Analyst (and Metaphysician)." ¹⁰¹

In another letter to Babbage, on August 11, 1843, Lady Lovelace expressed her goal in life as follows. "I wish to add my mite toward expounding and interpreting the Almighty and His laws and works, for the most effective use of mankind, and certainly I should feel it no small glory if I were enabled to be one of His most noted prophets . . . in this world." Apparently this humble desire was to be fulfilled by Lady Lovelace becoming the general director of the execution of a working Analytical Engine. Babbage would promise to confine his attention entirely to the actual construction of the machine and "to abide wholly by the judgement of myself . . . whenever we may differ on all practical matters relating to whatever can involve relations with any fellow creature or fellow creatures." Exactly what scheme Lady Lovelace had in mind, or how she intended to finance it, she would not say, but in any case the matter was never followed up. ¹⁰²

Babbage's descriptions of the Analytical Engine written in 1837 and 1841, discussed earlier, were doubtless drafts of intended publications, and in December, 1842, Babbage had sent to a friend for his opinion a collection of papers which he was considering making into a book on the Difference and Analytical Engines; ¹⁰³ however, with the appearance of the Menabrea-Lovelace paper, Babbage evidently felt satisfied, for he published nothing on his own, and did not try to write any other papers on the machines for many years. In 1846, he gave as a further reason for his never having published anything on the Analytical Engine "the maxim of never employing my faculties on any but what I consider the highest objects as long as they are capable of advancing them," the completion of the plans of the Analytical Engine being such a

"highest object". [104](#)

We have seen how Babbage's conception of the general character and possible applications of the Analytical Engine developed from 1834 on, and also the measures that he took to bring the new machine into public view, although he preferred that this be done through some other author, and, indeed, that it first be made public in a foreign country. We must now survey the practical work and development that was done during the ten years following the point in 1837 at which the state of the Analytical Engine was described earlier in this chapter.

The principle point that must be kept in mind in considering this development is that Babbage had no plans for actually constructing the Analytical Engine in the immediate future; indeed, as we have seen, he several times expressed the opinion that it would not be constructed during his lifetime. This meant that he felt himself to be under no temporal pressure or restraint, and thus free to pursue the consequences of any conceivable modification in the parts of the Engine to their most remote consequences; usually this was to see if the change would save any time. Further, he would often take up consideration of some contrivance which he had rejected some years before, to see if it would work any better in relation to some other device or change he was now considering.

This mode of proceeding on Babbage's part has the unfortunate consequence that the great majority of the work he did after 1837 is very uninteresting; it has the character of neither being a theoretical or practical breakthrough, nor of leading up to or at any point constituting any single complete, coherent and final design for the Analytical Engine, for, as mentioned, Babbage was under no pressure to come up with such a final design. Thus most of this work will not be covered in this thesis. But examples of how this kind of consideration could lead down both fruitful and useless paths will be provided, and a few ideas that are interesting because of their similarities to methods used in modern computers will be described.

One point that needs to be made clear is that the tendency of what might be called Babbage's perfectionist approach was not simply to make the machine more complex; rather there was always a conflicting pull between simplicity and effectiveness, say in speeding up the operation of the machine; for Babbage found simplicity of structure or operation for a device able to do a certain job (which we might call efficiency) to be just as theoretically satisfying as raw capacity in itself; and he always thought of himself as working on a machine that would eventually be built.

Babbage described these conflicting tendencies very clearly in describing the difference in approach to the Great Analytical Engine on which he was working before the trip to Turin in September, 1840, and the simplified Small Analytical Engine which he began after this trip. [105](#) In fact, although the description pictured these as two diverse enterprises, the distinction was not maintained in his own work, and the same two approaches were battling each other in everything he did. As Babbage said:

The principles on which the great Calculating Engine was designed and drawn were:

1 That it should execute all its operations in the smallest possible time. This was the great guiding principle and even single turns of the hand were considered.

2nd That although the mechanism employed should be as simple as could be contrived, yet in no case should simplicity be purchased at the expense of time, provided the mechanism was of such a kind that it could in the present state of mechanical art be successfully executed.

3rd Expense of construction was never to be considered; whatever plan was thought to be the shortest in time, possible in execution and durable in structure was always adopted. [106](#)

In the Small Analytical Engine on the other hand, the approach was quite different:

The great object for which this was undertaken was to reduce the cost of construction to such a moderate sum as might render it possible that it might be executed.

The guiding principle was to give up all the more complicated mechanism, especially that which only effected small savings of time, and even if necessary some of the larger savings when they required great expense. [107](#)

It may well be that Babbage decided to make the plans more practical as a result of the enthusiastic reception his ideas met with in Turin. But in fact, the distinction between Great and Small engines became one between two phases of his thinking through any given new idea. Babbage would go to extreme lengths to see if the idea would save any time; if it would, he would work on it in an attempt to simplify the mechanism necessary for him to adopt it in the machine. When this was done, he would consider the complexity of the device in relation to the time saved; if it was large, he would reject the device; if it was small, he would adopt it. Frequently, however, the efficiency of the device would be ambiguous, so that Babbage could not decide whether to adopt it or not.

An example of this process, which also illustrates the very complex trains of thought through which Babbage's mind worked over long periods of time, is the technique Babbage called Half Zero Carriage. It will be recalled that in his 1837 paper on the Analytical Engine, Babbage had believed that the theoretical minimum time necessary for adding a decimal digit in the machine would be ten units of time, where the unit was defined as the time needed for a figure wheel to turn from one digit to the next. [108](#) In the 1837 plans, the same minimum time was necessary for clearing a column, that is, reducing all its wheels to zero, by the method described earlier.

The Small Analytical Engine, as was said, was begun in November, 1840. One of the first crucial questions was whether to continue using multiplication and division by table (which required a lot of complex mechanism for the table axes and selection apparatus), or to go back to the earlier and much simpler method of multiplication and division by repeated addition and subtraction; the latter method, however, would make the machine much slower, requiring as much as seventeen minutes for division of sixty figures by thirty figures. [109](#)

The first thing Babbage realized was that he could reduce the number of table axes needed to five by the following method. On five axes were placed the first five multiples of the multiplicand; if a given digit of the multiplier was less than five, the selecting mechanism would enter the corresponding multiple in the usual way. If a digit greater than five was presented to the selecting mechanism, it had to, as Babbage put it, "move back from the fifth multiple by a number equal to the excess of that digit above five," that is, by the tens complement of the specified digit. The multiple corresponding to this complement was then subtracted from the result column, and the next higher digit of the multiplier was increased by one. [110](#)

This new form of multiplication would have allowed Babbage to reduce the number of table axes to five for the Small Analytical Engine, but it would have also made the process as a whole, particularly the problems of selection and control, much more complicated. This did not cause Babbage to abandon it, however, for it began to suggest things more interesting to him than the simplification which he had set out on.

On December 15, 1840, Babbage noticed that in one stage of the multiplication process he had accidentally allowed only five units of time for clearing a carriage column from a previous operation (this clearing was overlapping with another part of the operation), whereas the clearing required ten units. [111](#) Instead of lengthening the cycle by five units, Babbage reflected that it took ten units to clear a wheel only because if it stood at nine, it would have to be turned all the way around to get back to zeros but if it were turned back the shortest way, that is, in the other direction if the wheel stood at a number above five, then it would take only five units. This method Babbage called clearing by "Half Zero," seemingly because the zero stood in the middle of the segment through which the wheel might be turned in clearing it. [112](#) It was also clear that a similar method could be used for transferring a number from one column to another whose wheels all stood at zero; at first he intended to do this by putting the same number on two different axes, each to be turned one way, but this was not necessary. [113](#)

However, these ideas suggested to Babbage a method for a new process of division in which the selection process was not tentative (that is,

subject to reversal of a step because of a running up), and would thus be faster; the idea was to place on nine special axes the tens complements of the nine multiples of the divisor, and make selection by adding the dividend (or remainder at any given point) to all of these axes. This addition would cause a running-up on some of the axes; the number of the highest axis to run up would give the appropriate digit in the quotients further, the result of the addition on that same column would give the remainder at that point in the division; when this remainder was again added to the complement axes (after they had been reset), the next digit would be obtained, and so on. [114](#)

This method of division was sufficiently fascinating to Babbage that he lost interest in his efforts to devise a Small Analytical Engine that would be easy to build; also he continued to develop this and related ideas rather than that of half-zero figure wheels. In fact it was not until more than a year later, in April, 1842, that Babbage went beyond the use of half-zero for reducing columns to zero, for at this point he realized that he could use half zero for reducing the time of addition and subtraction themselves. [115](#)

This was to be done by a method quite similar to that used for transferring numbers by half zero (two reducing arms turning opposite ways), except that the column receiving the number would not be standing at zero. The effect of this was that if one number was being added to another, the digits standing at or below five would be added in the usual way, while the digits above five would have their tens complements subtracted; likewise in subtractions, the digits above five would have their complements added, while the lower digits would be handled normally. Again, the intention of all this was to reduce the basic time needed for these operations (exclusive of carriage) from nine to five units of time.

The great difficulty with this approach was that it required a new and much more complicated carriage mechanism, since the conditions which determined whether or not a carriage should take place were much more complicated than in conventional operation. As in the first stage of development of the Analytical Engine, Babbage considered using both hoarding and anticipating carriage, [116](#) and again decided that the latter was preferable.

Another circumstance that was important at this point was that Babbage had decided that as stepping numbers up or down only a single cage at a time took too much time, he wanted to be able to step any number of cages at once. He rejected the method of having a very large number of pinions which could be selectively put in gear (which he had considered back in 1834), since the number of pinions would have to be proportional to the square of the number of significant digits; instead he decided to take a number column and simply move it bodily up or down the desired number of cages. The great difficulty was that with his designs at this point, the columns already were about eight feet high and very heavy, so that it was not practical to move them around with any abandon. [117](#)

As the primary obstacle to reducing the height of each cage was the size of the carriage mechanism, it became desirable to redesign the carriage mechanism both to reduce its size and to make it possible to use half-zero addition and subtraction.

Babbage went on in the following months and years to work very extensively on the details of an anticipating half-zero carriage, and the requirements and possibilities which his designs brought forth continued to interact with and influence in substantial ways the design of the Engine as a whole. The details of the development will not be discussed here. It should be noted, however, that at times, as on August 1, 1845, the difficulties of half-zero carriage led Babbage to decide to abandon it, [118](#) although a few months later he was back to making plans for it. [119](#)

Rather than plunging further into this morass of detail, it will be well to cover briefly a few other important points or threads of development between 1837 and 1847. One subject in particular calls for further explanation, as the description of it in Babbage's 1837 paper, discussed earlier, leaves much to be desired: this is the function and operation of the Combinatorial Cards. The vague explanation of Combinatorial Cards in the paper dated December 26, 1837, may be accounted for by the fact that the first statement on the subject in the notebooks is dated December 13, 1837, and is itself rather vague. [120](#) Apparently what Babbage envisioned was that there would be a series of steps in a program which would be repeated many times at the beginning, and then some additional steps at the end that would be performed only once apiece; Babbage may have had in mind some such thing as computing a number of terms in a mathematical series, and then forming their sum. In any case, the plan was to have a special set of combinatorial counting wheels; on these would be placed the number of times the special set of operations at the beginning of the program was to be repeated. At the end of this set of operation cards would be a special combinatorial card; when it was reached, unity would be subtracted from the combinatorial figure wheels, and the operation cards would be turned back to the beginning. However, when, after a number of repetitions, the combinatorial figure wheels read zero, the index card at the end of the sequence would be ignored, and the Engine would go on to the next card.

Although by May 10, 1838, this plan had become somewhat more coherent, it had not become more flexible. [121](#) It provided only for backing the operation cards to a pre-determined point, although the number of repetitions could be varied. On February 9, 1839, Babbage mentioned another idea, whereby after a series of cards was completed, they could be turned to a point other than the beginning of the series; this was done by putting the number of cards that were to be turned on a special backing apparatus; when the point was reached where the transfer was to be made, the backing apparatus was geared with the card prism, and then reduced to zero, turning the cards as it went. The number that was to be put on the backing apparatus could be either computed internally or specified in advance by a number card, following the principle which Babbage was to express two years later in these words:

Any fact which is certain and known before execution... should be ordered by cards. Any fact which although equally certain is unknown previously to the actual working out of the formula should be governed by Mill or Counting Apparatus, etc. [122](#)

In late March, 1843, Babbage mentioned a method by which the operation on a single card could be repeated as many times as desired. Each operation card had punched on it the number of times it was to be repeated. The first time it was read, this number was put onto the card counting apparatus; the card was then used again to set the barrels, but the index on it was ignored, unity being subtracted from the card counting apparatus instead. When the number on it reached zero, the cards were advanced by one, a new index was taken in, and so on. It is not clear what this was supposed to accomplish, but seemingly it simply reduced the number of cards needed when an operation was to be done many times together, for this plan did not provide any increased power or flexibility to the Engine. [123](#)

In November and December of 1843, Babbage spelled this plan out a bit further. Each operation card was to be able to convey to a card counting apparatus any index number less than 1000. In order to save space on the card, this was to be done in the following way. Each digit to be conveyed had corresponding to it holes standing for one, three and nine; the holes for one and three also had holes to indicate if they were negative. By combining the digits +1, +3, and +9, any digit from zero to nine could be expressed, and thus numbers up to 999 could be represented by fifteen holes, rather than thirty. Also, there were to be several different card counting apparatuses on which the indexes could be placed; one might control the number of times an operation was to be repeated, while another would determine the interval through which the cards were to be moved after the repetition was complete. [124](#)

Although Babbage continued to consider various minor modifications of these schemes, the differences were not important. What can be said is that all the elements necessary for full flexibility in instruction addressing were available in the machine. Yet although Babbage was aware that a variety of repetitions and branchings would be necessary, he never felt compelled by the kinds of programs he got around to considering [125](#) to make explicit or coherent any, but simple examples of the methods of program control.

This discussion of the development of the Analytical Engine beyond the stage described earlier in the chapter may be concluded with a few examples of developments in it which are paralleled by features of modern computers. Perhaps the most interesting is Babbage's thoughts on the use of what we might call external memory, and especially the use of pre-computed tables to be consulted by the machine.

We have already seen how Babbage, as early as March, 1835, had intended to do multiplication (and shortly thereafter division) by constructing internal tables of the first nine multiples of the multiplier on special axes. On August 7, 1837, it occurred to Babbage that he might similarly form a table of the low integral powers of the digits one through nine, and that then the first digit of the corresponding roots of numbers could be found by working backward through this table. [126](#) At first it seems he thought of having this table internal, as with the

multiplication table, although they were substantially different, in that the multiplication table was specially computed for each different multiplier. However, in early September, 1837, Babbage was considering some matters connected with having the Engine punch its own cards, and it occurred to him that he could have the Engine form tables on cards for its own use. On September. 7 he considered having a table of one hundred cards corresponding to the digits from one to one hundred, each having also punched in it the first two digits of its square root. Then when the Engine wanted the square root of a number, it would turn through these cards to the one corresponding to its first two digits, and would then obtain the first two digits of the square root. In both these methods subsequent digits would be found by some method of successive approximations. [127](#)

Babbage realized that this technique could have wider applications than the extraction of roots, for on September 9, 1837, he noted that "possibly several systems of punched cards might be employed to reduce Astronomical and barometric observations by." [128](#) At about the same time Babbage also considered forming a table of the first one hundred multiples of a multiplier on cards; the selecting apparatus would then have turned to the card corresponding to a given pair of digits, and the multiple on the card would have been added to the appropriate column. This would have halved the number of separate additions (or subtractions in the case of division) necessary for a multiplication, and eliminated the need for table axes in the Mill. However, on September 19, Babbage rejected the idea, because turning through the string of cards to get to the right one would have required an inordinately large amount of time. [129](#)

The idea was not followed up until May 22, 1842, at which point Babbage described a considerably more elaborate system for having the machine be able to consult logarithmic tables in the course of its computation. The machine would itself have computed log tables, and placed on cards both the argument, with five digits, and its logarithm, with ten. The complete set of cards with this table would be placed in a drawer near the Engine. Then when it wanted a logarithm, it would ring a bell for the attendant and display the number whose log it wanted; he would fetch the corresponding card from the drawer and feed it into the machine. The Engine would then subtract the argument punched on the card from the number it had specified, and check that the first five digits of the result were equal to zero; if they were not, the Engine would ring "a great bell to tell [the] Assistant he had made a mistake." [130](#) Babbage also intended to have punched on the same cards the first and second difference of each logarithm, for use in interpolating to more than five figures in the argument. He also realized that the same method would work equally well for functions other than the logarithm.

Babbage was quite pleased with this method, not only because of its usefulness and relative simplicity, but because a description of the ability of the machine to know when it had been fed the wrong card, without a description of the simple means by which this was accomplished, made it sound as if the Engine had very peculiar powers. Consequently he gave a lengthy description of the technique in his book *Passages From the Life of a Philosopher*, and added the following very prescient observations:

It will be an interesting question, which time only can solve, to know whether such tables of cards will ever be required for the Engine. Tables are used for saving the time of continually computing individual numbers. But the computations to be made by the Engine are so rapid that it seems most probable that it will make shorter work by computing directly from proper formulae than by having recourse even to its own Tables. [131](#)

Remarkably, despite the tremendous alteration in the time scale of computation, this "interesting question" is still relevant today.

One advantage of feeding numbers into the Analytical Engine in this way was that it eliminated the possibility of error when wheels had to be set by hand. Babbage realized that this was equally true for the "formula" (program), since the great complexity possible in it made it especially important that it be fully "verified" (debugged). This made especially valuable the separation between the operation cards and the variable and number cards, since it was possible to verify a formula, and then be confident of its accuracy when at some later time it was run with some new set of data. [132](#) It would thus be possible to build up a "library" of verified formulae which would be used repeatedly. He also realized that not only could the Analytical Engine use formula cards that it had previously verified, or number cards that it had previously punched, but that one such machine could share its cards and programs with another, and that therefore a card copying machine would be useful. He went on to say:

It is desirable that all Analytical Engines should have cards of the same size. But it is very improbable that those first used will be of the best size. Hence in making the card copying machine it will be necessary to contrive means of changing the punches so that Cards may be copied in any given size. [133](#)

We may conclude by noting two further minor but yet interesting ideas that emerged during this period. One was that it would be desirable to have the Analytical Engine able to do calculations using pounds, shillings and pence, although it is not clear what sorts of monetary calculations Babbage had in mind. Curiously, he intended to accomplish this by altering the internal hardware of the machine, rather than by having special formulae for converting input and output. [134](#)

Another plan to modify the engine so that it could handle material which required something other than straightforward numerical output, was that of providing two extra kinds of cards to control the printing of results; these served a function essentially identical to that served by FORMAT statements in current FORTRAN programming. One set controlled the horizontal and vertical motion of the paper (or copper plate) on which the results were printed, while the other would insert such explanatory symbols and text between the data as was desired. [135](#)

This kind of development, mixing revision in general plans, refinements of details, and new ideas of peripheral improvements, continued steadily until late in 1846, at which point it was abandoned for just over ten years, and then resumed for the remainder of Babbage's life. The reasons for this hiatus and the character of the later work on the Analytical Engine will be discussed in the next chapter.

FOOTNOTES

[#1](#) S.B., "Vol. XV," p. 101, referring to the Analytical Engine.

[#2](#) B.C.E.. p. 212.

[#3](#) See B.C.E.. pp, 264-69.

[#4](#) See Chapter Two.

[#5](#) B.C.E., p. 220. The property of the even differences of the sine function which Babbage discussed is simply a generalization of the property of its second difference already described above.

[#6](#) B.C.E., pp. 216-19.

[#7](#) B.C.E., p. 216.

[#8](#) B.C.E.. pp. 216-19.

[#9](#) *Transactions of the Cambridge Philosophical Society*. Vol. III (1824), p. 218.

[#10](#) Reprinted in B.C.E., pp. 225-31.

[#11](#) This volume (henceforth G.S.B.) is related to, but not directly part of, the series of regular Scribbling Books at South Kensington. Two pages spreads will be indicated by the first line number on the verso sheet.

[#12](#) G.S.B., 1. 1231.

[#13](#) G.S.B., 1. 1261.

- [#14](#) B.C.E., pp. 268, 331. Apparently the only use of this phrase by Babbage at the time was in the outline of a paper to be called "Philosophy of the Calculating Engine," dated August 30, 1834 (Buxton, Vol. VII); this paper was not written.
- [#15](#) The first sketch of the circular arrangement is at G.S.B., 1. 1801; the sketch is not dated, but the next page has the date September 18, 1834.
- [#16](#) This account is from Babbage's paper "The Analytical Engine," p. 9, dated November 8, 1869; Buxton, Vol. VII.
- [#17](#) This account was reconstructed from very vague material in the vicinity of G.S.B., 1. 1801.
- [#18](#) Nowhere is any coherent account of this development given by Babbage, and it has been pieced together from scattered material, mostly in G.S.B. and S.B., Vol. I and Vol. II, plus the drawings from the period. Specific references will be given when possible. Note that S.B., Vol. I is sometimes wrongly called Vol. XIII (see Bibliography).
- [#19](#) G.S.B., 1. 1861.
- [#20](#) See S.B., Vol. I, pp. 175-167 (working backward) and S.K., Drawings II, 5-7 (this refers to the large drawings in the South Kensington collection, in this case numbers five through seven from Case II. See Bibliography on numbering of drawings).
- [#21](#) G.S.B. 1. 1861 and S.B., Vol. I, pp. 175-167.
- [#22](#) G.S.B., 1. 1891.
- [#23](#) S.K., Drawing II, 14.
- [#24](#) G.S.B., 1. 1891.
- [#25](#) S.B., Vol. I, p. 172; S.K., Drawing II, 3.
- [#26](#) S.B., Vol. I. pp. 175. 4; S.K., Drawing II, 4.
- [#27](#) On the following, see especially S.B., Vol. I, pp. 30-31, and G.S.B., 1. 1951, 1981. 2011, and 2301.
- [#28](#) See, e.g., S.K., Drawings II, 9 and 16.
- [#29](#) First notes on barrels and platforms; S.B., Vol. I, pp. 14-21, February 26, 1835.
- [#30](#) S.B., Vol. I, pp. 140-41.
- [#31](#) S.K., Drawings II, 29 and 35. .
- [#32](#) S.B., Vol. I, p. 40.
- [#33](#) S.B., Vol..I, pp. 167-165.
- [#34](#) S.B., Vol. I, p. 165.
- [#35](#) Reprinted in B.C.E., p. 5.
- [#36](#) S.B., Vol. I, p. 163.
- [#37](#) S.B., Vol. I, pp. 119-123.
- [#38](#) S.B., Vol. II, p. 19.
- [#39](#) S.B., Vol. II, p. 45.
- [#40](#) P.L.P., p. 126.
- [#41](#) First mention: S.B., Vol. II, p. 146; cf. Vol. I, p. 160.
- [#42](#) Curiously, Jacquard (1752-1854) had gotten the idea for his loom from an earlier one made by Jacques de Vaucanson, which he came across while rummaging among some old material at the Conservatoire des Arts et Metiers in Paris. See W.H.G. Armytage, *A Social History of Engineering* (Cambridge, Mass.. 1961), p. 110; John Timbs, *Stories of Inventors and Discoverers* (London, 1863), pp. 236-38.
- [#43](#) S.B., Vol. II, p. 150.
- [#44](#) Buxton, Vol. VII. Unfortunately the Buxton papers are in considerable disarray, and the pages of this paper are not all in order or even together. However, it can be reconstructed in full.
- [#45](#) References will be given here to the short title "Powers," with page numbers from Babbage's manuscript.
- [#46](#) "Powers," pp. 9-11. Note the limitations imposed by the inflexible treatment of the decimal point, in contrast with the exponential representation in current computers. This is one reason Babbage provided what seems like a very excessive number of wheels per column, since this did not in general yield nearly as many significant digits as it would seem.
- [#47](#) "Powers," p. 44.
- [#48](#) "Powers," pp. 12-13, S.B., Vol. III, p. 93.
- [#49](#) "Powers," p. 14.
- [#50](#) "Powers," p. 15.
- [#51](#) The relation of a barrel to its reducing apparatus and to the rest of the machine can be seen in [Figure 2](#); also shown is the operation of a variable card. The barrels could also be affected by the counting apparatus. See also S.B., Vol. IV, p. 144.
- [#52](#) The preceding section on the Mill is all from "Powers," p. 2-8.
- [#53](#) "Powers," p. 40.
- [#54](#) "Powers," p. 21.
- [#55](#) "Powers," pp. 24-26.
- [#56](#) "Powers," pp. 32-36.

[#57](#) Adapted from one by Henry P. Babbage; see B.C.E., p. 338.

[#58](#) "Powers," p. 27.

[#59](#) "Powers," pp. 27-28.

[#60](#) Ibid.

[#61](#) "Powers," p. 23.

[#62](#) See "Powers," pp. 31-32, 37, 46-53.

[#63](#) "Powers," p. 50.

[#64](#) S.B., Vol. III, p. 17 from back.

[#65](#) "Powers," p. 15.

[#66](#) S.B., Vol. IV, p. 385.

[#67](#) B.M., Vol. VII..ff..525-29.

[#68](#) B.M., Vol. VIII, ff. 292-93.

[#69](#) Held by the Burndy Library, in Norwalk, Connecticut.

[#70](#) MS. pp. 3-4.

[#71](#) MS. pp. 8-9.

[#72](#) "Powers," p. 53.

[#73](#) "Powers," p. 19. It is interesting to compare this passage with similar ones in recent works on computers. A good example will be found in *Faster than Thought*, ed. B.V. Bowden (New York, 1953), p. 29.

[#74](#) Although he was also writing the *Ninth Bridgewater Treatise* in 1837, and doing very extensive railway experiments in 1839, among other things.

[#75](#) B.M.. Vol. X. f. 67.

[#76](#) B.M., Vol. X, ff. 287-89.

[#77](#) Ibid.

[#78](#) B.M., Vol. X, f. 246.

[#79](#) P.L.P., p. 129.

[#80](#) B.M., Vol. X, f. 582.

[#81](#) Menabrea, 1809-1896, was an engineer and mathematician; he later served as a general in the Italian army and as prime minister from 1867-69; he became Marquis of Valdora.

[#82](#) P.L.P., p. 130. for quotations above and below.

[#83](#) B.M., Vol. X, f. 582.

[#84](#) B.M., Vol. X, f. 638 this draft is not dated, but internal evidence places it somewhat before August 12, 1841.

[#85](#) It is capitalized on B.M., Vol. X, f. 645.

[#86](#) See Chapter Two.

[#87](#) B.M., Vol. X, f. 645.

[#88](#) Buxton, Vol. VII.

[#89](#) Ibid.

[#90](#) Ibid.

[#91](#) Vol. XLI, New Series, pp. 352-376.

[#92](#) Vol. III, pp. 666-731.

[#93](#) B.M., Vol. X, ff. 532-33

[#94](#) Charles Babbage to Ada Augusta Lovelace, June 30, 1843; in the Lovelace. Papers. Quoted in Mabeth Moseley, *Irascible Genius* (London, 1964), p. 169.

[#95](#) Mosely, *Irascible Genius*, is the prime example, devoting over a quarter of her biography of Babbage to material on Lady Lovelace. Moseley is also convinced that Babbage served for many years as an intermediary between Lady Lovelace and the bookmakers to whom she became deeply and scandalously in debt, and that the generally quite trivial correspondence between her and Babbage involved some phantasmagorical secret code concerning this illicit activity; however, Moseley presents absolutely no serious evidence for this (See Mosely, Chapter 22, esp. p. 196).

[#96](#) B.C.E., pp. 19-20; the paper and notes are reprinted in B.C.E., pp. 4-50.

[#97](#) B.C.E., p. 25.

[#98](#) B.C.E., p. 44.

[#99](#) P.L.P., pp. 135-36.

[#100](#) See, for example, some of the amazingly arrogant remarks quoted in Moseley, *Irascible Genius*, Chapter 20.

[#101](#) B.M., Vol. XI, ff. 407-9.

[#102](#) B.M., Vol. XI, ff. 422-27.

[#103](#) B.M., Vol. II, ff. 205-6. It is not clear just what the papers were.

[#104](#) B.M., Vol. XII, ff. 347-57.

[#105](#) For date of change in emphasis, see S.B., Vol. III, p. 68 from back. See also S.K., Notations 172 and 173, dated November, 1840.

[#106](#) S.B., Vol. III, pp. 368-70.

[#107](#) S.B., Vol. III, pp. 374-77.

[#108](#) "Powers," p. 27.

[#109](#) At this point Babbage was considering thirty digits per column as standard, rather than the earlier forty.

[#110](#) S.B., Vol. IV, pp. 448-51, December 8-9, 1840.

[#111](#) S.B., Vol. IV, p. 460.

[#112](#) S.B., Vol. IV, p. 477.

[#113](#) S.B., Vol. IV, pp. 475, 501.

[#114](#) S.B., Vol. IV, p. 482, January 3, 1841.

[#115](#) S.B., Vol. V, p. 118, and S.K., Drawing II, 102.

[#116](#) S.B., Vol. V, p. 132.

[#117](#) S.B., Vol. V, pp. 183-89.

[#118](#) S.B., Vol. VI, pp. 32-33.

[#119](#) S.B., Drawing II, 136.

[#120](#) S.B., Vol. III, pp. 161-66.

[#121](#) S.B., Vol. III, pp. 75-76 from back.

[#122](#) S.B., Vol. IV, p. 514. February 2, 1841.

[#123](#) S.B., Vol. V, p. 389.

[#124](#) S.B., Vol. V, pp. 454-59, 469-77, 533-34.

[#125](#) Such as the program to compute Bernoulli numbers, described in Note G to the Menabrea paper, B.C.E., pp. 45-50. This was written by Babbage, not Lady Lovelace: see P.L.P., P. 136.

[#126](#) S.B., Vol. III, p. 90.

[#127](#) S.B., Vol. III, pp. 88-89.

[#128](#) S.B., Vol. III, p. 93.

[#129](#) S.B., Vol. III, p. 100.

[#130](#) S.B., Vol. V, p. 152.

[#131](#) P.L.P. p. 122. Compare Babbage's *The Exposition of 1851*. (London, 1851), pp. 185-87, where the ability of the Engine to reject wrong cards was given as an example of an apparently impossible power Babbage had given it, without the method being explained. The same mystification is attempted with the fact that the Engine could be made so that wheels being turned by hand at any time would not cause errors. Cf. S.B., Vol. V, pp. 334-35, January 28, 1843.

[#132](#) "Powers," pp. 41-43; P.L.P., p. 119.

[#133](#) S.B., Vol. V, p. 545, October 29, 1844.

[#134](#) S.B., Vol. V, p. 322, January 11, 1843

[#135](#) S.B., Vol. IV, pp. 216-18, September 21, 1839.

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CHAPTER FOUR

Babbage and Calculating Machines After 1846

He put this engine to our ears, which made an incessant noise like that of a watermill. And we conjecture it is either some unknown animal, or the god that he worships but we are more inclined to the latter opinion, because he assured us (if we understand him right, for he expressed himself very imperfectly), that he seldom did anything without consulting it. He called it his oracle. ¹

- After Babbage began work on the Analytical Engine in late 1834, he largely ignored the further development of the Difference Engine for over a decade, although he was still negotiating with the government as to the status of the project for its construction through 1842, as described in Chapter Two. Only occasionally did material on mechanisms for the Difference Engine or on ways to do finite difference calculations on the Analytical Engine appear in Babbage's notebooks. ² However, in October, 1846, Babbage abruptly turned his attention back to the Difference Engine, or rather what he called the New Difference Engine, ³ and later the Difference Engine No. 2, and away from the Analytical Engine.

Exactly why this great change in interest occurred is not clear. Writing in 1864 in *Passages from the Life of a Philosopher*, Babbage said that he turned his attention to the Difference Engine No. 2 "when I had mastered the subject of the Analytical Engine." ⁴ However, considerably closer to the event, in his

- book *The Exposition of 1851*, ⁵ Babbage gave a rather different account. He said that after the invention of the Analytical Engine, "I instituted a long series of experiments for the purpose of reducing the expense of its construction to limits which might be within the means I could myself afford to supply. I am now resigned to the necessity of abstaining from its construction, and feel indisposed even to finish the drawings of one of its many general plans." It is indeed plausible that Babbage had to an extent simply gotten tired of working on the Analytical Engine; although he was still turning out a fairly large number of Notations, the number of Drawings and the amount of space in the Scribbling Books taken up with the Analytical Engine had declined greatly from a few years earlier.

However, there was one other circumstance which may have caused Babbage to return to the consideration of the design of a Difference Engine at this time, although he gave no hint of it in any of his writings. In July, 1846, the Conservative government headed by Sir Robert Peel, who had finally terminated official support for the first Difference Engine, and who refused to admit that any gratitude or honor was due Babbage for his labors on it, was replaced by a Whig government with Lord John Russell as Prime Minister.

- Babbage apparently thought that an appeal to the new government might produce some redress of the injustice he felt he had suffered from the old one, and he correspondingly wrote a long letter to the Prime Minister in December, 1845, describing the many contributions he had made to science and art, and the many positions which had been refused to him despite his high qualifications. ⁶

Once again, as with Babbage's letters to the government in the 1830s, it is not clear what result he was attempting to produce. In very vague terms, Babbage simply appealed to Russell "against the injustice of the past. It is for you as the first minister of the crown to adopt or repair it." ⁷ How Russell could or should repair it Babbage did not suggest, and he also did not mention his efforts of the previous two-months to design "a Difference Engine of the simplest construction." ⁸ But that Babbage had in mind some scheme for getting the government to acknowledge the unjust neglect with which it had treated him, and then proposing that they undertake to construct the new Difference Engine, seems fairly clear,

- In any case, Babbage did not send his letter to the Prime Minister, although at some point after June, 1847 (possibly as much as two or three years after), ⁹ he extensively revised and shortened it, again apparently without sending it. Another letter, probably some later version of this same one, was prepared in December 1849, and sent to the Earl of Rosse, President of the Royal Society, for suggestions, but it is again unclear whether this letter was sent to Lord Russell. ¹⁰

In the meantime, Babbage had been working on the design of the Difference Engine No. 2, and by March, 1848, he had prepared a complete set of drawings and notations, ¹¹ although some additional work was done through March, 1849. ¹² However, on February 16, 1849, Babbage had written to a friend with respect to the Engine:

I am now winding up that affair; ill health and other circumstances have brought on a crisis, and I shall avail myself of it to close the account, I hope forever.

I agree with you entirely as to the magnitude of the debt this country owes to science, but I probably differ from you in disbelieving the capacity of the present race of statesmen either to feel or to repay it. ¹³

- Work on the Difference Engine ceased in March, 1849. For a short time thereafter Babbage returned to a consideration of the Analytical Engine, but this ¹⁴ was quite sporadic, and it ended on May 7, 1849. ¹⁴ After this there was no further work on any calculating machine plans until 1857. Already in March, Babbage had been attempting to find some other position for C. G. Jarvis, who had been working on the designs for Babbage's machines ever since the first Difference Engine; ¹⁵ whether he succeeded is not clear.

- Babbage wrote no general description of the Difference Engine No. 2, or of how it differed from Difference Engine No. 1, although he claimed that it was "an instrument of greater power as well as of greater simplicity than that formerly commenced." ¹⁶ However, from the drawings it appears that it was basically very similar in general design to the earlier machine. Digits were to be added from one difference to that above it by raising and lowering the various axes, as in the Analytical Engine, rather than by the somewhat clumsy method of bolting used earlier; but the basic principle of adding the odd and even differences in two groups was the same, and the method of carriage, on which Babbage had spent so much of his effort on the Analytical Engine, was basically the same as that used on the first Difference Engine. The main change from both earlier machines was that for the Difference Engine No. 2, Babbage had a complete set of plans for the whole machine, including the printing apparatus; Babbage was able to formulate one basic design for the whole machine and then draw all of the component parts consistent with it, as opposed to the invariable experimental altering of what was already designed characteristic of the plans for the Analytical Engine. Apparently the new Difference Engine was to have seven orders of differences, each column able to hold thirty digits. The whole machine would have been over ten feet long, but this was partly because the driving, calculating and printing sections were all strung out in a line. Despite Babbage's statement that the new Difference Engine would have "greater power" than the old, there is no indication that he planned to incorporate any mechanism for making the machine "eat its own tail."

- Such, very briefly, was the character of the new Difference Engine. Two circumstances led Babbage to believe that an attempt to construct it would be more successful and less expensive than that to build the first Difference Engine. First, Babbage felt that he had been quite successful in "simplifying and expediting the mechanical processes" of the Difference Engine No. 1. ¹⁷ Second:

circumstances had changed, mechanical engineering had made much progress, the tools required and trained workmen were to be found in the workshops of the leading mechanists, the founder's art was so advanced that casting had been substituted for cutting in making the change wheels even of screw-cutting engines, and therefore it was very probable that persons would be found willing to undertake to complete the Difference Engine for a specific sum. ¹⁸

- As mentioned above, Babbage had sent to Lord Rosse, President of the Royal Society, a draft of a letter to Lord Russell, Prime Minister, in December, 1849, many months after Babbage had completed working on the plans of the new machine. But whether this letter contained an offer of the plans to the government is not clear; in any case it appears that the letter was not sent. For some reason the matter rested until the spring of 1852, at which point the government headed by Lord Derby replaced that of Lord John Russell. At that point, Babbage decided that he would get Lord Rosse to present to Lord Derby an offer of the plans for the new machine, in order "that I may fulfill to the utmost of my power the original expectation that I should be able to

complete, for the Government, an Engine capable of calculating astronomical and nautical Tables with perfect accuracy." ¹⁹ Yet Babbage was not willing to devote his own time to building the new Difference Engines only to make the plans available. ²⁰ On the other hand, he would not propose that the government construct the Analytical Engine, since:

it is not so matured as to enable any other person, without long previous training and application, even to attempt its execution; and on my own part, to superintend its construction would demand an amount of labour, anxiety and time which could not, after the treatment I have received, be expected of me. ²¹

Babbage's letter to the Prime Minister, dated June 8, 1852, was presented to him by Lord Rosse along with some supporting material. ²² It reviewed the reasons the first Difference Engine had been undertaken and then abandoned, the injustice with which Babbage had been treated, and the increased simplicity and importance of constructing the new Difference Engine. Babbage concluded by asserting that in making this offer "I have discharged to the utmost limit every implied obligation I originally contracted with the country." ²³ Lord Rosse lent his support to Babbage's views on the importance of having a Difference Engine, and added, at Babbage's suggestion, ²⁴ that any doubts the government might have about the practicality and expense of the project could be resolved if they would "call upon the President of the Society of Civil Engineers to report whether it would be practicable to make a contract for the completion of Mr. Babbage's Difference Engine, and if so, for what sum." ²⁵

Babbage was not optimistic about the prospects of this offer. Replying to a letter from Rosse dated July 22, 1852, ²⁶ informing him that Rosse had presented the case to Derby, Babbage said that with respect to the likelihood of having the calculating machines constructed:

I have never entertained much hope, and I now feel a kind of relief at being no longer obliged to think on a painful subject.

I have been trying to exclude the idea by the enquiry into the great law of matter, but I am obliged for a time to vary my occupation, and am now busied with the Automaton player at Tit-Tat-To.

Perhaps if I were to make that toy, my countrymen right think there was some merit in the Analytical Engine. ²⁷

The Tit-Tat-To playing automaton referred to here was an idea with which Babbage toyed over a long period of time, though never developing it very fully. ²⁸ Babbage also considered at times the possibility of teaching the Analytical Engine to play chess; he was confident that it was theoretically possible, but aware that it would require a huge programming effort. ²⁹ In *Passages from the Life of a Philosopher*, Babbage gave an account of these interests, and said that he had considered the possibility of making several Tit-Tat-To machines and sending them around the country as exhibits to which admission would be charged; after a time enough money might be raised to pay for building the Analytical Engine. However, he enquired into the financial success of similar exhibits that had been tried, and decided it would be a waste of time. ³⁰ Yet it is clear in most cases, including the letter to Rosse just quoted, that Babbage considered the Tit-Tat-To machine more as an amusing diversion than as a serious subject.

The Prime Minister responded to the offer of the plans for the Difference Engine No. 2 on August 16, 1852. On that date, W.P. Talbot, secretary to Lord Derby, wrote to Rosse informing him that Derby had taken the documents sent him by Rosse under consideration, and had consulted with the Chancellor of the Exchequer (Benjamin Disraeli); his conclusion was:

that Mr. Babbage's projects appear to be so indefinitely expensive, the ultimate success so problematical, and the expenditure certainly so large and so utterly incapable of being calculated, that the Government would not be justified in taking upon itself any further liability. ³¹

In a letter accompanying a copy of this reply which Rosse sent to Babbage, Rosse suggested that they might be more successful if the matter were taken up in the House. ³² Babbage replied on August 27, saying that his first reaction was "that I ought to make no further attempt to force a generous offer upon a reluctant country, in fact it appears that I had thrown Pearls before Swine." ³³ He pointed out that the government had had neither the training nor the information to judge the expense of the Difference Engine No. 2, but that they must have decided the matter on the basis of the expense of the work done on the Difference Engine No. 1 at a time when machining was far more difficult and costly.

Curiously, Babbage somewhat misread the letter from Talbot, thinking that it attributed to Disraeli opinions said to come from Derby, and this mistake persisted through the account of the offer of the second Difference Engine given in *Passages from the Life of a Philosopher* in 1864. There Babbage blamed the whole matter on the Chancellor of the Exchequer, saying, for example, that "the machine upon which everybody could calculate had little chance of fair play from the man upon whom nobody could calculate;" ³⁴ and that "It can not only calculate the millions the ex-Chancellor of the Exchequer squandered, but it can deal with the smallest quantities. . . It may possibly enable him to un-muddle even his own financial accounts." ³⁵ And Babbage concluded, "The Herostratus of Science, if he escape oblivion, will be linked with the destroyer of the Ephesian Temple." ³⁶

Rosse replied to Babbage's letter of August 27 on the 29th. ³⁷ He pointed out that most of the points Babbage had made had already been expressed in the letter he had sent to Derby himself, accompanying Babbage's offer of the-plans. He also quoted two of the most important of these remarks, ones which he made on the basis of a statement he had elicited from the distinguished engineer James Nasmyth. ³⁸ As Rosse had expressed it to Derby:

From what I have heard from eminent mechanical engineers, there is no doubt that this Country has received an equivalent many times over for the expenditure on the Calculating engine, in the improvements in tools and machinery directly traceable to the attempt to make it. . . .

Tools and machinery are now in so advanced a state compared to what they were when the machine was commenced that it is probable some mechanical engineer would be found to undertake the work by contract. ³⁹

Whatever further desire or plans for furthering the construction of the Difference Engine No. 2 Babbage and Rosse had, they did not amount to anything, and the project was not pursued nor the machine again taken up. However, somewhat of a digression is justified in order to follow up the two remarks of Rosse just quoted.

In a speech to the Royal Society, as President, in 1855, Rosse gave an account of the history of the Babbage Difference Engine, and repeated the assertion that "the expense of the Calculating Engine had been more than repaid in the improvements in mechanism directly referable to it." ⁴⁰ It apparently occurred to Babbage after this address that he might get wide agreement on this point among engineers. He therefore wrote to three of the most distinguished engineers of the day, Joseph Whitworth, William Fairbairn and James Nasmyth, asking them to confirm Rosse's statement. ⁴¹ Whitworth's reply is not to be found, but from a further letter Babbage wrote to him it is evident that he misunderstood Babbage's request, for he offered to make a contribution toward the cost of constructing the Analytical Engine; this Babbage declined. ⁴² Fairbairn sent an elaborate formal statement, which concluded that "the labours of Mr. Babbage in devising and constructing the Calculating Machine have led to the most important results . . . in the general improvements referable to mechanical construction." ⁴³

The most elaborate praise was contained in the letter from Nasmyth, which also gives a nice indication of the high regard in which the mechanical arts were widely held at the time. Writing to Babbage on June 22, 1855, Nasmyth said:

I have no hesitation in stating that whatever were the direct results of your endeavour to carry out into a practical form your idea of a "Calculating machine," the indirect Results were most valuable to mankind in as much as that the admirable contrivances and tools which the late Mr. Joseph Clement in conjunction with yourself designed and constructed (for Executing with due perfection the Exquisite apparatus required to realize your great object) furnished such ideas to the mechanists of the world as gave an impulse towards the perfect in mechanism, such as has had no small share in bringing about the wonders which modern machinery has enabled us to realize.

Beginning with the admirable and ever to be remembered contrivances of Sir Samuel Bentham, who I hold to be the true originator of modern Engineering Tools, and taking next in order Henry Maudsley of glorious memory, we come to Joseph Clement and your worthy self, who in your joint endeavours to realize your ideas of a Calculating machine gave I may say the finishing touches to those mechanical agencies by the aid of which we are now almost getting the mastery over Time, Space and the matter of our globe, which I am fain to consider one of the grandest objects of human existence as a powerful means towards "the greatest happiness to the greatest number." ⁴⁴

Exactly why Babbage solicited these statements at this time is not clear, as it does not seem that he had any intention at this point of using them to gain support for any further construction of either the Difference or Analytical Engines. Perhaps he thought it appropriate to reassert his own claims to

recognition at the time when the Scheutz Difference Engine was getting wide public notice, as will be discussed shortly. It is clear that Rosse's speech had not suggested a new idea to Babbage, for he had recognized the importance of spin-off at least as early as 1834, as discussed in Chapter Two, and had published an assertion almost identical to Rosse's in 1851. ⁴⁵ Unfortunately, it is not easy to evaluate the truth of these assertions of Babbage's contributions to mechanics: Babbage's own clearest statement on the point was not made until November, 1869, in a letter to a "Rev. Pearson." He said:

I have heard at different times from men I had employed in former years that amongst their own class it was frequently said that:

Mr. Babbage made Clement.
Clement made Whitworth.
Whitworth made the tools.

When I first employed Clement he possessed one lathe (a very good one) and his workshop was in a small front kitchen.

When I ceased to employ him he valued his tools at several thousand pounds and he had converted a large chapel into workshops. ⁴⁶

It is clear that Clement built most of his important tools while he was working for Babbage. He had set up his own shop in 1817; ⁴⁷ in the years after this, descriptions of machines he had built were published on five occasions in the *Transactions of the Society for the Encouragement of the Arts*; ⁴⁸ for three of these inventions he was awarded medals by the Society. The first, in 1818, was for a drawing instrument; the three which were machine tools (two improvements in lathes plus his famous planing machine) were all built during the time he was working for Babbage.

Aside from these inventions, Clement's other greatest contribution to machinery, also developed while working for Babbage, was uniform threads for taps and dies. Previously, the number of threads had been made largely at random, so that different screws were generally incompatible; in 1827 Clement began making his taps with a certain integral number of threads to the inch, depending on the diameter, so that different screws would be interchangeable. This practice was learned by Joseph Whitworth (1803-1887), who worked for Clement between 1831 and 1833; Whitworth was later able to get the thread specifications, which he further improved, adopted as a uniform standard through most of the world. ⁴⁹

One thing that is more difficult to judge is what proportion of the work of Clement's shop was devoted to Babbage's machine. Smiles does not make this clear, although he states that Clement's "principal income" came from work done on his planing machine (the only one at the time capable of handling really large work), and that Clement at times employed as many as thirty assistants; ⁵⁰ this implies that work for Babbage was a relatively small part of Clement's business. However, although Smiles states that the planing machine was built in 1825, ⁵¹ Clement's nephew (who took over Clement's shop on his death in 1844 ⁵²) stated in reply to an enquiry from Babbage in 1855 that the planing machine was finished in 1831; ⁵³ it thus could not have been Clement's principal source of income before then. Further, the fact that in 1832 Clement was willing to consider moving to the special workshop being built for the Difference Engine ⁵⁴ strongly suggests that work on it was not a minor part of his business. Still, it is clear that by 1832 Clement's business was prosperous, and that he could afford to lose the Difference Engine work; but this is fully compatible with Babbage's statement, quoted above, that "Mr. Babbage made Clement."

Returning to the remarks made by Rosse to Derby in 1852, only one piece of evidence will be offered in support of the assertion that improvements in machine tools would make the construction of the Difference Engine No. 2 far easier than the work on the Difference Engine No. 1. In his address as the President of the Institution of Mechanical Engineers in 1856, ⁵⁵ Joseph Whitworth discussed the improvements in manufacturing technique that had been made since 1826. To cite only one specific point, the cost of finishing a cast iron surface by hand in the earlier year had been about twelve shillings per square foot but with the planing machines of the 1850s, the same operation cost about one penny per square foot, a reduction in the cost of a very basic operation by a factor of 144. This may go a long way toward explaining the high cost of the work on the original Difference Engine.

After 1849, Babbage had ceased working on the mechanical details of any of his calculating machines, and after 1852 he also ceased for a few years to make any substantial effort at promoting their construction or use. However, during the mid 1850s, he did spend a considerable amount of time supporting the Scheutz Difference Engine and helping its builders, and an account of this work must be given, though primarily from the point of view of Babbage's role.

Per Georg Scheutz (1785-1873) attended the University of Lund and Its Law School and served a few years of employment in the law, but in 1817 he entered the field to which he was to devote most of his life; publishing and journalism. For many years he served as co-owner of a printing company, publisher of newspapers and trade journals, and translator; he also served as a reporter for his own and other papers, particularly on economic and technical subjects, and after 1842 this was his primary occupation. Georg's son Edvard (1821-1881) was born in 1821 and entered the Technological Institute in Stockholm in 1835; he was still there when work on the Scheutz Difference Engine began. ⁵⁶

In 1834, Georg Scheutz read in the *Edinburgh Review* the article on the Babbage Difference Engine by Dionysius Lardner, ⁵⁷ "Unfortunately for himself, Mr. Scheutz was fascinated by the subject, and impelled by an irresistible desire to construct an engine for the same purposes," as Babbage was later to express it. ⁵⁸ Scheutz made a few models of different parts of the machine out of crude materials to test his ideas, but at first carried the project no further. During the summer vacation of 1837, Edvard Scheutz, now seventeen years old, became interested in the project, and father and son together revised and extended the earlier plans to the point where they were sufficiently satisfied with them to apply, on October 30, 1837, for support from the Swedish government to construct the machine; this was refused on February 21, 1838. ⁵⁹

The plans continued to be developed and improved, until, by mid 1843, the Scheutzes had produced working models of the different sections of this machine, including the printing apparatus. This crude demonstration version of the Difference Engine was inspected by a distinguished committee from the Royal Swedish Academy of Sciences on September 18, 1843, they issued a report describing the capabilities of the machine. Georg and Edvard Scheutz hoped to use this favorable report to help solicit orders for full, finished version of the Engine, but they were not successful, and the model stood idle for many years. ⁶⁰

For some reason interest in the machine was revived in December, 1850, when a new committee from the Royal Academy of Sweden inspected it; this led the Scheutz's to apply again to the government on January 28, 1851. The government referred the matter to the Academy of Sciences, which advised that the project should be supported, but on April 29, 1831, the government decided against giving support. However, the question was raised again in the Diet, and a motion was passed proposing that the Scheutzes be given the equivalent of £280, ⁶¹ providing that the machine when complete was found to work successfully. The Scheutzes had to petition, however, to receive the money in advance; this was granted on October 24, 1851, provided they obtained guarantees that the money would be repaid if the machine was not finished satisfactorily by the end of 1853; they were able to get pledges toward repaying the money in case they should fail from various members of the Swedish Academy.

The working drawings of the machine were completed on February 1, 1852, and the machine was built at the workshop of C.W. Bergström in Stockholm, under the superintendence of Edvard Scheutz, being completed in October, 1853. The Royal Academy pronounced the machine to be satisfactory, and as a consequence of their suggestion, the Diet awarded the Scheutzes an additional £280.

At this point a few remarks will be in order as to the relation of the Scheutz Difference Engine to the Babbage Difference Engine No. 1 (from a description of which the Scheutzes had begun), though nothing will be said by way of mechanical description of the Scheutz machine. In principle, the two machines were identical; even the basic approach to the mechanical design of the various operations was quite similar, though in the Scheutz machine the printing apparatus was much more fully developed. The principle differences lay in the actual detail of the adding and carriage mechanisms; partly these arose from the fact that the Scheutz calculating section was rotated ninety degrees with respect to the Babbage calculating mechanism; that is, each successive difference was arranged horizontally across the front of the machine, with a wheel on a given level of each successive axis corresponding to each successive digit of a given order of difference; yet although this made the machine look quite different from the Babbage version, it was not in fact a significant change.

More important was that the mechanism for adding individual digits was considerably revised, in such a way that it was considerably more compact and easier to construct, but on the other hand it was also considerably more delicate and unreliable. The other main change was in the carriage mechanism; in Babbage's machine carriages had been delayed and sequential, being caused by arms set in spiral form on axes which turned at the appropriate time; this allowed second and higher order carries to be made without difficulty. On the Scheutz machine the carries were still delayed and sequential, but they were performed by a special pair of devices which slid back and forth on tracks in front and back of the machine, and which bore, as Babbage said, "a

certain analogy to a railway having fifteen stations,"⁶² This carriage mechanism, though highly ingenious, was definitely less satisfactory than Babbage's; although a good deal more delicate, it was really no simpler in construction or operation. Worse, it was tremendously slower, taking about twelve to fourteen seconds for one set of carries, where the Babbage version would have taken about one second. In part this was offset by having some of the carries performed while printing was going on, but the printing mechanism was itself very slow, and even accepting it, half the carriage time was still wasted.

In short, though clever in design, the Scheutz Difference Engine was definitely inferior to the Babbage Difference Engine. It was substantially less reliable; worse, it was extremely slow; where the Scheutz machine took thirty seconds to calculate one new number, the Babbage machine could find it in about four seconds (although the provision of a printing apparatus might have slowed it down somewhat). Indeed, the only advantage of the Scheutz machine, real enough to be sure, was that it actually did get built.⁶³

The final reward to the Scheutzes for their work mentioned above was decided on by the Swedish Diet on August 11, 1854. As it was their hope to make some profit from their invention by obtaining orders for copies of it, particularly from foreign countries, they set off with the machine for England in October, 1854, and they spent the rest of the year in England and France, though the machine stayed in England. On October 17, 1854 they applied for an English patent for the machine, and it was issued on April 13, 1855.⁶⁴ In London, the Scheutzes were introduced to the firm of Bryan Donkin & Co., Civil Engineers, and the machine was deposited at the firm to be exhibited. There they met William Gravatt, who, together with Babbage, did the most to publicize, display and try to get sales for the Scheutz machines; through them it was deposited at the Royal Society, where it was repeatedly demonstrated by Gravatt, including among its visitors Prince Albert, on January 29, 1855.

On January 21, 1855 a special committee of the Royal Society, headed by George G. Stokes, issued a report on the Scheutz Difference Engine. It mentioned the relation of the Scheutz machine to Babbage's, and spoke approvingly of the smoothness with which the former operated, but it devoted most of its attention to the limits placed on the machine by the fact that it had only four orders of differences; this led to the conclusion that the machine would be useful primarily for recalculating old mathematical tables.⁶⁵

In June, Babbage heard of this report from Charles Wheatstone, another member of the committee, and he wrote to Stokes saying that he was glad that they had investigated the general problem of calculating tables on difference engines, although he had "no intention under any circumstances of ever making such a machine myself."⁶⁶ He went on to point out that the limitations discussed in the committee's report were to a degree overcome by the method he had devised for altering the last difference.

Charles' son Henry P. Babbage had been in India since 1843 in the service of the East India Company. In late 1854 he returned to England on an extended furlough. His father taught him the mechanical notation which he had invented in 1826 and subsequently developed, and on April 4, 1855, Henry was set to work using the mechanical notation to describe the operation of the Scheutz Difference Engine, which at that time was still housed at the Royal Society.⁶⁷ He continued working on this project through the summer, and the large charts which resulted were finished in time to be used as illustrations in a talk on the mechanical notation which Henry delivered to the meeting of the British Association in Glasgow in September 1855.⁶⁸ They were used again in a joint paper by Henry and Charles on the Scheutz machine and the mechanical notation delivered to the Institution of Civil Engineers on May 20, 1856.⁶⁹ On November 30, 1855, Charles delivered another paper on the Scheutz machine to the Royal Society, regretting that it had not been nominated for one of their medals, and suggesting that the lapse be remedied the following year.⁷⁰

On August 29, 1855, the Scheutz machine was sent to Paris to be displayed in the Great Exposition of 1855, where it was accompanied and demonstrated by Gravatt.⁷¹ The diagrams explaining it made by Henry Babbage in the mechanical notation were later sent to join the machine; the machine was eventually awarded the highest prize of the Exposition, a Gold Medal.

After the Exposition, the Scheutz machine was moved to the Imperial Observatory of Paris by order of the Emperor Napoleon III;⁷² there was some confusion about this, for at first Babbage was under the impression that the French government had purchased the machine, and he suggested that they should also make Georg Scheutz a member of the Legion of Honor.⁷³ In fact they had not purchased it, but asked the opinion of LeVerrier as to whether they should purchase it, and he recommended against this despite the fact that some other French scientists defended the machine, the government agreed.⁷⁴

Either through publicity from the Paris Exposition or from direct communication with Babbage, with whom he corresponded,⁷⁵ Benjamin Gould, director of the recently formed Dudley Observatory in Albany, New York, heard about the Scheutz Difference Engine, and on April 28, 1856, he wrote to Babbage asking about the powers of the machine, and requesting "information of the Yankee-est but of practical kind; is it for sale, and if so at what price?"⁷⁶ Independently, the United States Nautical Almanac office sent similar enquiries to Edvard Scheutz on June 15, 1856.⁷⁷

Babbage, however, still hoped to keep the Scheutz machine on the eastern side of the Atlantic. On June 23, 1856, Babbage wrote a letter - probably to the French astronomer Claude Louis Mathieu - suggesting that even if the French did not want to buy the Scheutz machine for practical work at the Imperial Observatory, "it might yet be worth of a prominent place in any collection of Machines for performing intellectual calculations." Babbage said that such a collection would also have to include an original Pascal calculator and a Jacquard loom, the latter being important because "all my experience in contriving the Analytical Engine leads me to believe that those cards upon which I have engrafted a new principle will always form the simplest and most powerful means of conveying the commands of the human mind to automatic machinery."⁷⁸

However, this plan did not work out, and later in the year arrangements were complete to sell the machine to the Dudley Observatory through Gould for the price of £1000. In a letter to Edvard Scheutz arranging the details of the transaction, dated December 22, 1856, Gould said:

What its fruits on this side of the Atlantic may be of course can not yet be anticipated; but I will trust that they may be such as to insure the absence of any regrets on your part that the product of your constant and toilsome labours for so many years should find its home in the western world.⁷⁹

Gould suggested that among the uses to which the machine might be put were the computation of ephemerides and of the Nautical Almanac. He also requested that any report of the sale made in England should mention that the machine was a gift to the observatory in Albany from "an enlightened and public spirited merchant of that City, John F. Rathbone, Esq."

Before this sale had been arranged, however, the machine had been brought back from France to England in July, 1856.⁸⁰ Apparently this was done (apart from the failure to sell the machine in France) in order to carry out a suggestion from Gravatt that "an endeavour should be made to obtain an acknowledgement of the practical usefulness of the invention by the publication of a collection of specimens of numerical Tables computed and printed by the machine."⁸¹ The machine was installed in Gravatt's house, and the work was executed by him and Edvard Scheutz, in consultation with Babbage. The first sample pages of specimen tables calculated by the machine were sent by Gravatt to Babbage on October 18, 1856.⁸² When finished, in about April, 1857,⁸³ the booklet contained nearly forty pages of tables, the bulk of them comprising a complete table of logarithms, samples of other kinds of tables forming the remainder. The Scheutzes wrote a long preface to the work recounting the difficulties they had encountered along the way, and they dedicated the volume to Babbage, whom they called "one of the benefactors of mankind, and one among the noblest and most ingenious of the sons of England."⁸⁴ Earlier, in February, 1856, the Scheutzes had expressed their gratitude for Babbage's help more personally in individual, formal letters of thanks;⁸⁵ they had remarked there that his generosity was all the more remarkable since it might have been expected that he would feel some resentment toward them for having taken over what was clearly his idea.

During this same period, in a passage struck out from the letter to Mathieu cited above, written June 23, 1856, Babbage expressed his disinterest in resuming work on his own machines, and a firm conviction that the Analytical Engine "will never exist during my life."⁸⁶ Some of his friends, however, wished that he would take up his work again. On July 28, 1857, I. K. Brunel, the noted engineer and a long time friend of Babbage, wrote him, saying: "Your name will ever be associated with the calculating machine, and the day will yet come (perhaps in your lifetime and mine) when your own comprehensive plans may be carried out; and this possibility might almost become a probability if the stone were once set rolling again." To set the stone rolling Brunel suggested that they raise money to build a second Scheutz machine, perhaps an improved model: "once set the system going and fresh wants would arise," perhaps ultimately leading to demand for an Analytical Engine.⁸⁷

Through exactly what process the construction of the second Scheutz Difference Engine, as proposed by Brunel, was arranged is not clear, but principally two main facts converged to make it possible. First, Edvard Scheutz arranged with the engineering firm of Bryan Donkin to jointly offer to construct

another model of the engine for £1200.⁸⁸ Second, the General Register Office had accumulated a mass of data from the censuses of 1841 and 1851, and the registrations of births and deaths from 1838 to 1854, and wished to use this data in computing and publishing a new set of Life Tables, primarily under the impetus of William Farr. The Registrar-General, with the concurrence of the Astronomer Royal, Sir George Airy,⁸⁹ recommended to the Home Department that the government acquire a Difference Engine for this work, so a contract was entered into with Donkin & Co., in about November, 1857, to build a new Scheutz machine.⁹⁰ The machine was built by Donkin's firm, basically unchanged from the original Scheutz version, and was finished toward the middle of 1859. Upon completion, the machine was set to work in the General Register Office in the preparation of the English Life Table, which was issued in 1864. It is difficult to tell just how the machine was used, but it seems that to a certain extent it was set to duplicate certain tables which had been calculated by hand so that the two sets could be compared and verified., In the published version, less than one quarter of the tables were printed from plates stereotyped by the machine.⁹²

The use of the English Scheutz machine was a source of some friction between Babbage and the Registry Office; Babbage felt strongly that it ought to have been exhibited at the British Exhibition of 1862, as an example of both calculating machinery and of the excellence of English workmanship; Babbage even had some scheme for exhibiting it alongside his own partial Difference Engine, having them both turned at slow rate by the same prime mover. The Registrar-General, however, felt that the use of the Scheutz machines in computing the Life Table was too important to be interrupted, and that the Scheutz machine was too delicate to be moved safely. Babbage eventually got quite angry at this and at the ill treatment he thought was shown toward his own machine when it was displayed at the Exhibition.⁹³

After the publication of the *English Life Table* it does not appear that the English Scheutz machine was further used, and although some modifications were made to make the original machine, at this point in Albany, work better, it apparently was put to no significant use.⁹⁴ For a few years the Scheutzes had continued trying to sell other copies of their machine, in the hope of finally making some profit from their years of work, but by 1861 this hope was abandoned, and Edvard Scheutz turned his attention to the invention of a new kind of rotary steam engine.⁹⁵ The two Scheutz Difference Engines were in the long run deposited respectively in the Smithsonian Institution and in the Science Museum in South Kensington. Similarly, after being displayed at the International Exhibition of 1862, the Babbage Difference Engine was transferred to the South Kensington Museum, newly formed at that time; despite Babbage's belief that the machine would not be properly understood there, and that it should go to Cambridge University, it has remained in South Kensington ever since.⁹⁶

Brunel's suggestion, in July, 1857, that promotion of the Scheutz Difference Engine would re-ignite interest in the Analytical Engine in the world at large, proved to be false. However, starting the previous month, Babbage's own interest had already been re-awakened, and he set to work on the Analytical Engine once again. He worked fairly steadily through the middle of 1859, and then abruptly stopped, doing almost nothing until February, 1863, when, as suddenly and unexplainably, he took the work up again, continuing it on and off from then until shortly before his death, on October 18, 1871.

Unfortunately, the character of Babbage's work during this period was much the same as that which he had done during the 1840s;⁹⁷ that is, it led to no coherent, final, definite plans for the Analytical Engine, and was often concerned with re-thinking some notion previously rejected, or changing the character of the machine he was trying to design. In the case of the earlier period, this had been quite understandable, since Babbage had had no intention of trying to construct the Analytical Engine, and thus was not obliged to try to come up with final working plans. But in the period after 1857, the contrary was true; either seeing the Scheutz machine completed and working, or the improvements in the art of machining that had taken place, or some other reason had convinced Babbage that he could and should build the Analytical Engine in a few years.

Rather the reasons for the indecisive nature of Babbage's work near the end of his life were temperamental and temporal. The temperamental reason was his inability to leave something unchanged when he could think of an improvement; this was characteristic of him throughout life, and indeed if it had not been, he would never have invented the Analytical Engine in the first place. The temporal reason was that Babbage was getting old; in December, 1862 he was already seventy years old, and while his mind was still perfectly clear, he seemed to be no longer very able to carry out a course of development of his ideas over a long period of time. This is also testified to by Lionel Tollemache, who met Babbage first in the fall of 1861, and later wrote: "Ever since I first knew him, though he still retained much power of thought, he had lost the faculty of arranging his ideas, and of recalling them at will."⁹⁸

An anecdote illustrative of Babbage's temperamental difficulty in constructing his machine was related by Lord Moulton in 1914. He visited Babbage a few years before he died, and was taken on a tour of the work-rooms. In the first room were parts of the Difference Engine, and Babbage explained that it was abandoned when the Analytical Engine was invented. In the second room were some parts from one version of the Analytical Engine; Moulton asked Babbage if he could see the whole machine;

"I have never completed it", he said, "because I hit upon an idea of doing the same thing by a different and far more effective method, and this rendered it useless to proceed on the old lines." Then we went into a third room. There lay scattered bits of mechanism, but I saw no trace of any working machine. Very cautiously I approached the subject, and received the dreaded answer, "It is not constructed yet, but I am working at it, and it will take less time to construct it altogether than it would have taken to complete . . . [the earlier version] from the stage in which I left it."⁹⁹

The result of these difficulties is that the last period of Babbage's work on the Analytical Engine was made up largely of his debating and deciding on some question which he had already considered and settled earlier, and would take up again later. One example of this vacillation is the number of variables Babbage was planning to provide for in the store at various times. In June, 1857, when Babbage resumed work on the Analytical Engine, he planned for 1000 variables of forty digits each;¹⁰⁰ in March, 1858 he planned fifty digits per variable;¹⁰¹ by March, 1859, Babbage had decided to use only 400 variables;¹⁰² after the hiatus in his work of several years, Babbage went back, in July, 1863, to planning for 1000 variables;¹⁰³ in November he was back to 400,¹⁰⁴ and in December to 1000 again.¹⁰⁵ Nor were those the only alternative sizes he also considered the intermediate values of 600,¹⁰⁶ 560,¹⁰⁷ 390,¹⁰⁸ at one point as few as 48 variables, for a kind of mini-engine.¹⁰⁹

A far larger amount of time was spent planning and considering the alternative forms of carriage; whole or half zero, hoarding or anticipating. On all too many occasions, Babbage would make a firm decision to adopt one kind of mechanism, and within a short time be considering the alternate possibility all over again.¹¹⁰ Further, Babbage's reasoning tended to shift its ground. Thus he would often argue for some more complicated mechanism, because it would save time (as half zero carriage); generally he would argue for a simpler mechanism on the grounds that its simplicity was worth the sacrifice of a small amount of time;¹¹¹ but sometimes he would argue that the machine was faster than needed anyway,¹¹² or even that the simpler form would turn out to be faster.¹¹³ All these same kinds of arguments also went into the question of whether the machine should do multiplication and division with or without table.

For all these reasons, it would not be profitable to survey in any detail here the multitude of forms through which Babbage's plans for the Analytical Engine fluctuated and varied during this last phase of his life. Rather, the brief account here will focus primarily on his external communications concerning the Engine, principally in his correspondence, but naturally in the context of the work he was actually doing.

As was said above, Babbage's interest in the Analytical Engine was revived in June, 1857,¹¹⁴ and in contrast to the period of his earlier work on the machine, he now intended actually to construct it. He immediately set about making drawings both of new general plans and of new forms of the detailed mechanisms; he also worked at designing various complex machine tools to use in the construction. By March, 1858, he had settled on what was to remain his ideal size for a full scale machine, namely one which could handle 1000 variables of fifty digits per variable, where each column was to be about sixty inches high.¹¹⁵ In July through November, 1858, Babbage corresponded extensively with Joseph Whitworth in Manchester, ordering from his factory various tools and parts he would need.¹¹⁶

He became concerned, however, that the machine would be too physically large to be easily constructed; in September, 1858, he conducted experiments with various alloys out of which to cast his gears; he found one whose strength satisfied him that he could reduce the size of the parts of the machine by one half, reducing the axes to thirty inches, and thus making even the necessary tools easier to build.¹¹⁷ Later he was to compromise and further reduce the size of the Engine by reducing the number of variables, as mentioned above.

The primary change in the overall design of the Analytical Engine during this period was the abandonment of the original plan of Mill axes arranged

around large central wheels with the Store extending linearly out one side along a set of racks, in favor of a plan where Mill and Store were both arranged rectangularly, with several sets of racks at right angles to one another and having the power to communicate between themselves, and thus between any different axes. This rectangular design took many forms, sometimes having the Mill and Store separate, and sometimes quite physically integrated, but the basic idea Babbage stayed with for the rest of his life. ¹¹⁸ The greatest advantage of this was that it allowed the machine to be much more compact; a Store providing for 1000 variables could be as small as three feet on a side; ¹¹⁹ it was also much easier to construct linear racks than immense central gears.

The progress he made gave Babbage the confidence to predict, in March, 1859, that he would complete the Analytical Engine "in two or at most three years." ¹²⁰ Yet for unknown reasons, in September, 1859, Babbage's work on plans for the machine abruptly ceased, and was not resumed in any substantial way until January, 1861; ¹²¹ as far as one can tell, all work on construction ceased also, though why the work was suspended is not at all clear. It was resumed again in the period from January to March, 1861, ¹²² but then dropped again until February, 1863. ¹²³

One suggestion that Babbage did not take up during this hiatus in the work was sent to him by William Gravatt, in a letter dated February 3, 1860. Gravatt said that he had heard of the invention by an Italian of "a machine for Weaving by Electro-Magnetism." Strips or sheets of gutta-percha were to be gilded or covered with tin foil; the metallic surfaces were to be painted in various patterns with a non-conducting pigment; then a loom could be controlled by the particular pattern of electrical flow set up when needles were pressed against the cards, in a manner analogous to that in the Jacquard loom. Gravatt said that he had not seen the machine and did not understand the details of it, but that the principle might be applicable to the Analytical Engine. ¹²⁴ In any case, Babbage did not choose to follow this suggestion up.

The causes which made Babbage take up the Analytical Engine for a few months in 1861 are not clear, but at least one factor instrumental in his return to it in February, 1863 can be pointed out. This was the encouragement of the Countess Teleki, who was perhaps the most prolific of Babbage's correspondents during the 1860s. The daughter of Henry Bickersteth, Lord Langdale, she married Count Alexander Teleki. ¹²⁵ Although she doubtless did not understand the principles of the Analytical Engine as well as had Lady Lovelace, it is clear from her letters that she understood Babbage much better.

The first important letter from her to Babbage was dated October 3, 1862. Apparently she had recently been learning about the Analytical Engine, and was distressed at Babbage's intention to have no more to do with it. She wrote:

The more I think of it, the more I am distressed at your thinking it possible that you should give up the Analytical Engine. To strangle an idea and a great invention after so much pains to bring it to perfection, appears to me a kind of moral murder, and an injury to the whole human race, which it cannot be right to inflict . . . It is certain that you, and you only, are capable of completing the Analytical [Engine], which if you abandon it, must perhaps remain unrealized for ages, and great tho' it be to conceive an idea hundreds of years in advance of one's kind, it surely is greater, by realizing that idea, to make the human race, in one generation, outstrip the progress of many. ¹²⁶

This was not enough to change Babbage's mind, however, for he replied a few days later, saying: "I find no flaw in your reasoning about the Analytical Engine; I admire it; but you are aware that it rests entirely on the hypothesis that I care for the 'whole human race.'" ¹²⁷

In February, 1863, the Countess was preparing for a trip to Italy, including a long visit to Turin, and Babbage wrote her a letter of introduction to General Menabrea. Although Babbage had by this time resumed work on the Analytical Engine, he said of it in this letter only: "Circumstances have not favored its completion. I hope however if I live five or six years more I may yet see it at work." ¹²⁸

On March 12, 1863, in reply to a now missing letter from Babbage, Countess Teleki wrote:

I was indeed somewhat surprised to hear of the immense change you have introduced into the construction of the engine, tho my chief feeling about it is pleasure at the great progress you seem to have made lately, and at the hope of completing the machine which you derive from its increased simplicity and diminished expense. ¹²⁹

Just what the "immense change" and "increased simplicity" in Babbage's plans were is not clear, but seemingly he was contrasting the character of the plans as developed in the period from 1857 to 1859 with that of the plans worked out in the 1840s, and especially the new rectangular arrangement discussed above, for this is suggested in the letter, and there are no other apparent important changes made at this time. Apparently Babbage was just building up his enthusiasm for the state in which the work had been when he laid it aside.

This enthusiasm was to continue. On August 6, 1863, Babbage wrote to John Henry Alexander in Baltimore, saying that he had:

succeeded in simplifying its structure beyond any expectation I formerly had. As far as my drawings and carefully made models of many parts go, I have no doubt in a few years I shall succeed in placing all the developments of Analysis under the dominion of mechanism; and also be able to execute all the most extensive processes of arithmetic in an unexpectedly short time.

I have not the slightest hesitation in expressing my perfect confidence that when the Engine itself is set to work it will be able to multiply any two numbers of fifty figures each and print the product of one hundred in less than one minute of time. The inverse operation of division may be accomplished to the same extent in an equally short time. ¹³⁰

To the modern reader, of course, jaded as he is by electronic computers, a multiplication - even of fifty by fifty digits - in one minute does not seem remarkable at all. That the contrary was true in the mid nineteenth century is well illustrated by Alexander's reply to Babbage, dated October 8, 1863:

What you tell me of your machine is perfectly marvelous; 50 figures by 50 figures in one minute seems almost to surpass the velocity of thought. In old times you certainly would have risked being burned as a witch. ¹³¹

While Babbage was quite confident of rapidly completing the Analytical Engine, Countess Teleki had a sufficiently clear understanding of his character to see the dangers lurking ahead, and she did not hesitate to point them out to him in reply to the letters he sent her in Italy regarding his progress. On September 4, 1863, she wrote:

I am very glad to hear your progress has been so satisfactory, and I hope that as you have now arrived at the ultima Thule of simplicity you will now really make the engine without searching for further improvements. Don't forget the proverb I have so often already quoted to you: *Le Mieux est l'ennemi du bien*. ¹³²

That the Countess's admonition was most necessary is well illustrated in a letter from Babbage to his friend H. Wilmot Buxton, dated November 5, 1863; despite the fact that Babbage had gotten to the stage of making working models of parts of the machine, he said "The model is being reformed, and I hope in a week to see it at work, but only as the step to a better model." ¹³³ The Countess repeated her proverb in a letter from Turin on November 26, 1863: she had finally met Menabrea, and she said that he also was anxious to see the Engine actually constructed. She also urged him to stop revising the draft of *Passages from the Life of a Philosopher*, the volume of memoirs he was writing at this time, and get it out in print. ¹³⁴

Countess Teleki expanded on these suggestions in her next letter, dated December 10, 1863:

I am delighted to hear that you are satisfied at last with the mechanism of the new carriage, and that you will not seek a better, for with your ingenuity, I am always afraid of some fresh idea striking you as likely to be an improvement, and of your setting to work in consequence on another set of drawings, instead of constructing the Engine itself; but this time I do hope you will be satisfied, since the carriage, which is the soul of the whole, is ready to do its work with all desirable speed and simplicity. ¹³⁵

On January 19, 1864, she added: "I wish I could hear of something more being done to the Analytical [Engine] than drawings only. My longing is to see it at work, with all its wheels and its carriages busy calculating. With all my belief in its powers, it would still be more satisfactory to see it really at work," ¹³⁶

In this same letter, the Countess commented at length on proofs Babbage had sent her of Chapter XXII of *Passages from the Life of a Philosopher*, which was a sketch entitled "Scenes from a New Afterpiece," satirizing Babbage's unsuccessful venture into politics in 1832. She said that while it was very amusing, those not acquainted with Babbage's true character might be misled by the self-caricature he provided in the play. ¹³⁷

The next letter of special interest was one discussing intended applications of the Analytical Engine, written by Babbage to the Emperor Louis Napoleon on November 16, 1864, accompanying a gift copy of *Passages from the Life of a Philosopher*, which had finally been published earlier in the summer. Babbage wrote:

The Analytical Engine, which has occupied me during the greater part of my life, is now so far simplified that I may reasonably expect, if I live some few years longer, to complete it and make it productive of extensive computations

The first task . . . which I shall propose for the Analytical Engine will be to recalculate the whole of the table of Natural Sines to every 10,000th part of the quadrant.

This however will be but a trifling exertion of its powers. In the earliest period of its existence it ought to be employed in recomputing the formulae and in verifying the coefficients of Laplace in his investigations of the problem of the three bodies. After that it might be used to develop the still more complicated problem of the three bodies when they are acting under the conditions that each is a magnet with several poles and that the transmission of magnetism unlike that of gravity is not instantaneous. ¹³⁸

During this period and the following years, Babbage continued to work on specific plans for the Analytical Engine, but this work became more sporadic and less productive as Babbage himself became older and more indecisive. He himself realized that the lack of progress was largely his own fault. For example, on November 20, 1858, he made the following rather plaintive entry in his Scribbling Book:

This day I finally ??? (I hope) resolved to give up the mechanism for shortening by a very short time the operation of Multiplication, and to confine the Analytical Engine to its own great laws of developing the science which it embodies in its mechanism. ¹³⁹

Babbage also continued in his desire to make his machines understood. Although *Passages from the Life of a Philosopher* had contained several chapters on the calculating machines, this had been of entirely a popular nature, and had amounted to little more than one fifth of the book. But already in that work he had announced his intention to publish another book, titled *History of the Analytical Engine*, to contain reprints of the material published earlier on the machines, and, supposedly, some additional material. ¹⁴⁰ Babbage reaffirmed his intention to publish such a work in February, 1865, ¹⁴¹ and continued working on it thereafter. However, at the time of his death only the first 294 pages had been prepared, and this included no new material. ¹⁴² After Babbage's death, Henry P. Babbage added some material and brought the volume out under the title: *Babbage's Calculating Engines*. ¹⁴³ This is still the best source book of published material concerning Babbage's machines. Babbage also on several occasions began new essays on the Analytical Engine, perhaps for inclusion in the projected volume, perhaps for the meeting of the British Association at Exeter in 1869, which at one point he considered attending to discuss the machine. ¹⁴⁴ In any case, all these essays were incomplete, and they did not contain new or clearer information. ¹⁴⁵ As for actual hardware, Babbage on several occasions put together working models of the carriage mechanism, or a complete adding column. ¹⁴⁶ But despite the fact that near the end of his life a rather large number and variety of parts had been made for use in an actual Engine, ¹⁴⁷ it does not seem that he ever assembled any significant portion of it.

In March, 1871, Henry P. Babbage reached England on a second furlough from his duties in India. In contrast to his furlough in 1854-56, however, on this occasion he did not become involved in his father's work, spending most of his time with his wife and children in a rented house in Bromley, visiting Charles only occasionally. However, when Charles became seriously ill in early October, 1871, Henry moved in with him to manage his affairs. A new will was signed on the 13th, leaving all effects connected with the calculating machines to Henry. After a painful illness, Charles died on October 18, 1871. He was buried six days later in Kensal Green Cemetery. ¹⁴⁸

We may consider and treat separately, though only in summary, two aspects of the post-history of the Analytical Engine after Babbage's death: first, further efforts to construct it, and second, the degree to which it was known and discussed in the world at large.

The attempted construction was carried on by Henry P. Babbage, who, as mentioned above, had been left all the material relating to the calculating machines belonging to his father. This included a number of parts which had been left unassembled when the construction of the Difference Engine No. 1 was abandoned; a large number of them had been sold to Babbage by the government for their value as scrap metal; ¹⁴⁹ subsequently, much of the metal was melted down for use in the Analytical Engine. However, enough of the original parts were left for Henry to assemble some six small sections intended to demonstrate the mechanical action of the Difference Engine, and he sent some of these to different Universities for their collections. ¹⁵⁰ He also inherited a number of parts for the Analytical Engine and tools intended for its construction. On March 1, 1872, Henry sold most of these, but he kept three lathes and some other tools; ¹⁵¹ he also retained the workman, Wright, who had been employed by his father, for he had already decided to try to complete the Mill, ¹⁵² and had been working sporadically on the carriage mechanism and other parts since his father's death. ¹⁵³ In March through August, 1872, work was continued on constructing and assembling the necessary pieces for making part of the Mill. Two adding columns and one carriage column, and most of the printing apparatus, together with the connecting racks, were completed, but the directive and driving apparatus, especially the card reading apparatus, were not made, so the section put together could not function even as a demonstration piece. It is quite hard to tell, but it seems that perhaps about half of the parts of this section of the Analytical Engine (now in the South Kensington Museum) were completed before Charles' death. ¹⁵⁴

In July, 1872, Henry had construction started on a workshop on some land he had purchased in Bromley, where he also was building a home for his family. In September, the house in Dorset Street in which his father had lived for over forty years was sold, and the tools and machinery were moved to the new workshop. Yet although Henry did not return to service in India for over a year, partly due to ill health, it seems that no further work on the machine was done. ¹⁵⁵

After his retirement from the Army, Henry Babbage returned to live in England. He worked sporadically on a new version of part of the Mill of the Analytical Engine, and with the engineering firm of W.B. Monroe, finished construction in 1910. The only work it was set to do was to construct a table of the first twenty two multiples of pi, expressed to twenty eight places, and this was printed up for exhibit. Despite the fact that this was an elementary problem in addition, it was found that there were several mistakes in it. ¹⁵⁶ The failure of this model to amount to much was no doubt in part due to the fact that Henry Babbage by this point was eighty six years old.

Knowledge of the machine by the world at large was a similar case of interest shown without bearing fruit. One of the earliest and most interesting expressions of confidence in the future importance of the Analytical Engine came from William Farr, who earlier had used the Scheutz machine in preparing the English Life Tables, and was now President of the Statistical Society of London (later the Royal Statistical Society), of which Babbage had been the principal founder. In an address to the Society on November 21, 1871, Farr included some extensive memorial remarks on Babbage, including the following:

I feel persuaded that ere many years an analytical machine will be at work, calculating accurately not only those elaborate numerical coefficients of the moon which puzzle the greatest adepts, but those still more complicated coefficients and variables which, it is easy to foresee, will be in requisition when future State problems are dealt with scientifically by a political Newton. ¹⁵⁷

On May 24, 1872, W.K. Clifford lectured on the calculating machines of Babbage at the Royal Institution; ¹⁵⁸ unfortunately neither the paper nor an abstract of it was published, so we know only that Clifford was "enthusiastic" about the Analytical Engine. ¹⁵⁹

Later the same year it seems that the extant portion of Babbage's Difference Engine No. 1 was given more prominent display among the Science Collections for Teaching and Research of the Victoria and Albert Museum in South Kensington, for in September, 1872, B. Herschel Babbage, another of Charles' sons, wrote up a manual on the machine, including instructions to the operator, which was published by the Museum. ¹⁶⁰

Clifford's interest in the Analytical Engine continued, for he was largely responsible for the formation of a committee of the British Association for the Advancement of Science, "appointed to consider the advisability and to estimate the expense of constructing Mr. Babbage's Analytical Machine." ¹⁶¹ They considered the published papers on the Analytical Engine, and inspected the drawings, parts and notes which Babbage had left behind, and reported their conclusions to the 1878 meeting of the British Association.

As to the theoretical significance of the Analytical Engine as a potential practical machine, they had no doubts, though they issued also a most interesting and far-sighted warning:

If intelligently directed and saved from wasteful use, such a machine might mark an era in the history of computation, as decided as the introduction of logarithms in the seventeenth century did in trigonometrical and astronomical arithmetic. Care might be required to guard against misuse, especially against the imposition of Sisyphian tasks upon it by influential sciolists. This, however, is no more than happened in the history of logarithms. Much work has been done with them which could more easily have been done without them . . . Yet, on the whole, there can be no reasonable doubt that the first calculation of logarithmic tables was an expenditure of capital which has repaid itself over and over again. So probably would the analytical engine, whatever its cost, if we could be assured of its success. [162](#)

It was exactly this last point which caused the committee to recommend that the British Association not seek to have the Analytical Engine constructed. That is, they did not consider the expected cost of construction to be the major obstacle, despite the fact that it "would be expressed in tens of thousands of pounds at least." [163](#) Rather their apprehensions were based on their opinion that "in the present state of the design, . . . we do not consider it a certainty that it could be constructed and put together so as to run smoothly and correctly, and to do the work expected of it." [164](#) The committee did, however, suggest that it might be worth constructing some part of the Mill by itself, to use for much more limited calculations.

Ten years after this report was issued, Henry P. Babbage himself read a paper to the British Association in which he commented on and to some extent rebutted the committee's opinion, and announced the forthcoming publication of *Babbage's Calculating Engines*; he also gave a clear, though limited, description of the mechanical principles and operation of the Analytical Engine. He took issue with the earlier report as to the amount of difficulty there would be in transforming the plans Babbage had left behind into working drawings. However, Henry added that he did not see that construction of the Engine would be profitable, and he did not intend to undertake it himself: "The History of Babbage's Calculating Machines is sufficient to damp the ardour of a dozen enthusiasts." [165](#) Those who wished to see the machine constructed, he suggested, would do best to show that it could be profitable in some way. [166](#)

Apart from the work done by Henry Babbage at the very end of his life, discussed above, this was essentially the last serious notice taken of the Analytical Engine by those who had in some way been more or less contemporary with it. And although the name of Charles Babbage continued to be remembered, it was more likely to be for his eccentricities than for the invention of the Analytical Engine.

The calculating machines were not forgotten by all, however; on the occasion of the Napier Tercentenary Exhibition in 1924 in Edinburgh, F.J.W. Whipple made the following remarks:

In these days of automatic tools, Babbage's [Difference] Engine could be constructed at a moderate cost . . . The story of Babbage's efforts end [sic] at present in a confession of national failure, and it would be gratifying to British mathematicians if a happier sequel could be written in our annals. [167](#)

More significantly, on the same occasion, P.E. Ludgate presented a paper on "Automatic Calculating Machines," or rather on the need for them. He mentioned the Babbage and Scheutz Difference Engines, and described at some length the concept of the Analytical Engine, though without mechanical detail. Clearly Ludgate felt that the construction of a machine along the lines of Babbage's would be quite desirable. [168](#)

What was evidently a more prevalent view was expressed shortly after this in the article on Babbage in the *Dictionary of National Biography*, where it was said of the Analytical Engine: "This extraordinary monument of inventive genius . . . remains, and will doubtless forever remain, a 'theoretical possibility.'" [169](#)

By the 1930s, the use of difference machines in scientific computation had become fairly common, and Babbage began to be remembered as the inventor of the Difference Engine, rather than for the Analytical Engine. This is well illustrated by a paper read at the Science Museum, in South Kensington on December 13, 1933, by L.H. Dudley Buxton, grandson of H. Wilmot Buxton, Babbage's friend and biographer. The paper and the subsequent discussion (entered by, among others, L.J. Comrie) dwelt on the Difference Engine at great length, almost totally ignoring the Analytical Engine. [170](#)

It was only four years later that Howard Aiken of Harvard wrote the "Prospectus" for the computer known as Mark I, which was finished in 1944, and is now often considered to have been the first operating general purpose automatic digital computer. Mark I and its successors will not be discussed here, but it must be noted that in the 1937 "Prospectus," Aiken described the Difference and Analytical Engines at some length in an historical introduction. [171](#) Where Aiken had learned about Babbage, [172](#) how much he knew about the Analytical Engine, [173](#) or whether he learned about it before or after he developed his own ideas for a computing machine, is not known.

Babbage's invention of the Analytical Engine was also discussed at length in the first volume of the *Annals of the Computational Laboratory of Harvard University*, [174](#) which was devoted primarily to Mark I. The historical introduction quoted extensively from Babbage's *Passages from the Life of a Philosopher*, and also concluded that Babbage's failure to complete either the Difference or Analytical Engines "was not due to a lack of understanding of the principles and purposes of the engines that he designed, but rather to his lack of machine tools, materials of construction and electrical circuits." [175](#)

The degree to which Babbage was immediately recognized as the true forerunner of the computer is also indicated by the fact that the review of this same volume of the *Annals* in *Nature* carried the title "Babbage's Dream Comes True." [176](#)

We may close by noting that the long period which elapsed after Babbage's death before computers were actually constructed, and the degree to which, after that, he was given credit for the invention, would have been no surprise to him. Writing in 1864 of the construction of the Analytical Engine, he had said:

Half a century may probably elapse before anyone without those aids which I leave behind me will attempt so unpromising a task. If, unwarned by my example, any man shall undertake and shall succeed in really constructing an engine embodying in itself the whole of the executive department of mathematical analysis upon different principles or by simpler mechanical means, I have no fear of leaving my reputation in his charge, for he alone will be fully able to appreciate the nature of my efforts and the value of their results. [177](#)

FOOTNOTES

[#1](#) Jonathan Swift, *Gulliver's Travels* (Penguin, London, 1967). PP. 70-71.

[#2](#) As: S.B., Vol. II, p. 226, November 19, 1836; S.B., Vol. V, p. 80, late 1841, and p. 460, November 11, 1843; also S.K., Drawing II, 99, April and May, 1842.

[#3](#) S.B., Vol. VI, p. 97.

[#4](#) P.L.P., p. 97.

[#5](#) P. 177.

[#6](#) B.M., Vol. XII, ff. 347-57.

[#7](#) B.S., Vol. XII, f. 357.

[#8](#) S.B., Vol. VI, p. 105.

[#9](#) See note on B.M., Vol. XII, f. 349.

[#10](#) B.M., Vol. XIII, f. 337.

[#11](#) S.K, Notation 385, Drawing II, 178 Sheet 1; the confusion in the numbering of the drawings of the Difference Engine No. 2 will be discussed in the Bibliography.

[#12](#) S.K., Notation 385; S.B. Vol. VI, passim.

[#13](#) B.M., Vol. XIII, f. 253; this letter is addressed to "Hayward."

[#14](#) S.B., Vol. VI, p. 301.

[#15](#) S.B., Vol. VI, pp. 267, 293; B.M., Vol. XIII, f. 266.

[#16](#) P.L.P., p. 105.

[#17](#) P.L.P., p. 104.

[#18](#) The Earl of Rosse (William Parsons), President of the Royal Society, in an address to the Society on November 30, 1854; *Proc. Roy. Soc.*, Vol. VII, (1854-55), p. 257. Doubtless Rosse was echoing Babbage's views.

[#19](#) From a letter from Babbage to Lord Derby, June 8, 1852; B.M., Vol. XIV, ff. 80-83, reprinted in P.L.P. pp. 100-107.

[#20](#) B.M., Vol. XIV, ff. 72-73.

[#21](#) P.L.P., pp. 104-5.

[#22](#) P.L.P., p. 100; B.M., Vol. XIV, ff. 108-9, 127-32.

[#23](#) P.L.P., p. 107.

[#24](#) B.M., Vol. XIII, f. 336 (though wrongly placed by the cataloguer).

[#25](#) *Proceedings of the Royal Society*, Vol. VII (1854-55), p. 257.

[#26](#) B.M., Vol. XIV, ff. 108-9.

[#27](#) B.M., Vol. XIV, f. 113.

[#28](#) See, e.g., G.S.B., 1. 4881-4942, 5751; S.K. Travelling Scribbling Book, pp. 186-87.

[#29](#) S.B., Vol. X, p. 394.

[#30](#) P.L.P., pp. 465-71.

[#31](#) B.M., Vol. XIV, f. 118.

[#32](#) B.M., Vol. XIV, ff. 119-20.

[#33](#) B.M., Vol. XIV, ff. 123-26.

[#34](#) P.L.P., p. 109.

[#35](#) P.L.P., pp. 110-111.

[#36](#) P.L.P., p. 111.

[#37](#) B.M., Vol. XIV, ff. 127-32.

[#38](#) As shown in B.M., Vol. XIV, ff. 108-9.

[#39](#) B.M. Vol. XIV, ff. 130-31.

[#40](#) *Proc. Roy. Soc.*, Vol: VII (1854-55).p. 255.

[#41](#) B.M., Vol. XV, ff. 251, 255.

[#42](#) B.M., Vol. XV, ff. 266-67.

[#43](#) B.M., Vol. XV, ff. 257-58.

[#44](#) B.M., Vol. XV, f. 251.

[#45](#) *The Exposition of 1851* (London, 1851), p. 176.

[#46](#) B.M., Vol. XVIII, f. 499.

[#47](#) Samuel Smiles, *Industrial Biography: Iron-workers and Toolmakers* (Boston, 1864 , p. 298; Chapter XIII of this invaluable book is much the best source of information on Clement.

[#48](#) Vol. XXXVI (1818), pp. 133-77; Vol. XLIII (1825), pp. 138-42; Vol XLVI (1828), pp. 67-105; Vol. XLVII (1829), pp. 131-35; Vol. XLIX (1832), pp. 157-85.

[#49](#) See Smiles, *Industrial Biography*, pp. 302-3; B.M., Vol. XV, ff. 264-65.

[#50](#) Smiles, *Industrial Biography*, pp. 306,313.

[#51](#) P. 304.

[#52](#) Smiles, *Industrial Biography*, P. 313.

[#53](#) B.M., Vol. XV, ff. 264-65; see also *Transactions of the Society of Arts*, Vol. XLIX (1832), p. 157.

[#54](#) Discussed in Chapter Two.

[#55](#) *Proceedings of the Institution of Mechanical Engineers* for 1856, pp. 125-33.

[#56](#) For biographical details, see; *Biographiskt Lexicon öfver Namnkunnige Svenka Män* (Upsala, 1847), Vol. XIV, pp. 54-66; and *Svenskt Biografiskt Handlexikon* (Stockholm, 1906), Vol. II, pp. 428-29.

[#57](#) See Chapter Two.

[#58](#) B.C.E., p. 260.

[#59](#) This and other material below without specific reference is from *Specimen Tables Calculated and Stereomoulded by the Swedish Calculating*

Machine (London, 1857), pp. vi-xv.

[#60](#) Apparently their publicity was not widespread, for certainly Babbage had not heard of the Scheutz machine until well into the 1850s.

[#61](#) B.C.E., p. 261.

[#62](#) B.C.E., p. 249.

[#63](#) All the material here on the mechanical aspects of the Scheutz machine is based on personal inspection.

[#64](#) British Patent 1854, No. 2216.

[#65](#) B.C.E., pp. 264-69.

[#66](#) B.M., Vol. XV, f. 253; cf. f. 304; and B.C.E., pp. 268-69.

[#67](#) *Memoirs and Correspondence of Major-General H.P. Babbage* (London, 1910), p. 85.

[#68](#) *Report of the 25th Meeting of the B.A.A.S.*, (London, 1856) Part II, pp. 203-5; reprinted in B.C.E., pp. 246-47; the charts are now in the South Kensington collection.

[#69](#) B.C.E., pp. 248-57.

[#70](#) B.C.E., pp. 260-61.

[#71](#) B.M., Vol. XV, ff. 302-3.

[#72](#) B.C.E., p. 261.

[#73](#) B.M., Vol. XV, f. 372.

[#74](#) B.M., Vol. XVI, f. 336 (though the letter was written about August, 1856, and is misplaced); of Vol. XIII, ff. 403-4 (also misplaced).

[#75](#) See, e.g., B.M., Vol. XIV, f. 547.

[#76](#) B.M., Vol. XVI, ff. 483-86.

[#77](#) B.M., Vol. XVI, f. 53.

[#78](#) B.M., Vol. XIII, ff. 403-4 (the year is not specified, but is clear from the context, although the letter was badly misplaced by the cataloguer; that the addressee was Mathieu is also suggested by the context). Cf. B.M., Vol. XV, f. 372 and B.C.E., p. 261.

[#79](#) B.M. Vol. XVI, ff. 136-37.

[#80](#) B.M. Vol. XVI, f. 77.

[#81](#) *Specimen Tables*, p. xiv.

[#82](#) B.M. Vol. XVI, f. 108.

[#83](#) B.C.E., p. 270.

[#84](#) *Specimen Tables*, p. xv.

[#85](#) B.M., Vol. XV, ff. 418-20.

[#86](#) B.M., Vol. XIII, ff. 403-4.

[#87](#) B.M., Vol. XVI, ff. 230-31.

[#88](#) *English Life Table* (London, 1864), p. cxli. But H. Wilmot Buxton, in a letter to Babbage dated August 20, 1863 (B.M., Vol. XVII, ff. 540-41), said that the contract had been for £1000, and that the firm had lost an additional £200.

[#89](#) In contrast with his recommendations concerning the Babbage Difference Engine No. 1 in 1842; see Chapter Two.

[#90](#) *English Life Table*, p. cxli; B.M., Vol. XVI, f. 251; *Journal of the Statistical Society*, Vol. XXXIV (1871), p. 416.

[#92](#) The machine calculated and stereotyped plates can be distinguished easily by their typography. In addition to the above two references, see *English Life Table*, esp. pp. xiii, cxxxix-cxlv; also *Companion to the Almanac; or, Year-book of General Information* for 1866 (London, 1866), pp. 6-15.

[#93](#) For the two sides, see P.L.P., Chapter X, and *English Life Table*, pp. cxxix-cxl.

[#94](#) But see the fine description of it in the *Annals of the Dudley Observatory*, Vol. I (1866), pp. 116-26. Further, there is some unpublished print-out from the Scheutz machine still at the Observatory.

[#95](#) B.M., Vol. XVII, ff. 142-43, January 25, 1861.

[#96](#) B.M., Vol. XVII, f. 467; Vol. XVIII, ff. 403-4.

[#97](#) See Chapter Three.

[#98](#) Lionel A. and Mrs. Tollemache, *Safe Studies* (London, 1884), p. 148.

[#99](#) *Napier Tercentenary Memorial Volume*, ed. Cargill Gilston Knott (London, 1915), pp. 19-20.

[#100](#) S.B., Vol. VI, p. 304.

[#101](#) "Description of the Analytical Engine as at present proposed," in S.K., "Sundry Papers;" dated March 16, 1858.

[#102](#) S.B., Vol. VII, p. 254.

[#103](#) S.B., Vol. VIII, p. 207.

[#104](#) S.B., Vol. VIII, p. 241.

[#105](#) S.B., Vol. VIII, p. 253.

[#106](#) S.B., Vol. IX, p. 500.

[#107](#) S.B., Vol. X, p. 200.

[#108](#) S.B., Vol. X, p. 217.

[#109](#) S.B., Vol. XI, p. 345.

[#110](#) As: S.B., Vol. X, p. 164 vs. pp. 205ff; also S.B., Vol. XII, p. 166 vs p. 139.

[#111](#) As: S.B., Vol. XI, p. 95.

[#112](#) As: S.B., Vol. IX, p. 13; S.B., Vol. X, p. 78.

[#113](#) As: S.B., Vol. X, p. 17.

[#114](#) S.B., Vol. VI, p. 304.

[#115](#) "Description of the Analytical Engine as at present proposed," S.K., "Sundry Papers."

[#116](#) B.M., Vol. XVI, ff. 324, 325, 354,373.

[#117](#) S.B., Vol. VII, pp. 146-47.

[#118](#) Although he considered switching back to central wheels as late as December, 1870; S.B., Vol. XII, p. 94.

[#119](#) S.B., Vol. VII, p. 173.

[#120](#) B.M., Vol. XVI, f. 406.

[#121](#) S.B., Vol. VIII, pp. 72-74.

[#122](#) S.B., Vol. VIII, pp. 74-130.

[#123](#) First in Travelling Scribbling Book, pp. 188-97; then in S.B., Vol. VIII, pp. 131ff.

[#124](#) B.M., Vol. XVI, ff. 489-90.

[#125](#) See: *Catalogue of Additions to the Manuscripts in the British Museum in the years 1900-1905* (London, 1907) pp. 491, 866. Contrary to what Moseley says in *Irascible Genius* (pp. 197, 241), her name was neither Countess Harley nor Countess Harley-Teleki.

[#126](#) B.M., Vol. XVII, ff. 406-7.

[#127](#) B.M., Vol. XVII, f. 405 (slightly misplaced).

[#128](#) B.M., Vol. XVII, f. 494. It is clear from the letter that Countess Teleki did not know Menabrea before this date, and the things Moseley says (*Irascible Genius*, pp. 22, 197) about her being an "intermediary" between Babbage and Menabrea are nonsense.

[#129](#) B.M., Vol. XVII, ff. 501-2.

[#130](#) B.M., Vol. XVII, ff. 531-32.

[#131](#) B.M., Vol. XVIII, ff. 1-2.

[#132](#) B.M., Vol. XVII, f. 548.

[#133](#) Quoted in: *Transactions of the Newcomen Society*, Vol. XIV (London, 1933), p. 50.

[#134](#) B.M., Vol. XVIII, ff. 9-10.

[#135](#) B.M., Vol. XVIII, ff. 13-14.

[#136](#) B.M., Vol. XVIII, ff. 38-39.

[#137](#) Moseley has quoted at length from these same remarks (*Irascible Genius*, pp. 241-42), but she has mistakenly taken them to apply to the whole book, not just the one chapter.

[#138](#) B.M., Vol. XVIII, ff. 151-52.

[#139](#) S.B., Vol. XI, pp. 45-46.

[#140](#) P.L.P., p. 496.

[#141](#) B.M., Vol. XVIII, f. 216.

[#142](#) B.C.E., Preface.

[#143](#) London, 1889.

[#144](#) B.M., Vol. XVIII, ff. 477-78.

[#145](#) The four major essays were "General Description of the Analytical Engine," May 4, 1869, S.B., Vol. XIA, pp. 134-36; and the following three from Buxton, Vol. VIII; "Of the Analytical Engine," July 19, 1869; "On the Analytical Engine," October 7, 1869; and "The Analytical Engine," November 8, 1869.

[#146](#) See S.B., Vol. VIII, p. 148; S.K., Drawing 199; B.M., Vol. XVIII, f. 257.

[#147](#) S.B., Vol. XII, p. 401.

[#148](#) *Memoirs and Correspondence of Major-General H.P. Babbage*, pp. 178-82.

[#149](#) See Chapter Two.

[#150](#) B.C.E., p. 341. There are examples of these small models at Harvard University; at the Museum of the History of Science at Oxford University; and in the collection of IBM, in New York. Henry Babbage mentioned having sent others to Cambridge University and to Owens College, Manchester.

[#151](#) S.B., Vol. XII, p. 181,

[#152](#) B.M., Vol. XVIII, ff. 558-59.

[#153](#) S.B., Vol. XII, pp. 158ff; that this is Henry Babbage's handwriting is confirmed on p. 163.

[#154](#) On Henry's work, see: S.B., Vol. XII, pp. 182-88; cf. p. 401.

[#155](#) Memoirs of H.P. Babbage, pp. 185-86.

[#156](#) Memoirs of H.P. Babbage, pp. 227-28.

[#157](#) *Journal of the Statistical Society*, Vol. XXXIV (1871), p. 415.

[#158](#) *Notices of the Proceedings of the Royal Institution*, Vol. VI (1872), p. 533.

[#159](#) Memoirs of H.P. Babbage, p. 184.

[#160](#) "Babbage's Calculating Machine; or Difference Engine," London, 1872.

[#161](#) Memoirs of H.P. Babbage, p. 184; B.C.E., p. 323. The committee report can be found in B.C.E., pp. 323-30. reprinted from: *Report of the 48th Meeting of the B.A.A.S.* (London, 1879), pp. 92-162.

[#162](#) B.C.E., P. 329.

[#163](#) B.C.E., P. 330.

[#164](#) Ibid.

[#165](#) B.C.E., p. 337.

[#166](#) The paper is printed in full in B.C.E., pp. 331-37.

[#167](#) *Modern Instruments and Methods of Calculation*, ed. E.M. Horsburgh (London, 1914), p. 75.

[#168](#) Ibid., pp. 124-27.

[#169](#) Agnes M. Clerke, "Charles Babbage," *Dictionary of National Biography*, Vol. I (Oxford, 1919), p. 778.

[#170](#) *Transactions of the Newcomen Society*, Vol XIV (1833-34), pp. 43-65.

[#171](#) The original draft copy of the "Prospectus" is in the Harvard University Archives.

[#172](#) There was a copy of *Babbage's Calculating Engines* at Harvard.

[#173](#) The fact that Mark I was in some respects a good deal more primitive than the Analytical Engine (as with its provisions for program branching) suggests that Aiken didn't know much about Babbage's plans.

[#174](#) Vol. I, Cambridge, Mass., 1946.

[#175](#) *Annals*, p. 7.

[#176](#) *Nature*, October 26, 1946 (No. 158). pp. 567-68.

[#177](#) P.L.P., p. 450. Babbage's rough estimate of fifty years before a computer would be built brought him to 1914; this was some ten to fifteen years before the construction of Mark I would have been feasible, but thirty years before it was actually finished.

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CHAPTER FIVE

Conclusion

His great engines never cranked out answers, for ingenuity can transcend but it cannot ignore its context. Yet Charles Babbage's monument is not the dusty controversy of the books, nor priority in a mushrooming branch of science, nor the few wheels in the museum. His monument, not wholly beautiful, but very grand, is the kind of coupled research and development that is epitomized today, as it was foreshadowed in his time, by the big digital computers. ¹

= Having given, in the previous chapters, an account of the invention, development and fate of the Difference and Analytical Engines in fairly narrow, chronological terms, an attempt will be made here to examine the character of Babbage's work in a much broader perspective.

It was the opinion of most of Babbage's contemporaries that he was a kind of eccentric dreamer, obsessed with a slightly mad vision; even those who tried to understand that vision would generally concede only that it was an interesting theoretical possibility. From the perspective of the computer age, with Babbage's vision as it has been realized in hardware not only understood, but reshaping the world, Babbage appears rather differently. He is seen as an unheralded prophet of the modern era, an impractical genius who could not reconcile the grandeur of his vision with the technological capabilities of his own age, and who therefore wasted most of his talents. He was, it is said, a hundred years ahead of his time.

Both of these views of Babbage point to two principal facts about his work on calculating machines: his invention of the Analytical Engine was a truly remarkable phenomenon, and his attempts to bring his machines into being were almost complete failures. Yet neither view attempts any explanation of these facts. It must then be asked: what difference between Babbage and his contemporaries gave his work its special character? Casting the question in another way, what was the divergence of Babbage's work from the mainstream of technological development that made his inventions both so brilliant and such failures?

On the surface, the statement that Babbage was a hundred years ahead of his time suggests that he happened to invent a machine which, while sound in theory, could not be built until engineering capabilities had advanced one hundred years. Yet this is not adequate. On the one hand, it is clear that in some sense the idea itself, not just its constructability, was out of keeping with Babbage's time. On the other hand, it is doubtful that the machine was so impracticable. While the attempted construction of the Difference Engine during the 1820s was pushing at the technical capabilities of the day, and thus became an expensive and protracted failure, the Difference engine almost certainly could have been constructed at much lower cost during the 1850s, as is shown by the successful construction of the two Scheutz machines. And while it would be virtually impossible to prove, it seems that the construction of the Analytical Engine in the 1860s would have been less of a strain on the available technology than that of the first Difference Engine had been in the 1820s. Conversely, the existence of adequate technical capabilities does not assure the construction of machines such as the Analytical Engine; this is illustrated by the fact that all the components necessary for the construction of Howard Aiken's computer, Mark I, were available for many years before it was built, or even conceived.

Thus the prophetic character of Babbage's work, and his failure to complete it, cannot be explained simply by the inadequacy of the machining techniques of the times; two additional factors must be brought into the account. On the one hand, there was little support for the construction of the Analytical Engine because there was no widely felt need for it; not only did few people understand the machine, but the age did not require the manipulation of large amounts of data or the frequent execution of complex calculations. On the other hand, many of Babbage's difficulties seem to have arisen from his own temperament; in relation to his efforts to construct his machines, Babbage was too much of a perfectionist; he was unable to recognize when his plans were good enough, and stop improving them.

Yet although these factors may explain why the Analytical Engine was not constructed, they do not explain why it was invented, and they do not help in understanding Babbage's character, for they require the assertion that Babbage was an impractical man, and was not in touch with the needs of his own age. That this is true in a certain special sense will be granted below, but certainly it was not true in general. Babbage was a practical man both in the sense that he was (and was recognized to be) extremely knowledgeable about the practical affairs of his time, and in the sense that he was able to get things done in cooperation with other people, as his successful and important role in founding several major scientific societies illustrates. Some deeper understanding must be sought.

Babbage's work appears peculiar, and his failure remarkable, only when he is considered as an inventor and engineer in the usual sense, and this is a complete misunderstanding of his motives and methods. To make this clear, let us consider what is meant by a "technologist" of the successful, conventional sort, and how Babbage diverged from this model.

The prime characteristic of the conventional technologist is that he is motivated by the desire for profit and success in a clear-cut goal. This generally means two things. First, the goal that he selects must be either to do something that cannot yet be done, but for which there is some demand, or else to do something that already can be done, but faster, cheaper, or in some other way better. Second, given a range of problems he might attack, the technologist will tend to choose the one that he thinks will be easiest to solve; he must at least be confident that the problem is soluble. These two facts have the effect of assuring that in most cases technology will advance by small gradual steps; generally the problems solved are those where the technologist knows in advance that the solution will be both practical and profitable.

Further, such a solution of a technical problem generally consists of the combination in a slightly new way of components or techniques which are already known and available, or in relatively minor modifications or additions to them. For unless such elements are already being combined in more or less the proper way, and in an application somewhat similar to the one to be solved, it is quite possible that no one will notice the possible connection between the parts and the problem. This can, for example, explain why machines such as Mark I are not built whenever the necessary components become available.

It is clear that Babbage does not fit this picture of the conventional technologist. Certainly he did not invent his calculating machines for profit, or to solve some practical problem; rather he found the process of inventing them to be his own reward, as a purely intellectual exercise. To be sure, it was the unsatisfactory character of manually calculating and checking mathematical tables that first directed his attention to the desirability of machines to do the job; but once he began considering them, their perfection became an end in itself, and the tables from which he had begun were no longer important. Of course, the Difference Engine was interesting only because it could actually calculate tables, but this was more a theoretical than a practical point. And clearly the Analytical Engine was not invented because of the need for a table which the Difference Engine could not handle.

Thus it is vitally important in understanding Babbage's character that he was not a technologist who happened to have a scientific background, but rather a scientist and intellectual who happened to be working on technical problems. It was crucial in the development of Babbage's interests that before 1822 he had not found any area of scientific research that was wholly satisfying to him. After he began considering calculating machines for practical reasons, he found that working on them was a kind of problem-solving activity that was highly enjoyable and well suited to his own talents as an end in itself. In this sense, Babbage's work on calculating machines was more similar to his interest in cyphers, word squares, and a tic-tac-toe machine than it was to the construction of the Scheutz Difference Engine. This characterization of Babbage's motives may explain his being "a hundred years ahead of his time." Since he was dealing with gears and pinions as if they were primarily theoretical entities, he was not especially concerned if they could not, at the time, be made with sufficient precision for the resulting machine to be practicable. Likewise, although he sometimes wished to justify his work to the rest of the world by arguing for its usefulness, practical applications of the Analytical Engine were by no means the crucial factor in his own mind. Rather he was constructing an elegant theoretical structure more comparable to an abstract mathematical theory than to the productions of a conventional engineer.

For these reasons, the results of Babbage's work had a character opposite from that of normal technical activity. Babbage found the progress through small steps of the conventional technologist to be uninteresting, since it was not intellectually challenging, although he recognized its importance to society more than most of his contemporaries. What Babbage strove for was the kind of great leap forward which the technologist avoided, pushing ideas to their limits to see what would happen to them, and synthesizing elements between which there had been no obvious relationships.

Thus Babbage's being "a hundred years ahead of his time" is related not as much to the mechanical practicability of the Analytical Engine as it is to the fact that the invention of the Engine required too large a mental jump to mesh with the main thrust of the technological progress of the time. The machine's character was too strange for engineers to imagine building it. More important, the scientists who might have been interested in using it were accustomed to carrying on their work in ways which were too different from what the Analytical Engine would make possible - and indeed require - for them to comprehend its potential as Babbage had, or to generate pressure for its construction.

It seems that to a large extent Babbage himself understood the abnormal character of his inventive activity. During the main period of his work on the Analytical Engine, he had no intention of constructing it, although potential constructability was always required. Yet he was always confident that the Engine would eventually be built, though perhaps long after his death, and that it would have a large impact on the world when introduced, even if in ways which he could not predict. Babbage's sporadic efforts toward constructing the Analytical Engine toward the end of his life were not so much a change in his attitude, as they were a result of his belief that he had not been adequately rewarded for his work, and of his desire for justification and recognition.

It may also be noted that Babbage understood the character of the Analytical Engine as a **general purpose** computer well enough to realize that when a computer was eventually built, it would in principle be identical in function to his own machine, even if designed much later and wholly independently.

The idea developed here of the crucial and fundamental difference between practical and intellectual motivation in technological development, and of the difference in the kinds of change that result from each, has implications reaching beyond the case of Babbage. Indeed, many examples of each type could be given from within the history of calculating machines and computers. However, such an undertaking is beyond the scope of this thesis.

In final conclusion, if one were to draw a moral from the history of Charles Babbage and his calculating machines, it would have to be that while there is certainly truth in Countess Teleki's maxim that "The Best is the enemy of the Good," it is also true, as illustrated by Babbage's life and work, that "The Satisfactory is the enemy of the Marvellous."

Appendix

The Operation of the Babbage Difference Engine

It will be assumed that the mathematical principles of the method of finite differences is understood from the description given in Chapter Two. The basic features of the operation of the Babbage Difference Engine, as exemplified in the partial section assembled in 1832, will be described here.

The basic organization of the machine is as follows. The core of the machine is three vertical axes; the right axis is the Table Axis, where the results are produced; the middle axis holds the first differences; and the left axis holds the second difference, which here will be assumed to be constant. For each axis, each digit of the number on the axis is held on a Figure Wheel, which turns freely on the axis. The Figure wheels are placed at equal spaces along the axis, with that for the lowest digit at the bottom; it will here be assumed that the lowest digit corresponds to the units place.

The way in which addition is performed can be understood in terms of the method of adding any single digit, since all digits are added alike; we shall consider the way the units digit of the second difference is added to the units place of the first difference.

Each figure wheel is divided into ten sections, corresponding to the digits from zero to nine. The units digit of the second difference - let us suppose it to be five - is set by turning the lowest Figure Wheel on the second difference axis so that "5" faces the front. Immediately above the Figure Wheel on the second difference axis is a mechanism called the Bolt, which is fixed to the axis, and turns with it. Immediately above the bolt is another wheel, the Adding Wheel, which is held by the axis, but turns independently of it. This Adding Wheel in turn gears with the Figure Wheel for the units of the first difference, in the column to its right; thus the Figure Wheel on the first difference column is slightly higher than the corresponding Figure Wheel in the second difference column (similarly the units Figure Wheel on the Table Axis is slightly higher than that on the first difference axis).

Addition takes place as follows. At the beginning of a cycle, the Bolt is activated in such a way that it engages with the Adding Wheel above it. Then the axis is rotated; this turns the Bolt, the Adding Wheel, and thus the Figure Wheel in the next column to the right, in this example the units wheel of the first difference. The axis is given a full turn, but when it has rotated through an amount corresponding to the number on the Figure Wheel (in this case five), the Bolt hits a projection on the Figure Wheel below it which disconnects the Bolt from the Adding Wheel above it; this projection is in the correct position by virtue of the proper Figure Wheel having been set before the operation, in this example to five.

The effect of this action is that after the axis has been rotated through a full turn, the Bolt is back to its original position, and the units digit of the second difference, namely five, has been added to the units Figure Wheel of the first difference. This sequence can be repeated later in the operation as many times as necessary.

The units digit of the first difference can be added to the Figure Wheel of the Table Axis in exactly the same way. However, two things must be noted. First, if the second difference were added to the first difference at the same time that the first difference is added to the Table, the two additions would interfere; therefore the two additions are performed alternately. Second, whereas the units figure of the second difference remains constant, the units figure of the first difference is always changing; this does not matter, however, as it simply means that the projection which disconnects the Bolt is in a different position on successive cycles.

Naturally, the addition of a digit will in many cases make a carry necessary. In order that this not interfere with the basic addition, carries are delayed and sequential, as follows. When a Figure Wheel passes from nine to zero, it cocks a spring and lever above it. When the addition is complete, a separate carriage axis turns, and an arm on it releases the cocked lever and spring, adding one unit to the next higher Figure Wheel. As this carry might itself make necessary a second order carry, the arms on the carriage axis are staggered around the axis so that they release the levers in sequence, one at a time.

Thus the entire cycle consists of four parts. First the second difference digit is added to the first difference; then the necessary carries are performed on the first difference; then the first difference digit is added to the Table; then the carries are performed on the Table. All the digits on any one axis can be handled at the same time and in the same way. The activation of the Bolts at the correct time and the rotation of the various axes in the correct sequence is all controlled by a series of gears on top of the machine; these gears are turned by stroking a long lever back and forth by hand.

A more complete Difference Engine, using more orders of difference, would not require a longer cycle, as all the even numbered differences could be added together, followed by all the odd numbered differences together. Similarly, each column could include as many digits as desired, without lengthening the time of operation.

The assembled Difference Engine section incorporated a few other special features. It was arranged so that a single digit third difference (actually stored at the bottom of the first difference axis) could be added to the lowest Figure Wheel of the second difference. Three Figure Wheels at the top of the second difference axis could be disconnected from the rest of the axis and made to serve as a cycle counter. Each axis had a bell which could be set to ring when any Figure Wheel or combination of Figure Wheels on that column reached zero; this might be used to indicate when it was necessary to manually alter a difference in some operations; it could also be used to locate maxima and minima of a function.

Finally, there was a special provision whereby any one digit on the Table Axis could be added repeatedly to any one Figure Wheel on the second difference axis; this was to demonstrate Babbage's method of handling transcendental functions, discussed at the beginning of Chapter Three.

BIBLIOGRAPHY

As the body of this thesis is a documentary history of the calculating machines of Charles Babbage, drawing predominantly on the manuscript collections,

the main text must serve as the principal guide to the sources.

The purpose of this bibliography, therefore, is not to be exhaustive, but to discuss the three main manuscript collections on their own, and then to discuss the most important published sources.

Manuscript Collections

There are three main collections of Babbage manuscripts. Most of his papers were left to his son Henry P. Babbage; the voluminous correspondence was deposited in the British Museum, while the technical papers, including all notebooks and drawings on the calculating machines, were given to the Science Museum in South Kensington. In addition, some years before his death, Charles Babbage had given to his friend H. Wilmot Buxton a collection of privately printed and manuscript papers concerning the machines, including most of the explanatory essays Babbage had undertaken (but never completed or published) describing the two Engines. It was Babbage's intention that Buxton should compose an account of his life and scientific work; this he did, but it was never published. The Buxton biography and the collection of papers Babbage had given him are deposited in the Museum of the History of Science at Oxford University.

British Museum.

The material at the British Museum is much the most straightforward and best organized, and will be dealt with first. It is part of the collection of Additional Manuscripts, bearing the catalogue numbers Add.MS. 37,182-37,201. Thus the catalogue number for any of the twenty volumes may be found by adding 37,181 to the number of the volume. As each volume contains on the order of 500 folios, the entire collection makes up about 10,000 folios.

The letters are arranged chronologically in Volumes I to XVIII, with Volumes XIX and XX containing letters that cannot be dated. When possible, letters without dates are placed approximately in sequence, as suggested by the context; inevitably, some of the placements are questionable and some are definitely wrong, but on the whole the cataloging is quite competent. Since almost any important letter will have at least some clues as to the date, the material in the last two volumes is generally very uninteresting.

Since Babbage made one or more drafts of all important letters, and of most minor ones, the collection has letters from him as well as to him, although not the copy actually sent. It is clear that there are some items missing from both categories, but on the whole the correspondence seems fairly complete.

The printed catalogue relating to the material (*Catalogue of Additions to the Manuscripts in the British Museum in the Years 1900-1905*, London, 1907) does not have an inventory of individual letters, but many of them are indexed by correspondent at the end of the catalogue.

For this study, the entire collection was examined, and some 2000 folios were selected for closer study. Only a fraction of these are actually cited in this thesis.

In addition to the letters, the British Museum holds, as Add. MSS. 37,202-37,205, a collection of manuscripts and privately printed papers concerning Babbage's interests in mathematics, astronomy, geology, lighthouses, cyphers and mathematical games.

Science Museum.

The collection of Babbage manuscripts at the Science Museum in South Kensington is much more diverse and confused, and it is not catalogued. At the beginning of World War II it was packed up in several crates and deposited in a warehouse away from London, for its own protection. It remained there, largely untouched, until the summer of 1967, when it was very kindly brought back to London for examination by the author. It has subsequently been placed in the Library of the Science Museum, and hopefully it will soon be arranged and catalogued.

Although the collection is not catalogued, there are two guides to it. One is a section of *Babbage's Calculating Machines* (pp. 271-94) prepared before Charles' death, including a list of Notations and Drawings of the Analytical Engine and a rather confused list of Scribbling Books, this material now being in the Science Museum. The other guide is a much more complete and careful inventory of the Museum collection prepared by G.H. Dennis in 1927.

This inventory consists of almost 100 large typewritten pages, and there would be no point in trying to duplicate it here. Rather a brief and hopefully less confusing guide will be provided to the most important material.

Bound Volumes.

The most important items are the Scribbling Books, in which Babbage made most of his day to day notes. The descriptions here will standardize the names and numbers as much as possible, although even Babbage's own terminology for them was often confused; for example, he intended to change the name of the volumes to Sketch Books beginning with Volume III, but later went back to calling them Scribbling Books. They are all bound volumes, most running between 200 and 600 pages.

The first important volume is not actually a Scribbling Book proper, but it came to be called the Great Scribbling Book. It was originally intended to record share appropriations for the Protector Life Assurance Society, and the pages are divided accordingly and marked with line numbers, but Babbage used it as a general notebook. Much of the material in it is undated (and often uninteresting), but the dates given range from 1829 to 1847. The volume is important because between about lines 1231 and 2301 it contains material, mostly very rough sketches, from the summer and fall of 1834, the crucial period when Babbage was developing the Difference Engine into the Analytical Engine, as discussed in Chapter Three.

The first volume of the regular Scribbling Books was at some point given the number XIII by mistake (see B.C.E., p. 294), and this number is still on it, but it was originally marked "Vol. I," and this is its proper number. Its main working dates were from February 1, 1835 to October 30, 1835, but there was some material from 1836 at the end.

Scribbling Book Volume II ran from November 6, 1835 to February 8, 1837, that is, through the adoption of punched cards and the first full development of the Analytical Engine. Volume III was begun February 9, 1837, and continued through August, 1838; after this there was miscellaneous material with dates through 1841, much of it copied from Volume IV; additional material was entered upside down from the back of Volume III, with pages numbered from the back, and confused dates from 1838 through 1841. Volume IV was similarly confused; its main working dates were from February, 1839, through May, 1841, but there were some earlier notes, and some as late as 1846.

Volume V ran fairly coherently from May, 1841, to December, 1844. Volume VI picked up in December, 1844, and ran rather quickly to October, 1846, at which point there began to be obscure notes on the "New Difference Engine;" these notes continued through 1848; in March and April, 1849, there were again some notes on the Analytical Engine, as well as a statement that accounts had been settled with Jarvis, Babbage's assistant. Then there was an abrupt jump to June, 1857, when the Analytical Engine was again taken up; notes on it continued in Volume VI through early 1859, but with little after January, 1858.

Volume VII ran from March, 1858, to June, 1859, with Volume VIII continuing this material, almost all on the Analytical Engine, from June, 1859, to December, 1864. Volume IX went from December, 1864, through November, 1866, with a few notes from 1867 and 1868 at the end. Volume X ran from December, 1866 to October, 1868, with Volume XI starting then and going to August, 1870. A Volume called XIA was mostly blank, but had some scattered interesting material from 1868 and 1869. Volume XII, the last of the regular Scribbling books, ran from August, 1870, to Babbage's death, with a few notes after this by Henry P. Babbage.

Apart from the Scribbling Books, there are several miscellaneous notebooks. One which is now called Volume XIIA has only about fifty pages used, mostly containing obscure material on the first Difference Engines; the few dates given are from 1830. Another, which has gotten the name Volume XIV, was originally called the Travelling Scribbling Book; it has dates from 1845 to 1863, but little on calculating machines; the most interesting material, irregularly from p. 8 to p. 85, with a few later pages, is a very rough development by Babbage of a highly mathematical theory of supply and demand in economics; this deserves further study.

A volume with the number XV, but no original title, is mostly blank, but has some obscure mathematical figuring connected with the Analytical Engine; the only date mentioned is August, 1860; there are also some long calculations concerning the ways in which spherical and ellipsoidal molecules might be close-packed, and some other interesting material not connected with the Engines.

Another volume, without number, but saying on the flyleaf "Analytical Engine 4 Feb. 1859," is almost entirely blank; it contains an index listing parts of the Analytical Engine, with corresponding headings on the appropriate pages, and was clearly intended for recording progress on the Engine at that time; but it was never filled in.

A volume called "Tool Book Vol. 1" is sometimes confused with Scribbling Book, Volume I (which was mistakenly given the number XIII, as mentioned above); the Tool Book has material from 1841 and 1842, with some inserts dated April, 1844, but it is almost entirely obscure small sketches; there is, however, on pp. 132-35, a description of a universal planing machine. The final bound volume contains mostly similar obscure sketches, with dates from 1842 to 1860; it has neither a volume number nor a title, but is in any case uninteresting.

Drawings.

The Science Museum collection also contains nearly 300 large, carefully executed Drawings, mostly of the Analytical Engine, each measuring approximately two by three feet. No full listing of these will be given here, as lists may be found in *Babbage's Calculating Engines*, pp. 288-93, and in the Science Museum inventory. However, a few obscure points about their character and order must be cleared up.

The Drawings are contained in three Mahogany Cases, numbered 1, 2 and 3. These cases are very handsome and ingenious, and apparently were especially designed by and built for Babbage. They are solid enough to protect the Drawings and allow them to be easily carried about; when opened, special fittings can be drawn up to provide a convenient stand on which to hang and view individual Drawings; the Drawings are also held within the Cases in a way which allows any single Drawing to be removed from and returned to any part of the sequence without disturbing the order of the other Drawings.

Mahogany Case Number 2 contains Drawings numbered from 1 to 116. Drawings 1 to 106 are general plans and details of the Analytical Engine, with dates from 1834 to 1842. Drawings 107 to 116 are plans for a large planing machine. At the back of the Case are general plans of the Difference Engine No. 1, which for some reason have the numbers 197 and 198.

Mahogany Case Number 2 begins quite straightforwardly, Drawings 117 to 144 are plans for the Analytical Engine, with dates between 1842 and November, 1846. Drawings 145 to 158 are plans for the Difference Engine No. 2, made during 1846 and 1847. At this point, however, confusion sets in, for the same number will often refer to more than one Drawing, of different dates and of different machines. Drawings of the Analytical Engine have numbers running from 159 to 207, with dates from July, 1857, to August, 1870; in cases where there are Drawings of the Difference Engine No. 2 with the same numbers (this occurs through number 181) the Analytical Engine Drawing is marked with an asterisk, as 159*. In some additional instances there will be two Analytical Engine Drawings with the same number; one will be marked with an asterisk.

The Difference Engine No. 2 Drawings are more confusing. There are twenty six Drawings of the Difference Engine with numbers between 159 and 177 which also form a distinct sequence of Drawings with numbers from 1 to 20 (there are four Drawings each for numbers 6 and 8), although the order of the two sets of numbers is quite different. The Drawings in this special set are not dated, but they probably correspond to the set of twenty four referred to on p. 180 of Babbage's *The Exposition of 1851* (London, 1851).

At the end of Mahogany Case 2 there are also some miscellaneous Drawings, some unnumbered, some copies of Drawings earlier in the Case.

Mahogany Case Number 1 contains a separate set of Drawings of the Analytical Engine with numbers from 1 to 47, and dates from June, 1857 to March, 1859. Apparently this was an attempt to form a complete set of Drawings of the machine when Babbage began work on it at this time, for there is only one Drawing from this period in the main sequence of numbers in Case 3; but for some reason Babbage shifted back to the old series of numbers early in 1859. Also in Case 1 is a series of Drawings with numbers from T.1 to T.19 (plus one that is unnumbered), and dates from 1857 to 1861, showing a series of Tools Babbage was apparently planning for use in the construction of the Analytical Engine.

Notations.

The Notations are contained in loose-leaf form in seven portfolio volumes. They are numbered from 1 to 388 (some numbers are duplicated, but not in a confusing way), and dated from 1835 to 1848; a few at the end refer to the Difference Engine No. 2, the rest being of the Analytical Engine. The order of the Notations is quite straightforward, and as there is a full annotated list of them in the Science Museum inventory, and both a list and a "Classed Catalogue" in *Babbage's Calculating Engines*, pp. 273-87, no further guide to them need be given here.

Miscellaneous.

The Science Museum collection also contains a large quantity of additional miscellaneous papers, drawings and notations, often in fairly random order. Most of this material is not important, and it is too confused to make easy reference possible; therefore no general description will be attempted here. Hopefully this confusion will be alleviated when the Science Museum Library has catalogued the material; in the meantime, their inventory list will have to serve as the only guide, although the material is no longer in the order in which it was listed.

One item from this group must be mentioned, however. It is called "History," and is a series of seventeen sheets, each corresponding to a year between 1834 and 1850. Each sheet is divided into rows corresponding to the different months, and columns corresponding to different aspects of the Analytical Engine. In the spaces are entered references to Scribbling Books, Drawings and Notations which Babbage felt were significant in the development of the machine. Seemingly Babbage was intending to write a history of the Analytical Engine, and began to prepare this guide to the original material; possibly he filled it in as the work progressed. In any case, the references are rather incomplete, and the material referred to is often quite cryptic, so the usefulness of the outline is diminished; however, it does frequently indicate what steps Babbage thought to be important. The sheets for the last few years are mostly blank, but there are some references to material on the Difference Engine No. 2.

Hardware.

In addition to manuscript material, the Science Museum collections contain the section of the first Difference Engine put together in 1832, the second Scheutz Difference Engine, and two sections of the Analytical Engine, one put together and one redesigned by Henry P. Babbage, as discussed in Chapter Four. Also in the collection are various loose wheels, axes and other parts from the Analytical Engine, together with some moulds for casting them. These items are described in: *Catalogue of the Collections in the Science Museum, South Kensington; Mathematics: I. Calculating Machines and Instruments*, compiled by D. Baxandall (London, 1926), pp. 30-35.

Oxford.

As mentioned above, the Babbage material at the Museum of the History of Science at Oxford University came from Babbage's friend H. Wilmot Buxton. Quite a lot of this material is not interesting, being such things as proof sheets from some of Babbage's publications; some, however, is very important, and it will be described.

The most extensive Babbage manuscript (MSS. Buxton, Vol. 13) is a volume entitled "The History of the Origin and Progress of the Calculus of Functions during the years 1809, 1810 . . . 1817." It is a 289 page account of the mathematical work in which Babbage was involved during this period, centering around the Analytical Society. It would be extremely important to anyone working on this phase of Babbage's life, but was not used in or relevant to this

thesis.

MSS.Buxton, Volume 9 contains the following manuscript papers of special interest. First, "Engine for table of differences" (11 pp. with some small sketches); Babbage added a note at the beginning, dated August, 1840, saying: "This is the first idea and earliest sketch of the Cal. Engine probably in 1820;" in fact, the paper was doubtless from early 1822. Second, a paper called "Of an Engine to multiply n figures by m figures" (3 pp. with sketches); this paper has no explicit indication of date, but was written about the same time as the first. Third, introductory pages to a paper to be called "The Science of Number reduced to Mechanism" (4 pp.); this paper is not dated, but elsewhere in the Buxton manuscripts there is an outline of a paper with the same name, dated November 26, 1839; it was to be a long paper, mostly on the Analytical Engine, but clearly all Babbage wrote was the first few pages, on the early stages of the Difference Engine. All three of these Babbage manuscripts are discussed early in Chapter Two of this thesis.

In MSS.Buxton, Volume 7 there are the following Babbage manuscript papers on the Difference Engine. First, an untitled paper on the early development of the Difference Engine (26 pp.), dated November, 1822. Second, an introductory fragment of a paper to be called "History of the invention of the Calculating Engine" (3 pp.), dated September 6, 1834. Third, "Sketch of the Principles of the Analytical Engine" (2 pp.), dated September, 1841; this is actually an introductory fragment on the Difference Engine, but is not very interesting. Fourth, an untitled paper, (3 pp.), dated October 3, 1843; this is a very vague introductory fragment from a paper apparently intended to justify Babbage's position in relation to the government and their large expenditures on the Difference Engine.

There are also two privately printed items concerning the Difference Engine in Volume 7. One is Babbage's letter to Lord Derby, Prime Minister, dated June 8, 1852, recounting the history of the Difference Engine No. 1, and offering the government the plans for the Difference Engine No. 2 (this was reprinted in P.L.P., pp. 100-107). The other such item is a forty three page pamphlet entitled "Statement of the Circumstances Respecting Mr. Babbage's Calculating Engines," and is dated August, 1843; it was originally printed anonymously, but when reprinted as Chapter VI of *Passages from the Life of a Philosopher*, it was stated to have been drawn up by Sir Harry Nicolas from papers Babbage made available to him. This last item must be distinguished from the similarly titled paper "Statement of the circumstances attending the Invention and Construction of Mr. Babbage's Calculating Engines," written by Babbage, and appearing in *Babbage's Calculating Engines*, pp. 1-4, reprinted from the *Philosophical Magazine* for September, 1843. Babbage himself apparently confused the two titles in the list of his publications appended to *Passages from the Life of a Philosopher*.

MSS.Buxton, Volume 7 also contains the following papers on the Analytical Engine. First, "Of the Mathematical powers of the Calculating Engine" (53 pp.), dated December 26, 1837; this was Babbage's most complete description of the operation of the Analytical Engine, and has been quoted extensively in Chapter Three of this thesis. Second, "Of the Analytical Engine" (28 pp.), dated October, 1841; this is another interesting paper, but it has many quite confusing changes and additions. Third, an untitled paper on the Analytical Engine (13 pp.), dated September, 1842, and/or September, 1844; this is partly on the operation of the Analytical Engine and partly on Babbage's ideas about the psychology of invention. Fourth, "Of the Analytical Engine" (9 pp.), an incomplete paper dated July 19, 1869. Fifth, an incomplete and untitled paper on the Analytical Engine (14 pp.), dated October 7, 1869. Sixth, "The Analytical Engine" (30 pp., sparsely filled), apparently dated November 6, 1869. The last three of these papers are quite elementary introductions to the Analytical Engine, and are generally not nearly as interesting as the earlier papers; the last one does, however, give a simplified account of the transition from the Difference Engine to the Analytical Engine. There are also a few additional miscellaneous sheets in this volume of the manuscripts, but most of them are not very important.

MSS.Buxton Volumes 3 and 8 contain fair copies of the Babbage manuscripts in Volumes 7 and 9, made by either Buxton or an amanuensis. There is no new material, but the fair copies are usually much easier to read than the originals, and they occasionally supply words or portions of the papers which are missing from or no longer legible in the original autograph copies. The one minor problem is that the most important paper on the Analytical Engine, "Of the mathematical powers of the Calculating Engine," dated December 26, 1837, is quite incomplete in the fair copy; as the missing section is, in the case of the original in Volume 7, out of order and separated from the rest, it is likely that it was similarly misplaced at the time it was being copied; it therefore can only be read in full in the original version.

MSS.Buxton. Volumes 16 and 17 are Harry Wilmot Buxton's manuscript biography of Babbage, called "Memoir of the life and labours of the late Charles Babbage, Esq. . . . Comprising a descriptive and historical account of his Analytical and Difference engines, derived principally from his posthumous M.S.S. and papers" (no date). Although this biography gathers together more material on the calculating machines than any other single source, it does not add new information. It is made up largely of extensive extracts from the Babbage manuscripts in the Buxton collection, together with quotations or paraphrases from published material. Unfortunately, the biography is rather poorly organized, and evidently Buxton did not understand Babbage's machines sufficiently to form his extracts into a very clear or coherent account of their development, purpose or operation.

Published Sources

The published material is described below in two categories; the first contains material of a general biographical character, while the second contains material specifically related to the calculating machines. The important published sources were few in number, although many minor extracts from these have been published; no attempt has been made here to be exhaustive.

General Life.

There are two extensive general books on Babbage's life. One is Babbage's own memoirs, *Passages from the Life of a Philosopher* (London, 1864; reprinted London, 1968); although quite selective, and, having been written in old age, not always wholly accurate, it is a fascinating and delightful book. The other major biographical work is Mabothe Moseley's *Irascible Genius: A Life of Charles Babbage, Inventor* (London, 1964); this is more a personal than a scientific biography, and some of its drawbacks have been discussed earlier in this thesis, but it is still useful.

One other book that serves as a general source on Babbage's life is *Charles Babbage and his Calculating Engines*, edited and with an introduction by Philip and Emily Morrison (New York, 1961). This book is made up almost entirely of selections reprinted from *Passages from the Life of a Philosopher* and from *Babbage's Calculating Engines*, but it also contains a nice biographical sketch as an introduction; this introduction is based in part on an earlier article by the same authors: "The Strange Life of Charles Babbage," *Scientific American*, Vol. 197, No. 4 (April, 1952), pp. 66-73.

There are a number of briefer sketches of Babbage's life. The best of these are his obituaries, most notably the following: *Nature*, Vol. V (1871-72), pp. 28-29; *Monthly Notices of the Royal Astronomical Society*, Vol. XXXII, No. 4 (February, 1872), pp. 101-9; and the memorial remarks by William Farr in his Presidential Address to the Statistical Society of London (later the Royal Statistical Society) on November 21, 1871, printed in the *Journal of the Statistical Society*, Vol. XXXIV (1871), pp. 411-417. The last item emphasizes Babbage's contributions to statistics and life insurance, and discusses the *English Life Table*.

Two later biographical sketches which are valuable are the Babbage article, written by Agnes Mary Clerke, in *Dictionary of National Biography* (Oxford, 1917 and later), Vol. I, pp. 776-78; also *Faster than Thought*, edited and with an introduction by B.V. Bowden (New York, 1953), pp. 6-31; Bowden also reprints the Menabrea-Lovelace paper on the Analytical Engine in an Appendix.

There are a number of other brief biographies of Babbage which are entirely secondary or tertiary, and are of little value; examples are: John Fyvie, *Some Literary Eccentrics* (London, 1906), pp. 179-209; Alexander Macfarlane, *Ten British Physicists of the 19th Century* (New York, 1919), pp. 71-83 and passim; Royce W. Van Norman, "Charles Babbage (1792-1871)," in *The Journal of Industrial Engineering*, Vol. XVI, No. 1 (January-February, 1965), pp. 3-71; Jeremy Bernstein, *The Analytical Engine: Computers - Past, Present and Future* (New York, 1966), pp. 30-46; and Paul L. Garwig, "Charles Babbage (1792-1871)," in *American Documentation*, October, 1969, pp. 320-24.

A number of sources written by Babbage's contemporaries give accounts of his character or particular incidents in his life. Charles' son Henry Prevost Babbage's *Memoirs and Correspondence of Major-General H.P. Babbage* (London, 1910) is mostly about Henry's life in India, but there is some information about Charles' family life (see esp. pp. 10-11, 80-95, and 181-82); there are also brief appendices on Henry's involvement late in life with some of Charles' work.

Other such personal accounts may be found in the following works: *Harriet Martineau's Autobiography*, edited by Maria Weston Chapman (Boston, 1877), Vol. I, pp. 265-68; Mary Lloyd, *Sunny Memories* (London, 1880), pp. 47-69; The Hon. and Mrs. Lionel A. Tollemache, *Safe Studies* (London, 1884), pp.

148-58; Samuel Smiles, *Life and Labor* (New York, 1888), pp. 166 and 271; *The Diaries of William Charles Maccready* (1833-1851), edited by William Toynbee (New York, 1912), Vol. I, pp. 157 and 409-10, and passim; finally the Inaugural Address by Lord Moulton in the *Napier Tercentenary Memorial Volume*, edited by Cargill Gilston Knott (London, 1915), pp. 19-20.

Babbage's own published works will not be discussed here exhaustively, though those concerning the calculating machines will be covered in the next section, and some of the major ones will be mentioned below. But a fairly complete list of his papers can be found in *Passages from the Life of a Philosopher*, pp. 493-96; it was reprinted in the Morrises' *Charles Babbage and his Calculating Engines*, pp. 372-77, and in slightly revised form as an appendix to *Babbage's Calculating Engines*.

Babbage published some seventeen papers on mathematics before he became interested in the Difference Engine; this early work is treated in J.M. Dubbey, "The Mathematical Work of Charles Babbage" (unpublished Ph.D. thesis, the University of London, 1968).

Babbage gained a vital role in the struggle over the reform of the Royal Society which eventually led to the founding of the British Association for the Advancement of Science through two publications: "Account of the great Congress of Philosophers at Berlin, on 18 September, 1828," *Edinburgh Journal of Science*, Vol. X (1829), p. 225; and *Reflections on the Decline of Science in England, and on some of its Causes* (London, 1830). Babbage's book stirred up a great deal of controversy, and provoked favorable responses, such as the review of it by David Brewster in *The Quarterly Review*, Vol. XLIII (1830), pp. 305-342, and unfavorable responses, such as Gerard Moll, *On the Alleged Decline of Science in England* (London, 1831). The circumstances surrounding Babbage's break with the British Association in 1839 are dealt with in his pamphlet "Letter from Mr. Babbage to the Members of the British Association for the Promotion of Science" (privately printed, London, 1839).

More general treatment of Babbage's role in the reform of scientific institutions can be found in: Charles F. Mullett, "Charles Babbage: A Scientific Gadfly," *The Scientific Monthly*, Vol LXVII (1948), pp. 361-71; D.S.L. Cardwell, *The Organization of Science in England: A Retrospect* (London, 1957), Chapter III; and George Basalla, "Science and Government in England: 1800-1870" (unpublished Ph.D. Thesis, Harvard University, 1963).

Babbage published three main items on economics and industrial development and management: *On the Economy of Machinery and Manufactures* (London, 1832, with several later editions); *An Analysis of the Statistics of the Clearing House during the year 1839* (privately printed, London, 1856); and *The Exposition of 1851; or, Views of the Industry, the Science, and the Government, of England* (London, 1851); the last item also included material criticising scientific organization, and some discussion of the calculating machines. The significance of this aspect of Babbage's work is discussed at length in Richard S. Rosenbloom, "Men and Machines: Some 19th-Century Analyses of Mechanization," *Technology and Culture*, Vol. V (1964), pp. 489-511. See also Friederich Klemm, *A History of Western Technology* (Cambridge, 1964), pp. 287-89, 305.

Babbage's work on insurance was published as *A Comparative View of the Various Institutions for the Assurance of Lives* (London, 1826); this work and Babbage's calculating machines as useful to insurance companies are discussed in Cornelius Walford, *The Insurance Cyclopaedia* (London, 1871), especially in the articles "Babbage" and "Calculating Machines."

Although Babbage occasionally published notes on particular ciphers he had decoded, he wrote no general work on deciphering; but he discussed his work on the subject in Chapter XVIII of *Passages from the Life of a Philosopher*. David Kahn, in *The Codebreakers* (London, 1967), pp. 204ff., argues that Babbage foresaw the principles of the modern science of cryptoanalysis.

Babbage discussed his Mechanical Notation in Chapter IX of *Passages from the Life of a Philosopher*. He published a brief description of the fully developed notation as used in the Drawings and Notations of the Analytical Engine, for distribution at the Exposition of 1851, as *Laws of Mechanical Notation* (privately printed, London, 1851; reprinted in B.C.E., pp. 242-45).

Finally, three other Babbage publications which will simply be listed were: *A Table of the Logarithms of the Natural Numbers from 1 to 108,000* (London, 1826); *Notes Respecting Lighthouses* (privately printed, London, 1852); and *The Ninth Bridgewater Treatise* (London, 1837). The last item mentioned included some discussion of the Difference Engine in Chapters II, VIII, XIII and XVIII, and in "Note B."

Calculating Machines.

Much the most useful book on Babbage's work on calculating machines is *Babbage's Calculating Engines: Being a Collection of Papers Relating to them; their History and Construction*, edited by Henry P. Babbage (London, 1889). This volume, on which Charles Babbage had been working before his death, reprinted almost all the important published material on the Babbage Difference and Analytical Engines, and the Scheutz Difference Engine.

Two other general discussions of Babbage's calculating machines, interesting because they were published shortly after the construction of the first computers, are: Howard H. Aiken, et. al., *Annals of the Computation Laboratory of Harvard University*, Vol. I (Cambridge, Mass., 1946), Chapter I; and in Vol. XVI of the same *Annals* (Cambridge, Mass., 1948), "The Work of Charles Babbage," by Richard H. Babbage.

The Babbage Difference Engine.

Babbage published four papers on the Difference Engine during 1822. The first, read to the Astronomical Society on June 14, 1822, was a "Note on the Application of Machinery to the Computation of Astronomical and Mathematical Tables," *Memoirs of the Astronomical Society of London*, Vol. I, Part II (1825), p. 309 (reprinted in B.C.E., p. 211). The second was Babbage's "Letter to Sir Humphrey Davy," dated July 3, 1822, also called "On the Application of Machinery to the Purpose of Calculating and Printing Mathematical Tables" (privately printed, London, 1822; reprinted in B.C.E., pp. 212-15). The third was "On the Theoretical Principles of the Machinery for Calculating Tables," being a letter to David Brewster, dated November 6, 1822, and printed in the *Edinburgh Philosophical Journal*, Vol. VIII (1822), pp. 122-28 and reprinted in B.C.E., pp. 216-19). The fourth paper, read December 13, 1822, was "Observations on the Application of Machinery to the Computation of Mathematical Tables," *Memoirs of the Astronomical Society of London*, Vol. I, Part II (1825), pp. 311-14 (reprinted in B.C.E., pp. 220-22).

Babbage wrote little on the Difference Engine later in life. In September, 1843, he published in the *Philosophical Magazine* (Vol. XXIII, London, 1843, pp. 235-39) a "Statement of the Circumstances attending the Invention and Construction of Mr. Babbage's Calculating Engines" (reprinted in B.C.E., pp. 1-3). In *Passages from the Life of a Philosopher*, Chapter V concerned the Difference Engine No. 1, and Chapter VII discussed the Difference Engine No. 2.

Of the brief descriptions of or notices about the Difference Engine published by others shortly after its invention, the following may be mentioned: unsigned items appeared in the *Edinburgh Philosophical Journal* as "on Machinery for Calculating and Printing Mathematical Tables," Vol. VII (1822), pp. 274-81, and "Mr. Babbage's Calculating Engine," Vol. IX (1823), p. 197. A much more interesting account was Francis Baily's "On Mr. Babbage's New Machine for Calculating and Printing Mathematical and Astronomical Tables," printed in the *Philosophical Magazine*, Vol. LXIX, May, 1824 (and reprinted in B.C.E., pp. 225-31). But much the best and fullest account of the Difference Engine published to date was Dionysius Lardner's "Babbage's Calculating Engine," in the *Edinburgh Review*, Vol. LIX (1834), pp. 264-327 (and reprinted in B.C.E., pp. 51-82).

In August, 1843, Babbage privately printed a pamphlet called *Statement of the Circumstances Respecting Mr. Babbage's Calculating Engines*; it was originally published anonymously, but when reprinted as Chapter VI of *Passages from the Life of a Philosopher*, it was said to have been drawn up by Sir H. Nicolas. In the same year, Sir David Brewster gave a superficial but highly enthusiastic account of the Difference Engine in his *Letters on Natural Magic Addressed to Sir Walter Scott, Bart.* (New York, 1843, pp. 263-67).

Another account of Babbage's relations with the government, particularly as mediated by the Royal Society, was given as Chapter XI of C.R. Weld's *History of the Royal Society* (London, 1848). Babbage had this chapter, together with some notices concerning it from the *Athenaeum*, reprinted as an appendix to his *The Exposition of 1851*; Babbage believed that this material established that the abandonment of the Difference Engine was the fault of the government. Another account of the Difference Engine was given by Lord Rosse in an address to the Royal Society in 1855 (*Proceedings of the Royal Society of London*, Vol. VII, 1854-55, pp. 255-58); Rosse also discussed the offer to the government of the plans for the Difference Engine No. 2.

Another description of the Difference Engine No. 1 was given in John Timbs' *Stories of Inventors and Discoverers* (London, 1863), pp. 139-44. Timbs also discussed the Scheutz machine, and gave biographical sketches of many of Babbage's contemporaries, such as John Rennie and M.I. and I.K. Brunel. A more detailed description of the operation of the Difference Engine, written by B. Herschel Babbage, one of Charles' sons, was *Babbage's Calculating*

Machine; or Difference Engine (London, 1872), a pamphlet to be sold in connection with the display of the assembled section in the Science Collections of the Victoria and Albert Museum (later these collections became the separate Science Museum).

Finally, a skillful description of the operation of the Difference Engine was given in a paper called "Charles Babbage and his Difference Engine," read at the Science Museum on December 13, 1933, by L.H. Dudley Buxton, grandson of Babbage's friend and biographer H. Wilmot Buxton; it was printed in the *Transactions of the Newcomen Society*, Vol. XIV (London, 1835), pp. 43-65. This paper also included a general biographical introduction.

The only biography of Joseph Clement of real value is Samuel Smiles, *Industrial Biography: Iron Workers and Tool Makers* (Boston, 1864), pp. 289-313; the same book gives biographies of other major mechanics and engineers connected with the Difference Engine. Descriptions of tools invented or built by Clement will be found in the *Transactions of the Society of Arts, Manufactures and Commerce*; Vol. XXXVI (1818), pp. 133-77; Vol. XLIII (1825), pp. 138-42; Vol. XLVI (1828), pp. 67-105; Vol. XLVII (1829), pp. 131-35; and Vol. XLIX (1832), 157-85.

A paper by Babbage "On the Principles of Tools for Turning and Planing Metals" was printed in Charles Holtzapffel, *Turning and Mechanical Manipulation* (London, 1846), Vol. II, pp. 984-87; see also Holtzapffel's notes on this paper (pp. 983-84 and 987-91), and a number of references to Clement throughout the work. The progress in and reduced cost of machining in the period between the first and second Difference Engines was discussed by Joseph Whitworth in a Presidential Address to the Institution of Mechanical Engineers in 1856 (*Proc. Inst. of Mech. Eng.* for 1856, pp. 125-33).

The Scheutz Difference Engine.

Many varying accounts of the Scheutz Difference Engine were published, but only the significant ones will be mentioned here.

The most important source on the development of the Scheutz Difference Engine was given in the Preface to *Specimen Tables Calculated and Stereomoulded by the Swedish Calculating Machine* (London, 1857). An excellent account of the mathematical theory underlying the Scheutz machine was given in the "Report of the Committee Appointed by the Council [of the Royal Society] to examine the Calculating Machine of M. Scheutz," Printed in the *Proceedings of The Royal Society of London*, Vol. VII (1854-55), pp. 499-509 (reprinted in B.C.E., pp. 264-69). A nice description of the operation of the machine was given in the *Annals of the Dudley Observatory*, Vol. I (Albany, N.Y., 1866), pp. 116-26.

Henry P. Babbage wrote a paper on the Scheutz machine, illustrated with several large diagrams in Babbage's mechanical notation (the diagrams are now in the Science Museum, South Kensington), which he delivered on several occasions. The most extensive report on this talk, drawn up by Charles Manby, Secretary of the Institution of Civil Engineers, was given as "Scheutz' Difference Engine and Babbage's Mechanical Notation," in the *Minutes of Proceedings of Civil Engineers* for May, 1856 (and reprinted in B.C.E., pp. 248-57).

Accounts of the use of the Scheutz machine at the General Registry Office can be found in the *English Life Table* (London, 1864), pp. xiii and cxxxix-cxlv, and *Companion to the Almanac for 1866* (London, 1866), pp. 6-15.

Babbage's fullest account of his high regard for the Scheutz machine were given in a paper called *Observations Addressed, at the last Anniversary, to the President and Fellows of the Royal Society, After the Delivery of the Medals* (London, 1856, reprinted in B.C.E., pp. 260-21).

The Analytical Engine.

There were relatively few publications specifically on the Analytical Engine. The most important was L.F. Menabrea's "Sketch of the Analytical Engine invented by Charles Babbage, Esq.," translated and with notes by Ada Augusta, Countess of Lovelace; this appeared, with some introductory material by Richard Taylor, in Taylor's *Scientific Memoirs*, Vol. III (1843), pp. 666-731, Menabrea's paper had originally appeared in the *Bibliothèque Universelle de Genève*, Vol. XLI, New Series (1842), pp. 352-76. The translation and notes were reprinted in *Babbage's Calculating Engines*, pp. 6-50. Babbage himself discussed the Analytical Engine in Chapter VIII of *Passages from the Life of a Philosopher*.

The "Report of the Committee . . . appointed [by the British Association] to consider the advisability and to estimate the expense of constructing Mr. Babbage's Analytical Machine, and of printing Tables by its means," was published in the *Report of the Forty-Eighth Meeting of the British Association for the Advancement of Science* (London, 1879), pp. 92-102; it was abstracted in *Nature*, Vol. XVII, August 22, 1878, pp. 438-40, and reprinted in *Babbage's Calculating Engines*, pp. 323-30.

Henry P. Babbage's paper "The Analytical Engine," in part a reply to the above item, was read to the meeting of the British Association at Bath in September, 1888; it was abstracted in the *Report of the Fifty-Eighth Meeting of the B.A.A.S.* (London, 1889), pp. 616-17. and printed in full in *Babbage's Calculating Engines*, pp. 331-38.

Only two more recent treatments of the Analytical Engine (apart from those in works cited earlier) will be mentioned here. One, interesting as an indication of continuing knowledge of the Analytical Engine in the early 20th century, was some brief discussion of the machine in *Modern Instruments and Methods of Calculation: a Handbook of the Napier Tercentenary Exhibition*, edited by E.H. Horsburgh (London, 1914), pp. 75, 124-27. The other, interesting as a description of the Analytical Engine in the light of modern computers, was Douglas Hartree, *Calculating Instruments and Machines* (Urbana, Illinois, 1949), pp. 69-73.

FOOTNOTES

[#1](#) *Charles Babbage and his Calculating Engines*, edited and with an introduction by Philip and Emily Morrison (New York, 1961), p. xxxii.

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