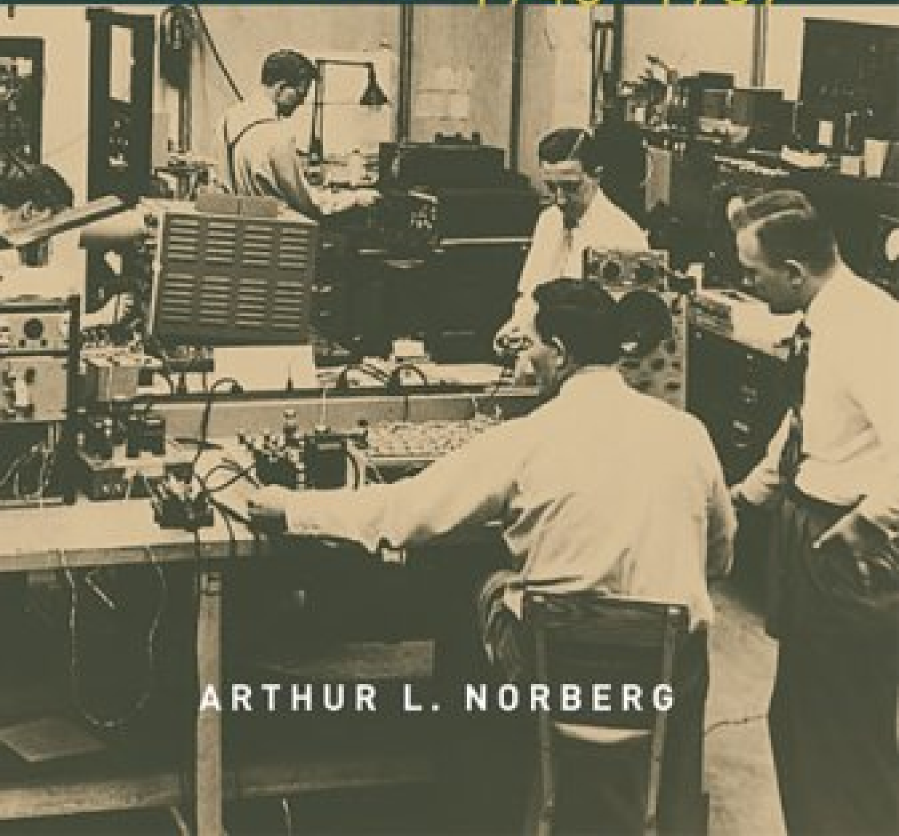
COMPUTERS AND COMMERCE

A Study of Technology and Management at Eckert-Mauchly Computer Company, Engineering Research Associates, and Remington Rand, 1946–1957



ARTHUR L. NORBERG

Computers and Commerce

History of Computing
I. Bernard Cohen and William Aspray, editors

John Agar, *The Government Machine: A Revolutionary History of the Computer*

William Aspray, *John von Neumann and the Origins of Modern Computing*

Charles J. Bashe, Lyle R. Johnson, John H. Palmer, and Emerson W. Pugh, *IBM's Early Computers*

Martin Campbell-Kelly, *From Airline Reservations to Sonic the Hedgehog: A History of the Software Industry*

Paul E. Ceruzzi, *A History of Modern Computing*

I. Bernard Cohen, *Howard Aiken: Portrait of a Computer Pioneer*

I. Bernard Cohen and Gregory W. Welch, editors, *Makin' Numbers: Howard Aiken and the Computer*

John Hendry, *Innovating for Failure: Government Policy and the Early British Computer Industry*

Michael Lindgren, *Glory and Failure: The Difference Engines of Johann Müller, Charles Babbage, and Georg and Edvard Scheutz*

David E. Lundstrom, *A Few Good Men from Univac*

René Moreau, *The Computer Comes of Age: The People, the Hardware, and the Software*

Arthur L. Norberg, *Computers and Commerce: A Study of Technology and Management at Eckert-Mauchly Computer Company, Engineering Research Associates, and Remington Rand, 1946–1957*

Emerson W. Pugh, *Building IBM: Shaping an Industry and Its Technology*

Emerson W. Pugh, *Memories That Shaped an Industry*

Emerson W. Pugh, Lyle R. Johnson, and John H. Palmer, *IBM's 360 and Early 370 Systems*

Kent C. Redmond and Thomas M. Smith, *From Whirlwind to MITRE: The R&D Story of the SAGE Air Defense Computer*

Alex Roland with Philip Shiman, *Strategic Computing: DARPA and the Quest for Machine Intelligence, 1983–1993*

Raúl Rojas and Ulf Hashagen, editors, *The First Computers—History and Architectures*

Dorothy Stein, *Ada: A Life and a Legacy*

John Vardalas, *The Computer Revolution in Canada: Building National Technological Competence, 1945–1980*

Maurice V. Wilkes, *Memoirs of a Computer Pioneer*

Computers and Commerce

A Study of Technology and Management at Eckert-Mauchly Computer Company, Engineering Research Associates, and Remington Rand, 1946–1957

Arthur L. Norberg

The MIT Press
Cambridge, Massachusetts
London, England

MIT Press books may be purchased at special quantity discounts for business or sales promotional use. For information, please email special_sales@mitpress.mit.edu or write to Special Sales Department, The MIT Press, 5 Cambridge Center, Cambridge, MA 02142.

This book was set in New Baskerville by Interactive Composition Corporation. Printed and bound in the United States of America.

Library of Congress Cataloging-in-Publication Data

Norberg, Arthur L. (Arthur Lawrence), 1938– .
Computers and commerce : a study of technology and management at Eckert-Mauchly Computer Company, Engineering Research Associates, and Remington Rand, 1946–1957/Arthur L. Norberg.
p. cm. — (History of computing)
Includes bibliographical references and index.
ISBN 0-262-14090-X (hc : alk. paper)
1. Electronic digital computers—History. 2. Computer industry—History. 3. Eckert-Mauchly Computer Corporation (Philadelphia, Pa.)—History. 4. Engineering Research Associates—History. 5. Remington Rand, Inc.—History. I. Title. II. Series.

QA76.5.N665 2005
621.39′09—dc22 2004058198

10 9 8 7 6 5 4 3 2 1

Contents

Preface

Before 1946 digital computer activity was developmental and in a preliminary stage. After 1956, a short decade later, use of digital computers was spreading and a digital computer industry was beginning to flourish. This decade represents a critical period in the development of digital computer technology, often perceived today as unmatched by any previous technological development. Whether this perception is correct or not, the computer stimulated technical developments and modes of social behavior that made the computing enterprise into a major phenomenon. This study explores the developments in the critical first decade of the electronic digital computer industry 1946–56. The overriding objective is to illustrate what made this decade so important in the history of computing. To build an effective fully electronic stored-program digital computer required several new developments in storage components, input–output systems, and programming concepts. The study explores these developments by focusing on two new firms established in 1946, Engineering Research Associates, Inc. (ERA) in St. Paul, Minnesota, and Eckert-Mauchly Computer Company (EMCC) in Philadelphia, Pennsylvania.

The work of ERA and EMCC necessitated a major financial partner, a role assumed by the U. S. government. Hence, in analyzing this decade, the study explores the interaction between the two companies and the government. It investigates the institutional context of technological change, how innovations developed under navy and army auspices were transferred to civilian use, and how, when new technologies were introduced, people in and out of the defense establishment responded to them.

A major portion of this work presents the origins, development, contributions, and interactions with others of ERA and EMCC from 1945 to 1951. By 1950–51, both companies were having problems with financing and had to resort to transfer of control to backers in order to survive. Remington Rand acquired both ERA and EMCC at this time. The study contains significant attention to the operations of ERA and EMCC inside Remington Rand, when the former firms acted as independent subsidiaries. During this ostensibly free period, EMCC concentrated on commercial trade and ERA continued to serve the military market, though not exclusively.

In 1955, Sperry Gyroscope and Remington Rand merged to form Sperry Rand. Sperry created the Univac Division and began a formalization of the activities of the two former divisions into civilian and military product producers. However, this did not happen smoothly within the new company. Old wounds were still raw, and infighting resulted in decisions about management personnel and reporting lines that were unsatisfactory to many. Groups formed in a less formal age felt threatened by the changes. Moreover, these men had ideas for new products that were not acceptable to the new management, and the groups began to dissolve. New companies were organized and the complexion of the computer industry began to change substantially. Indeed, the industry as we know it today began to emerge. The study closes with an account of the management history of Remington Rand, its two computing subsidiaries, and of Sperry Rand as it established the Univac Division in 1956.

Acknowledgments

Over the course of twenty years, an author accumulates many debts as he talks to a large number of people and visits a significant number of archives. I accomplished the writing in three waves, during three different phases of my life at the University of Minnesota. The first wave occurred in my early years as director of the Charles Babbage Institute. I observed in the early 1980s in magazine and newspaper reporting that several areas were touted as important in the computer industry, but if Minneapolis-St. Paul came in for a line or two, it was always as a previously important setting. Conversations with citizens of this area led me to believe that the history was worth telling, even if the glory years for computing were all in the past. I conceived the idea for a study of Engineering Research Associates. Grants from the National Endowment for the Humanities (NEH RO-21098) and the National Science Foundation (NSF SES-8420418) got the project off to a good start between 1984 and 1987. A contract from the Department of Defense (DARPA/IPTO)

interrupted the research and writing while we investigated the IPTO program and wrote a book on its support-groups activities. This manuscript went to the press in mid-1995.

The second wave occurred after I stepped aside from the directorship and after a bout with cancer in the mid-1990s, while I was a faculty member only in the university's Program in the History of Science and Technology and serving as Director of Graduate Studies. The university granted me a one-term leave and I began writing again. Progress was insufficient to bring the manuscript to completion when I was recalled to the directorship of CBI in 1999. In 2001, I returned to the manuscript determined to complete it. Through all this time, CBI also contributed to the project, so it too should be considered one of the funders, along with NEH, NSF, and the university.

In the course of the two decades I worked on this project, much more became known about the early years of the industry in the United States, more documents came to light, and historical study of the industry took on increased sophistication. I owe a great debt to many authors, all of whom, I believe, are noted in the footnotes to the chapters. Perhaps more important, I realized that the story of ERA could not be told well without also recounting the history of Eckert-Mauchly Computer Company and Remington Rand during the years 1946 to 1957. These additions essentially tripled the size of the project and the resulting manuscript—and the time!

There are a number of people to whom I am indebted for more specific reasons. Several conversations with Erwin Tomash, Arnold A. Cohen, and Willis K. Drake helped me to frame the initial study about ERA and the grant proposals that followed, as well as helped with many questions throughout the course of the project. My dear friend Erwin Tomash helped me in numerous ways, too many to acknowledge here, but I offer my profound gratitude. A number of people gave freely of their time through interviews: Walter L. Anderson, Dean Babcock, William W. Butler, H. Dick Clover, Arnold A. Cohen, Hugh Duncan, Robert Herr, John L. Hill, Frank C. Mullaney, William C. Norris, John Parker, Sidney M. Rubens, Edward C. Svendsen, James Thornton, Erwin Tomash, James H. Wakelin, Joseph Walsh, and Robert L. Westbee.

My historian colleagues—William Aspray, Martin Campbell-Kelly, Jeffrey Yost, Philip Frana, and James Cortada—served as sounding boards for many ideas good and bad. They have been a constant source of help and encouragement. I want to take special note of William Aspray, who has been a dear friend over the years, and was a great and stalwart supporter of this project and so many other things I have tried to do during our twenty-year friendship. Richard Seaberg, vice president and chief executive in Minnesota, and Jack Nichols, head of public relations in Minnesota, of the Minnesota Sperry Rand facility granted me access to the records of Sperry Rand at the Eagan, Minnesota, site. We uncovered many very useful ERA records, which were then transferred to the Hagley Museum and Library.

A debt I will never be able to repay I owe to Bruce Bruemmer, former archivist of CBI. During phase one, Bruce helped me in many ways large and small to obtain records and photographs, and offered advice on where to search for unavailable items. Later, in phase three, Carrie A. Seib, assistant archivist of CBI, helped me with Web searches, the identification and selection of photographs, and with citations for arcane sources. To these two members and others of the CBI staff I say thank you.

At the Hagley Library, depository for the Sperry Corporation Records and other collections relevant to this study, I obtained much research help from Michael Nash and Marjorie G. McNinch. Michael and I had many conversations about matters to do with Eckert-Mauchly and Remington Rand over the years, and occasionally he went out of his way to look for materials at Unisys Corporation to supplement my materials. They, too, deserve many thanks. Lee Johnson and Marjorie Ciarlante of the National Archives and Records Administration helped me examine records of the National Defense Research Committee related to the Naval Computing Laboratory at National Cash Register during World War II and relevant U. S. Navy records related to the founding of ERA.

William Aspray and James W. Cortada read the entire manuscript before I sent it to The MIT Press. In the review process, I received comments from Erwin Tomash, Jeffrey Yost, and an anonymous reviewer for The MIT Press, which, when attended to, added strength to the manuscript. I am deeply grateful to all of these colleagues.

Introduction

Early Digital Computer Developments in the United States

During World War II, designers of computing equipment crossed a threshold from the old world of punched-card tabulating equipment to fully electronic computing devices. In the United States, this transition occurred in four projects, all connected in some way with military specifications. Three projects were centered in university settings. Howard Aiken at Harvard, after designing an electromagnetic system with substantial aid from IBM, engaged in several machine projects for the U.S. Navy.[1] Jay Forrester and others at MIT focused on digital techniques to design a flight simulator for the U.S. Army Air Corps, later altering the design to a computer system for Whirlwind for use in a U.S. Air Force defense system, the Semi-Automatic Ground Environment (SAGE).[2] In 1943, the U.S. Army gave a contract to the University of Pennsylvania to develop a new type of calculating device. The university announced its major accomplishment in electronic computation from this project, ENIAC, to the public in February 1946, too late to have an effect during the war.[3] Finally, the interests of the U.S. Navy cryptographic service led to development of new types of data analysis devices based on digital techniques.[4] Developments in and spinoffs from these projects became the basis of the new U.S. digital computer industry, which also influenced developments around the world.

The ENIAC, designed and built at the University of Pennsylvania, putatively for wartime needs, has come to represent the transition between mechanical and electromechanical calculators (prevalent in the 1930s) and computers with internal programs governing calculation and symbol manipulation through its successor the EDVAC. Even during the ENIAC development period the principals were discussing the design of future internally controlled computers and of the prospects for commercialization. Not long after the war's end, John Mauchly and J. Presper Eckert expressed their intent to patent the design of and manufacture a new general-purpose machine with stored-program capacity based on the EDVAC concept. They moved quickly to establish their priority. Thus, the new industry emerged immediately after the war ended, but many other people besides Eckert and Mauchly endeavored to develop new computers.

Digital computing underwent rapid development in its first decade, 1946 to 1956. Four special characteristics of this first decade in digital electronic computer history stand out.

(1) During the decade, stimulation of the digital computing enterprise resulted from a special interaction of academia, government, and industry. Research projects organized at universities could not have happened so quickly without the funding by government, and the complex nature of the systems under design required assistance from industry. Peculiar problems appeared in components, which did not arise when vacuum tubes were used in radios or calculating machines. As the number of computer system components climbed into the thousands, stability and reliability became more problematic. Often government planned to use such machines in several locations and wanted mass production style construction as a result. If more than one machine was to be built from one design, universities were not equipped for the task, and industry assumed this task. Perhaps not the least important reason for this combination was that government was the principal, often the only, purchaser. After the mid-1950s as the industry matured and more systems became available, the interaction among these sectors changed and in later years new combinations displayed different characteristics.

(2) In this period as computer systems appeared in greater variety and larger numbers, a shift took place from calculating machines and punched-card storage systems to automatic computers. In the 1930s, routine large computation problems were accomplished using punched cards for the storage of data and automatic reading and sorting machines to distinguish among data elements and calculators to compute simple results. Scientific and technical developments just before and during World War II set the stage for a range of new possibilities that both stimulated and required new computational devices. Arithmetic routines for business and scientific and engineering research provided specifications for problem solutions the new computing machines tried to meet; early success indicated that the new machines would allow a

previously unaddressed set of problems to be approached. And out of this came a new world that, over the next five decades, contained new opportunities and new tensions. The seeds of these opportunities and tensions were present in the efforts of the men and women in this emerging enterprise in the decade beginning in 1946.

By 1956, these tasks were being handled, along with a great variety of others, in automatic computers that could store the data and instructions inside the computer. Moreover, each machine could do analyses of several types and were not confined to a given problem type. And, even with the shortness of the development period, these machines were now beginning to sell in the hundreds, and in the early 1960s in the thousands, just as electric calculating machines did in the 1930s. The year 1956 also became a critical transition point in the industry as IBM marketed computer systems that served as the standards for the industry thereafter. The settlement of the IBM antitrust case in the mid-1950s opened the way for companies to sell similar machines and compatible components, and later led to the establishment of a software segment of the computer industry.

(3) Early computer designs were slow, had small storage, and were insufficiently reliable to encourage faith in their use. The search for better technical capability was intense and widespread among the actors in the enterprise. In this decade designers conducted a search for a system that would be faster, have greater storage, and be more reliable. For example, ENIAC could store twenty numbers (or words) and required 200 microseconds to complete addition of two numbers. EDSAC, an immediate successor built in England on the EDVAC concept, could store 500–1000 words and complete additions in about the same time. Speed could be increased in two ways: decreasing interaction time of parts of the computer, such as reducing distances electrical signals must travel, and increasing the amount of data and instructions stored inside the machine. Thus, an array of research programs in and out of industry pursued techniques to increase storage and decrease the time to isolate a single data element, keeping costs in mind in most cases. This search culminated in the development of magnetic core memory, which swept the industry in the mid-1950s.[5] The reliability issue was, of course, twofold also. The need for reliability in components led to new developments. Industry developed a range of new components suitable for use in computers, including mass production techniques for their manufacture. Designers contrived more reliable circuits for the transfer of data and instructions

internally. Reliability was a very important aspect of military specifications for obvious reasons. By the mid-1950s, computer systems were more reliable, and increased storage capacity made the systems more useful.

(4) Working with their early (one might say their first) customers helped designers to understand the need for a range of applications. Machines of the 1930s calculated only. Whatever the application, the machine accomplished only arithmetical operations; thus the role of such machines was relatively small in science and business. During World War II, this situation began to change as machines were designed to go beyond this to compare data, seek patterns, and coordinate data to run machinery. The tasks performed were still simple, but illustrated what might be possible. Designers of new computing machines recognized two types of problems: the large data bank requiring simple, repetitive calculations and the more intricate data analysis requiring less calculation and more logical decisions. The former type of problem is more characteristic of commercial situations and the latter of scientific, so firms developed separate machines for scientific and commercial uses. By 1956, two lines of machines were available from manufacturers. But during the decade, manufacturers often started with only one of these lines, making competition difficult to assess. By the 1960s, it was clear to designers that only one type of hardware was needed to accomplish both types of computing, and the differences to address problems could be incorporated into software.

The technical aspects of these characteristics—the search for better storage systems, improved instruction sets, better performance, reduced size—continued to be hallmarks of the computing enterprise over the succeeding decades after 1960. Indeed, it is arguable that the tenor of innovation in the enterprise of the last fifty years, at least until the 1990s, was set in this early decade, and while new techniques of problem solving and alternate computer systems came into being later, the character of the enterprise remained the same. On the other hand, interactions among academic, government, and industry groups took different, often more confined, paths in the next four decades.[6] And while many successes emerged from these later interactions, the closeness in the working arrangements and in the setting of objectives can only be seen in the decade after 1946. (We should acknowledge that these characteristics have deep roots in activities of the 1930s and 1940s.)

In this first decade of the new industry, innovation occurred in many places. New and established firms in the business machines and defense industries focused on new designs for computer systems to accomplish many civilian and military purposes. University projects did similar types of research and contributed equally to computer development. Some innovations, such as the transistor that was to have an enormous influence on computer development, resulted from research in the Bell Telephone Laboratories. University systems served the research and program needs of university departments, leading to many new developments later marketed by industry. Industry systems were developed for use in new ways in government agencies, academic administrative areas, and especially for businesses. By 1956, system design was becoming standard, and industry had assumed the role of supplier for all sectors of the economy.

After 1956, the characteristics of the developing enterprise were much like those of any industry doing business with government and other industry sectors. Volume buying encouraged standard setting rather than design specifications. The military bought similar designs to serve many purposes, rather than single designs for one purpose. Companies and universities similarly acquired multipurpose computer systems. This circumstance resulted from the developments and interactions of that first decade. University computer research programs in the late 1950s diverged from concerns for hardware to programming, theory, and the training of students. And, as the computer became more ubiquitous, the computer industry focused more on the business and consumer markets. It was not so obvious in 1946 that this would be the outcome, but it was by 1957, and it was a few far-sighted organizations and individuals who led the way.

The decade represents a critical period in the development of this technology, often perceived today as unmatched by any previous technological development. Whether this perception is correct or not—and significant evidence exists that other technologies grew as quickly,[7] the computer stimulated technical developments and modes of social behavior that made the computing enterprise into a major phenomenon.[8]

The New Industry

A brief review of the emerging industry shows that at the end of World War II, the Office of Naval Research and the National Bureau of Standards, along with several of the military services, let contracts for new designs of computers to defense contractors and to a few new computer firms. Government contracts stimulated the nascent industry to conduct research programs on a variety of problems facing designers, and to develop components and system designs. Contracts specified that these new designs should be suitable for census counting, intelligence information analysis, and business accounting. All these firms faced the same technical challenges. All raced the clock to be first to market, a market then seen to be small, making success even more urgent.

The electronic digital computer industry emerged tentatively onto the world stage in 1946, with the founding of several new engineering companies and the incorporation by several large firms of the new electronic computing ideas into their planning, responding to the interest of government agencies. After 1946, the emerging industry was a hodgepodge of firms looking for a way to gain a foothold in the new market using the new technology and, as a result, was very volatile. Only a handful of large firms in the United States participated originally in designing and constructing new computer systems—IBM, Raytheon, Bendix, and Burroughs. Burroughs organized its first computer development laboratory in 1948 in Philadelphia with people from the ENIAC/EDVAC project. Raytheon acquired much of its staff from the group around Aiken at Harvard. The small start-up firms included Eckert-Mauchly Computer Corporation (1946), Engineering Research Associates, Inc. (1946), and Technitrol (1947). Technitrol, another firm staffed with people from the University of Pennsylvania, designed components for computer systems and is still an important electrical components manufacturer. Eckert-Mauchly Computer Corporation (EMCC) and Engineering Research Associates (ERA) were eventually absorbed into Remington Rand in 1950 and 1952, respectively, giving Remington Rand its start in the digital computer business.

Hughes Aircraft instituted development of military computers in 1948 with an active program for a general computer system between 1950 and 1953, when Hughes sold the activity to Ramo-Wooldridge. Computer Research Corporation spun out of Northrup Aviation in 1950 and was absorbed into NCR in 1953. A group of National Bureau of Standards engineers began Electronic Computer Corporation in 1950, only to become part of the Underwood Corporation, the typewriter manufacturer, two years later after they introduced their first computer system to the business market. RCA developed a series of systems in the early 1950s delivering BIZMAC in 1954. RCA continued to develop a series of computer systems for the next fifteen years before exiting the business. The same can be said of General Electric, whose highpoint was the development of the Electronic Recording Machine—Accounting (ERMA) for Bank of America (1956).

From Iowa State University, a group, including Clifford Berry who helped design and build the Atanasoff-Berry Computer (ABC) in the early 1940s, organized Consolidated Engineering in 1951. Consolidated's computing activity became Electrodata in 1954 and disappeared into Burroughs in 1956. Raytheon later confined its computer efforts to fire control and missile systems, and Bendix, after developing several computer systems, became part of Control Data Corporation in 1962.

We know less about companies' involvement with the military and intelligence communities, partly because of the secrecy imposed by these communities.[9] This explains in part why southern California, Texas, and the upper Midwest have received little analysis in public statements about regions of computer development in the United States over the years. This is unfortunate, because it gives an eastern United States bias to views about the computing enterprise. For example, it misses the important early work in the Los Angeles area, a center of development for military computing, computing in the aerospace industry, and the origins of National Cash Register's (NCR) origins in computing and some of Burroughs's computer involvement.[10] Rather than develop computing technology internally, a number of business machine and defense companies entered the field either by acquiring computer companies or by obtaining government development contracts. For example, Remington Rand Corporation acquired EMCC in 1950 in an attempt to sell computers to their large tabulating machine business customer base. Later in the 1960s, General Electric, with experience in development of military computers, tried to enter the developing time-sharing computer market with development money from the government. A study of these developments is also needed.[11]

All these firms provided an important stimulus to the early computer industry in the United States. These businesses were organized at a time before a stable computer design was available, and they participated in the development of standard schemes for designing, manufacturing, and servicing computer systems. But three firms in the decade 1946 to 1956 played major roles in the development of what became the standard design of computer systems: IBM, EMCC, and ERA. Each of these companies had varying amounts of capital, and except for IBM whose talent base was large, each had a small but talented group of industrious designers determined to succeed.

IBM, EMCC, and ERA

IBM jumped to an early start during the war, giving design and construction aid to Howard Aiken at Harvard, as we noted above. After the war, IBM organized several of its own projects, starting with the Selective Sequence Electronic Calculator, and moving on to the Tape Processing Machine, before going completely electronic and digital with the IBM 701, the start of an illustrious series of machines. During this decade, IBM underwent a rapid and effective transition from a tabulating firm with an overwhelming share of the market to an electronic digital computer company with a range of products that would dominate the new market as well. Over the decade, IBM initiated a series of projects, first in electronics for accounting machines, then in component systems to test things like magnetics and drums, and finally to a complete stored program computer system. This approach is a hallmark of IBM's design strategy for new system development up to the 1980s.

Occasionally, IBM tested itself against the efforts of competitors. For example, as it worked on development of a magnetic drum system in the first decade, the company engaged ERA to accommodate its drum design to IBM specifications. The IBM evaluation of the two drum designs convinced management that its internal design was at least equal to ERA's and more suitable to IBM manufacturing practices. This drum came to market in the 1954 IBM 650 computer system. To avoid possible infringement suits when the IBM drum came to market, IBM purchased the right to a number of ERA patents associated with drum design and construction. Up to now, historians have mostly focused on the history and accomplishments of IBM because of its major part in determining early standards through successful development and marketing. Indeed, IBM deserves its place in the sun. However, the history of the early decade illustrates that IBM was no more advanced than several other new firms in the industry.

IBM tried to parlay an earlier customer base in tabulation into an entry into the new field with great success. *IBM's Early Computers* recounts in hearty detail events at and designs done by IBM in the period from 1935 to 1956.[12] This exceptionally well-executed analysis enlarges our knowledge about events inside IBM for the critical decade beginning in 1946. It shows that IBM has contributed greatly to the computer field over the years, both in technical and business ways, by concentrating on business applications and on the customer's needs.

Maurice Wilkes, the accomplished computer scientist who built the first operating digital computer in England, the EDSAC, wrote in his memoirs of a conversation he had with John Mauchly in the early autumn of 1946 about the future of computers. The conversation took place on a train from Philadelphia to Washington, D.C., after the famous Moore School Lectures on computer design that summer, which Wilkes attended. The reminiscence emerged from Wilkes's report that he had often been asked to what extent the small group of early people in the field of computer design understood what the future could be like using these computer systems. His emphatic answer over the years is that not only did J. Presper Eckert and Mauchly and their associates appreciate the future role, but "they succeeded in communicating this understanding to those of us who were on this course."[13] While Eckert and Mauchly may have successfully envisioned the future of computers in 1946, they, and others, were a long way from plotting the path to a successful design, and there was much controversy about how to accomplish one. With hindsight, we can see they were in something of a race with the other groups designing systems they hoped would succeed in the market. Eckert and Mauchly had a difficult time countering the arguments of their critics in the late 1940s. But succeed they did and led the way for a brief spell. The Eckert-Mauchly Computer Company (EMCC) they established played a major role in educating, training, and persuading people in government and industry of the rightness of their vision.

Most early accounts of ENIAC and its successors, the EDVAC and UNIVAC, address in detail only technical issues, focusing on machine design and development. Nancy Stern, in her study of the Eckert-Mauchly Computer Company, attempted to correct this imbalance. She concentrated on analysis of the relationship between J. P. Eckert and J. Mauchly, the larger relationships between the engineering and mathematical communities in this period, the role of John von Neumann, the performance of BINAC, and the troubled financial history of EMCC. She chose to leave aside any robust technical appraisal of the hardware, and she did not discuss the role of these machines in the digital computer industry. Moreover, nothing is said about the relationship of EMCC's development program with computer development projects elsewhere. Her story stops at 1952 with the absorption of EMCC into Remington Rand.[14] What Stern illustrates well is that EMCC emerged out of a strong desire on the part of its founders to bring new computational machinery into the commercial world, and EMCC never deviated from this objective to provide machines to customers across the economy.

Many details of the development by this firm in the late 1940s still need to be presented and an account of EMCC as a subsidiary in Remington Rand is long overdue. The new details presented in this volume about EMCC's early history strongly support Stern's assessment of EMCC.

Two major developments in this decade involving IBM and ERA stemmed from the interest of the U.S. Navy in computing. The navy's Bureau of Aeronautics, anxious during the war to train pilots quickly and safely, contracted in 1943 for a new analog simulator that would provide lifelike situations for prospective pilots in early training.[15] At war's end, this simulator project became a low priority. Instead, both the navy and MIT became interested in an electronic digital device, and the aircraft simulator project was transformed into Project Whirlwind, to build a computer as the cornerstone for several new defense systems, including ground-to-air missiles and a detection system for such missiles (SAGE).[16] These systems required a computer that would control a missile and act on it continuously—what is now called a real-time computer. The MIT team concluded that designing a unit to the new specifications provided by the military with old ideas in mind would be exceedingly difficult and ineffective. It was then that the designers adopted the new digital techniques and went on to invent a major new memory design, the magnetic core, which was to have an enormous effect on the computing field. This was magnetic core memory. The Redmond and Smith administrative history of this project provides insight into the project's nature and results.[17] For the technical history of the development of magnetic core memory, one needs to turn to the history by Emerson Pugh.[18] This academic project at MIT became the basis for the computer industry around Boston, and because of the involvement of IBM in the manufacture of SAGE computer systems, helped IBM develop manufacturing systems for computers.[19] In later years, MIT was to play a similar role in the emergence of other techniques and companies, such as those associated with numerical control machinery, time-sharing systems, and applications software.[20]

Another part of the navy, the cryptology unit, expended some effort before and during World War II on new mechanical techniques for analyzing data. The purpose of this unit required that cryptologic work on intelligence about another country be kept secret. Thus, up to now we have had only a few glimpses into the nature and influence of this work.[21] These glimpses provide some evidence of the effect of this work on the growth of the U.S. computer industry. By the middle of 1945, navy personnel were convinced that the effort to enhance analysis techniques by new data processing concepts should continue and these techniques should make as much use as possible of the newly developing computing ideas. In the navy, this work was done primarily under the direction of the Communications Supplementary Activity—Washington (CSAW). CSAW was composed of a hastily assembled group of cryptologists, mathematicians, physicists, engineers, and chess and bridge masters. Foiled at keeping this prime group together after the war as civilian employees to pursue such work under direct supervision, the navy assisted in the establishment of a private company, composed of many of those same men, to perform the same investigations with classified contracts. This company was Engineering Research Associates, Inc. (ERA), located in St. Paul, Minnesota.[22]

ERA enjoyed a cozy arrangement with the U.S. Navy's intelligence group. Many of the ERA employees worked in naval intelligence during World War II and continued to develop improved data processing systems for intelligence work after the war under private auspices. Specifications for early projects usually came direct from the navy personnel, after which the navy and the ERA group worked out a final design. ERA's objectives can be just as simply stated as those of EMCC, but the company was buffeted on all sides because of its involvement with the military. It was not until the early 1950s that ERA possessed enough talent to realize its ambition to design systems for the marketplace by itself. When ERA decided to go commercial in a manner similar to EMCC, it encountered the same problems as EMCC. By the time of ERA's commercialization, both ERA and EMCC were part of Remington Rand, which placed a new set of constraints on the two firms.

EMCC and ERA are an interesting comparison in the emergence of the new computer industry after World War II. While they worked on similar problems, their approaches were different. Neither firm had the resources of an IBM, still a moderate-sized company at the time, yet controlling a major part of the tabulator market. Yet in their separate ways, they, along with IBM, the MIT Whirlwind project, and Princeton's Institute for Advanced Study (IAS) project, led the field of computer system design into the future.

The computer designs of these firms constituted a revolutionary technology. They required a rethinking of how problems should be solved and a search for ways to improve business practice. The cast of characters in the development was broad, and there was much rivalry, difference of opinion, alternate approaches, and varying success in the early history of the computer field. The emphasis in historical writing so far has been on individual project results (Whirlwind; IAS), struggles inside a project or firm (ENIAC, IBM), firsts, glory grabbing, and biography. With few exceptions, at least brief histories are available for all these companies. Both MIT and IAS have been thoroughly studied.[23] Some analysis of EMCC and ERA has appeared in the literature.[24] And, as noted above, IBM technical history is elegantly described in several books from the IBM Technical History Project.[25] IBM histories are divided into the tabulator and electronic computing phases, with little continuity.[26] The same can be said of Burroughs and National Cash Register (NCR). Indeed, Burroughs and NCR still need to find their historian.[27] Studies of newer firms—Intel, Sun, Oracle, and so forth—are mostly worshipful success stories, with little, if any, analysis.[28] The present work is an attempt to balance the still-lacking story of EMCC, ERA, and Remington Rand with the histories of these other major computer activities.

The general outlines of the history of activity in EMCC and ERA are well known. However, there are aspects of these stories that the participants have exaggerated or told incorrectly. In addition, there are aspects that have lain hidden all these years that reveal more robust activities within each company and greater understanding of what they needed to achieve to be successful. Historians know about the arguments of the critics of EMCC and ERA through their studies of other projects and firms, but they have not examined how EMCC and ERA responded to their critics and won them over. In this history, the strategies of both firms to counter their critics are recounted, in many instances for the first time. Historians have speculated on what happened inside Remington Rand to alienate the ERA group, especially their leaders, and what Remington Rand did to lose the competition to IBM in the middle 1950s. These aspects are connected and reveal a great deal about the parent firm and their treatment of their new subsidiaries. It is a classic case of a merger handled badly at first, but eventually turned around, although too late in many ways. There was incompetence, misjudgment, ignorance, and the application of past valid practices to a new area where they were less useful, such as in sales. There was also talent, remarkably good designs, and ambition to succeed in the market. Remington Rand, later Sperry Rand, had its boosters, and eventually the Univac Division including EMCC and ERA succeeded in the marketplace of the 1960s. The story of the ambitions, struggles, successes, and relationships within the firm constitute a dramatic story of the origins of this revolutionary industry.

ERA influenced the field in ways both similar to and different from EMCC and the Whirlwind project. Among the similarities are major inventions for storage techniques, the commercialization in the early 1950s of a machine produced originally for a military purpose, and as a fountainhead for new companies. The principal differences are the manner of operation of the company: tight classification in the early years; production of a volume (published in 1950) that contained an assessment of techniques available in 1949 for design of computers that influenced developments worldwide; and a prudent, some might say ineffective, manufacturing and marketing strategy.

Remington Rand was not successful in melding an effective unit out of Eckert-Mauchly, ERA, and their own punched-card manufacturing units. Remington Rand merged with the Sperry Corporation in 1955. Even with better management, Sperry Rand took almost a decade to produce a profitable computer unit. And at that time the technology was taking a new turn. IBM had begun its System/360 development, which was a system based on advanced microelectronic circuitry and new computer architecture. This design, part of the so-called third generation of computing equipment, had a remarkable influence on the industry, and further increased IBM's revenues and profits.[29] Others simply had to follow.

Outline of the Present Volume

As a contribution to the history of information technology, the present volume is a detailed study of ERA and EMCC, from their inception to 1957 when they became components of the new Univac Division of Sperry Rand. Most of this history about ERA's and that of EMCC's years in Remington Rand have not been told previously, though some of the details have become part of other stories, such as the founding of Control Data Corporation in 1957.[30]

The story of ERA in itself is compelling for several reasons. In at least one sense, ERA was a unique enterprise because of the nature of its founding and the close oversight it experienced. In contrast to EMCC, IBM, and others, there was no single objective governing ERA activities in the company's formative period of 1946 to 1951. Indeed, among the founders, a rather sizable group of fifty-one, several objectives were being promoted by small sets of people. Even though the company was reminded from time-to-time that their principal task was navy business, often developments for the navy were examined inside the firm with a critical eye to commercialization. Colin Burke has gone so far as to conclude that the tug-of-war between company personnel and navy overseers was the prime contribution to ERA's early downfall as an independent firm. Contrasting ERA with EMCC, which suffered a similar early downfall, reveals that navy pressure was only part of the problem. To understand ERA completely, we must make a careful examination of how several conceptual relationships played out in the company. I refer to the relationships between science and technology, research and development, invention and innovation, and military and civilian outlooks. While ERA did not begin as a computer company in the same sense as say EMCC did, the desire to be one lurked in the background and was ultimately achieved, both because and in spite of the navy. To appreciate these relationships and to understand how ERA moved from data processing to computer design, we need to examine in detail technical developments within ERA, and their contributions to, and borrowings from, the rest of the enterprise. In this volume can be found a complete analysis of ERA's founding, a study of the principal actors in its technical developments, contributions to intelligence and commercial computing, the decision to sell the company to Remington Rand, and the effects of ERA activity on that of other computing groups. Over the past two decades, we have gained a good understanding of the role of government agencies in the emergence of the computer industry and of computer system design.[31] The one lacuna in this understanding is still ERA, a lacuna filled here.

At first sight, it may not appear that ERA was a pioneer in this industry—a number of contemporaries, among them J. P. Eckert, dismissed ERA, and several historians have seen it merely as a captive of the navy. However, as I will show, ERA deserves to be ranked with EMCC, Remington Rand, and IBM as an important early element in the great success of the computing enterprise in the last half century.

Among the questions needing to be answered about these two new firms are:

Who were the principal actors in founding EMCC and ERA?

How did they devise the original objectives of the firms, and how did these objectives change over time in response to what stimuli?

What was the form of interaction with the customer?

How were the specifications for designs arrived at?

What was possible and what compromises had to be made because some things were not possible?

How quickly was information disseminated within the community?

What was the nature of the activity these men and women were trying to automate? How did their understanding of this nature develop?

How did the two firms perform inside Remington Rand? And how did Remington Rand try to absorb them?

While answering these questions about the histories of EMCC, ERA, and Remington Rand in the critical decade 1946–1956, we will focus on two concerns. One concern is to illustrate what made this decade so important in the history of computing. Virtually all histories of the computer industry focus on the events that inaugurated competition in the early 1950s and say little about the preceding development period in companies other than IBM.[32] This work is not an attempt to revise the history of the industry to suggest that its competitive activities began before the early 1950s. But in other works, a focus on competition, especially the winner IBM, led authors to dismiss many important and influential developments that occurred in other settings before the early 1950s.[33] A second concern is to show how innovation in computing was driven by problems in scientific computation, routine business transactions, methods required to analyze large data sets such as census data and military and intelligence needs. Of course, such innovation had already begun in the 1930s,[34] but wartime needs stimulated and concentrated research in many scientific and military areas, which had an impact on computer components and programming after 1946 as noted above. We will see how the new entrepreneurial companies in the nascent computer industry used the results of this research to guide the development of major computer systems.

To market an effective fully electronic stored-program digital computer, our overarching interest in this study, required several new developments in storage components, input–output systems, and programming concepts. The demands of the development process to achieve this system necessitated a major financial partner, a role assumed by the federal government.[35] Hence, in our analysis of this decade, we will explore as well the interaction between the companies that participated in these developments and the federal government. Again our focus for exploring this interaction in detail will be on the two new firms established in 1946: ERA and EMCC.[36] The issues investigated include the institutional context of technological change, how innovations developed under navy auspices were transferred to civilian use, the need to design software for effective use of these new computer systems, and the activities of these two firms after their purchase by Remington Rand.

The material presented here for 1952 to 1956 is mostly new. My concentration for these years will be events inside each subsidiary (ERA and EMCC), interactions between the two subsidiaries, and the context for the two subsidiaries inside Remington Rand and then Sperry Rand. Exploring the successes and failures of the two subsidiaries, as well as their interaction with the Norwalk Laboratory of Remington Rand, helps us to understand the issues. Comparing them with each other and with other activities has not been done previously.

As each operated as a separate subsidiary until the purchase of Remington Rand by Sperry Corporation, EMCC concentrated on commercial trade; ERA continued to serve the military market, though not exclusively. Sperry created the Univac Division and began a formalization of the activities of the two former subsidiaries into civilian and military product producers. However, this did not happen smoothly within the new company. Old wounds were still raw, and infighting resulted in decisions about management personnel and reporting lines that were unsatisfactory to many. Groups formed in a less formal age felt threatened by the changes. Moreover, these men had ideas for new products that were not acceptable to the new management, and the groups began to dissolve. New companies spun off as the complexion of the industry began to change substantially.

Of course, not all of the reasons for the emergence of the new industry are to be found within the machinations of the Sperry Rand Company. Other companies had not been sitting on their hands. IBM's overall objective was quite similar to that of EMCC: to obtain commercial customers for the new machinery. IBM followed an R&D strategy that was analogous to that of ERA and EMCC.[37] Tracing the influence of these various firms in the industry is not straightforward. As noted earlier, the first decade of this history was very volatile. Information was readily passed from group to group. Government classification of projects meant that government personnel could decide to circulate or withhold documents as they chose. To their credit, they did not withhold the information, but instead circulated it broadly. This circulation and the influence of the documents on the thinking of others are difficult to measure, because it is difficult to know who saw what when. And we still have that most nagging of historical questions concerning when or whether a report received had an effect on someone else's work. This traditional puzzle for the historian is much more difficult here because of the rapid rate of growth and large number of players in the computer enterprise.

But questions of influence are the stock in trade of historical study. Several other problems are more specific to studies of twentieth-century industry. In the early 1980s, a study such as this on EMCC, ERA, and Remington Rand was hardly possible. Few documents seemed to exist, and it appeared as though oral history would be the only recourse. During the 1980s, many documents were uncovered in the Sperry company, documents now in the Hagley Museum and Library. Colin Burke did an exhaustive search of the National Security Agency and the National Archives and Records Service collections to tell the story of navy developments and, in the process, uncovered many documents about ERA. A cache of records was also uncovered in the Twin Cities area.

There is a second problem in trying to use these records to explain early events—a problem faced by all historians interested in the beginnings of anything. While bureaucratic organizations may carefully assemble records, groups in the early stages of a development are decidedly haphazard about record keeping. Classification and advanced legal structures help enormously. But a problem remains: few records are created and fewer survive.

Ironically, the computing field also suffers from the complementary problem of superabundance of materials, for example, the immense legal case files on the validity of the ENIAC patent, on the MIT magnetic core memory patent, and patenting of the basic computer concept itself. Many original documents found their way into exhibits for these court cases. Attorneys in these cases organized many documents into arbitrary chronologies of events by trying to prove precedent (or the lack of it). Moreover, these original records are spotty and no doubt some are unavailable.

The wealth of materials also includes a large collection of oral histories of widely varying quality. Oral history fills some gaps, but it is notoriously flawed by bad or conflicting memories or insufficient preparation on the part of the interviewer. Where no correlative documents exist (or have come to light), how do we evaluate this material? We can be confident some discussion went on among the principals. What to do about those gaps is another dilemma. Artifacts also tell us a great deal about developments. However, as the court cases reveal, an artifact exhibits only the result and not the origin of or influence on an R&D program.

Study of these documents led me to conclude that something clearly magnificent transpired in the first decade of this industry. No stored-program computer existed before it began; many examples existed after. No companies were involved in designing and manufacturing electronic digital computers before the decade began; several around the world engaged in the activity by the end of the decade. Applications were difficult to design in the early period because of small storage, but perhaps more important the companies did not think in the early years that this needed to be done. By 1957, this view had changed among computer developers; the industry had entered the period when companies formed to independently fill this software need. Work on component design, particularly semiconductors, began to contribute to technical aspects of computer design. And perhaps most significant of all, an active market existed in 1956, where only a decade earlier the market existed only in the minds of a few visionaries.

Chapters 1 to 4 in this volume alternate between the history of ERA and of EMCC, beginning with the early years of ERA. Both chapter 3 and 4 end with the sale of ERA and EMCC, respectively, to Remington Rand. Then chapter 5 relates the story of these two companies as subsidiaries in Remington Rand, the attempt by Remington Rand to provide a sales strategy for computing systems, the management difficulties faced by the two subsidiaries, and the final amalgamation of the two divisions into the vaunted Univac Division of Sperry Rand. The history ends with the establishment of the Univac Division and the sharp separation of the development and sale of commercial and military computer systems. The commercial side of the Univac Division followed the EMCC approach; the military followed the ERA approach. Simultaneously, there was a diaspora of technical personnel from Sperry Rand to other companies, especially Control Data Corporation in Minneapolis–St. Paul.

A note about the time taken to do this study: as indicated above, the materials for this study came from many sources, and a large number of the documents were found in the course of this investigation. This study began twenty years ago, with an award of grants from the National Endowment for the Humanities and the National Science Foundation. These awards were specifically made to study ERA. But the ERA story by itself, while significant, lacked context without some comparative analysis of its main counterpart in Remington Rand. With that recognition, a shift in emphasis occurred, which necessitated a thorough study of Eckert-Mauchly Computer Company, followed by investigation of Remington Rand. What made it possible to adequately portray the histories of these companies was the vast array of records uncovered by Bruce Bruemmer and me in the Twin Cities area and the assembling of the Sperry Rand records at Hagley by Michael Nash. The Mauchly collection at the University of Pennsylvania contained documents unavailable in the other two repositories. The extensive collections of manuals, product literature, and government documents at the Charles Babbage Institute allowed many technical details to be checked and elaborated. Not the least reason, the historical writings about other events during this decade in the intervening twenty years provided a rich background against which to frame this study.

1

The Founding of Engineering Research Associates, Incorporated

Origins in Naval Intelligence during World War II

The Communications Division of the U.S. Navy, labeled OP-20, out of which ERA emerged, had cognizance over the broad field of radio, telegraph, and telephone communications. This division was composed of a number of sections, which handled electronic traffic, prepared codes and ciphers, developed new electronic equipment for interception and analysis of traffic, provided liaison with various war plans offices, and interacted with other technical divisions of the navy.[1]

One of the sections involved with communications and security became known as Communications Supplementary Activity—Washington (CSAW), located on Nebraska Avenue in northwest Washington, D.C. CSAW's label was OP-20-G, and it bore responsibility for the navy's own codes and the breaking of enemy codes. It contained three sections. GX handled interception and direction finding, including traffic analysis. GY's responsibility was the breaking of Japanese codes and ciphers. GZ actually tried to read messages, making complete or partial translations of the messages based on their importance and the stage of recovery.[2] A mathematics section, called M, which worked on problems associated with electronic equipment and code solution techniques, aided these groups. The men associated with the founding of ERA mostly came from section GX and the mathematics group.

For our purposes in understanding what ERA was to do for the navy after the war, we need to distinguish between codes and ciphers.[3] Each of these is developed to translate a plaintext, or message, into a secret form. A code consists of thousands of words, phrases, letters, and syllables with the code words or code numbers that can be used in substitution that convert the plaintext to secret text. For example,

code number	for	plaintext
1792		ship
9601		island

Here a codebook with the equivalencies needs to be provided.

Ciphers are a different form of substitution. The plaintext is divided into its alphanumeric parts, where each letter and number has another letter or number substituted for it. For example,

plaintext letters	a b c d e
cipher letters	L B Q A C

Ciphers, then, are more susceptible to mechanization than codes. In fact, machines were often used for this purpose, and by World War II, several sophisticated machines had come into general use. The principle behind these machines was the use of rotors that are interconnected such that when they spin in response to an electric current they substitute a code letter for the letter of plaintext. Run in reverse they decode the secret form to reveal plaintext again. Since such machines were in general use by all combatants, improvement of such machines to ensure greater secrecy of communication was a high priority. The process of breaking an enemy's ciphers was very difficult, and reverse machinery for this purpose was in high demand. In short, the tasks of CSAW involved development of better ways to code Allied messages and to intercept and decode enemy messages.

The amount of intercepted traffic is an essential but troublesome element in the code-breaking activity. Increased traffic provides many messages to compare in the hope of having an easier time in breaking codes and reading messages. On the other hand, increased traffic implies an increase of activity of interest to the code breaker and a need to read messages faster. However, the art of code breaking is such that speed is not always, one might even say rarely, possible. One way to increase speed is to use mechanical means, the faster the device the better. The U.S. Navy began considering forms of mechanical devices in the 1920s, when mechanical encryption devices came into use in several nations. As Colin Burke has shown so well, Vannevar Bush, of the MIT engineering faculty, and Stanford C. Hooper, a navy officer who specialized in radio, played key roles in the attempt to mechanize decryption in the period

1925 to 1950.[4] Their work energized the navy intelligence group, which subsequently played a key part in ERA's history.

Retelling this story of development in the 1930s would take us necessarily too far afield, but three aspects are essential to our understanding of later activities in and organization of ERA. First, the frame of meaning used by Bush and his development group at MIT and by Joseph Wenger, Laurence Safford, and Stanford Hooper in the navy set the pattern for mechanical approaches to decryption in the navy before, during, and immediately after World War II. The navy's series of projects to develop such machines in the 1930s and 1940s became known as the Rapid Machines Project.[5] This pattern dominated early work on data processing in ERA. Second, the organizations concerned with intelligence activities in the navy provided many of the personnel that founded ERA. Third, the shortcomings of the various mechanical designs up to 1945 became the starting points for research and development in ERA in 1946.

Bush became interested in automation of information in order to aid the scientific and engineering communities in research in publications. As the journal literature increased, he and others looked for ways to automate the literature to make searches by mechanical means fast and reliable. Laudable as this aim was in the 1930s, it was navy interest in one of his machines, the so-called Comparator, which led to his first contract to build a machine, not interest of the scientific and engineering communities. After receiving a contract for a 1936 rough design, Bush, in consultation with the navy, chose a decrypt analysis technique called "the Index of Coincidence" to focus the design and build a machine. The Index technique, developed in 1920 by William F. Friedman while an employee of a private concern—the Riverbank Laboratories near Cornell University—is based on the laws of probability, not on brute force logic, and could attack any type of cipher system.[6] Friedman modified the technique during the 1920s, eventually providing a solution of a cipher machine using cryptographic rotors, or wired code wheels, the basis for machines like Germany's Enigma of World War II fame.[7] The device in operation encrypts the first message with a running key, and starts the key for subsequent messages with the third, fifth, and so forth, key letters. The machine encryption occurs as a result of cascades of transposing rotors that change one letter into another. As the transpositions take place, a long sequence of letter substitutions result with no repetition and no discernible pattern. The first E in a message may become H, with the next X, and the third Q. While seemingly random, the results are not quite so, making messages subject to decryption as long as the key is used. If two messages are encrypted using the same key, even though the encrypted messages will be different, a well-known number of coincidences will occur. These coincidences can be used to break down the code, learn or guess at the key, and decipher messages for as long as the key is in use. The decryption analysis is done by setting up the message in vertical pairs and searching for coincidences. Finding any, one message is shifted one step with respect to the other to search for more coincidences, and the process is repeated through all the messages. Cryptanalysts repeatedly apply the technique to the intercepted message traffic until sufficient coincidences help to decode the messages.[8] Analyzing two messages by comparing the encrypted sequences takes many hours by hand, hence the search for an automated system in the 1930s, especially as war in Europe and the Far East seemed more and more likely.

In Bush's Comparator design, optical sensing and electronics would do counting, and memory would be kept on some form of tape, possibly microfilm. An automatic control device would accomplish advance of the memory tape. To appreciate the demands to be made on this device, we need only note that a message composed of 200 letters (not uncommon in war time) required almost 40,000 comparisons to decode the message. Messages using this technique require $(n(n \quad 1))$ comparisons, where n is the number of messages. The longer the message the better the chance of decipherment, so the machine had to contain a large memory.[9]

Over the next decade, attempts to build a successful Comparator all fell short. Though the concept seemed a good one, the combination of electronics, counting, and memory components could not be made to function effectively. During World War II, successful devices for using the Index method were developed in England, Poland, France, and the United States, but by 1945 a successful Comparator was not one of them.

Having turned the task of adapting technology to the design over to a group of graduate students at MIT, Bush turned his attention to another automatic machine design using film, optics, and electronics for library applications, which went through five designs in 1936, 1937, two in 1938, and 1940—the Rapid Selector.[10] This project, too, he assigned to several MIT graduate students—John Howard, John Coombs, and Lawrence Steinhardt—all of whom subsequently became part of ERA through the Naval Computing Machine Laboratory. As talented as these men were, over the next few years attempts to make this design function were equally unsuccessful. We will return to the history of these designs after the war below.

In the late 1930s, John Howard spent several years working with Vannevar Bush at MIT on the Rapid Selector project. Eastman Kodak and NCR sponsored the development.[11] Because of the role this technology played in later developments at CSAW and ERA, it is worth a lengthy review here.[12]

A reel of movie film had photographed on it a mass of data, perhaps 200,000 frames, each of some sort of document. The edge of this record film had a set of transparent dots on a black background that coded the adjacent frame. One set up the code of an item to be searched for by depressing a number of keys. As the roll of record film progressed through the machine, every time the set code coincided with the code of a frame a group of photocells triggered a flashing lamp, and that item was photographed onto a new strip of film—the reproduction film. Thus one could run through the reel and promptly receive a reproduction of every item in the collection called for by the set code.

Several significant differences between this system and the usual movie projector had to be developed. First, a greater speed was needed to cover more documents per unit time. Second, when a desired document appeared, the designers wanted to be able to photograph the document without stopping the film and without blur. And third, a coding scheme had to be developed so only the desired documents were photographed.

To introduce the people in the navy group who founded ERA, we begin with the navy's involvement with these machine projects. Initially, work on both these machines occurred at MIT, with monitoring by the navy. Navy officers Joseph Wenger and Laurence Safford took turns, between duty tours at sea, encouraging, goading, placating, and smoothing the way for the application of the machines to navy intelligence problems. As we noted above, navy intelligence in the 1930s became the OP-20-G office under the Chief of Naval Operations, which office by 1941 was composed of three sections and a mathematical group. In November 1942, to facilitate design and construction of several types of intercept and decrypting machines, a Naval Computing Machine Laboratory (NCML) was instituted at the National Cash Register Company (NCR) in Dayton, Ohio.

During the war, the navy contracted with several companies—IBM, NCR, and Eastman Kodak—for the design and construction of codebreaking machines. NCR received the lion's share of these contracts, and became responsible for R&D, design, and building production runs of new devices. Because of the extreme classification of this work, the navy exercised tight control over NCR efforts through the presence in Dayton, Ohio, of the new Naval Computing Machine Laboratory (NCML), a

Bureau of Ships field engineering activity. NCML had a large staff, including some twenty officers and senior enlisted technicians, commanded by a captain. An early 1943 photograph of the staff shows over 100 people, about half of them WAVES. According to Donald Ream in an interview with David Boslaugh, the work of the laboratory included interpretation of navy technical requirements, participation in research projects, and assembly and testing of new devices. By 1945, a number of new devices by NCR and CSAW contained thousands of vacuum tubes and had the ability to add, subtract, and multiply in a preprogrammed manner by switch and plug board settings. Because of the uses for these machines, the group modified existing devices in a slow progression toward electronic digital computing devices.[13] There, several able electronics engineers, led by Joseph Desch of NCR, developed electromechanical and electronic devices. In 1942, Coombs and Howard worked at NCR; Steinhardt was stationed in Washington, D.C.

At the beginning of the war, the intercept area was of special concern. William Norris, a member of the intelligence GX group, described this situation thus: "You've got to get the stuff before you decode it and it's not always easy to intercept. Also when I went in, the situation in the Atlantic was very, very serious. The submarine warfare was going against the United States . . . they had a direction finder network, which was fairly useful. It certainly would put a submarine within a 500-mile area or maybe less if atmospheric conditions were not too unfavorable. There was always the desire to enhance the knowledge of the position, in other words, get it closer. And so at first I was working on ways to do that, which were classified, and in the process, also worked on some other projects just to get information in faster."[14]

These other projects, for example, involved design of radio position fixers for use in automatic communications systems, and a time division de-multiplexer for teletype. (A de-multiplexer circuit takes a single data input and one or more address inputs, and selects which of multiple outputs will receive the input signal.) Teletype was mostly mechanical and too slow. The navy was trying to speed up the process of getting the information to the intelligence groups by shifting to electronic technology. With the exception of the Bush designs, design of this new electronic equipment occurred mostly within the navy unit, with the aid of the several commercial companies mentioned above.[15]

Howard T. Engstrom, Lt. Commander USNR, headed OP-20-G's mathematics section. Engstrom began his professional activities with a degree in chemical engineering, earned in 1922. He spent several years working for Western Electric on matters in communications. Following that, he taught in several New England colleges while he earned a Ph.D. in mathematics from Yale (1929). Engstrom served on the Yale mathematics faculty until 1941, when he joined the naval intelligence group in Washington.[16] He had worked in algebra and was a specialist in polynomial substitutions.[17] Engstrom was well known in the 1930s as a young algebraist. During the war, he became infatuated with computers. While at CSAW, located in a former girl's school on Nebraska Avenue in the District of Columbia, he assembled an able group to analyze communication security problems. Engstrom showed adeptness for the application of mathematical coding principles and electronic machinery during the war years at Nebraska Avenue. The mathematics group eventually took over system design projects as well as tending to mathematic cryptographic techniques, and grew to a size of some 1,000 mathematicians, physicists, engineers, and social scientists.[18] At the end of 1942, he and several of his associates relocated to NCR to participate in the design and construction of several of the rapid machines built there for the navy. Among the tasks assigned to the mathematics group were designs of better intercept equipment, the Rapid Selector design, and fast, automatic electromechanical decryption devices, which became known by the British name Bombe.[19] With a successful design of the "American bombe" under construction at Dayton, Engstrom relocated back to CSAW for the remainder of the war. Engstrom's managerial accomplishment with the mathematics group, plus his extraordinary ability to lead technical teams toward new designs, would, according to the navy, render him indispensable to successful formation of ERA.

By the end of the war, the personnel at the NCML and at CSAW had become very knowledgeable about the techniques involved in designing high-speed digital computing devices. In fact, they were among the most knowledgeable in the world. Many of them played an important role in the emerging computer industry. Desch, along with his longtime NCR colleague Robert Mumma, developed the NCR 304, an early solid-state computer. Engstrom went on to help found ERA, and later to serve as deputy director of the National Security Agency. Norris also helped found ERA, and then led Control Data Corporation from its beginnings in 1957 to his retirement in 1986. Ralph Meader, another naval officer at NCML, also became involved in ERA, though without great success. These men, and many others from CSAW whom we will meet later, played important parts in the founding of the new computer industry in the United States.

Postwar Planning in the Navy

As the war progressed, CSAW became more dependent on highly specialized electronic equipment. Navy personnel, believing that the information load in the postwar period would be just as heavy, began to consider their unfulfilled needs along with postwar needs as early as the fall of 1944 and how these needs could be filled. Questions about how to conserve a cadre of well-trained personnel to work on such equipment, what to do about the Naval Computing Machine Laboratory (NCML) at National Cash Register (NCR) in Dayton, where significant electronic machinery was developed during the war, and how to pursue research and development of new and better electronic machines became the subjects of analysis among several OP-20-G staff. During 1945 it became clear that each of these sets of questions carried deep concerns for the navy. One stumbling block became NCR's refusal to continue involvement in computer development and cooperation with NCML.[20] Many of the people in CSAW working on machine problem solutions preferred to return to civilian life. In addition, there were already signs that naval budgets would be reduced, causing cutbacks in personnel.[21] The intelligence group concluded they would need to do more with less. One bright spot seemed to be that there were enough of these people who were willing to merge navy interests in this machinery and their interest in civilian life that it seemed possible to plan some sort of arrangement. As early as 1944 it was realized by interested officers that the very effective arrangements worked out during the war could continue to benefit the navy and the nation if some workable means could be found to continue them, with as little real change as possible, in the postwar period. In the fall of 1944, the director of naval communications, Rear Admiral J. R. Redman, USN, verbally requested a study of the problem of continuing, after the war, some arrangement similar to the Naval Computing Machine Laboratory—National Cash Register Company set-up for Communications Intelligence research and development. Captain H. T. Engstrom, USNR (OP-20-G), and Captain Ralph I. Meader, USNR (BUSHIPS), were assigned the task of formulating plans to this end.[22]

By February 1945, a small group composed of Commanders Howard T. Engstrom and Ralph I. Meader, Lt. Commander William C. Norris, and Lt. John H. Howard had prepared a plan for the consideration of OP-20-G.[23] When asked how the idea for a new company to carry out this plan came about and who first raised it, Norris responded in the following way.

Well, it was brought up one day. I think Howard Engstrom mentioned it . . . "we've got to start thinking about what we're each going to do." [Will we] "go back to where we came from? I for one don't want to go back to Yale, so I'd like to think in terms of something else." And I said, while I like Westinghouse all right, I didn't necessarily have to go back. So out of this we talked about different alternatives. It was very clear that we had a very unique agglomeration of talent and the Navy was concerned about that being dispersed, so that just kind of naturally led us to the point that we could set up a government laboratory. But that didn't appeal to anybody. Or we could set up a private company and perhaps do work for the Navy on a contract basis. That was more appealing to both Howard and myself. And we just kind of gravitated in that direction.[24]

The plan they devised involved the formation of a company called the National Electronics Laboratory (dated February 12, 1945). The idea for a National Electronics Laboratory was submitted to Admiral Redman on February 20, 1945, and a group of naval officers, including Engstrom and Meader, met to discuss the concept. Following this meeting, a memorandum was composed labeled "Research and Development Plan," dated February 22, 1945, describing the navy's needs in this area and attaching a copy of the plan for a proposed company.

The memorandum asserted that problems in communications and analysis are of two types: fundamental and applied. Further, the authors stated, "most of the problems of military research are not at the fundamental level. These problems, to a large extent, require engineering and development to provide in actual operating equipment a practical expression of fundamental advances." The memorandum goes on to say that the only completely successful attempt to do this during the war was through the liaison between the NCML at NCR and CSAW. It was this combination they wanted to keep alive after the war.

The proposed private corporation would have three objectives, according to the enclosure.

(1) To keep together a group of electronic engineers who were familiar with military and naval problems and who would provide the nation in time of emergency with facilities and talents to enable them to form an integral part of the military services in providing instruments and equipment quickly for communications intelligence;

(2) To provide incentives to officers in the service and others who had been doing war work to keep them alert to technical research problems that bear on the national welfare; and

(3) To provide technical manufacturing concerns with laboratory facilities with the varied and specialized talents which they were either unable to support or which provided a more efficient and widespread application of technical talent.

The proposal noted that this idea was not without precedent. "There are many examples in other military fields, such as Ford Instrument Company; Maxon, Inc.; Norden Bombsight; etc." They apparently took a survey that led them to conclude that no other group could meet the research needs of CSAW.

National Electronics Laboratory would be a joint venture of the group of technically trained people from CSAW and NCML and a financial investment group. The memorandum enclosure listed nine people and companies as potential investors.[25] However, the navy history of the founding of ERA notes that " the use of existing commercial companies was thoroughly considered but was rejected for several reasons."[26] In time, a number of companies and people were approached.

The navy conditions may have made it even more difficult for a company to organize itself in the postwar period to meet this need. Moreover, "no other [than NCR] existing company was considered to possess the experience necessary to begin with." The navy believed that no existing company would absorb the navy's specialist personnel under sufficiently attractive terms.[27]

Besides this proposal from the National Electronics Laboratory group, another was being circulated by a group involving James H. Wakelin. Wakelin, aid to Admiral Furer, head of the Office of Research and Development (later the Office of Naval Research), was "interested in gathering a few people of my own to form an R and D company and consulting group."[28] The company this group contemplated was a research and development business that focused on chemical and materials problems, consistent with Wakelin's and the others' backgrounds.[29] Over the course of the months from May 1945 to November 1945, when the National Electronics Laboratory had become Engineering Research Associates with a firm plan for the future, the two proposals merged and separated. For example, materials sent to potential investors included a list of "Potential Products and Services." This list was complementary to whatever would be done for the navy or other military agencies under the communications intelligence scheme. Ten areas included in the list ranged from electronic telephone and dispatching systems for businesses and individuals, to high frequency heating devices for metal plating, annealing, and heat treatment. By November 24, 1945, a document entitled "Prospectus for the Special Projects Division Engineering Research Associates" had been prepared by Wakelin and two others. The work to be done was more in the line of chemical materials than communications. This idea, in a modified form and without most of these people, was eventually included in ERA's organization, but in direct response to a need to fulfill a military contract.[30]

The surviving records do not reveal how the two groups developed their list of potential product areas. The "Articles of Incorporation" contain only general language about the development of machinery.[31] Various documents reveal conversations with executives of American Airlines and IBM in June 1945 that could have contributed to a better understanding of what industry needed, or at least was willing to buy. For example, Engstrom, Howard, and several others visited IBM on June 13 and 14, 1945, "to secure information on recent developments of this company which might be helpful to them in some of the statistical problems that were confronting them."[32] The IBM staff described work on electronic accumulators, the principles of recording magnetically on a magnetizable tape and of reading the signals, IBM's involvement with Harvard and Aberdeen Proving Ground, and research on the reduction of magnetic principles to use with IBM's tabulating equipment. One week later, Engstrom, in the company of C. Russell MacGregor of the Unexcelled Manufacturing Company of New York, heard a lengthy description of the communication needs of the aircraft industry from Mr. Ralph Damon, president, and Mr. David Little, radio engineer in charge of operations, of American Airlines. Among the items discussed were instrument landing schemes, ticket and reservation systems using automatic registers, and radio frequency allocation problems.[33] It is interesting that on the "Potential Products and Services" document there is discussion of only "electronic computing devices such as mechanical transient analyzers, electrical transient analyzers and devices for solving higher degree mathematical equations."[34]

Discussions with prospective companies continued through the summer and fall of 1945, mostly with companies involved with high frequency technology war work. In several cases, there was serious interest, but even for these companies, transition to peacetime was uppermost in their minds and how to get their companies back on track. "One of the factors that was working against us is that every company was sort of reorganizing, rethinking its plans, getting back to what it has been doing and so forth and it was very difficult for them to stretch their minds a little bit to something that they really hadn't envisioned. I think that was the real big handicap."[35]

At this time, Admiral Lewis Strauss, a partner in the Wall Street firm of Kuhn-Loeb, was on active duty in the Office of the Secretary of the Navy. The naval group sought advice from Admiral Strauss on two counts: (1) navy endorsement of the proposed company and (2) possible sources of financing. Strauss submitted the plan to James Forrestal, secretary of the navy, and it was discussed with several high-ranking navy officials. They gave the plan the navy's blessing.[36] On the question of financing, Strauss apparently sought advice of the senior partner of Kuhn-Loeb, Elisha Walker, but after some weeks, they rejected any involvement on the part of Kuhn-Loeb.[37]

Attempts were made to obtain a place on the program of the December 1945 meeting of the National Association of Manufacturers to discuss electronics "to give [Engstrom] prestige in an eventual meeting with any of the heads of the companies we propose to contact."[38] Either this presentation was not arranged or the Engstrom group did not believe it was necessary, because during December 1945 they had their first contact with the group that would finance ERA.[39]

Establishing ERA

The decisive contact for ERA came about through the fourth member of the group, Lt. Commander Ralph I. Meader.[40] While Engstrom, Howard, and Norris were stationed at CSAW, Meader's billet was at the NCML in Dayton, Ohio. Among his friends was one from Dayton serving in the U.S. Army. Captain Nelson S. Talbott served in the Army Quartermaster Corps stationed in Chicago. Talbott came from a wealthy, prominent, and influential family in Ohio. One of Talbott's principal contracts was Northwestern Aeronautical Corporation (NAC), a St. Paul, Minnesota, company specializing in the manufacture of troop-carrying wooden gliders. John E. Parker founded NAC at the outset of the war to salvage whatever he could of a failing airplane manufacturer, Porterfield Aircraft Company.[41] With the end of the war, all contracts for gliders had been cancelled and Parker was in the process of closing down NAC. Talbott approached him on behalf of the Engstrom group.[42]

Parker later remembered being approached by Talbott in late 1945 and meeting with Engstrom, Meader, and Norris. From them, he learned only that "this was a group that had been doing some very classified work during the war and under certain circumstances they would like to continue to carry out this work and be together."[43]

The group wanted half interest in the company, and for this, they would bind themselves together under a three-year contract. Financing would come from Parker and others. Parker, a graduate of the Naval Academy, discussed this proposition with officials of the navy, principally Admiral Chester Nimitz, then chief of naval operations, before agreeing. In the end, he agreed essentially to the original plan.[44]

The final arrangement for ERA consisted of two groups: a set of investors known as the financial group, and a group of technical people called the Associates. While the company was capitalized at 300,000 shares of stock, initially only 200,000 of these were distributed at ten cents per share.[45] Each group received half of these 200,000 shares. Thus, the initial investment came to $20,000. The Parker group agreed to provide a line of credit of $200,000 and the facilities and equipment at NAC.[46] The NAC plant was owned by the Defense Plant Corporation, and was available for any new navy program.[47] The company was established with Parker as president and director, Engstrom, Meader, and Norris as vice presidents and directors, and Talbott and Richard C. Lilly as outside directors. Lilly was a former partner of Parker's in at least one venture in Minnesota (Toro Manufacturing), and was president of the First Bank St. Paul, the bank that both NAC and ERA used. The new firm opened an office in Washington to recruit additional employees and solicit business.

Among the variety of business activities of ERA, two concerns stand out. Primarily, consistent with the reasons for its organization, the company served the interests of the navy, especially in the development of new electronic data processing systems. But they also did a substantial amount of business with the aviation industry to stimulate better cash flow. The backgrounds and experience of the founders influenced these activities by the contracts they sought and the people they engaged to help them.

Government policy prevented contracting with firms until adequate evidence existed that the firm would be able to meet the terms of any contract. Since ERA had no history, the navy could not contract with it under prevailing rules. The association with an established firm such as NAC allowed the navy to contract with NAC, which then subcontracted with ERA to perform the research and development of interest to the navy. ERA was established as an independent company in January 1946. This also provided NAC with an opportunity to stay in business with a new mission, preserving the jobs of the employees of NAC, most of whom eventually moved over into ERA. Simultaneously with the letting of contracts to NAC and ERA in the spring of 1946, the Naval Computing Machine Laboratory moved from Dayton to St. Paul and occupied quarters in NAC adjacent to those of ERA. These arrangements were reviewed by navy personnel at a meeting on January 5, 1946. It was the approval of this group that initiated the contracting process with NAC and the orders to move NCML to St. Paul.[48]

Who were these men who founded ERA? John Parker (fig. 1.1), boisterous, well-met, blustery, and with many contacts in the navy, made a good leader of the organization. The company, however, had few products to sell in the 1940s. Parker's business activities before involvement with ERA brought him into contact with many of the country's major airline and aircraft manufacturing companies, hence, he was able to convince airline companies to give special contracts to ERA, which for a period kept the company in some position of cash flow. After several

Figure 1.1
John E. Parker, president, ERA, in his office.
Courtesy of the Charles Babbage Institute.

years as a commissioned lieutenant in the navy obtained on graduation from Annapolis, he joined his father-in-law's investment firm, G. M. P. Murphy and Co. In 1938, upon the death of Colonel Murphy the company was liquidated. Parker retained the Washington, Baltimore, and Philadelphia offices and merged them with Auchincloss, Parker, and Redpath of Washington, D.C., and John Parker—no relation to the Parker in the company name—became part of this firm. His specialty, as with G. M. P. Murphy, was aviation! While Parker was with the firm, it had participated in the founding of Pan American Airways and United Airlines. He had also become a member of the board of Northwest Orient Airlines and assumed the presidency of Porterfield Aircraft Company when Auchincloss, Parker, and Redpath took it over for reorganization. As noted above, part of the reorganization of Porterfield involved the formation of a new company, Northwestern Aeronautical Company. Parker's business experience with firms involved with the federal government and his navy training and knowledge made him eminently suited to serve as head of ERA. This background also shows how ERA became heavily involved in aspects of the aviation industry. His military academy background gave him entree to the officer class that allowed Parker to run interference when needed with upper-level brass. But as far as the computer business was concerned, he had neither the knowledge to sell this complex machine nor the visionary interest to effect business change using the computer systems. To his credit, he made no pretense to aiming to do either of these things. He was out to make a profit, and in the postwar period before the Cold War, ERA appeared a useful vehicle to achieve at least small profits before moving on to something bigger. Without the knowledge of computing, he placed his trust in men like Howard Engstrom and Ralph Meader.[49]

After the war, Howard Theodore Engstrom (fig. 1.2) became an important link between ERA personnel and navy people concerned with data processing. Besides serving as vice president of ERA he became head of ERA's Washington, D.C., office, from which he had frequent contact with the navy, indeed with all government groups interested in ERA products. At his side was a former lieutenant of his from CSAW days, Charles B. Tompkins (fig. 1.3). Tompkins, son of an army physician, entered the University of Michigan graduate mathematics program, following graduation from the University of Maryland in the early 1930s. He specialized in the calculus of variation. By the end of the 1930s, Tompkins was an instructor at Princeton University. A member of the

Figure 1.2
Howard T. Engstrom, vice president, ERA.
Courtesy of the Charles Babbage Institute.

Naval Reserve, he was called to active duty early in the war and assigned to CSAW, where he became involved with Engstrom. Engstrom coordinated virtually all the technical computing projects of ERA, the person to whom Coombs, Arnold Cohen, and Sidney Rubens, heads of R&D projects, reported, often through Tompkins.

Jobs were scarce in 1932 at the height of the Depression, just as William Norris graduated from the University of Nebraska with an electrical engineering degree. For two years, he worked on the family farm. But in 1934 Norris received an offer from the Westinghouse Electric Company to work in the sales department of its x-ray division.[50] In 1940, Norris began working for the navy as a civilian in the Bureau of Ordnance working on fire control. He found this "damned interesting work,"[51] though his job involved little more than drafting. At this point,

Figure 1.3
Charles B. Tompkins.
Courtesy of the Charles Babbage Institute.

he joined the Naval Reserve, and at the end of 1941, he received a commission in the navy. He was assigned to the intelligence unit at Nebraska Avenue, by a route unknown to him now, and began his work in communications interception.

Although he came from CSAW, Norris (fig. 1.4) was one of the new breed. Norris is difficult to evaluate in hindsight, because his later accomplishments at Control Data Corporation have overshadowed his earlier work at ERA, and because several people have projected later demonstrations of ability in the 1960s and 1970s back into the 1940s and decided he must have been more important to ERA than at first seems obvious.[52] This latter position is difficult to sustain from the records. Norris's abilities became evident when he had a corporate structure to deal with and accommodate to in Remington Rand. In the late 1940s,

Figure 1.4
William C. Norris, vice president, Engineering and Research.
Courtesy of the Charles Babbage Institute.

he served mostly in the Washington office, and busied himself with contracts and sales. He ventured a strong voice in executive committee meetings about how to coordinate parts of the ERA program to make them at least appear stronger, if not actually become stronger. Here we see a foreshadowing of the later corporate Norris.

Another link in the chain was Ralph I. Meader, who graduated from Dartmouth College with a degree in electrical engineering. When he received his degree in 1919, he had already served in the navy during World War I. Meader held several positions after the war with Western Union and Postal Telegraph, and then engaged in various business ventures.[53] As World War II approached, he went to work for the navy, first as a civilian, and then took command of the Naval Computing Machine Laboratory in Dayton. This laboratory monitored development and manufacturing of communication security equipment at NCR. The NCML enjoyed a reputation for producing new decoding machinery or

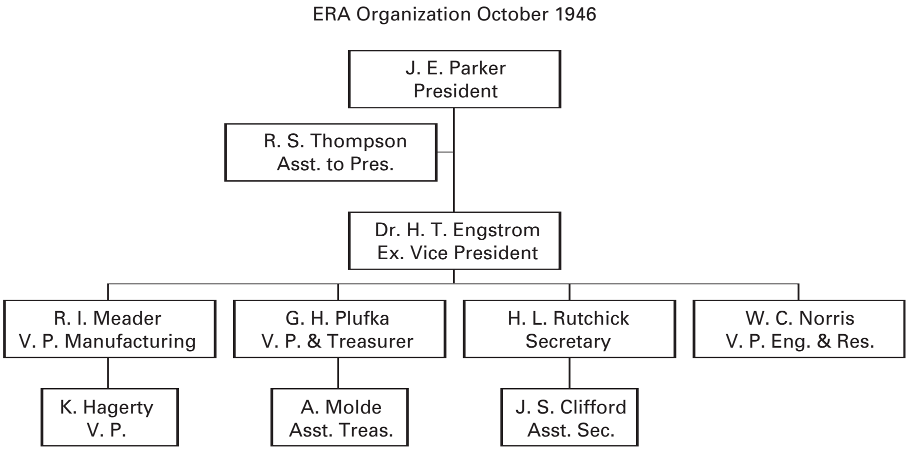


Figure 1.5
ERA organization chart from October 1946.

components for old machines that made them more productive. The navy saw him as another of the important insiders knowledgeable about their needs. Something of an inventor himself, Meader showed little aptitude for the new field of data processing. Eventually he ran afoul of Parker and Norris and was pushed out of ERA with great rancor. Because of the classified nature of ERA contracts, he seems to have gone quietly. See figure 1.5 for the organization of ERA in 1946 to learn where these men fit in the hierarchy of the company.

Engstrom and Tompkins helped the navy to develop specifications for new data processing machines and translated these for the ERA people in St. Paul. John Coombs, John Howard, Arnold Cohen, and Sidney Rubens in the 1940s, aided by Frank Mullaney, Seymour Cray, and James Thornton in the 1950s, designed and oversaw the building of the machines for delivery. It is worth noting that 40 percent of the 1943 electrical engineering graduates of the University of Minnesota (Ericson, Helms, Keye, Mullaney, Murname, and Tomash) joined ERA after the war and a significant number (Cray, Kisch, Thornton, and Zimmer) of the class of 1951 accepted their first job at ERA. Like the other new computer companies, they worked on only a few designs in a decade.

Engstrom and Tompkins arrived at ERA with sterling reputations in mathematics. As a complement to this, John Coombs acquired excellent training in engineering under Vannevar Bush at MIT, where he worked on information processing problems with Bush, John Howard, and

Lawrence Steinhardt. A rather quiet and somewhat unassertive man, Coombs worked well with the technical personnel at ERA and saw his duty as R&D leading to functioning devices. He possessed a deft touch and led the technical projects in St. Paul with remarkable accomplishment. Project leaders reported to Coombs first, and he relayed the reports on to Engstrom with his own insightful commentary when needed. With the sale to Remington Rand, Coombs left to join IBM, where he became involved in the SAGE computer project.

Two very talented scientists backed up Coombs: Arnold A. Cohen and Sidney M. Rubens. Both physicists, they approached data processing machine development in a scientific manner. After receiving his Ph.D. from the University of Minnesota, Cohen, a soft-spoken kindly man with a pronounced Midwestern drawl, worked at RCA, where he became familiar with the characteristics of newly developed vacuum tubes. While working on mass spectrometry, he designed circuits using these tubes and integrated this knowledge with later data processing designs at ERA. Cohen spearheaded circuit design for the new storage machines of the late 1940s, along with the able assistance of William Keye and George Hardenbergh. Cohen's approach was basic and experimental, testing designs and evaluating breadboard models of circuits and prototypes.

In the 1940s, computer systems designers focused on storage systems, because this would extend the capability and range of machines. Furthermore, since the navy contracted with ERA for storage devices, this was further incentive for a concentration there by ERA. Rubens joined ERA especially fit for R&D on magnetic storage systems, one of the options being discussed in the field. His prior training for a Ph.D. in physics was in the area of magnetism and, during the war, he worked on magnetic problems while at the Naval Research Laboratory. His leadership with respect to magnetic materials and magnetic storage perfectly complemented Cohen's on design circuitry for storage systems. Although they were not a team in the sense of the Wright brothers or Eckert and Mauchly, they did consult closely and subsequent designs bore both their stamps.

John Lindsay Hill received a bachelor of science in electrical engineering degree from Rochester Institute of Technology in 1930. After two years as a junior design engineer at General Railway Signal Company in Rochester, New York, he joined 3M in St. Paul, Minnesota, where he specialized in the design of plant production and control equipment. He moved from 3M to ERA soon after it was founded in 1946. At ERA, he demonstrated equal talent for the design of computer systems. He oversaw projects on ERA's Atlas I, the 1101, and much of the non-data-processing work of the firm.

Lacking the depth of the IBM staff, ERA nevertheless possessed a group with complementary leadership and technical skills to engage in the new computing field. In spite of their talent and resourcefulness, the group at ERA did not possess the vision or the ambitions of, say, Eckert and Mauchly (and, one might add, the arrogance), nor did the firm have the resources of IBM, Burroughs, or Remington Rand. And their backers, the U.S. Navy, made no attempt to encourage such vision and ambition. It simply did not serve the navy's needs and desires. This is not to say that men like Norris and Mullaney[54] did not possess vision. In the 1940s and 1950s, they were loyal citizens determined to help the government solve its data processing problems and company team players wanting to aid in company successes. It took a decade of frustration to make them decide to take large risks to achieve great gains. It was then, with the founding of Control Data Corporation (CDC) that they exhibited the kind of vision and ambition that has become a hallmark of the computing enterprise. Just as they were ready, so were such men as Seymour Cray, James Thornton, Erwin Tomash, and Willis K. Drake, who took varying paths to found companies of their own in the 1960s.[55]

These men, then, became the backbone of the new firm. Parker, with his knowledge of the aviation business, was able to use this knowledge to generate contracts for ERA in the aviation world even before a good automated reservation system had been developed. World War II had been as much a "mathematician's war" as a physicist's, and Engstrom served in the thick of it. After the war, the combination of mathematical and computation experience, along with sensitivity to security matters, made him an invaluable resource to military groups with new needs of this kind. Needless to say, his contacts proved equally valuable to ERA. Norris, by his own account and the testimony of others, brought management skill to the new endeavor, and not a little technical ability.[56] At least in the early years of ERA, Norris possessed that rare skill of a manager of engineering research projects with relevant technical ability. The training Howard received under Bush and his experience later at CSAW provided that needed level of technical project management whose results would enhance the reputation of ERA. Howard served under Norris.

These men set about to interest other engineers in ERA. Some two dozen of the early employees of ERA came from the communications intelligence group of the navy. Among them were Lawrence R. Steinhardt, an associate of Howard's at MIT; Charles B. Tompkins, before the war a postdoctoral fellow with John von Neumann at Princeton; Joseph M. Walsh, trained in business and part of the intercept activities in navy intelligence; and Hugh S. Duncan, a 1942 electrical engineering graduate from Stanford, who had specialized in radio engineering. The recruitment of men outside this group came initially from friendships. Sidney Rubens reported how he was brought into the fold. As a Ph.D. in physics from the University of Washington and a member of the Naval Reserve, he joined the staff of the Naval Ordnance Laboratory in 1941. NOL at the time was concerned with magnetic questions: the (1) degaussing of ships to protect the veracity of compasses and other magnetic instruments on steel ships and (2) magnetic mines. Rubens fit right in, as did a number of his colleagues. His first roommate in Washington, D.C., was Arthur Hammindinger, who later went to Los Alamos. Hammindinger worked on magnetic mines at NOL with a mathematician by the name of Robert Gutterman. At first, security prevented these people from discussing their work, so there was very little mixing among the groups.

> Later, when the research division was formed, we were together, [according to Rubens]. One day Hammindinger brought Gutterman home, and we became good friends. It turned out that Gutterman was a former student of Howard Engstrom's at Yale. They were very close friends, because they lived in the same apartment house in Arlington [Virginia]. And Engstrom told Gutterman about this ERA that they were considering, and he told me about it. I suggested that as long as this is going to be in Minnesota, there's one other man here that [they] ought to tell about it and that [was] Howard Daniels. I knew that Howard was from Minneapolis, and I thought he would like to get back home. Daniels and Hammindinger and I were good friends. We spent quite a bit of time together.

By this time, Rubens had married. "Both my wife and I were not interested in staying in Washington [D.C.] forever. Both of us came from the West. My wife was from California. That's where I met her. And we figured going to Minnesota would be one step toward going back to the West Coast. If it didn't work out [in Minnesota], we'd look for something in the West."[57]

Rubens learned from Gutterman what Engstrom and his group had been engaged in at CSAW. He assumed from his earlier work in cosmic ray research that the equipment in use at CSAW was digital and involved electronic circuitry using flip-flops and counters—all things he was very familiar with. Gutterman introduced Rubens to Engstrom and Norris, probably in early 1946, after ERA had opened its first office in Washington.[58] He was not relieved from active duty at NOL until the

The persons listed below participated in forming Engineering Research Associates, Inc. (ERA), as members of the founding technical group. These were the original "associates" in the firm's name.

Donald W. Ammerman
William R. Boenning
John G. Briggs
Royal C. Bryant
Harry D. Clover
Louis Y. Chaloux
Alton O. Christensen
John M. Coombs
Howard L. Daniels
Hugh S. Duncan
Robert B. Einfelt
Howard T. Engstrom
Victor A. Gill
Donald T. Greenwood
William L. Grogan
Robert P. Gutterman
Arthur H. Hausman
Herman W. Herget
Raymond Hollos
William P. Horton
John H. Howard
Donald Iacoboni
William N. Jaus
Robert E. Kilham
Arthur A. Kotz
Nels Larson
Glen Ward Lund
Ralph Meader
Robert E. Miller
Walter J. Moe
Herbert G. Nilles, Jr.
David L. Noble
William C. Norris
Earl C. Olofson
Robert K. Patterson
Fred L. Ribe
Thomas O. Robinson
George W. Roenning
Sidney M. Rubens
Arthur W. Sloan
George F. Smith
Dorval Clifford Sprong
John H. Stallard
Lawrence R. Steinhardt
Charles B. Tompkins
William L. Vandal, Jr.
James H. Wakelin, Jr.
Joseph M. Walsh
Harry F. Zimmerman

Figure 1.6
ERA's Technical Founding Group, 1946.

Source: Arnold A. Cohen, in *High Speed Computing Devices* (New York: McGraw-Hill, 1950; reprint Los Angeles, Tomash, 1983). This list is largely consistent with company directories of 1946. Since it took a while for several of these people to be released from the military, we find 29 active in the company in March 1946 and 42 active in November 1946. Directories are from the Sperry Corporation Records, Acquisition 1825, Hagley.

summer of 1946, and arrived in St. Paul for work at ERA in August 1946. Daniels relocated to St. Paul, but Gutterman remained in the ERA Washington office. The early structure of the company can be seen in a 1946 organization chart shown in figure 1.5. Figure 1.6 presents a list of the founding group known as the Associates.

The Navy Contracts with NAC

ERA and the navy designed a series of contracts. The first of these was let in February 1946 to NAC. The contract, Nobsr-28476 from the Bureau of Ships, was designed to fund NAC to keep the necessary personnel together to provide services to the Communications Intelligence activity as had been done by the Associates while still in the service.[59] The contract involved a series of projects, many of which did not begin until June due to lack of personnel. It took almost five months for personnel to be released from the service. By August, the work under this contract was well under way, and "all work under the previous National Cash Register contracts has ceased."[60] Another negotiated contract, this time to ERA, with ONR (N6onr-240) became available in August 1946.[61] This contract contained three objectives, and because of the contrast with a later, important NBS contract to Electronic Control Company to be discussed in the next chapter, it is worth quoting in full.

The Contractor shall furnish the necessary personnel and facilities for and conduct, in accordance with any instructions issued by the Scientific Officer or his authorized representative, the following:

(1) A survey of the computing field, including

(a) an analysis of all information now available concerning the problems involving extensive computations which have arisen, particularly in connection with military research, and of the problems which are likely to arise, in order to determine for computing machines:

(i) the accuracy required,

(ii) the amount of storage required,

(iii) types of programming of machines which will make possible the maximum utilization of the machine, and

(iv) optimum formulation of problems for solution by computing machines;

(b) an investigation and report on the status of development of computing machine components; and

(c) a formulation, as explicit as possible, of the requirements for new components or techniques needed for the solution of naval problems.

(2) Research looking toward the development of these new components and techniques. The availability of multiplexing techniques for use in storage and transmission of data will be investigated. A prototype will be designed and developed if techniques emanating from laboratory work prove practicable, and original detail and assembly drawings for such prototype equipment will be provided by the Contractor; and

(3) The furnishing of consulting services to the Office of Naval Research on questions concerning the development and application of computing equipment and techniques.[62]

The extent of this contract was not as encompassing as that given to Eckert-Mauchly, most likely because Eckert-Mauchly already possessed a machine design that could be evaluated. Here we have a contract that calls for ERA to examine everything other projects were trying to accomplish and to design a storage device with multiplexed input and output. It was from this clause in the contract that the final form of magnetic drum storage was to emerge. Mina Rees later remembered that the task to prepare a book on the status of developments of computing-machine components "was an outgrowth of my early discussions with

Tompkins about the state of the computing art and was based on a conviction we shared that a significant contribution to the development of the new computers and their integration into the many fields of application would be served by consistent attention to a broad dissemination of information about advances being made. Since ONR's major focus was on educational institutions, this was a natural point of view for me."[63] In fact, this view of what ONR should support under its own initiative gave rise to the many projects related to computing: the 1946 Moore School lectures on computing, support for Howard Aiken's graduate training course at Harvard in 1947–48, the surveys of machines, the many symposia over the late 1940s and early 1950s, and publication of the *Digital Computer Newsletter.*

With these two contracts to NAC and ERA, the company was in a position to begin work on military equipment and an assessment of the computing field. The objectives of ERA were not as firmly defined as those of Eckert and Mauchly's Electronic Control Company founded in the same year, and it took some time for them to move from data processing equipment for intelligence purposes to commercial general purpose digital computers. Their contributions along the way were often dictated by the requirements of the government, and as often as not influenced by the backgrounds of the individuals employed at ERA. The group was not as tight as that of Electronic Control Company, but it was every bit as well trained. That training was to influence the solutions they proposed to solve problems, and it ultimately influenced the types of machines they designed and constructed. Thus, these two companies—ERA and ECC—provide a good contrast for the early decade. They allow us to analyze technical contributions, interaction with government, and marketing thrusts, to name only a few of the comparisons of importance in the decade under study here. In several important respects, these two companies educated their sponsors and potential customers. This influence was especially true with Remington Rand, which had to decide between the EMCC path and the ERA path. The interaction of EMCC with Northrup Aviation employees influenced the beginnings of the computer industry on the West Coast.

Both companies took about five years to place systems on the market. UNIVAC I was delivered to the Census Bureau in early 1951. An earlier design, the BINAC, which incorporated many features prominent in the later UNIVAC, was delivered to Northrup Aviation in mid-1949. The first of two Atlases (of ERA) went to the National Security Agency from ERA in December 1950, and its commercial counterpart, the ERA 1101, was announced in December 1951, but no sales were made.[64] Development at IBM on the 701 and the 650 took just about as long.[65] Many other machines remained in development longer. Compared to other technological systems, five years for design and construction of an engineering marvel like UNIVAC is not excessive at all. However, the view in 1946 that such a device could be constructed from standard radio parts did not prepare the designers or the anxious users for the large number of obstacles the designers needed to overcome before an operating machine became available. To appreciate this accomplishment, we need to examine the nature of the problem, the R&D programs organized in these two companies, and the technical solutions used to overcome the obstacles.

Designing Computer Systems at ERA

The nature of the contracts to ERA, as well as those to other groups, reflects the uncertainty about what was needed before full-scale computer systems could be put into manufacturing. Research was needed on storage for memory, circuits for controlling the various parts of the system, getting data into and out of memory and into and out of the processing unit, and on the components themselves. The field was off to a good start in 1946, but it was a long way from building a working stored-program computer.

ERA, for their part, did not start out to design a complete machine. As we saw, they developed a special relationship with the navy, especially with the intelligence community. They also tried to establish a role for themselves with other branches of the navy, notably with the Office of Research and Inventions (ORI). For ORI, they saw a special requirement "to develop components needed in computing machines, especially of the digital type."[66]

The more general interests of ERA are reflected in their assumption that the navy's Office of Research and Inventions (ORI)

> may wish to undertake a general survey of the computing field. Such a survey might at this time include profitably a complete analysis of all information now available concerning the problems in computing that have arisen and that are predictably likely to arise, all information as to the computing components which have been tried and the degree to which each has been successful, a complete analysis of the general systems of combination and integration of components into machines and the degree to which each system has been successful, a listing of problems whose solutions seem not to be obtainable practically by

combination of known computing techniques, a formulation as explicitly as possible of the requirements for new components or techniques for solving the problems, and the development of these needed techniques and components.[67]

ERA personnel believed that some such analysis of problems should be done first before "planning for economic use of future machines can be made." They suggested in this proposal that specific requirements of all branches of the navy should be assembled and plans to meet them were imperative before machine designs were contemplated. "Attention would probably be given to the standardization of machines so that information from one machine could be read into another conveniently."[68] This statement was part of a major proposal developed by ERA in the first two months of 1946. The company did not take all of its direction from the navy.

Essentially, three areas of investigation were proposed. First, ERA wanted to make an assessment of the type and nature of problems arising for solution on such machines. This type of investigation would generate information about the similarities and differences among problems with an eye toward formulating them to fit the machines "recently developed" and understanding the required accuracy and amount of storage. The problems not solvable by known machines could be used for a second area of investigation: decisions about "the direction of development of the computing machine art." The third area would involve ERA in the design and construction of the various components needed for new solutions.[69]

This proposal illustrated a forward-looking nature as it went on to discuss what ERA saw as the first problem needing attention: storage.

The storage problem is one of the most difficult in building computing machines; it seems likely that investigation will lead to a conclusion that the equivalent of a few million marks and spaces will have to be stored in some way which will permit their immediate utilization. Generally speaking, four types of storage are possible for this:

a) Static storage permitting immediate recovery
b) Static storage requiring mechanical manipulation for recovery
c) Moving storage at speeds synchronized with the addition cycle
d) Moving storage at speeds higher than the addition speed (multiplexing).[70]

Appendix II of the proposal reviewed the components used or possible for each of these methods of storage along with comments about them. For example, under the method (a) flip-flops were listed with the comment that this circuit is "satisfactory in ENIAC, but many tubes are required." Five component types were listed under the second static method: magnetic tape or wire, photographic tape, embossed or other recordings on acetate or wax, punched cards, and punched tapes. They viewed magnetic tape or wire as the "most promising of these," but "speed control may be difficult."

Each of the moving storage methods was classified according to three substrate media: supersonic waves, electromagnetic waves, and charged particle streams. Many of these concepts were limited by the physical situation and the signals produced were either distorted or inefficient. Supersonic waves in liquids seemed to them to be the most promising.

ERA recognized that "reading in and reading out" of data would be as difficult as storing the data. "In the design of components serious consideration should be given to the probability that data from distant points will be desired in some machines, and the problem of designing components for introducing data in a manner compatible with easy transmission of radio or by land line should be investigated at an early date."[71]

This issue, of what later was called networking, emerged from their navy experience in intelligence where so many intercepted radio messages had to be transcribed to punched tape before they could be manipulated for decryption.

The proposal is forward looking in another way as well. In thinking about designing data processing machines for multiple purposes, the proposal discussed the need for programming. "Present machines have been designed with individual problems in view. Although the designers have made the programming sections as flexible as possible, no serious study has been completed and published as to how flexible this must be in order to utilize the machine to the fullest extent. As a matter of fact, it seems clear that any answer to this question must depend on the gathering of a large amount of information concerning the problems themselves, preferably from the originators of the problems."[72]

Thus, they returned to where they began with a call for a study of problem types and the machines for possible solution. For $100,000 in the first year, ERA wanted to pursue this program, primarily to aid in the solution of navy problems. And what better way was there for ERA personnel to learn all there was to know about this new computing field?

In a few months, from sometime in mid-1945 to March 1946, the ERA people—Engstrom, Tompkins, Steinhardt, and Howard, in particular—had analyzed this new field and reached the level of the Eckert-Mauchly group in Philadelphia and the von Neumann–Goldstine group at the Institute for Advanced Study in Princeton in an appreciation of the nature of the problem. Each of these groups went in separate ways, of course. But this proposal shows that the ERA team was just as thorough as the other two in identifying the nature of the problem and carrying out a promising direction.

The reaction of ORI must have been swift, because by April 10, 1946, ERA had submitted a supplement to the proposal. This supplement closely resembles the contract let to NAC/ERA by ONR,[73] which we described above. The supplement, "a result of conferences with representatives of" ONR, specified a priority for the first tasks ERA would perform for the navy. Task I was to be devoted to an investigation of general methods of storage, "essentially as described on page 6 of the original proposal," which referred to the use of multiplexing techniques. Task II required ERA to provide consulting services to ONR.[74]

In the contract agreed upon, Section F of Task Order I required submission of a set of "general specifications for bread-board models of a computer." As ERA stated in a later report on progress, this notion of bread-board models as applied to a computer "seems puzzling."

"Generally speaking, a bread-board model refers to an experimental construction, and for this, preset specifications, no matter how general, seem out of place. However, the field of extensive computations using sequence-controlled machinery is a particularly complicated one, and it is springing almost full-grown into existence. Neither machine nor experienced computers are presently available in any quantity. . . . What is being sought is a computer sufficiently easy to use and sufficiently reliable for use by various naval activities to carry out computations required by or useful to their functions."[75] They understood that besides adequate storage and good input–output facilities, the computer system must be easy to use and reliable. Even at this early date, while concentrating on components, especially storage systems, ERA was already working on theoretical designs of a computer system.

But this was not the only sticking point in the negotiations for the contract. Somewhat similar to the experience of Electronic Control Company later in the year, ERA negotiations with ORI revolved around financial questions with respect to any contract. James Clifford, assistant secretary and counsel in ERA, in a June letter to John Parker, described his discussions with George W. Carter of ORI about allowable costs and general burden under any contract. ERA wanted a "7% fee on all estimated costs including overhead of 140%." Carter was unwilling to allow this, according to Clifford. Engstrom recommended they let Carter process the paperwork for the contract as he saw fit, and if it was unacceptable to ERA, "be prepared to obtain the favorable recommendation of Carter's superiors."[76] Carter used the overhead rate ORI granted to universities (75 percent) as his guide. For their part, the ERA people pointed out that "a private company was in a different category." Carter seemed to insist that a university team could do the work more cheaply than a company.[77] The navy ultimately had its way. For the first six months, only a 50 percent overhead rate was allowed and there was no fixed fee allowed in either contract to NAC/ERA. The navy agreed that at the end of six months, satisfactory performance would allow NAC to reopen the discussion. Parker thought they should accede to the navy's demands, and the contracts were awarded.[78]

Under its contract with the Bureau of Ships, ERA continued the more specific work that had been begun at the Naval Computing Machine Laboratory at Dayton. Work at the NCML associated with NCR during the war seems to have been of two types. One type of work was the electronic circuitry needed to operate a processing system, counter circuits to regulate activity in the system. As part of these circuits, the researchers developed a range of circuits for storing and retrieving data. The second type of work was the design and construction of decoding machines, that is, the American Bombe. They passed these systems on to CSAW in Washington, which used them in the decoding of Axis messages, with a great amount of success. Personnel in Washington, D.C., and Dayton, Ohio, worked closely together to achieve reliable systems. Washington also had access to a Bombe built by the British to help in breaking German codes enciphered using the German Enigma machine. The point to keep in mind here is that only a few of the men who joined ERA had been directly involved with the design and construction of these machines. ERA only gradually moved into design and construction of computers as the two project areas converged. Toward the end of World War II, the Naval Computing Machine Laboratory tried to improve on the equipment that was in use at the navy's intelligence facility in Washington. As we described above, rapid scanning equipment was one way used to search for similarities in messages in order to reveal the cipher technique used in the coding. Searching for "hits" by comparing messages was done to determine priority for attempts at decryption. This, of course, needed to be done as fast as possible to ensure that the messages were deciphered in time to be of use. Punched card machinery was used for the purpose as early as 1938.[79] Later, paper tape machines came into use following their development at NCR, under contract to the NCML. In some respects, the replacement of these machines with better storage devices was ERA's primary concentration in 1946. But from the beginning, ERA wanted to be more than this.

The navy relocated the NCML to St. Paul shortly after the war and kept close account of what was being done at ERA through people close to machine design, such as James Pendergrass and Joseph Eachus, members of the navy intelligence group. The navy adopted a go-slow approach to contracting with ERA, and ERA gained a reputation as a project company for the navy. But, as we have seen, the company had early pretensions to move beyond this project category to the design and construction of complete computer systems.

Toward the end of summer 1946, Joseph Walsh distributed a list of project numbers, titles, and assigned personnel to all ERA employees. In this list, four different types of work were in progress. The A group (eight projects) concerned aviation projects, such as a ground speed recorder and a parachute landing shock reducer, mostly contracts for various sections of the U.S. Air Corps. The B projects (four in number at this time) included several for navy and army agencies. Another set of airline projects (E, eleven in all) was sought by Parker to stimulate cash flow, in order partly to make up for the low overhead rate allowed by the navy. These ranged from radio broadcast consulting to plans for an airline reservation program, many of which were in the original prospectus for ERA. And there were thirteen N projects for the navy with such colorful names as Celery, Alcatraz, and Orion.[80] Because of what ERA became, we will be interested in only two of these project areas: B and N, and will focus on Orion in the Ns and the computing projects beginning with B-3001. Others, such as the airline reservation system, will be mentioned as they are affected by the various computer projects in ERA. A complete list of projects in September 1946 can be seen in figure 1.7.

By June 1946, ERA had organized several projects related to the search for a better data storage system. One of these was to analyze the use of photographic film as a potential tape source. Another was to examine solid-state delay lines as a storage medium. Yet another focused on the use of magnetic media as a storage source. The photographic technique became focused on input–output. The magnetic technique focused on storage. In the beginning, these projects went under the codenames Orion or N-1011.

We noted above work in the 1930s and 1940s for the navy on the Rapid Selector, a device designed by Vannevar Bush, and worked on by

Project Number	Project Title	Project Number	Project Title
A-2001	Ground Speed Recorder	E-9	Radio Frequency Signal Generator
A-2002	Tire Deflecting Indicator	E-10	Vibrating Wire Drawing Die
A-2003	Parachute Landing Shock Reducer	E-11	Metallic Oxide Dielectric
A-2004	Electronic Parachute Opener	N-1001	Celery
A-2005	Cargo Delivery Container	N-1003	Lemon
A-2006	Ground Release Device	N-1004	Turnip
A-2007	Automatic Visual Control	N-1005	Apple
A-2008	Maintenance Deck Skis	N-1006-I	Alcatraz
B-3001	Computing Project	N-1006-II	Alcatraz
B-3002	Sinbad	N-1006-III	Alcatraz
B-3003	Squid	N-1007	Grouse
E-1	Vibrating Machine Tool	N-1008	Mole
E-2	Broadcast Consulting	N-1009	Spinach
E-3	Wired Wireless	N-1010	Equipment Maintenance & Repair
E-4	Electrocardioscope	N-1011-A	Orion
E-5	Airport Service Truck	N-1011-B	Goldberg
E-6	Airline Reservation Program	N-1011-C	Venus
E-7	Airline Automatic Ticketing	N-1012	Leo
E-8	Airline Special Ticketing	N-1013	Mercury

Figure 1.7

Projects in ERA in September 1946. Many projects were small in comparison with B-3001 and N-1011, the examples chosen to follow in detail in this book. A few of the E projects were later shifted to the B category as the company began to use computers as the processing unit for the systems. ERA's reputation is not based on the A and E projects, which were done for private firms. A number of the N projects were classified. The bulk of the records for the N projects that remain are for N-1011.

Courtesy of the Charles Babbage Institute.

Howard, Coombs, and Steinhardt first at MIT and later at NCML. A reel of movie film stored some 200,000 frames of data, along the side of which was a set of transparent dots indicating coding of the information on the frame. By setting a code to be searched and passing the film through a group of photocells, items of interest could be selected. This selection process was especially helpful in the coding and decoding of intelligence information. Even in the early stages of development, several significant problems were noted and worked on with little success up to 1945. Howard and his group sought for greater speed, the ability to photograph documents as they passed without stopping the film and without blur, and to provide a coding scheme so only the desired documents were photographed.

This third problem of a coding scheme contains the most interest for us in our analysis of ERA, because of the way the coding worked. Bush described the principle, and we know from Randell's article on COLOSSUS that a similar technique was used in the British wartime data processing projects.[81] Opposite each frame in the long film were the transparent dots, say a hundred of them, arranged in groups of ten each. At a keyboard, one punched out the code of the item desired, producing a small card with ten holes punched in it, arranged in a pattern according to the keys that had been pressed. The card was inserted in the selector so that the fast film ran close under it and was strongly illuminated. As the record film moved, light passed through the card and a dot in the film registered in position. If nine or fewer such coincidences occurred, the photocells remained inactive and paid no attention. But if there were such coincidences, indicating that the frame then in position corresponded exactly to the impressed code, the photocell triggered the flash lamp to take a picture. Since, at the exact instant this occurred, the chosen frame was not in a position to be easily photographed, a delay circuit was introduced, and the flash lamp fired when the fast moving film had advanced two frames, to bring the chosen frame in front of the camera lens.

Figure 1.8
The main ERA site in St. Paul, Minnesota, in the late 1940s.
Courtesy of the Charles Babbage Institute.

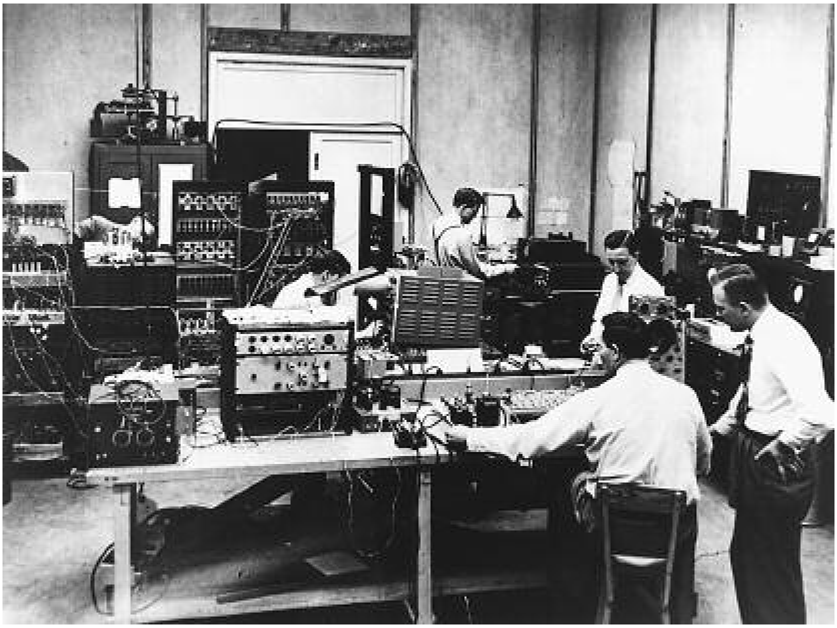


Figure 1.9
ERA Research Laboratory around 1950.
Courtesy of the Charles Babbage Institute.

A similar technique was used in various intelligence comparison machines in the United States and Britain. Howard brought this knowledge with him to CSAW and to ERA.

Eventually, the general objective of this scanning program of ERA became "the production of reliable high speed tape scanning equipment to be used on a variety of problems and to replace the many special scanning devices now in use [by the navy]." ERA investigated "the possibilities and limitations of storing information on a magnetic medium for use in high speed scanning devices."[82] So from the very beginning, ERA emphasized magnetic media, even though under the navy's urging they continued to investigate other possible storage media. Let us focus on the storage problem as an example of R&D in ERA.

In the early months of the project, a number of subtasks were going on at the same time, and it is often difficult to sort out the various aspects. One can look at this project as an attempt to develop a new reliable processing system—the "high-speed tape scanning equipment." As part of this objective, there was an attempt to develop better data storage devices, hence the search for different types of tape-storage systems. These investigations proceeded while ERA continued to examine the possibility of magnetizing disks of various types of material. It took a few months to sort this out and center on the development of a combined storage and processing system in the form of a magnetic drum. Therefore, one can also view this project as the first stage of a larger digital project. The development of high-speed tape scanning equipment bore the code name Goldberg. We proceed with a description of the Goldberg project first, and return to the computer studies in chapter 3.

Project Goldberg

To save time and expense in the initial phase of the project, the Goldberg team, led by John Howard and assisted by Lou Chaloux and Donald Ammerman, began by examining existing magnetic recording apparatus for test purposes. They requested apparatus and reports from a number of sources. From the Brush Development Company of Cleveland, they received several magnetic recording devices developed during the war. The Naval Research Laboratory sent reports on the captured German Magnetophon, an early tape recorder developed in the mid-1930s and brought to the United States at the end of World War II. Speed Graphic cameras came from the Naval Communications Annex in September.

During June and July, the team assembled a range of reports on wartime developments in magnetism. By June 28, construction of a scanning disk made of mild steel was under way. Simultaneously, ERA requested an experimental disk apparatus for recording data on the edge that Lt. Ralph Palmer, who by this time had returned to IBM, built at the NCML in Dayton.[83] This device arrived on July 3 and was set up for testing. The monthly report for June noted that "most of the articles deal with magnetic recording of sound and are not directly applicable to this project." It appears that they were useful, however, in educating the staff "on the basic principles of magnetic recording and the techniques and materials used."[84] Within ten days, Palmer's apparatus had been assembled and a pole piece was used for writing on the edge of the disk. Different voltages were used for recording dots on the disk, both with the disk stationary and moving. For recording, the stationary position worked best; for erasing, a "dc with a sliding resistance was found to wipe the disk cleaner than ac with a variac."[85] Later in the month, they began to vary the pole piece position and the air gaps between the piece and the disk.[86] The results were not very satisfactory, partly due to the low coercivity of the steel disk, which meant the disk's ability to retain magnetic data was low.[87]

By the end of July, the magnetic aspects of the project had clearly separated into two parts: Phase A, a magnetic recording investigation, and Phase B, development of a scanning machine entitled "Goldberg."[88] The high-speed scanning disk, whose construction had begun in mid-June, was ready and they expected to start tests in the near future. "Tests using this [disk] will be started based on experience gained with Lt. Palmer's apparatus."[89] The group's understanding of the standard knowledge of magnetic phenomena known at the time seemed to increase rapidly in this period. For example, in the first two weeks of August, they continued study of the magnetic flux distribution in the disk and plotted curves of the flux distribution for various currents. These curves compared favorably with the results reported in the literature. "Future experiments will continue with various shaped pole pieces in an effort to increase the number of signals on the periphery of the disk."[90]

During the next week the team abandoned the use of the Palmer apparatus. They mounted magnetophon tape on the edge of the ERA high-speed scanner and began to use the heads from the Palmer model for reading and writing. In addition, they tried wrapping magnetic wire around the edge of the disk, but this seemed to differ little from the magnetophon tape.[91] Further attempts were made using a pole piece from a Brush wire recorder.[92]

Sidney Rubens, affectionately known as Sid, joined ERA on August 15, 1946. He was assigned as Project Engineer on Orion, replacing Howard, who served as research supervisor for this and other projects. Rubens brought a good knowledge of magnetism and its literature to ERA. Not long after arriving, he translated a seminal 1937 article by the German von Heinz Lubeck, one of the principal developers of the Magnetophon.[93] This work alone provided a good basis for a magnetic research program, and under Rubens, Orion began to expand. Rubens remembers that his first assignment was to look into different ways of storing data; one was the magnetic recording techniques we have been describing here and the other was "to investigate the possibility of solid-state delay lines."[94] Rubens began making changes right away. "Robert Perkins built me a small 5-inch drum and we put it on a grinding drill to spin it. I used to take the Scotch off the Scotch Tape by passing the tape through toluene and holding it against the spinning drum and put a piece of tape around it."[95] The very next report described this disk system and the resulting improved resolution obtained with it. Rubens went on to say in the report, "It may be that the resolution can be increased by using a head of improved design or by using the Magnetophon head in contact with the tape during the play-back operation." Whether this was ever tried is not clear; it seems it would have caused rapid wear of the tape. What is striking about this first report under Rubens is the greater specification of projected plans, giving the impression that an organized research program with a careful set of hypotheses to be investigated was being devised.

The projected program for continuing this work with Magnetophon tape includes:

(a) further studies of resolution by use of the present Magnetophon heads,

(b) investigation of the effects of handling of the tape on the permanence of recorded signals,

(c) development of techniques for photographing C-R oscillograms, and

(d) investigation of the possibility of recording and reproducing 2 or more sets of signals along parallel lines on the same piece of tape. Photographic equipment and dark-room facilities will be needed for (c).[96]

So far, signals had been recorded only with the disk at rest and read with the disk spinning, but with good results.[97]

Responding to a memo from C. B. Tompkins of September 9 asking for "a set of specific objectives" for Project N-1011-A, Rubens submitted a one-page handwritten note, most of which was later incorporated into three pages of a larger report, which Rubens believes was written by Tompkins. Rubens emphasized the aim of, the materials to be investigated in, and the results desired from the project.[98] The primary objective of the project was to develop analytical devices that permitted the recording, reading, and erasing of magnetic pulses. Rubens intended to investigate several magnetizable materials, among which were ferric oxide, metals plated with ferromagnetics, and solid ferromagnetic tapes, wires, disks, and drums.

The investigations on each material should yield answers to the following questions:

(1) What is the signal to noise ratio, signal level, signal shape and maximum resolving power that can be obtained at various recording and reading rates?

(2) How are these characteristics affected by type of magnetization (longitudinal, transverse and perpendicular), recording and reading head design and displacement between the head pole-pieces and the recording medium?

(3) What are the mechanical, thermal, and other non-magnetic properties of each medium which influence the electromechanical design of any system in which the medium may be used?[99]

Tompkins's request for a statement of specific objectives must have been made of a number of groups in ERA, and may have occasioned the corrected list of projects circulated in September 1946 by Walsh. Research on film, magnetic, and delay lines for storage were now closely related as one project labeled N-1011 A, B, and C, code-named Orion, Goldberg, and Venus. Orion was to investigate the recording–reading mechanism. Goldberg was to construct a substrate, such as a drum, for storing data. And Venus was to investigate other possible media.[100] After September 22, 1946, these separate phases were referred to as Goldberg Parts A, B, and C, though A and B, or I and II as they were sometimes called, predominate in the surviving reports of the period.[101]

Throughout the remainder of 1946, work continued on Goldberg according to the program laid out by Rubens and Tompkins. "Work has continued on dynamic recording on moving magnetophon [tape]. . . . Preliminary tests with Brush Development Company coated paper indicates that it is about as satisfactory for pulse recording as is magnetophon tape type L."[102] "The former is about twice as sensitive as the latter, but the Brush paper has a much larger noise background so that the signal to noise ratio for Type L Magnetophon tape is at least three times that for the Brush paper."[103] "A model 79-B Measurements Corp. pulse generator has been used to supply pulses for 1 to 40 micro seconds in width. These have been recorded on tape moving at 408 inches per second at pulse rates up to 40,000 per second."[104] Successful dynamic recording at 20,000 pulses per second was achieved on the Magnetophon tape at this time.[105] "Preliminary tests on [a reel of magnetite-coated paper tape from Brush Development] indicate that this material is identical in characteristics to the material of which the Mail-a-Voice paper discs are made."[106] "Some 'Hyperflux' (metal-alloy coated paper) tape has been received from the Indiana Steel Products Corporation. This substance has a much high[er] coercive force and remanence than tape L Magnetophon and other magnetite tapes. Thus it will require a specially designed recording head for adequate testing . . . preliminary tests gave a much large[er] signal than is obtained with magnetite tapes with about one half the signal to noise ratio obtained with type L Magnetophon tape."[107]

By early November, Rubens's group had received from the shop a new steel spinning drum and an aluminum drum. They conducted tests "to determine whether or not metal drums to which magnetite tape is bonded are practical for high speed recording."[108]

They continued to examine the effect of erasing current, pulse duration, and resistance for the recording heads on these various tapes, and by November 10 they were bonding the three types of magnetic tape to plastic drums, as we noted above.[109] Plastic drums were being used to avoid spurious effects due to eddy currents in the metal drums. Gap widths, pulse widths, and drum speeds were varied continuously to ascertain the most effective combination of materials and variables. Rubens found that "there is no evidence that the design of the German Magnetophon head can be greatly improved for longitudinal recording on a drum with air gaps maintained between the drum and the recording-head and reading-head."[110] During October and November, Rubens used heads taken from a German World War II Magnetophon recorder for these tests. At the end of November, he acquired a new head from the Brush Development Company and found that with this head the gap between the head and the drum could be wider and the pulse widths could be increased in size without loss in resolution.[111]

In his continuing efforts to obtain as many different types of magnetic materials for testing as possible, Rubens turned to another St. Paul company, the Minnesota Mining and Manufacturing Company (3M). Two of his former associates at NOL joined 3M in 1946—L. Robert Herr and Byron Murphy. Another former navy veteran, William Wetzel, had joined 3M from the Bureau of Ships. Wetzel had his own reputation in magnetics and was to publish several important papers in the field in the late 1940s and 1950s.[112] Wetzel and Herr were investigating better emulsions for making the magnetic materials for 3M tape. In mid-December, some of their new tape (lot 31) was provided to Rubens. Each side, Rubens of ERA and Herr of 3M, remembers the series of gifts to ERA of tape or emulsions as a favor to the other. Rubens wanted the very best magnetic materials he could acquire. Herr remembers that the ERA people were "taking lab samples and giving me a free analysis of the recording characteristics and signal strength, and noise."[113] Rubens found, for example, that lot 31 had a greater signal-to-noise ratio than the Brush recording materials, and that the gap width could be even larger.[114] Over the next few weeks, more samples arrived from 3M.[115] "A sample of MMM Co. magnetite-coated tape (lot 32d) was tested for signal to noise and compared with other specimens of magnetite-coated tape. This sample gave about the best signal to noise as yet observed with this type of tape. It is understood that MMM Co. is attempting to produce a coating that will be even freer from noise than this one."[116] And so it went for the next two months.

On January 31, 1947, a number of the people involved in the magnetic recording research program met in William Norris's office: Norris, Tompkins, Rubens, John Coombs, Robert Gutterman, another former NOL staff member, and Arnold A. Cohen, a new staff member from RCA. "It was decided that top priority would be placed on completion of design of recording and reproducing heads for Goldberg. R. P. Gutterman will be responsible for the design of the aforementioned heads, and Mr. Hogan and Mr. Christensen will assist him in this work. S. M. Rubens is responsible for getting experimental data necessary for Goldberg, and specifically head design, and Mr. Horton and Mr. Eulberg are assigned to him to assist in this work."[117]

The parts of the Goldberg project were in various states of completion. Part I was estimated as being 15 percent complete, and Rubens estimated that Part II was 60 percent complete on February 9, 1947. At this same time, Horton reported that Part III, the solid delay line study, was completed and work ceased.[118]

There were six aspects to the Goldberg project listed in these early February reports:

Testing, writing, and reading circuits with a disk

Development of an electronic counter

Design of film passing equipment

Construction of a model film punch

Writing specifications for the control circuits

Experimenting with methods of applying a magnetic coating to a wheel

We saw above that Rubens and his team were trying to read and write on a disk, with some success. For these experiments, they had been adhering magnetic tape to the disk. Now they would attempt to put a magnetic emulsion directly onto the disk. John Coombs was working on an electronic counter by mid-December 1946.[119] The problem of the film passing equipment was given to Jack Hill.

During the war, tapes containing intercepted intelligence were run past each other at high speed in the Bombe machines, similar to the action in Bush's Comparator. The greater amount of intelligence after the war required greater efficiency in its analysis. The navy believed this might be possible if the tape could be scanned faster, but one of the weak points in the process was at the splices where two strands of tape were fused. Therefore, one early part of this project was to examine the film splice technique, Hill's project.

While the results of this aspect of the work at ERA were not exciting, the project was important because there was no necessity to classify it.

Apparently a number of new employees waiting for clearance worked on projects of this kind. This is why Jack Hill believes he was assigned to this project when he arrived at the beginning of 1947. A report from what appears to be the spring of 1947 describes a device for smoothing the splice regions so that they would flow through the scanner without incident.[120] The report has no date, but the information in it is the same as Hill's description of what he did to solve the problem. Several types of film were analyzed, from Standard Safety film (developed) to Dyed Aero Leader Stock, using Eastman Cine Film Cement for the splices. As he reported in a 1986 interview:

> They had run that stuff just about at its physical limit. And someone in the organization or somewhere had suggested that if they would put this same information on photographic film they could reduce the size. They could reduce the amount of footage that they had to pass to get a particular amount of work done. And there was the possibility also of running the film faster than it had ever been done before. The first time they tried it it came apart at the splices after just a few minutes because of the discontinuity of thickness of the splice. That was a given when I started what I was doing. My obligation here was to attempt to find out how to do the splicing to minimize this breakage. And I found out how to do it.[121]

A conventional splice consisted of the two tape ends overlapped and cemented. At first he tried tapering the tape ends before cementing, but this did not work too well. "I went through several weeks of attempting to accomplish that and decided, well, you might first make the splice and then eliminate the discontinuity by abrading off all the excess until you have the splice no thicker than the rest of the film. Worked beautifully."[122] Hill built a rig for testing the tape but did not try the tape on any scanning equipment that was being developed at ERA or elsewhere.[123]

In the last quarter of 1946, work on drums increased in intensity and ERA planned new fixing of magnetic materials on the drums. Coombs reported at the end of January 1947 that "the base and supporting frame for the magnetic drum is being built by the Industrial Machine Works." The Works was slow due to a holdup in obtaining half-inch thick aluminum sheets. This drum was one in a series built in this period.[124] Earlier drums, as we have noted, had the magnetic tape fixed to the surface of the drum; this drum was being prepared for spraying the magnetic oxide onto its surface. A new spinner had been crafted toward the end of 1946, and with this they tested the effect of altering the peripheral speed of the drum.[125] "With a single winding of the Brush head used for recording and for reading, the signal is nearly proportional to the speed for frequencies up to 14 kc per second. For pulses recorded at 14 kc per second, a 50% increase in tape speed gave a 50% increase in signal amplitude. . . . With sufficiently low impedance heads for recording it may be possible to use tape speeds considerably in excess of 400 inches per second."[126] In the ERA lab, they proceeded with assembling and testing Coombs electronic counter, Cohen's design of control circuits, and the Hill film project mentioned above.

The results of this R&D project were promising enough that ERA and the navy decided to cast their lot with a magnetic storage system, rather than with the storage systems being developed at other sites. This was confirmed when the Bureau of Ships provided an additional instruction for the Goldberg project following discussions between the Bureau of Ships and NAC in early February.

> The contractor should be informed that construction of the machine required under the subject problem will be subject to the following:
>
> A. The internal memory unit should be magnetic . . .
>
> B. The overall design of this equipment should be accomplished in a way to provide for the eventual replacement of the magnetic internal memory unit by an internal memory unit comprised of storage tubes.
>
> C. Provision should be made for an external memory unit (magnetic) of fourteen or more channel capacity and so constructed that while the machine is in operation with the data already present in the internal memory unit, another set of data may be passed into the external memory unit. . . .[127]

This memorandum authorized construction of the unit, and stated that the input mechanism, to be supplied by the navy, would be a "double-headed IBM tape reader."

The Goldberg machine had to analyze data of a "teletype nature" at a rate of 20,000 pulses per second. "It is to be a general purpose machine and will be made as flexible as possible." Goldberg was a Comparator-like device for analyzing two streams of data, noting and counting coincidences among corresponding characters.[128] There were to be six functional parts to the Goldberg machine. (1) An IBM tape reader would be used for punched tape input and output to the machine. (2) Two magnetic drums were to be constructed, one for internal and one for external memory. The internal memory drum of 31 inches diameter was to have 22 or more tracks and store 5,000 magnetized "spots" around its circumference. The drum should be capable of receiving data from the external drum at the rate of 100 items per second. The navy specified that the data on this drum should be analyzed at a rate of 20,000 items per second. Three magnets would be employed for reading, erasing, and rewriting. The external memory drum would contain 14 tracks and receive data at a rate of 8 pulses per second.

The calculational part of the machine was composed of translators and counters. (3) Goldberg was to have three types of translators for converting data from one system into binary code. The complexity of these translators went from two-unit translators with two inputs and four outputs, to six-unit with six inputs and 64 outputs, to a 36 36 matrix. (4) There were 36 electronic pulse counters, each with a maximum capacity of 9,999, controlled by a gate tube in the input signal circuit. (5) Four control signals for timing, starting, stopping, and cancelling, and it was necessary to provide control circuits for these. In addition, the plan specified a set of control circuits for the functioning of the counters, reading schemes, and printing results—a total of nine circuits in all. And (6) a mechanical printer was to be supplied having a capacity of 38 five-digit numbers. (This printer was developed as part of the Alcatraz project.)[129] Later the navy simplified the drum requirements, allowing ERA to deliver two identical drums that could operate as internal or external memory interchangeably.[130]

During January, ERA examined twelve Brush recording heads for uniformity in characteristics and use. But they soon concluded that "commercially available magnets for reading and writing magnetic tape signals are not well designed for use on Goldberg," and set about to design a new head.[131] Gutterman consumed most of March designing new heads, and reported slow progress "due in the main part to problems of instrumentation and tool manufacture which have proven to be surmountable but time-consuming."[132] Coombs, to whom Gutterman reported on this project, suggested to management that the "rate of progress on this work could be greatly increased by the acquisition of a small annealing furnace, a set of sheet-metal reducing rolls, and a very flexible oscilloscope" (a Dumont Type 248).[133] In spite of these difficulties, ERA projected completion of Goldberg in January 1948.[134] But before the Goldberg machine was delivered to, by this time, the National Security Agency (NSA), a new project, Demon, superseded it. Demon (Task 21) used data stored on the drum to perform a specialized form of table lookup. Like Goldberg, it used a large 34-inch diameter drum that rotated at 240 rpm, equivalent to a data transmission rate of 20,000 pulses per second. The first five Demons were delivered in October 1948. Samuel Snyder asserted that "as far as we know" this was the first drum memory in practical operational use in the United States. Demon also incorporated a marginal checking routine to evaluate the voltages of vacuum tubes in the device.[135] As a result, Goldberg was not delivered and made operational until summer 1951.

Because of its impact on ERA R&D activities, we should return to the discussion of the research aspects of Project Goldberg. Parts I and II of the Goldberg project seemed to diverge during the first half of 1947. The Part I modification in February placed emphasis on construction of the machine, as we have seen. At the same time, Part II turned to more general investigations "concerning the possibilities and limitations of magnetic storage to serve as a guide in the planning and developing of analytic devices in which it might be employed."[136] While some of the results, such as new recording head designs, were taken over from Part I to Part II, more of the work in Part II was on magnetic pulse recording of a general kind, later diffused into other ERA projects.

It is tempting to speculate that this generalization of Part II R&D was the result of discussions at the January 1947 Harvard Computation Laboratory Conference on magnetic phenomena. Coombs, Howard, Steinhardt, Tompkins, and Wakelin attended from ERA.[137] The sessions ranged over descriptions of existing calculating machines (Mark I and II, ENIAC, Bell Laboratories machines), logic systems, storage devices, methods and problems for solution, "programming," and input–output devices. All of this would have been of interest to the ERA attendees. But we should note particularly presentations by Benjamin Moore of Harvard on "Magnetic and Phosphor Coated Discs" and Otto Kornei of the Brush Development Company on a "Survey of Magnetic Recording."[138] Moore reported that the Harvard people were considering two types of storage system, one dynamic and one static. "It was hoped that more experimental results would be available to report at this meeting, but unfortunately the experimental work has not kept pace with expectations. Consequently, most of this report will deal with proposed ideas rather than with accomplished results."

Both storage systems proposed would make use of a "disc or drum rotated at a high speed." In one case, the drum would be coated with a phosphorescent material, which would be activated by light pulses. In the second "more promising" case, the drum would have a "layer of magnetic material capable of recording sharp pulses." He projected a pulse repetition rate of 60,000 per second. "Information gathered up to the present time would encourage the belief that the problems involved in recording pulses at the rate of about 60,000 per second may be solvable." As we saw, shortly thereafter ERA was considering a pulse rate of 20,000 per second as the requirement for Goldberg.

Kornei offered a review of magnetic field theory and its application to magnetic tape and recording head production. He concluded with a few remarks "regarding the probable merits and limitations of magnetic recording for computing machines. The restricting term 'probable' has to be used since little actual experience exists with this particular application." He predicted that the difficulties in achieving a system using this type of storage would be overcome.

Between these two talks an informal session took place to discuss magnetic recording. This discussion was reported by Edmund C. Berkeley to his superiors at the Prudential Insurance Company, for whom he wrote an extended report on the conference.[139] Highly technical issues were discussed, for example, how the information signal may go on a magnetic tape, either as a square wave or as a sine wave. "The first question [according to Berkeley's report] is how short can the pulse or square wave recording be made. The pulse recording apparently, according to Dr. Chu, can be made as short as 0.003 inches or 3 mils. This is experimental work at the Moore School. According to Dr. Tompkins, the recording can be as short as 0.030 or 30 mils, with commercially available recording heads."

Berkeley then went on only to list the other topics discussed: "Plated wire or tape instead of solid wire or tape. Resolving power. . . . The gaps between the poles of the magnetizing head. Strength of magnetic fields. . . . Distance of recording head to tape. . . . Moving or stationary recording." Among the items in Berkeley's list, ERA had been focusing on the size, strength, and sharpness of the magnetic spot, distance of the recording head to the tape, shape of the pole piece, and moving or stationary recording. Berkeley's report suggests that no one had yet developed a satisfactory technology for magnetic recording and reading for a computer system. ERA's investigations had a dynamic flavor to them, in that they tried to achieve maximum signal with minimum parts (such as windings of wire on the recording head) and most reliable magnetization on the recording medium. One can see in this the navy's requirement for reliability as well as ERA's concern for manufacturability at lowest cost.

Spurred on by what they learned at the Harvard Conference and wishing to maintain priority for their R&D results, within two months there was a move at ERA to divorce the research on magnetic recording from the Goldberg project. ERA engineers felt strongly enough about their results that Coombs and Hill prepared an invention disclosure at the end of March 1947 on a "Memory System for Storage of Numerical Data," essentially the Goldberg system.[140] The disclosure had a secret classification and was meant to protect ERA's invention in any future priority disputes.

Several conferences took place in St. Paul in April. On April 15, they agreed that the work on magnetic storage under Goldberg, Part II, be transferred to the Computer Project, B-3001.[141] To facilitate planning for this move and obtain approval from the relevant navy officers, Cohen and Rubens were instructed to visit various groups, among them NBS, Moore School, Harvard, IAS, and to meet with Rees while they were at the May American Physical Society meeting in Washington, D.C. "It must be recognized that contact with certain of these groups has already been made by Dr. C. B. Tompkins. It is evident, therefore, that our method of approach must be such as not to jeopardize our reputation or relations with these groups and with the Office of Naval Research. Dr. Tompkins has done a great deal of preliminary work in this regard but it is not clear at this time whether or not those visits resulted in a definite understanding that other of our personnel engaged in the same work would be welcome."[142] This is a recognition that Tompkins's visits were for ONR as part of the consulting services contract NAC had with ERA. Simultaneously, ERA believed it appropriate to prepare a Part II report on the magnetic storage drum, because "if dissociated from the ultimate use of the equipment, it appears it would be declassified by the Navy."[143] In fact, several reports were prepared. These reports became available in June. One focused on the "Storage of Numbers on Magnetic Tape" and another on "Magnetic Recording of Pulses for the Storage of Digital Information," dated June 17 and 19, 1947, respectively. It appears that the reports were not classified and had only limited distribution. The information was included in ERA's report to ONR, published as "High-Speed Computing Devices" in 1950.

The attempt to declassify the magnetic storage program from Goldberg must also have had something to do with the desire to commercialize the system. Several actions in May 1947 point to this conclusion. First, on May 7, Coombs prepared a memorandum for Howard Engstrom containing a proposal to build a model storage system for demonstration. "It seems to be ERA policy to obtain publicity for the magnetic storage drum." But he felt "reticent" about this, "because we have not developed, nor will we develop on this project, the associated electronic circuits essential for a storage device of the type in which most of our potential customers or competitors are interested." He went on to point out the device under construction "performs only the same function as a punched file. The data is inscribed sequentially from a teletype tape, and is then read sequentially at a faster speed. The associated circuits will count coincidences of various types. That is all the equipment will do. I feel that it will not impress a layman because a great deal of imagination is required to see how the drum can be used in computing machines."[144]

He related that he knew of only one group that had built such circuits: the EDVAC group at the Moore School. Coombs thought it would be more convincing if "we could build a complete small scale storage system which could be operated from a keyboard, and would print out numbers on demand." He went on to describe what such a task would involve, both in construction and in operation, and gave an estimate of the resources needed. He argued the value of this task for the men as a learning experience, which would need to be done for such projects as B-3001 anyway. In a memorandum of the following day, Coombs set out the technical details of a "magnetic recording system, complete with part numbers and sizes, construction characteristics for the drum and heads, and the stock lot for magnetic tape from 3M."[145] And he and Hill prepared a summary report entitled "Storage of Numbers on Magnetic Tape," which was essentially the same as their patent disclosure.[146]

Meetings between navy people from Washington and ERA personnel occurred on a regular basis as has been pointed out several times above. One of these between Joseph Eachus, another civilian navy employee, and Coombs concerning Goldberg took place on March 17, 1947, out of which came further modification of the design. The two drums were now to be "exact duplicates of each other." The drums would function alternately to receive and store pulses from the tape reader at a rate of 8 bauds per second. This was an attempt to design the equipment so that it could be used continuously for analysis.[147] During April 1947, the drum drive system had been redesigned to reduce the peak mechanical forces during the slow speed writing cycle and improve the accuracy of placement of the written pulses. Six Brush heads were required and they reproduced signals with enough similarity to allow ERA to plan production of 250 such heads. Coombs's team regretted that their development program on head design had not "evolved a significantly improved type of head. It is apparent that an improved head will not be developed in time to be utilized by this project and research work on magnetic recording heads had been discontinued."[148] They were also working on final designs of circuits. A completely new timing generator had been produced to be used with a new reading amplifier. In a later report, reasons for the necessity of a timing circuit were given. "If a timing signal is not used [to control reading on the drum], the rewritten marks are shifted slightly. This shift accumulates so that after several thousand revolutions the marks on the various tracks have all been moved by different distances from their original positions. . . . By using a timing signal to gate the pulses so that they are all rewritten at the same instant, slight variations in the reading-head-to-writing-head spacings become unimportant, and the random migration of cell positions on the drum is corrected."[149]

The timing circuit contained two amplifier tubes (6AQ5s), a one-shot multivibrator (6J6), and a cathode follower. They had produced a prototype counter ring and began procurement of parts for 156 similar units. A carry-over chassis in combination with four of these counter rings constituted one counter unit. All electronic components were being designed as plug-in units and for easy access for maintenance. Finally, ERA sought to modify a printer unit in the Alcatraz project for use with Goldberg.

During May, the final designs for the reading and rewriting amplifier and the electronic memory units were completed, and production prototypes were under construction by the end of the month. But other circuit design changes were being undertaken, especially in the carry-over chassis. The continuous read, erase, and rewrite feature was successfully tested for durations of up to ninety minutes. "No deterioration of the pattern was observed." Other circuits were in various stages of design. A comprehensive study of control circuits and equipment began. Much work still remained to be done over the next seven months—the projected completion date of drum construction.[150]

As noted above, Coombs and Hill prepared their summary report on the Goldberg design in June 1947. They described a 34-inch diameter drum 10.25 inches wide onto which was fixed 0.25 inch magnetic tape (Type SL10012 Scotch Sound Recording Tape). Three heads for writing, reading, and erasing were used for each tape. The writing was done by advancing the drum approximately 0.020 inches along the circumference of the drum and recording from a teletype reader. The reader advanced at about eight steps per second. Holes in the tape were recorded as magnetized marks on the tape. Reading was accomplished at the rate of 225 rpm, giving a pulse scanning rate of 20,000 pulses per second.

In many ways, this machine was not very much advanced over the Bombes used during World War II. It seems safe to conclude that Goldberg was used for the same kind of "hit" analysis that Bombe accomplished. Whether Goldberg was even any faster than Bombe is debatable. In the next few years, Nebraska Avenue contracted for other types of devices, and moved quickly into digital computing equipment. When that move came, ERA was prepared to be of assistance because of ideas that Tompkins and Engstrom espoused early in ERA's history in the long-sought computer project.

A Capsule View of ERA at the End of 1947

The sorting out and education processes that occurred from mid-1946 to mid-1947 allowed ERA to learn the field of computing, accumulate the engineering skills to pursue research and development on an organized and sustained basis, and to carve out for themselves an area of computing machine development that would have an important influence on the field. Thus, the critical years in ERA's growth were 1947 and 1948. In these years they changed from an electronic project shop to a computer design company.

In 1946 and 1947, the magnetic storage system was an end in itself for ERA, but it developed into a project for a complete machine with the aid of NCA and NCML—the Atlas I. ERA pursued investigation of storage systems in a fashion similar to that of the other computer development projects. A major difference between ERA's work and other computer development projects was the firm's focus on magnetics and storage systems to such an extent that it became known for this and not seen as capable of developing a computer system. Indeed, when IBM wished to measure its own capability to design a magnetic drum storage system, it made a contract with ERA for a drum design and compared it with its own design. This contract held out the possibility of significant commercial business for ERA, and might have spelled the difference between independence and absorption. IBM decided its design was equally as good as ERA's and meshed with its manufacturing process better, so nothing came of the contract for ERA in the long term. ERA benefited from the transfer of information of many groups as they honored their contract with ONR to prepare a report on techniques of computer system design. Navy contracts provided a systematic learning and R&D period for ERA, during which they could advance from smaller to larger scale system contracts.

In 1947, ERA's engineering activities were divided into three parts: applied research, consulting services, and product development. ERA further divided product development according to product application, primarily according to electrical and mechanical backdrops. In the mechanical category were items such as dock skis, cargo containers, and airport vehicles. We have nothing to say about these except how they affected the bottom line to be discussed below. The electrical category contains circuits for various products, magnetic storage R&D, and eventually computers. The firm's R&D and design functions were associated primarily with product development, especially since products had such common features. This unification of the design function allowed ERA to organize one laboratory under a single director, who had line control of research, all product lines, laboratory services, and design. A director of research and a director of engineering reported to the laboratory director, who coordinated with company management. Product engineers designed circuits and electrical layouts. Other engineers concerned themselves with development. Under mechanical design, ERA listed parts design, structural planning, styling, standardization, drafting, and engineering the product for manufacture. We need, however, to recognize that up through 1950 there was little repetitive work. Often the first model built was the only one delivered.[151] Nevertheless, through the Goldberg project, ERA had learned a great deal about data processing system design, circuit elements and components, and the need for complete systems if they wished to enter commercial markets.

At this time, the company believed it had competency to address problems in the areas of electronics, communications, computing and calculating, wave propagation, electromagnetism, supersonics, physical chemistry, jet propulsion, and aeronautical instrumentation.[152] Though it is doubtful the company could have mounted major projects in all these areas simultaneously, they did try. In their first year of operation, ERA obtained contracts principally with the navy, but also communications work with Trans World Airlines on an airline reservation system, the Air Transport Association on work for all-weather flying, and with Princeton University under a subcontract to evaluate present developments in jet propulsion. They investigated the application of electronics to chemical problems for the National Sugar Refining Company. In addition, ERA obtained a contract from IBM to produce 2,000 to 3,000 radio receivers for use at a United Nations conference, and a contract for wooden trailers, based on earlier work of Northwestern Aeronautical Company on wooden gliders. ERA pursued such commercial contracts vigorously over the following three years "to become self-sufficient without the need of government contracts."[153] As examples, we can cite proposals to 3M for design and fabrication of a special heat-activated reproduction machine; American Steel and Wire Company for die-contour measuring equipment; Prudential Insurance Company for electronic computing machinery; E. J. Longyear Company for a new approach to the drill rod coupling-self-centering chuck device; Trudeau Candy Company for a candy assembly machine; Vallen, Inc., for a pilot model of an ultrasonic garage door opener; Waxed Paper Institute, Inc., for a device to measure ink; and Burroughs Adding Machine Company for magnetic storage systems.[154] Some commercial contracts came their way, but mostly ERA subsisted on government contracts. So much so, that when threats of federal budget reductions resulting from military reorganization were imminent in mid-1949 the ERA Management Committee received a plan from John Parker for reducing personnel. At the time, ERA's contracts totaled $2.5 million, and it had $2.0 million under consideration. If these had been contracted, ERA could expect to operate at the same level in the following year. Expectations ran to half the $2.0 million, and if the military cut back as anticipated, it would be necessary to reduce staff by 34 percent. Ultimately, ERA did reduce the staff, and this can be seen as a bellwether of events to come, when less and less income meant that ERA was losing its critical mass to design new products. A group of people left for Remington Rand's Norwalk Laboratories to work on upgrading tabulator systems for the emerging computing market. Over the next few years, others left for IBM and to found new companies, but I am getting ahead of the story. ERA's hopes were still high at the end of 1947, and continuing to go higher when they obtained a contract from the navy for a complete computer system. Before we embark on a discussion of this computer project, we need to examine the founding and early efforts of Eckert-Mauchly Computer Company and how they approached R&D and market questions in order to compare and contrast the approaches of the two companies.

2

Research on the Commercial Frontier of Computer Machinery: The Eckert-Mauchly Computer Corporation

While ERA moved from conception to operations, J. Presper Eckert and John Mauchly contemplated their own futures and that of their brainchild the EDVAC, successor to the ENIAC. In the period after the ENIAC design was frozen, Eckert and Mauchly, in particular, focused on changes that would make the digital electronic computer more effective and efficient. Eckert adumbrated a design for a magnetic drum in 1944, and in the same month, briefly described the stored-program idea. With U. S. Army support, the group around Eckert and Mauchly, which included John von Neumann, designed a new machine: the Electronic Discrete Variable Arithmetic Computer (EDVAC). EDVAC would be built after ENIAC was in operation. In spring 1945, von Neumann sketched the ideas behind EDVAC in a controversial "Draft Report on the EDVAC" circulated in June 1945 under his name.[1] The EDVAC became the forebear of virtually all subsequent computer designs.

Eckert and Mauchly resigned from the University of Pennsylvania in March 1946, following a dispute over patent rights.[2] They set out to develop a computer based on the EDVAC design, but not identical to it, a subject explored in detail below. Distinctions among their various machine designs of the next decade had to do with components, timing, input–output systems, word size, and memory size. To appreciate the starting point of Eckert and Mauchly in the summer of 1946, we need only review the EDVAC design, which can be found in no better source than the Moore School lectures given in the summer of 1946 in Philadelphia. The road from EDVAC to UNIVAC, the ERA 1101, and to the Defense Calculator of IBM was not an easy one, a story that is an integral part of the history told in this book.

The twenty-eight registered "students" at the Moore School lectures constituted a core "Who's Who" of computing for the next two decades. Many students represented government installations, and in their administrative capacities guided acquisition of systems in their agencies. Five came from MIT, and two of these played a major role in Whirlwind. Three worked at the National Bureau of Standards, and significantly influenced computer design and acquisition over the next decade. The lone representative of the Naval Communications Annex (OP-20-G), Joseph T. Pendergrass, a lieutenant commander in the Annex, went on to prepare the initial specifications for the ERA Atlas I task and worked very closely with the ERA design group in elaborating a final set of Atlas characteristics. There were no representatives from ERA at the Moore School meeting. The only companies represented were GE, Bell Telephone Laboratories, and Reeves Instrument Company. To top off this brief list, both Cambridge University and Manchester University in England sent people.[3]

Eckert, speaking in the lecture series, contrasted ENIAC and EDVAC to illustrate that in EDVAC the memory elements were divorced from the arithmetic operations and multiplication was done in the addition mechanism. "We are not going to do any arithmetic operations in parallel with any other arithmetic operation not only to save equipment, since the adding mechanism is considerably more complicated than a few memory elements, but also to simplify the planning of a problem for the machine."[4] This meant there would be no irrelevant timing between the various steps if the steps have different lengths of time in the calculation. The plugboards, cords, and most of the switches in ENIAC were not carried over to the EDVAC. Mauchly pointed out in several places that there were three characteristics of this type of machine, which have a bearing on the handling of problems. (1) An extensive internal memory; (2) A few elementary instructions to which the machine will respond; and, most important (3), the ability to store instructions as well as numerical quantities in the internal memory, and modify instructions so stored in accordance with other instructions.[5] The memory held the information electronically and fed relevant pieces of information in response to the program into the control circuits to sequence the machine in conducting its operations. The memory unit was to hold at least one thousand ten-digit decimal numbers each with a sign. Thus an eleven-digit word length would be required, and instructions would have the same length with two digits representing the operation to be performed and three three-digit numbers for addresses. In his presentation in the Moore School lectures, Eckert listed eleven operations and four instructions for input–output, labeled Code A, a code developed by Mauchly that would be further developed by EMCC for broad use in other projects.

Von Neumann, in the "Draft Report," offered a similar code where instructions and data were in binary numbers.[6] The code covered the basic arithmetic functions, comparison of numbers, transfers, shifts of decimals, increase, and extract.[7] The relationship between the development of Eckert, Mauchly, von Neumann, and others in the transition from ENIAC to EDVAC is still a matter of debate among historians.[8]

If we accept Herman Goldstine's assessment of reports and memos on the EDVAC deliberations in 1945, the group contributions seem to be split between technical developments by Eckert and Mauchly and logical developments by von Neumann, Burks, and Goldstine.[9] The emphasis in von Neumann's "Draft Report" in June 1945 on the logical philosophy of EDVAC clearly shows his interests in the logical design. However, that emphasis on logic developments deemphasizes the work of Eckert and Mauchly, and therein lies a tale outside the scope of this work—except to point out that the starting point for machine design in 1946 and early 1947 at EMCC and ERA, and perhaps MIT and Raytheon, is the EDVAC report and the Moore School lectures. In fact, Goldstine in 1972 made this quite clear.[10] Goldstine conveyed his recognition of the significance of the "Draft Report" when he wrote: "In a sense, the report is the most important document ever written on computing and computers."[11] Eckert and Mauchly wrote in a September 1945 report on the EDVAC project: "Von Neumann . . . contributed to many discussions on the logical controls of the EDVAC, has proposed certain instruction codes, and has tested these proposed systems by writing out the coded instructions for specific problems. . . . In his report, the physical structures and devices . . . are replaced by idealized elements to avoid raising engineering problems which might distract attention from the logical considerations under discussion."[12]

But Goldstine's assertion that it was von Neumann's work on the logical functions that was paramount and "the electrical aspects were ancillary"[13] downplays the tremendous effort carried out in a number of settings over the next several years in designing and constructing computer systems, including the IAS machine. Evaluation of influences on ERA and EMCC, especially, places the several later von Neumann group papers of 1946 and 1947 in a different light. Later historians have focused more on the later developments from the IAS project.[14] I should point out that this does not alter the assessment of the contributions of von Neumann and his group, but it places the spotlight in a different direction, which allows us to highlight the contributions of others in the working out of practical designs based on the sketchy information of the earlier documents.

What is the argument here? One, the starting point in computer design in the United States and the United Kingdom was the "Draft Report on the EDVAC." Two, the design characteristics of that report came from the interaction of the ENIAC design group, Goldstine, and von Neumann as reported in the various summaries submitted attesting to progress by the project. Three, Eckert and Mauchly took this as their starting point to develop BINAC and UNIVAC, and were probably little influenced by subsequent reports of other design groups. Four, ERA began at this same point with the information about EDVAC filtered through Pendergrass at the Naval Communications Annex. Thereafter, ERA personnel consulted frequently with the NCA group on design and application and with the Whirlwind group on circuit designs. ERA received the IAS reports, but usually too late to be very influential. Five, some work at Harvard on magnetics proved valuable to ERA and EMCC, but the threads are too difficult to unravel given the surviving records. Six, we should not be misled by attention paid to component development into thinking there were several different design approaches in the period 1946 to 1950. Here, von Neumann's influence in logical design through the 1945 "Draft Report" is paramount. Seven, electronics advanced rapidly in these years in response to several new needs and this heavily affected computer design. Contra Goldstine, such advances are not ancillary; indeed, implementing the logical design effectively required such advances, and here the MIT reports on circuits and components are at least as important. Eight, IBM absorbed lessons from all these groups, thus making their task easier in the early 1950s, though they, too, learned through a series of similar R&D projects in the late 1940s.[15]

For our comparison we need only acknowledge the starting point of machine design in 1946 as EDVAC. The principles under girding this machine design (it was constructed at the Moore School between 1945 and 1950) became the starting point for BINAC/UNIVAC, the IAS machine at Princeton, the ERA 1101 (and the ERA Atlas, its predecessor), and the Raytheon design. IBM machines follow from the IAS design; eventually ERA and UNIVAC designs merged into a single 1100 series. Exactly how the ERA and EMCC systems differ is the subject of this and the next two chapters. Using these systems, a comparison is provided between the work and trajectories of the two firms.

Even with the experience of ENIAC and intense discussions among the best people in the computer design activity at the time, Eckert and Mauchly, as well as members of other groups, still faced an uphill task to convert all these concepts and ideas into an artifact. Even the name UNIVAC came later. For several years, the Eckert-Mauchly machine was called the EDVAC II. Many obstacles had to be overcome. Staff had to be assembled; workspace had to be found; and above all, money to finance the activity had to be uncovered. Solicitation from private individuals and groups yielded very little money. The government seemed to be the logical source of funds. As we will see below, Mauchly had been exploring this possibility for over a year-and-a-half, when they founded their new company. The contacts he made only opened doors; they did not close contracts. In an attempt at efficiency, several agencies placed their trust in the National Bureau of Standards, and it was to this agency that Eckert and Mauchly turned for funds in 1946.

The Founding of the Eckert and Mauchly Company

In mid-1946, the National Bureau of Standards conducted a survey of the state of development of large high-speed digital computing machines. Among the machines in operation listed in their report were the Bell Laboratories relay computers at the Naval Research Laboratory and Fort Bliss, Texas; the IBM relay computers for Aberdeen Proving Ground; the various computers associated with fire control devices; the Harvard-IBM sequence controlled electromechanical calculator; and the ENIAC. They listed three active relay computer construction projects: two Bell Laboratories machines under the technical direction of George Stibitz; the Harvard machine destined for the Dahlgren Naval Proving Ground; three IBM machines for the Watson Laboratory at Columbia University and Dahlgren.

In the category of machines in the early stages of construction, NBS listed only electronic machines: EDVAC, the RCA-Institute for Advanced Study machine; and “the machine being constructed by Atanasoff at the Naval Ordnance Laboratory in White Oaks, Maryland.” Last, they listed components that had been put into satisfactory operation, among which were paper tape, photographic film and magnetized metallic tape or wire readers and input devices; electronic counters, relay and cathode ray tubes as memory devices; and under “computing organs,” the various relay machines, the IBM electronic multiplying unit (“constructed in about 1937”); and ENIAC, the latter two employing electronic counters for computing.[16] It was on the basis of this information—knowledge of the EDVAC and RCA-IAS machines, and the proposal of Eckert and Mauchly to the Census Bureau—that the NBS was trying to decide on the next steps in the development of the computing field. The IAS machine, as it is more commonly known today, was funded by the U.S. Army and was not under consideration for funding by NBS. Thus, attention focused on the ideas of Eckert and Mauchly and EDVAC and the best way to build machines for the government. Eckert and Mauchly fought hard to obtain a contract from NBS for their fledging company, founded as a partnership in June 1946. Eckert and Mauchly had resigned from the University of Pennsylvania in March 1946, leaving the EDVAC project, in order to implement their ideas in a commercial setting. Commercialization of the computer was not a new idea for them.

Even before ENIAC was completed, Eckert and Mauchly began designing a new machine. Defense needs demanded that the design of ENIAC be frozen early, in the hope of having a working machine in time to be useful in wartime. One aspect left out of the early machine was instructions stored internally. In January 1944 as this planning for a follow-on machine began, Eckert wrote a description—that in legal terms

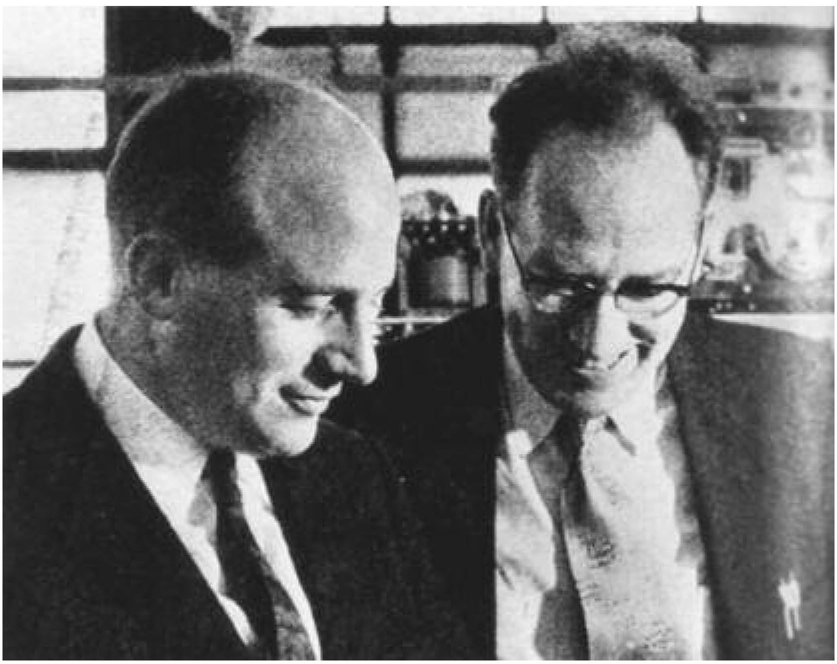


Figure 2.1
J. Presper Eckert, Jr. (left), and John William Mauchly.
Courtesy of the Charles Babbage Institute.

would later be seen as a disclosure—of a new machine that would contain a stored-program capability.[17] But little time could be spent on this new design in 1944; ENIAC consumed all the time they could give to it in an attempt to bring it into service. ENIAC was tested in the fall of 1945 and it ran problems for Los Alamos National Laboratory in November 1945. Formal dedication took place on February 14, 1946.[18] The story of the founding of the new partnership, indeed one crucial part of the story of the founding of the new digital computer industry, goes back to early 1945 in Philadelphia. The designers of the ENIAC began to engage in their postwar planning, and they slipped easily into a plan to build a faster, more efficient electronic computing machine. By the spring of 1946, a commercial enterprise was firmly established in their minds.

Within nine months of this 1944 disclosure on the stored-program concept by Eckert, Mauchly was engaged in conversation with people about their computing needs. Over the succeeding six months, he prepared memoranda describing these meetings and the nature of the conversations. For example, in early October 1944, Mauchly met with a William Madow of the Census Bureau and they discussed the "interest of the Census Bureau in having rapid recording, computing and sorting equipment."[19] Madow and Mauchly discussed the operations of the Bureau, noting that four IBM punched cards were needed per individual and information was difficult to sort across cards. The bureau used some one-half million cards per census, and any reduction in the volume of these cards "would be a valuable contribution." The conversation went so far as to include specific suggestions of the mathematical solutions that would speed the work. Mauchly ended with the assertion that these suggestions could be incorporated into a single device. This meeting was followed two weeks later by a visit by two of Mr. Madow's colleagues to the University of Pennsylvania to view the ENIAC.[20]

In the same month, Mauchly met with Lt. Colonel Solomon Kullback of the Army Signal Corps to discuss the army's use of codes and ciphers. The work involved the use of many punched card machines "for sorting and manipulating the ciphered texts which they collect from enemy sources."[21] Mauchly concluded his memorandum with the comment, "Kullback indicated that a project for the development of more flexible and faster devices for carrying out their work could be very important and somewhat jokingly remarked that he would like to order about 30 of these things as soon as he could get them." Another conversation with Lt. Colonel Kullback on this subject occurred on April 12, 1945, during which substantially more detail about the sorting and computing needs were described by Kullback.[22] In a separate memorandum written on the same day as he prepared his notes on the Kullback meeting, Mauchly made a recommendation concerning the EDVAC planning under way. He suggested that they consider a more detailed inquiry into problems of sorting, classifying, collating, and so forth, bearing on the design of a high-speed computer such as the EDVAC. He believed that it would be prudent to examine whether EDVAC could handle sorting problems "within its high-speed system" or "by simple adaptation of the input and output devices."[23] Thus, by April 1945, strong interest in the Census Bureau's and other government agencies' computational problems existed in the Eckert-Mauchly group, at least in the minds of the two principals.

The story behind the founding of Electronic Control Company, a partnership, later reconstituted as the stock company Eckert-Mauchly Computer Corporation, is simpler to tell than that of ERA. As we saw above, as early as the fall of 1944, John Mauchly had discussed problems in mechanically computerizing sorting problems in cryptology and census taking. Discussion continued between Mauchly and several government agency representatives in April 1945.[24] Early in 1946, Eckert and Mauchly participated in discussions at the Census Bureau about designing an electronic computer for the needs of the census. Between March and May 1946, they attended a series of meetings with various groups in NBS and the Census Bureau, and with navy coordinating groups.[25] It was during these meetings that specifications emerged to guide design of any new machine. Following a meeting of the Census Bureau's Committee on Tabulation Methods and Mechanical Equipment, Eckert and Mauchly were given representative problems from the Industry, Foreign Trade, Agriculture, and Population divisions of the census for solution electronically.[26] Eckert and Mauchly presented solutions and "Some Tentative Specifications of Proposed Computing Machines" to the Census Bureau on April 30, 1946.[27]

On April 10, 1946, they attended a conference of the navy's Mathematical Computing Advisory Panel. This panel had been established to coordinate efforts among the various activities of the navy interested in the fields of applied mathematics and computation in order to establish a program for sponsoring scientific research in these fields. Representatives of eight navy facilities attended the meeting, along with Howard Aiken of Harvard, Derrick Lehmer and Raymond C. Archibald of Brown University, John Curtiss, and Eckert and Mauchly. Incidentally, two persons soon to be prominent in ERA also attended: John H. Howard for the chief of naval operations and James H. Wakelin of the Office of Research and Inventions (soon to be the Office of Naval Research).[28]

Among other things, the people at this meeting decided "to organize a complete survey of this field." Perry Crawford, one of the representatives from ORI, presented an outline for gathering the necessary information in this survey, and the people present enlarged it by suggesting that in the finished statement of the problems, a section be included describing problems that had been solved by "rough and ready methods" and problems that could not be solved at all. The panel asked that each participating group prepare a report on its computing problems, that ORI survey outside computing facilities, and that ORI "obtain the services of consultants in the field of computing."[29] "During the meeting, John Curtiss of NBS discussed the requirements of the Census Bureau for a machine to be developed by the Bureau of Standards. This machine should be capable of solving least squares problems involving the solution of n linear equations in n unknowns where n is a large integer of the order of 100 or more and in addition be capable of making numbers of sorts with subtotals."[30] No mention is made in the report of the meeting that either Eckert or Mauchly entered into discussion of this matter when Curtiss invited discussion by the panel. Apparently by the next meeting of this panel on May 15, 1946, members of the panel had also received the tentative specifications and solutions prepared by Eckert and Mauchly.

These multiple deliberations resulted in a decision by the Census Bureau and NBS to engage Eckert and Mauchly for work on a "general purpose electronic computing machine" following the NBS specifications. In a letter dated May 20, 1946, John Curtiss conveyed to Mauchly the information that one or more contracts, totaling $300,000, will be let for "projects leading to the design and construction of such a machine."[31] Eckert and Mauchly then set about to fix their legal status, in order to be in a position to accept government contracts.

On June 5, 1946, Eckert and Mauchly entered into an agreement to share and share alike the benefits and liabilities that resulted from each of their inventive activities with regard to electronic computing machines. This agreement did not pertain to the manufacture of such machines.[32] This agreement was made at the same time as they designed a company, though did not legalize at this time, which they named the Electronic Control Company. In a document on the proposed company, they made some interesting assumptions and assertions. The company was to be headed by Eckert and Mauchly. They noted that some others "who have worked with [us] are available for the proposed company." They asserted that the physical plant and laboratory needs were not stringent because "[an] electronic computer is built mainly by assembling components manufactured by others. Most of the components are standard radio parts."[33] Eckert and Mauchly estimated their expense needs to be about $360,000 for the first two years and expected about $285,000 of this to come from the Census Bureau contract, though on what grounds is not clear. Contracts for other machines of the same type would absorb some of the research and development costs. They assumed they could deliver the first machine within two years, because they estimated that the research and study phase would take six months, the design phase would take the next six months, and the remaining twelve months would be enough for construction and testing of the first machine. This was overly optimistic, the research and study phase alone took over a year. But this was not foreseen on September 25 when the contract with the NBS was signed.

During the summer of 1946, Eckert and Mauchly sought funding for their proposed venture. Because of the Eckert family connections in Philadelphia, they talked with a number of people whom they thought might be interested in the new venture, but without success. In his acerbic style, Eckert later ascribed this failure to the lack of foresight on the part of Philadelphia's manufacturing and financial communities. "The real reason . . . was that Philadelphia was the center of industry at one time for the United States, but it was heavy industry, Baldwin Locomotives and Midvale Steel, and circuit breakers, and GE and Westinghouse, real heavy stuff, you know. We were talking about little bitty chicken stuff. There can't be much money in that. The other thing was, they didn't understand it; it was completely over their head. I think both the university and the banking crowd in this area were dead."[34]

Next they went to several New York investment houses. According to Eckert, these were houses backing established electronics companies, but apparently not for electronic ventures.[35] All attempts failed. Finally, rather than see the new company come under control of people outside Philadelphia, Eckert, Sr., signed a note to borrow $25,000, allowing Eckert, Jr., and Mauchly to raise "several hundred thousand" from friends in Philadelphia.[36] It seems these pledges were enough for Eckert and Mauchly to proceed with founding of a company, which would enable them to seek contracts from NBS. This partnership, Electronic Control Company, was founded in October 1946.[37]

A number of books and articles have been published about ENIAC and its successors, and each of these includes some description of the backgrounds of Eckert and Mauchly.[38] Therefore, here we can content ourselves with the briefest of description, offering more information on the group of engineers and mathematicians they assembled around them.

When John W. Mauchly's father, Sebastian J., became chief of the Section of Terrestrial Electricity in the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, the family moved from Cincinnati to the Maryland suburbs of Washington, D.C., John enrolled in Johns Hopkins University and subsequently received a Ph.D. degree in physics there in 1932. He decided to continue his work in low energy physics upon graduation, measuring energies characteristic of molecules. The computation procedure was done with the aid of adding machines. When he learned that others were doing similar work more efficiently using IBM punch card machinery, he changed his research to questions of meteorology.[39] The calculations involved in the statistics of weather prediction proved to be every bit as time consuming as those associated with molecular energy level calculation. Mauchly began to search for mechanical and electronic techniques to accomplish such calculations more efficiently.[40] It was this knowledge that became important in the subsequent development of the ENIAC.

When he first encountered Mauchly, J. Presper Eckert, Jr., was a twenty-two-year-old graduate student in electrical engineering at the Moore School of the University of Pennsylvania. Even during his graduate career, Eckert had been involved in consulting projects, and according to Mauchly, he was well acquainted with design problems.[41] Mauchly and he became friends, and Mauchly described his ideas about electronic computation during a series of meetings between the two over coffee. Eckert saw no reason why the idea was not feasible. Events in the world at large were about to make it possible for these two men to work together on a regular basis.

The war induced many changes in personnel and U.S. organizations beginning in 1941. At the Moore School, Professor Irvin Travis, a navy reservist, was called to active duty in July 1941. Mauchly applied for his position, not wishing to return to Ursinus College, in Collegeville, west of Philadelphia, where he taught physics. Dean Harold Pender hired Mauchly. At the same time, Eckert was an assistant in one of the war-related courses being taught at the school. As we noted above, both men stayed together through the ENIAC project and founded the Electronic Control Company in 1946.

Among the people who joined the new company between October 1946 and October 1948, several came from the ENIAC and EDVAC projects at Pennsylvania. For example, C. Bradford Sheppard received his electrical engineering degree in 1942 from the Moore School, and spent the next three years working in various aspects of radar development. In 1945 he accepted a position in the EDVAC project at the Moore School. His first assignment involved design of a mercury memory system for EDVAC. He left the Moore School at the same time as Eckert and Mauchly. Within a year, he had joined the Electronic Control Company and pursued the same objective of the proposed EMCC system.[42] Frances Elizabeth Snyder (later F. E. S. Holberton) was a computer, in the human sense, at the University of Pennsylvania, working under the supervision of Herman Goldstine. In mid-1945, she was reassigned to a group that was to learn how to "program" the ENIAC.[43] Robert Shaw had been one of the logic designers of the ENIAC, who along with John Davis, "made major contributions to pieces of the machine such as the accumulators and function tables."[44] H. Frazer Welsh came to EMCC in 1946 from Pan-American World Airways. By 1941, Welsh had been awarded a B.S. in engineering sciences and an M.S. in aeronautical engineering from Harvard. He spent the war years with Pan-American, where he was in charge of the maintenance and modification of instruments and electrical equipment. In particular, he was engaged in the heating, pressurizing, and hydraulic systems of the CONSTELLATION. Welsh acclimated to the world of the electrical engineer with seeming ease, and became the "proving ground" for many of Eckert's ideas.[45]

The first of the new wave to join the company was Isaac Auerbach, a young Drexel University electrical engineer. Auerbach spent a short period studying at Harvard University, where he took at least one course from Howard Aiken, before returning to Philadelphia. He later reported that when he informed Aiken that he had accepted a position at the Electronic Control Company, Aiken refused to speak to him, a condition that lasted for several years.[46] After Auerbach, other members to join the company were Herman Lukoff, a Moore School electrical engineering graduate, who had spent some time on the ENIAC project in 1943 working on circuit designs before entering the service; Lou Wilson from the Whirlwind project at MIT; and James Weiner from Raytheon, who became chief engineer. Weiner's career included wartime work at RCA as a research engineer and as a group leader in radar system projects at the Columbia Broadcasting System in 1945. While at Raytheon, he was

Figure 2.2
ENIAC project team members, many of whom joined EMCC in the late 1940s. From left: James Cummings, T. Kite Sharpless, Joseph Chedaker, Robert F. Shaw, John H. Davis, J. Chuan Chu, Harry D. Huskey, J. Presper Eckert, Jr., Herman H. Goldstine, Arthur W. Burks, C. Bradford Sheppard, F. Robert Michaels, and John W. Mauchly.
Courtesy of the Charles Babbage Institute.

concerned with the design of guidance and control equipment for missiles, and he formed and supervised a digital computer section. As a result, he brought broad and deep experience to EMCC. This group formed the core staff of the new company and they became the principal designers and programmers of the BINAC and UNIVAC.

George V. Eltgroth came to EMCC in January 1948 to coordinate the legal and patent activities. He was ideally suited for this task with degrees in electrical engineering (Johns Hopkins University) and law (University of Maryland), and sixteen years of technical and legal experience with Bendix Aviation in several divisions. T. Wistar Brown graduated from Princeton University in 1936, and thereafter worked for the Insurance Company of North America and IBM successively, after which he served

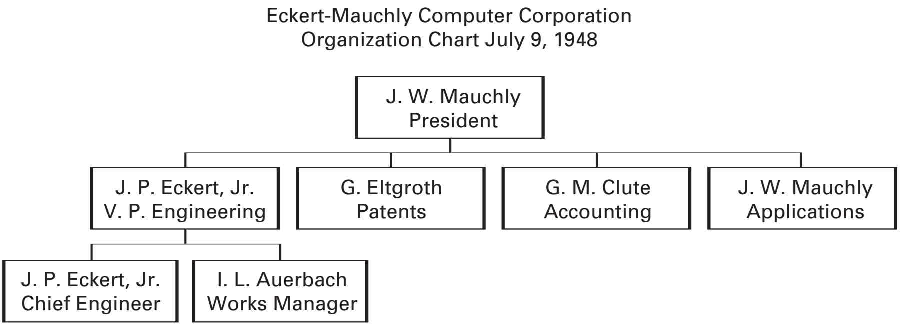


Figure 2.3
EMCC organization chart 1948.

in the signal corps from 1941 to 1945. He rejoined IBM after the war, and left there two years later, in June 1948, to become director, sales manager, and secretary of EMCC.

James R. Weiner's experience and training matched closest that of Eckert when he joined the company in late 1947. He possessed two degrees in electronic engineering from the University of Illinois and Polytechnic Institute of Brooklyn, and had done some graduate work at MIT. During the war, he worked in radar counter measures and color television with CBS. Before joining EMCC, he supervised the newly formed digital computer group of Raytheon.

However, in September 1946, as they waited for a contract from the NBS, the only professional staff members who could work on the contract were Eckert, Mauchly, and Welsh, a far cry from the staff numbers at ERA at this time.

The Search for Development Funds

The contract with the NBS, accepted by EMCC in September 1946, called for the company "to supply the necessary qualified personnel and facilities for and prepare plans, specifications, and wiring diagrams for automatically sequenced electronic digital computing machine or machines suitable for general mathematical computations and for preparation of census reports, and construct and test such models of components as may, in the opinion of the Contractors or Scientific Officer, be necessary to insure the adequacy of these plans and specifications."[47] The initial sum for the contract was $50,000.[48] While there was some flexibility in the contract, the NBS kept a tight rein on the company through its Scientific Officer for this contract, John H. Curtiss.

Curtiss elaborated later that the research and study phase would provide specifications and scale models of two mercury delay tubes for storage "complete with associated pulse shaping and regenerative circuits" and for one complete tape transport mechanism "with necessary drive motors" at a slightly higher fixed fee of $75,000.[49] Earlier, Eckert and Mauchly estimated the development costs to be between $413,000 and $671,000, representing the minimum and efficient requirements.[50] The two partners assumed they would be able to obtain other contracts for sale of the machine that would provide additional development funds. As Stern noted, "In light of the state of the art in 1946 and their financial position, Eckert and Mauchly were more than optimistic, they were naive."[51] Often, work on engineering designs was interrupted by the demand for another meeting with yet another potential purchaser.[52] Eventually several contracts were obtained and they all became the basis for the design phase of EMCC's activity. Before proceeding with a description of the engineering activities of EMCC, it is useful to describe their attempt to interest other parties in their work.

Among the many contacts made by Mauchly in late 1946 and early 1947, four stand out because of later contracts: Army Air Forces; Northrop Aircraft, Inc.; A. C. Nielson Company; and the Prudential Life Insurance Company. For example, toward the end of 1946, Mauchly began conversations with the Nielson Company, and on January 4, 1947 he sent a proposal for the construction of a group of "electronic statistical machines" to them. The two parties had agreed that one Nielson department needed two computers, twenty key tape recorders, and three printers. Mauchly estimated the costs of the first and subsequent units of each machine, including development costs discussed at the front of the proposal.[53] On February 6, 1947, Mauchly sent an apparently blind letter to the Air Materiel Command inquiring about their interest in the development of electronic computing devices. A reply dated February 21 stated that "[t]his Command is, at present, engaged in the development of an electronic continous range computer for use by flight engineers in long range aircraft."[54] Attached to the letter was a set of design criteria for the desired computer, whose diagrams bear a date of July 15, 1946, indicating that the Command had been considering this for some time before the EMCC letter. "The computer shall be designed in such a manner that, with the true airspeed in nautical miles, pressure altitude in feet, rate of fuel flow in pounds per hour, and amount of fuel remaining in pounds, automatically fed into the computer during level flight, it will continuously indicate the maximum range of the airplane in nautical miles and endurance in hours and minutes."[55] The weight of the continuous range computer "shall not exceed 120 pounds[!]" Curves of actual flight tests would be used in the integration process. This requirement could have been met by an analog computer, a conclusion I assume was reached by Mauchly. The criteria did not match those for the machine EMCC had contracted to design for NBS, and nothing further about it appears in the records of the company.

Another Army Air Forces contact is represented in a description of a requirement for an electronic computer to do overall program analysis following a general policy decision of air and defense officials.[56] The type of problems the Army Air Force wanted to solve with this machine included order 100 matrix manipulations; 6,000,000 multiplications in from one to two hours; store data of up to 30,000,000 twelve-digit numbers; and analyze data at the rate of 500 to 1,000 twelve-digit words per second. The size and capability of the machine can be inferred from these problem types, but the document went on to state them explicitly. Internal memory was to have about 5,000 registers, each holding one twelve-digit decimal number, or 10,000 six-digit numbers. The input–output devices should be capable of handling punched cards, teletype tapes, and other media. And the army wanted consideration given to hookups to communication devices, so that data on magnetic tape or similar media could be transferred directly to the computer. Printing devices were to have a range of capabilities, including multiple copies production and a graphical device for smooth curve production. Visionary to be sure, but premature by at least a decade.

The specifications for this machine design seemed to fit well with the objectives of the company at this time, perhaps given some adjustment of the numbers downward, but it seems that this design was not taken up either. The reason for not doing so seems to be connected to the interaction between Northrop Aircraft, Inc., and Mauchly. In early April, Mauchly was hired as a consultant to the Northrop Company. Northrop, and North American Aviation as a subcontractor, were working in the missile program—the Snark—of the Army Air Force, through their command at Wright Field. Mauchly spent ten days from May 5 to 16 at the Northrop facility in Hawthorne, California. Each day he spent two hours "instructing a small group on the subject of electronic digital computers." The purpose of the instruction was twofold: first, to inform the group on what had been accomplished in the field so far, and, second, "to explore the possibility of applying similar techniques to control problems encountered in the project work."[57] In his trip report on the visit, Mauchly noted that the group had no knowledge of the field; they had not seen any reports on the ENIAC or the EDVAC. To help with their education, he supplied them with the September 30, 1945, EDVAC report.

During the ten days, Mauchly and Robert Rawlins of Northrop discussed progress on the Northrop project, which Mauchly concluded was very slow. The Northrop group was investigating various counting techniques and magnetic means for storing data. According to Mauchly, because of this slow progress and because "the laboratory group working on this problem apparently have not acted upon Rawlins' suggestion [about the use of multiplexing techniques for storage]," Rawlins concluded that it would be better to have EMCC develop the needed computing and recording devices.

Design problems were being worked on with IBM multipliers, and the Northrop people were not altogether happy with the service of these machines. Mauchly discussed with Rawlins ways in which an electronic digital computer would improve the company's calculating ability.

By late June, Rawlins had entered negotiations with EMCC for a computer "to prove the feasibility of a particular method of navigation." The computer would need to fit on an airplane, though this was not stated in the final contract, so it should be less than 20 cubic feet in volume and less than 700 pounds in weight.[58] This machine would be called the Binary Automatic Computer (BINAC), and in the minds of Mauchly and Eckert would serve as a prototype for the larger machine to be designed for the NBS. The BINAC contract was let on October 9, 1947, and the machine was to be completed by May 15, 1948, for a total of $100,000. Northrop provided $80,000 of this immediately, giving EMCC a needed influx of working capital.

On March 28, 1947, Mauchly wrote a letter to Edmund Berkeley at Prudential in response to a memorandum circulated to computer machine companies by Berkeley a week before. He pointed out that the specifications presented by Berkeley "do not call for arithmetic speeds such as we will provide in an EDVAC, and it may be that you are not yet convinced that this speed is essential for the type of work which you expect the machine to do." It was Mauchly's contention that speed translated into reduced cost of operation. What Mauchly was calling for was no less than a reconsideration of how work was done in the insurance company.[59] EMCC wanted to evaluate the work to be done and demonstrate how it could be done better with their machine design. A meeting for April 1 had already been arranged.

This was not an unconsidered problem for the Prudential, however. Berkeley had already spent over six months on evaluation of the need for calculating machines in the company. In a memorandum of September 30, 1946, to H. J. Volk, second vice president, Berkeley wrote about the merits of the Harvard/IBM ASCC, ENIAC, and Bell's Relay Calculator for performing "thousands of calculating operations."[60] He reported that "to apply to business and managment problems generally, a sequence controlled calculator would need a considerably larger internal memory of perhaps 2 or 3 hundred numbers, supplemented by tables of perhaps 100,000 numbers; but it would only need a capacity to perform chains of perhaps from 10 to 1,000 steps." This was a more modest capability than that of the machine desired by the Army Air Forces. Berkeley believed that design on a machine with this capability "is rapidly progressing."

While he investigated organizations that might design and build one of these machines, he recommended that the company study the places where sequence controlled calculators could be applied. He listed twenty departments in the company that might benefit from such a machine. The possible manufacturers were RCA, ERA, Bell Laboratories, and MIT. IBM was not included because "of their paramount investment and interest in punch card accounting machines, and the great backlog of demand for such machines." Berkeley had made arrangements with Bell Laboratories to run a few of Prudential's problems as a test.

A month later, Berkeley crafted another memorandum for Mr. Volk, in which he described tentative specifications for a Prudential machine.[61] Speed of operation was similar to the ENIAC; memory size was similar to that suggested in the earlier memorandum. In most respects, these specifications were similar to those of the relay calculators of Bell Laboratories, and not of an EDVAC-type machine. Moreover, the machine should cost "not more than $10,000 to $20,000." Much was asked for little money.

Berkeley's evaluation of the field continued in the succeeding months. By mid-December, he had talked with people at many organizations involved with calculating machinery, and he had concluded that the problems of the Prudential could only be handled on a general-purpose digital machine.[62] An analog machine would not do. He reviewed progress in design of memory systems and listed the organizations involved in design, which now included the university groups. He recommended a survey be made of these groups through visits. Noticeably absent from the list is

EMCC. Last, he reviewed in more detail the problems of the Prudential that were amenable to solution by a computer, and pointed out several other business areas in which application of computers would be forthcoming, among them freight car handling and airline reservations.

Berkeley attended the Harvard symposium at the beginning of January 1947. In a 28-page synopsis of the meeting, referred to in chapter 1, Berkeley offered his superiors a much-enlarged picture of the state of the field.[63] Three items reported in this summary added to the Prudential's knowledge about the field. First, the technical description of developments went beyond any Berkeley previously provided to his employers. Second, the list of organizations involved in development had been expanded. Three were noted as in the process of building electronic digital machines: EMCC, Census Bureau, and the Naval Research Laboratory. And third, the cost of the Mark II at Harvard was given as $400,000, but he did not relate this to the possible cost of machines for the Prudential, though the figure must have been included to illustrate the possible cost of such machines.

The approach to EMCC in the winter of 1947, then, should come as no surprise to us. By this time, Berkeley had decided to approach companies for construction of a machine, and his March 24 memorandum included a comparison of possible suppliers. In his March 28 letter, Mauchly reviewed the ongoing activities of EMCC to learn more about the range of problems addressed by business groups for which the EDVAC-type machine could be used. He argued that EMCC was the best company to aid the Prudential. Moreover, the fact that most of the development costs for these new machines were being borne by the government meant that the cost of a single machine to the Prudential would not exceed $150,000.

After their meeting with Berkeley, Eckert and Mauchly prepared a two-part proposal for the Prudential on the "Application of High Speed Computing Machines to Certain Problems of the Prudential Life Insurance Company."[64] The proposal was about equally divided between a discussion of the problems faced by the company susceptible to solution by an EDVAC-type machine and a description of the machine system under design by EMCC. On April 3, Mauchly had confidentially noted in a memorandum to the EMCC engineering personnel that EMCC "has an excellent opportunity to obtain the contract with Prudential."[65] The proposal was submitted on May 16, in the hopes of landing a contract for another machine. Mauchly's eye was not only on the Prudential. There was also some hope that a contract with the Prudential would also lead to one with the Metropolitan Life Insurance Company. With these two contracts—Prudential and Northrop—as background, we can proceed to a discussion of the Census Bureau machine design and return later to a consideration of the BINAC and the Prudential machines and how they fit with the Census machine.

The search for multiple contracts provided the advantage of sharing the R&D costs across contracts. Mauchly believed the initial cost of the central computer components would be as low as half the cost given in their proposal to the Prudential, namely $75,000—a tremendous underestimate.[66]

The Census Machine Contract

In its own evaluation in June 1946, NBS had considered several methods for funding contracts to obtain a computer. They had considered issuing (1) invitations for bids on detailed specifications; (2) a negotiated contract for the entire task; (3) a group of development-type negotiated contracts; (4) a series of contracts for successive parts of an entire project; and (5) building a machine at NBS.[67] Issuing bids on detailed specifications, option 1, was difficult at that time, according to Curtiss, because "detailed design specifications cannot be written at this time" and "performance specifications can be laid down only in general terms." Therefore, the NBS and the Census Bureau would not have good control of the project. Curtiss also noted another disadvantage of this option: that of ruling out Eckert and Mauchly and George Stibitz, now an independent consultant, for financial reasons. Curtiss was wary that contracting for the entire job, option 2, would lay the NBS open to charges of favoritism. The fifth option, to do the task inside the NBS, does not seem to have been discussed at this meeting.

Attention at the meeting centered on options 3 and 4. The advantages of a group of development-type contracts, option 3, were close control and tie-in with the NBS program and insurance in case one contractor failed to complete the contract for one reason or another. The difficulty of defining the successive tasks existed here also. The fourth option had been the one recommended by Stibitz, NBS's consultant in this case. Stibitz had recommended a three-phased project. First, a contract would be let for development of an overall plan, including schematic drawings, and paper design of proposed elements for sorting, scanning storage, and printing. Second, models of critical elements proposed in the first phase would be constructed. And third, a contract would be let for the manufacture of an operating device. To meet a delivery schedule of two years, Curtiss believed that phase one should start "within a month" and be completed within ten months. Phase two would overlap phase one by starting within three months and end within twenty months. The design would be frozen at the ten-month date. "It is believed that an 'obsolete' device which is in advance over present equipment and is in actual operation will be of more real value than a succession of starts or progressively improved devices no one of which reaches completion." Mauchly had criticized this proposal and Curtiss duly noted his criticism. "This plan sounds O.K. for relay computers built of known components." Eckert and Mauchly were already well along with plans called for in phase one, and were prepared to start building models of the critical organs called for in phase two of the NBS/Stibitz plan.

Reading Stibitz's analysis of the Eckert and Mauchly specifications for the census computer, one can conclude that he saw their proposal not as a design for a new machine, but as a device for solving a specific problem. "The purpose of writing specifications for a computing device for the Bureau of Census is to define computing facilities capable of handling part or all of the Bureau's problems in a way which will be more economical in the long run, than are the present facilities. . . . Thus it is always conceivably possible to make use of a sufficient number of low speed devices operating simultaneously to attain an over-all speed equal to that of any high speed unit. . . . I have objected to many of the Mauchly-Eckert specifications on the ground that they define a special solution to the problem instead of the general solution."[68]

Two things seem to be contained in this philosophic view. First, one can interpret the second sentence of this quotation as a suggestion that relay devices would serve the census's purpose just as well as electronic devices, suggesting either that Stibitz did not fully understand Eckert and Mauchly's design, or did not see any reason why such a machine should be designed in a rush for the census problem, which would be solved with other equipment.[69] Second, the fact that Eckert and Mauchly had not treated, according to Stibitz, the general problem, though he did not elaborate what the nature of this general problem was, Stibitz wanted a return to a basic design project. It is clear that the Stibitz view was narrower than the view of Eckert and Mauchly, who saw the census problem as only one example of what their "EDVAC-type" machine was capable of solving. Thus, for Eckert and Mauchly the census machine was a step on the way to greater significance.

With such conflicting advice, what did the NBS decide to do? Curtiss sent a memorandum to the director of the Census Bureau, J. C. Capt, on

June 12, 1946, outlining the NBS position. First, NBS proposed to let two or three contracts negotiated in parallel "for the making of an overall plan, including schematic drawings and paper design of proposed components. The contractors will be furnished with performance specifications and a set of rules to evaluate proposals. A time limit of about six months will be imposed for these contracts."[70]

Steps two and three were to start construction of models of critical elements ("part of which will be done at the NBS") and let a contract for the construction of the operating device, respectively.[71] The progress made already by Eckert and Mauchly, he thought, justified entering into immediate negotiations with them. At the same time, a "carefully worded letter" would be sent to other possible contractors, such as IBM, NCR, GE, and Westinghouse. Curtiss reviewed the NBS's reasons for proceeding this way, not the least important of which was that Eckert and Mauchly would be eliminated for financial reasons if a full contract were to be let at this time. Meanwhile, planning for a central government computing agency, already begun at NBS, should be continued, and plans should be made for NBS to seek funds for and organize such a facility.[72] NBS circulated a two-tiered proposal for a research study contract and a development contract. This request for proposals was sent to a few of the major manufacturers, and two responded: Raytheon and Hughes Tool, though Hughes did not submit a request later for a contract.

Raytheon began operations in the hazy days following World War I, when it began to construct vacuum tubes. These were gas-filled tubes used for a variety of purposes. But the 1920s and 1930s were a difficult time for small manufacturers of tubes. The major companies, RCA, General Electric, and Westinghouse controlled the market to such an extent that contracts for radio components specified that they had to be purchased from major companies.[73] This situation endangered the small company, but the Boston backers did not withdraw their support from Raytheon. Defense needs in World War II saved Raytheon. During the war, they were a principal supplier of magnetrons, a small power tube used in countless radar systems; they also built radar systems and other electronic equipment for the military. The company emerged from the war a larger, stronger firm. After the war, they continued this emphasis on military components and equipment; by the 1950s, Raytheon was a principal supplier of triodes, rectifiers, and klystron tubes, and later entered the transistor field.[74]

Laurence K. Marshall, president, decided after the war that the company should enter new fields. For the field of computation, Marshall hired George Stibitz as a consultant at the time that Stibitz was engaged in helping NBS define specifications for contracts in the area.[75] As we have seen, NBS was interested in two machines: one for the Census Bureau and another for several agencies of the Department of Defense. Raytheon submitted a bid. Raytheon received a contract from NBS in the fall of 1946 to design a system, and in August–September 1947, submitted a preliminary design for an automatic digital computing system, the design that was to become the RAYDAC.

Raytheon benefited from their proximity to Harvard. Many members of the new design team had been trained under Howard Aiken. Among the early people at Raytheon were Richard M. Bloch, Robert V. D. Campbell, James R. Weiner (who joined EMCC in September 1947), Charles F. West, John E. de Turk, and Murray Ellis.[76] Bloch and Campbell had been assigned by the navy to the staff of the Mark I in 1944. Campbell, whose background was in communications engineering, had worked on the electrical design of the Mark II. These special-purpose machines were electrically controlled and mechanically driven. The RAYDAC would be electronically controlled.

Slow Start for EMCC

With the signing of the contract with NBS on September 25, 1946, EMCC believed that it was only a matter of days before money would be available and they could begin to make financial arrangements, rent quarters and hire people.[77] This was not completed until the last week in October. As noted above, the contract did not specifically outline the tasks to be performed. On November 12 Curtiss wrote requesting that EMCC submit "a program of work to be performed under your contract. . . . It is essential that the Bureau be informed at this time of the machine components for which you believe the construction and testing of models will be necessary."[78] Bureau personnel planned to visit EMCC during the week of November 18. In a report of November 21, Edward Cannon and Curtiss reviewed NBS progress, noting that the EMCC contract had been let and that two of the four other firms contacted about parallel studies sent affirmative replies.[79] In at least a partial response to Curtiss's request, Mauchly and Eckert believed it was necessary to construct and test models of magnetic tape input and output devices "in order to insure the adequacy of the plans and circuit diagrams."[80] Cannon also found during the meeting that EMCC believed that work on input–output devices at Ordnance was relevant to their design and requested access to the Ordnance work.[81] Inasmuch as some work on magnetic tape had been done at the Moore

School under Eckert's direction, Mauchly wrote directly to the Ordnance Department requesting that the summary report by J. Chaun Chu be made available to them.[82] This request was also made known to NBS; it occasioned Curtiss's memorandum to Harry Diamond at Ordnance on December 11 asking for information on developments on input–output devices accomplished at Ordnance.[83] This information was about to be presented to the January 1947 Harvard Symposium.[84] At the beginning of 1947, Diamond agreed to furnish complete information.[85]

Eckert set out to develop a detailed design for delay line tubes for storage, a device he claimed to have invented during World War II when he worked on a radar project.[86] Basically, the delay line is a tube with a viscous medium for transmitting acoustic or electrical signals. The tube has a transmitter at one end and a receiver at the other end, and the signal is circulated through the tube as often as desired to store the signal. By way of an electrical circuit at the receiving end, the signal can be diverted to other parts of the computer system without loss of the original signal, which can be recirculated in the delay line for later use. For this reason, the design is particularly suited for a computing machine, because the data can be stored until needed for a computation, when it is diverted to another part of the machine, and the original data preserved. The early delay line storage built for BINAC, for example, contained a mercury tank of 18 channels, each of which could hold 32 words of 36 bits each. Those designed for UNIVAC had 100 channels, each of which could hold ten 91-bit words. Each of these memories held approximately 1,000 pulses per channel.[87]

In their first progress report to NBS, EMCC reported that "a great deal of effort had to be spent in locating and purchasing the special equipment and supplies essential to the constructing and testing of [the] design and models and possible component devices."[88] The delay was caused by the necessity to have the technical personnel comb "surplus channels" rather than attempt to acquire the tools from manufacturers. Shop facilities were organized and construction of mercury delay lines for test purposes had begun.

EMCC divided the task into six parts.

(1) Memory: besides the mercury delay registers, the group investigated other methods, such as beam deflection tubes.

(2) Electronic circuits for arithmetic and control units: here, also, an array of circuits suitable for several memory systems were under investigation. "Present study is aimed at simplification of equipment without loss of flexibility."

(3) Magnetic tape materials and reading and recording heads: "since test methods for such materials are not standardized, all promising materials are to be subjected to comparable tests." (This is similar to the findings of ERA at this same time.)

(4) Key-operated input mechanisms and automatic output printers. EMCC decided that already designed equipment would be the best solution to problems here.

(5) Servo devices for controlling tape: "the accelerations needed to achieve the desired tape motion have been shown to be easily achievable," though the report did not describe what tests had been done to ascertain this.

(6) Logical design: the group noted only that special control features which might allow more compact and efficient problem coding had been devised.

Though it was to be several months before EMCC concluded contract negotiations with the Nielson Company, examination of the January 4 proposal made to Nielson reveals that EMCC was proposing the same system to them.[89] In an effort to keep cash flowing, EMCC contracted in late February to construct two modified panels for ENIAC, soon to be in its new quarters at Aberdeen.[90]

In February 1947, EMCC was trying to acquire metal strips to specification as the substrate for magnetic tape. In a letter to the Indiana Steel Products Company, John Davis asked "what ultimate length of tape might be hoped for in one piece?" EMCC wanted a tape two mils thick, about 4,000 feet long. A shorter piece would have been acceptable if it were thinner and had the same hysteresis characteristics of the thicker strip. Ultimately, the Census Bureau would need tape lots of "several miles."[91]

Davis wrote R. D. Huntoon of the NBS Electronics Section suggesting they purchase the test metal tape, since this would be a development contract with the supplier. Davis went further, citing Eckert's views, to say that NBS consider letting several such contracts, in order to ensure a number of suppliers and price competition.[92] Huntoon replied that one contract for some 200 feet, enough for testing at EMCC and NBS, be let to Indiana. He went on to say that "we do not feel that it is within the terms of our contract on components for Ordnance to undertake to get several suppliers set up to insure a market. This is particularly true because both the EDVAC and IAS computer will use wire."[93] Huntoon also asked why wire was not suited to the EMCC purpose. "The wire certainly affords a much more efficient storage space utilization than any of the tapes now considered." Wire was cheap and seemed to be suitable for "basic storage." It is interesting that by this time ERA had rejected wire as a suitable storage medium for data processing equipment.

Input–output concerns were under consideration at IAS at this time also. They were corresponding with NBS about the use of Model 19 Teletype sets. Apparently, Huntoon brought the EMCC metal tape project to their attention. Replying to an IAS letter from Ralph Slutz in late March, Huntoon noted with dismay that nothing had been said by Slutz about the "tape vs. wire problem." He reported that NBS had received a detailed analysis of the problem from EMCC, which claimed definite evidence that "pulses can be spaced in channels 14 mils apart center to center on metal tape." According to EMCC he said, only half as much metal tape would be required as wire. In an earlier letter, Slutz had offered the remark that the volume of metal "tape needed for a given number of pulses is of the order of 30 times as much."[94] Huntoon was understandably confused and asked Slutz for a greater analysis of the problem at some future time.

The quarterly progress report of the Electronics Section, written in early April 1947, just a few days after Huntoon's letter to Slutz about wire recording, baldly stated that "it has been definitely decided by both the Moore School and the Institute for Advanced Study that coded information will be carried to and from their respective computing machines via magnetic wire, at least for initial operation. This decision will obtain until more can be learned about the problems of computer operation."[95] NBS would develop the input and output devices to deliver to or accept data from wire; the calculating system would be the responsibility of the respective project groups.

As an aside, an interesting development occurred in March 1947, which reveals the intense competition at this time among the various design groups. In early March, the University of Pennsylvania issued a press release describing work on the EDVAC, "a new electronic supercalculator."[96] Comparison of the ENIAC and EDVAC did not include any information that the mercury delay line to be used as memory in EDVAC had been designed during the ENIAC project, nor was mention made of Eckert and Mauchly. The same day Mauchly sent a letter to Dean Pender of the Moore School, with copies to a number of people at the Moore School, NBS, and Ordnance, complimenting the Moore School staff on the work they had accomplished on EDVAC and taking them to task for not giving scientific courtesy to Eckert and Mauchly for their part in the design. He was particularly annoyed because "according to the [*Philadelphia*] *Inquirer,* you have stated that the Moore School is 'prepared to lend technical supervision for its commercial application.'" He requested "that you reply to this letter by assuring us that in all discussions, written papers, publicity releases, and so forth, after this date, possible misunderstandings will be avoided by explicitly crediting us with those contributions which we have made."[97]

EMCC issued its own press release later in the week. They referred to the university press release, called the university's work the EDVAC I, and pointed out that not only were they the inventors of the ENIAC and the EDVAC I, but they now held the contract for the EDVAC II.[98] Apparently NBS also prepared a press release for the same day.[99] In their attempt to clarify the computer scene, EMCC stated that "EDVAC is *not* a name for any single machine built by any one organization, but is a name for a type of machine employing a new design principle." There followed a description of the principal elements of the design, and a brief account of how EDVAC II differed from EDVAC I. From this point on, EMCC referred to their design as the EDVAC II, but the problem seems to have weighed on Mauchly's mind.

Meanwhile, as the end of the six-month term for the EMCC contract with NBS neared, it was clear that more time would be needed. A two-day conference was held by the staff at EMCC to evaluate progress. Mostly, EMCC was concerned about input–output and sorting speed.[100] Succinctly, the problem in sorting was that card machines were very good at this task, and EMCC acknowledged that sorting was "the operation on which an EDVAC may be poorest." "Although magnetic tape feeds are considerably faster than card feeds, the fact that binary rather than decimal sorting is to be used offsets this gain by a factor of 3 or 4." Their plans called for tape feeds with a rate of 20,000 decimal digits per second. Each ten-decimal digit word would be obtained in about 0.5 milliseconds. They projected that obtaining a word from a mercury tank would take about the same amount of time. This constituted a gain of only about 2.5 times the card-sorting rate. What worried them was that machines to be used for scientific computing tasks that did not involve sorting would contain gains of 100 to 1,000, a bad comparison for EDVAC II.

EMCC engineers considered reducing the size of the tanks to decrease the retrieval time there (this would double the number of vacuum tubes to be used); running input and output tapes simultaneously (which involved more control circuitry); go further than this and maintain simultaneous running of internal operations and tape reading and writing;

and try to develop ways to transfer input–output data in blocks rather than word by word. After considering the changes in equipment required for each of these options, they concluded that reduced tank size and simultaneous running of internal operations and input–output devices was feasible. Another alternative considered was a doubling of the internal pulse rate, keeping the tanks at the twenty-word size. Reliability concerns led to the conclusion that smaller tanks were preferable. The added hardware to achieve this reliability, largely production line items, raised no special issues for them.

Considerable time at this conference was spent on coding questions. Coding for reading and writing on tape, subroutine calls, and start and stop orders were all discussed. Two examples will suffice to give the flavor of this part of the conference. First, the team believed it was essential to provide a conditional transfer of control and convenient to have an unconditional transfer order. Thus, two orders "c" and "u" were provided. They saw a problem in how to terminate a subroutine and change the control back to the original program. Since a subroutine might be used for a number of purposes in a single program, the closing transfer order could not be placed as the last order in the subroutine. Instead, the final subroutine instruction directed that the control be returned to register 000. This location would contain the instruction inserted there as part of the original program.

There was a further complication. Because orders were designed to occupy only half a register, to use space in a register efficiently, another order was designed so that the first half of this register contained the order to begin a subroutine and the second half contained the instruction that would set up control at the end of the subroutine run. The subroutine program was designed to return control to the second half of the register that originated it.

Second, there were many differences between ENIAC and this design in the start and stop orders to be used at various times in the machine's operation for checking and monitoring purposes. Desirable operations included an "initial clear" button to bring everything in the machine to a new standard condition; a "one operation" mode (in contrast to "continuous") employed a manual push button; a "reader start" began the input from a tape; a stop condition implied a "resume" instruction; and they considered the addition of an instruction to "read the typewriter" so that data and instructions could be entered manually. EMCC also considered a few instructions that were analogous to the coding scheme of ENIAC. For example, they considered a "one word" instruction, a finer "one operation" instruction, which corresponded to the "one addition time" on the ENIAC. They concluded that too much control equipment would be needed to accomplish this and so did not consider it further.

In the progress report submitted at the end of March, EMCC noted only that "discussions relating to the instruction code for the machine have led to the formulation of a system which is believed to be appropriate for a general purpose statistical machine. These matters are closely related to circuit design and economy of equipment. In a few days a report on the tentative code will be prepared for evaluation and trial by Census Bureau and Bureau of Standards personnel."[101]

Instead, in the report they concentrated on the hardware developments for memory and tape drive devices. They reported that test equipment for experiments to determine optimum repetition rates in mercury delay registers was being set up, and with the results of these tests, a final design would be done. Scale models of flip-flop and other basic circuits were under construction, as well as a pulse counter for control of the tapes. The servo devices for controlling intermittent tape feed were also in the test stage.

Needless to say, they were far from ready to submit "plans, specifications and wiring diagrams for an automatically-sequenced electronic digital computing machine." EMCC needed an extension for their contract. In their letter to NBS, EMCC stated that "the reason for time extension . . . was to enable the Contractors to construct the test components beyond that contemplated in the original contract." Curtiss reminded them of the contract requirements. "[T]he Contractors are hereby requested to construct working models of (1) two mercury tube acoustic delay lines, complete with associated pulse shaping and regeneration circuits, so arranged that they will carry the same pulse pattern in synchronism. (2) one complete tape transport mechanism, including necessary drive motors." There is a bureaucratic coldness in the letter, especially in Curtiss's suggestion that the terms be fulfilled by May 15, 1947.[102] The extension, granted March 13, went until June 15, however.

The supplemental agreement contained a very important addition. As noted above, the original amount of the contract was $50,000. Work in the first six months indicated that the original thought that there was no way of predetermining the total costs for the completion of the contract was correct. In late February, Alexander and Cannon recommended to Curtiss that the contract amount be raised to $65,000 (later increased to $75,000).[103] Such an amendment was made to the contract effective as of April 21, 1947.[104]

The Proposal to the Prudential

A detailed consideration of the Prudential contract sheds light on at least three areas. (1) The proposal revealed EMCC's progress in design of applications and assessment of the machine's capability, which supplements information in the reports sent to NBS; (2) at the same time, it provided evidence of the considerations that slowed EMCC's progress on the NBS contract; and (3) it highlights EMCC's emphasis on applications. While Eckert and Mauchly, particularly Mauchly, evaluated the Prudential's tasks and designed ways that EDVAC II could handle them more efficiently, they had that much less time to complete the design of the machine. But if EMCC had not expended this effort on applications, the entire process of machine design might have been slowed anyway due to insufficient development funds, and it might have had as little reception in the market as early ERA systems as a result.[105]

The first part of the proposal outlined the way the machine would handle three principal activities of the company: premium billing, mortality studies, and group insurance. For each activity, EMCC described the machine's approach, the number of people required to use the machine, the cost to the company of the basic service, including the cost of the machine, and the cost to convert the punched card and other files to magnetic tape. They emphasized that the cost of conversion was a one-time cost. One example given of cost savings involved people in premium billing. In the old scheme at Prudential, some 180 people were involved in this effort, 150 caring for the files and 30 people typing changes. The typing pool, according to EMCC, would be cut in half with the use of a computer system, with 15 printers running a single shift to make out the bills. With the files all on magnetic tape, the machine ostensibly would replace the 150 file clerks, or so the proposal implied.

The tape reels were designed to hold 4,000,000 digits, and each policy was assumed to require 200 digits on average. In 1947, the Prudential was carrying approximately 4,000,000 policies, making the required number of reels of tape 200, a straightforward ratio. At four minutes running time per reel, 13.3 hours would be required to run through the 200 reels, plus some small amount of time for calculation. Inserting a doubling for external manipulation of data, another doubling for checking, and some time for comparison, EMCC estimated that keeping the file on the machine would require 75 hours per two-week period. Adding time for the computation of dividends, recording of payments, and valuation of policies, led to a working week of 63 hours for the machine. EMCC suggested two machines to avoid downtime and for cross checking. Listing all the people for the accomplishment of these tasks under the old method (653) and those required for running the tasks on the new machine (65), EMCC believed they had a clinching argument in the expected reduction of personnel by a factor of 10. They did not compare outright costs of personnel against the machine costs, however. The machinery costs came to $373,500, which could be reduced to about half under a scheme to distribute development costs. No mention was made of the costs to be absorbed, if any, under the NBS contract. "The first computer would be completed in somewhat less than a year if Prudential makes arrangements to start fairly soon. This would include a few key tape recorders and several printers. The remainder of the equipment would require three to four months more."

The second part of the proposal contained a detailed description of the order code to be used in the machine, called Code C-2 (dated May 7, 1947). The code contained twenty instructions for such tasks as division and graphical output. EMCC noted that less than a dozen instructions "would provide for all the possibilities which can be achieved by machines with much more elaborate codes." They noted that more extensive codes could serve only two purposes: "convenience to the coding personnel" and "saving of memory space by making the instructions more compact and saving of machine operations time in certain cases." The extended set of instructions in Code C-2 was intended to accomplish some or both of these purposes.[106]

Included with the code plan was a general description of the components of the machine. EMCC presented detailed design specifications of the tape system and how data would be recorded on the tape (with no more than 20 percent loss of space), the typewriter operation and speed, the contents capability of delay line memory, and methods of checking. They also offered some comments on the manner of operation of the control circuits. Incidentally, the information provided to NBS at this time did not contain this level of specificity, yet EMCC was six months into the NBS contract.

What was the Prudential response to this proposal? On May 24, Edmund Berkeley prepared a memorandum for Prudential management evaluating the proposal.[107] He decided not to make detailed comments on the proposal, but noted that it would be possible to do so. "For example, perhaps the figure of 653 clerks saved in the premium billing problem should be nearer 500. Or, perhaps a magnetic disk rapid memory would be preferable to a mercury tank rapid memory." He wanted instead to focus on "the question which now needs to be answered. Have we reached the point where we can say to John W. Mauchly and

J. Presper Eckert of Electronic Control Co. that we intend to make a contract with them for an installation of electronic information machinery in the Prudential?" The answer depended on broad considerations, he thought, not on details of the proposal.[108]

Berkeley summarized the specifications of the machine, its costs, and performance. He concluded that "success is very likely," the "saving very great," the "purchase price low," and a "safety factor in punch card system" existed in reciprocal conversion and use of punch card machinery in case of a breakdown.

An important part of the evaluation was an appraisal of EMCC. Describing the capacity of EMCC, he remarked that Mauchly, Eckert, and Welsh "seem to be remarkable for their imagination, energy, intelligence, enthusiasm, knowledge of electronics, scientific attitude, courage, modesty, and understanding of our problem as a business problem instead of a scientific problem." His reason for the latter remark: "they alone of our prospective suppliers wished to come and survey in a day or two our typical problems at no cost to us, saying it would be very valuable to them to know if their machine could not handle our problems." The company was likely to have some permanence, because they already had a contract for component design with the Census Bureau (the NBS contract), were just about to sign a contract with Nielson, and had come to an agreement with Northrop. "Judging from the experience and caliber of the men in the company, the steadily increasing demand for electronic information machinery, and the company's existing and imminent contracts, it would seem that Electronic Control is well on the road to permanence as an organization." Other suppliers, among whom he mentioned Raytheon, ERA, and Reeves Instrument (connected at that time with the Moore School), would not be suitable. The central interest of these companies was not electronic computing machinery; the companies were not as "seasoned" as EMCC; they had not begun to investigate the components necessary for business applications; and their cost figures were "materially higher."[109]

Berkeley thought the Prudential would obtain a return on their initial investment in EMCC as R&D costs were recovered by the firm through further sales of UNIVACs to them and others. While the cost of a UNIVAC was underestimated, Berkeley expected to receive about one-third back at least.[110] Prognosis to complete the system appeared very good to Berkeley and the saving to the Prudential high. Purchase of an EDVAC II, as it was called then, would cost less than one-half the annual rent to IBM for punch card equipment. Protection for the Prudential under any contract included a design guarantee from EMCC that the system would be effective, though standard parts acquired from other firms might be inadequate in time. EMCC would promise to furnish the best available devices. EMCC would provide instruction on employment of the system to Prudential employees. Maintenance service would come with the system.

Berkeley suggested some of the clauses that should be included in any contract with EMCC as a protection for the Prudential. He wanted a design guarantee from EMCC; training for Prudential employees; spread out payments; key-man insurance on Eckert and Mauchly; and EMCC should provide service and maintenance. Furthermore, as a precaution Prudential could use Howard Aiken as a consultant on technical decisions. He noted that dependence on IBM would be reduced with such a supplier as EMCC, and in the interim IBM's charges might go down.

His recommendations, therefore, were quite straightforward. First, "we tell Electronic Control that we intend to make a contract with them." Second, "we divide our objectives according to (1) the device needed, and (2) the timetable for it." And third, he recommended that a contract be drafted. He was confident that this was only the first such automated machinery the company would try to acquire, and that the design for the EMCC machine was advanced enough that the Prudential could handle any questions about details as they arose. In early June, EMCC received "a rough preliminary draft" of a contract from the Prudential.[111]

After reading the various memos written by Berkeley in March 1947, Mauchly sent a letter emphasizing some points that Berkeley seemed to overlook. Mauchly suggested Berkeley and the Prudential give increased consideration to the issue of calculating speed. Mauchly thought the specifications named by Berkeley did not call for the arithmetic speeds "such as we will provide in an EDVAC." He thought Berkeley was not convinced that speed in the Prudential's work was essential. Mauchly asserted that in EMCC's study of problems of other companies and the census they found high internal operating speed led to cost reductions when the machine was operated properly. Mauchly stressed flexibility as an essential character of computer systems, giving rise to many solutions to a given problem, whereas a single-purpose machine provided only a one-solution path limiting operations of a company.[112]

Mauchly called for foresight in using the new system. According to Mauchly, this system called for a "complete reconsideration" of the procedures for any given task. Simple translation of step-by-step methods in use with card machines would limit a computer system's effectiveness.

The design of new procedures would lead in time to other new ways to employ a computer in a company like the Prudential. Mauchly saw their design as effective across company and agency settings, further evidence of its great flexibility. "It can reasonably be argued that only after a first machine has been operated and experience gained in its effective use can one determine with any certainty what sort of machine would be better suited to your needs."[113]

With this as a potential contract, it was time to remove the confusion between the name of the EMCC machine and the Moore School's EDVAC. As we saw above, Mauchly was already giving thought to this in March, because of the University of Pennsylvania's press release on the EDVAC. Mauchly returned to the subject of a new name in May. He wanted a "short and distinctive name." To preserve the "AC" ending that suggested a family of machines, he proposed Universal Automatic Computer, or "UNIVAC." "The sooner we use such a name, the more we will benefit."[114]

The considerations about commercial contracts, as well as other delays, prevented completion of the NBS contract by mid-May, Curtiss's new deadline. In early June, Mauchly notified the engineering staff that it was time to begin the final report on the "Census Bureau Machine," to be ready by the first of July. "It is intended that this report include circuits as well as block diagrams and specify parameter values for such circuits." The rough draft of the Prudential contract, and presumably any final contract, included a requirement for a demonstration of a mercury delay line memory and a magnetic tape testing apparatus about July 1, similar to the requirements of the NBS contract. It was EMCC's intention to satisfy both these requirements with the same apparatus.[115]

While the report was in preparation, Mauchly asked for another extension of the NBS contract to August 1, 1947. He offered three arguments in favor of the extension. First, EMCC had had difficulty obtaining some "special electric motors" for testing. Second, EMCC wanted to look into some alternative designs, though these were not specified. Third, an improved design "should" result for the additional time.[116] Ten days later, Mauchly proposed a specific work plan for the added time, which involved testing the reliability of various reading and recording methods for magnetic tape, doing such tests on a full-scale, model tape transport mechanism, and evaluating the mercury delay line storage devices using the pulse envelope system. Time would also be devoted to design of high-speed flip-flop and gated oscillators for regenerating signals in mercury delay lines.[117] NBS agreed, and the contract was extended once again, this time to August 15, 1947.[118]

In mid-July, NBS reported that EMCC had a design EMCC considered satisfactory and "was engaged in refinements of [their] design and the preparation of final reports on the design it proposes to submit to the [Census] Bureau."[119] These refinements were not seen by NBS as affecting the basic design of the machine. Work continued, according to the bureau report, on model building due to the earlier unavailability of standard equipment and parts.

The contract with the Prudential proposed a series of demonstrations of component apparatus beginning within one week after September 1, unless changed by mutual agreement. The first test was to be of the magnetic tape apparatus consisting of a revolving loop. "At least 100 pulses in each channel per inch of length of tape may be stored in the tape," and at the rate of 7,500 pulses per second per channel.[120] This type of requirement offers evidence of the kind of thing that continued to slow down the development process. In the contract, the Prudential specified that a device would be available to count the number of pulses stored in a section of tape. Such a device would need to be designed, built, tested, and calibrated. On the same day, a demonstration of the mercury tank memory was to be provided as well.

Two weeks after this test, the Prudential expected a demonstration of the transfer of information between the electric typewriter and the magnetic tape.[121] At the time, EMCC was testing a Globe Wireless typewriter "to determine the maximum speed of reliable operation of the typewriter as a printing device for computing machines." They had also tested other standard typewriter machines.[122] After two more weeks elapsed, the Prudential wanted to view the operation of a "pure" binary adder. And so it was to go through demonstrations of the tape feed mechanism and the decimal adder. In addition, several reports were due between August 15, and September 1 or thereabouts, on collation-sorting, preparation and checking of magnetic tapes, and the transfer of information between punched cards and magnetic tape. Finally, EMCC would submit a complete design and detailed description of an electronic machine, including auxiliary equipment, by November 1, 1947, after which the Prudential could exercise an option to buy such a machine under the conditions set forth in another place of the contract.[123] For all this, EMCC would receive a total of $30,000 in three installments: at execution of the contract, on September 1, and at submission of the design. There was also a penalty clause if the report, and so forth, were not delivered by January 1, 1948. The reader probably needs no reminding about the Northrop contract for the BINAC, but it should be pointed out that the order for this machine was placed on July 25, 1947, and accepted by EMCC on

August 27.[124] Everyone's expectation seemed to be that such contracts could be honored in a reasonable time. Events were to show that this was a very optimistic stance.

The attempt to honor this contract was hindered by work on the NBS report, so within a month, Mauchly was writing to Prudential Vice President F. Bruce Gerhard, only a few days after accepting the Northrop contract, asking for an extension of dates for the demonstrations. He told Gerhard that the NBS report, which would be submitted to the Prudential, "will in fact constitute the major part of the data which is called for under Item (3)" (the design and development plan for a machine).[125] Since by contract this item was not due until November 1, Mauchly noted that while "part of our program with regard to your work is at the moment slightly behind schedule, you will understand that other parts are in effect ahead of schedule." Why the letter then?

So in August 1947, EMCC was bringing the NBS machine design contract to a close in the hope of obtaining the contract to build the machine for the Census Bureau; accepted a contract with the Prudential to design a similar machine for them (most of the problem here was application codes and demonstration of equipment needed, as we have seen); and accepted a contract from Northrop to design and build a different but somewhat similar computer (this one by May 15, 1948). The total amount of the last two contracts was $130,000, or over the life of the contracts $13,000 per month average. This sum plus the NBS contract amount summed to less than half of the needed development funds estimated by Eckert and Mauchly in June 1946.

Software Development at EMCC

Many of the decisions about system design involved discussions about coding and how best to maximize the interaction among the various parts of the system. Very early in the history of EMCC, John Mauchly assumed responsibility for programming, coding, and applications for the planned computer systems. His early interaction with representatives of the Census Bureau in 1944 and 1945, and discussion with people interested in statistics, weather prediction, and various business problems in 1945 and 1946 focused his attention on the need to provide new users with the software to accomplish their objectives. In this, Mauchly and EMCC were in advance of virtually every company in the new computer business.[126] Mauchly knew it would be difficult to sell computers without application programs, and without training in how to use the systems.

And so, EMCC began to assemble a staff of mathematicians interested in coding in early 1947. We noted above that Frances Elizabeth Snyder (later Holberton) was one of the early people to join EMCC (1947). She had already had an illustrious career in computing, as one of the original members of the ENIAC computing group. Shortly after graduation from the University of Pennsylvania with a degree in journalism, she joined the Philadelphia Computing Unit at the Moore School in 1942. This group worked on problems associated with the tables being produced by the Aberdeen Proving Ground. Snyder, and another member of the group, Betty Jean Jennings (later Bartik), developed a trajectory program used to control the operation of the ENIAC during the public demonstration in February 1946. In 1947, Snyder transferred to Aberdeen when the ENIAC was moved there. She served EMCC as a part time consultant in February through April 1947, and in July of 1947, she left the civil service and became an employee of EMCC.[127] She stated later that she had actually asked Mauchly if she could join EMCC.[128]

Jean Jennings Bartik graduated from Missouri State Teachers College (now University) in 1945, where she was a mathematics major. She studied analytic geometry, trigonometry, and physics. In summer 1944, she worked at Pratt & Whitney Aircraft in Kansas City on engine work, but did not want to engage in that type of work after graduation. She applied for a job at the Aberdeen Proving Ground but located at the University of Pennsylvania. After two months, she received a letter offering her the job and she left for Philadelphia the next evening. Not long after, Bartik applied for a position as an ENIAC coder, and she, Snyder, and several others were chosen and sent to Aberdeen in June 1945 for training. After several months at Penn coding for the ENIAC, Bartik was selected to head a group to generate programs to turn ENIAC into a stored-program system. She decided not to move to Aberdeen when ENIAC moved there, and after completing this programming work she accepted a job at EMCC in early 1948.[129]

There was no organized department during 1947; Mauchly designed the process as time and machine design determined needs. Snyder and Mauchly studied the effectiveness of various kinds of computer instructions. "The objective was to devise an instruction set that gave the greatest data manipulation and arithmetic capability in the shortest execution time."[130] Many conversations occurred between Mauchly and Snyder, on the one hand, and prospective customers on the other. Snyder remembered early trips to the Census Bureau, NBS, and Martin Marietta. Later, she visited many UNIVAC I sites for consultation on programming problems.[131] As she pointed out in her interview for CBI, she had no training in computing, no courses in formal logic.[132] Indeed, when she interviewed potential programmers for EMCC and elsewhere, she asked such questions as "Did you like plane geometry?" in an effort to establish whether the people had puzzle-solving abilities, which might make them good programmers.[133] But this line of questioning did not always produce the desired result. At the UNIVAC conference in 1990, Jean Bartik reported that in the early days of UNIVAC

> We used to argue about what kind of a person [made the best programmer]. We had this little test that Art Katz worked out. We used to give these people this little test, and then, basically, I don't know what anybody else used, but their enthusiasm for doing something new was what always impressed me personally. But anyway, Hildegard Nidecker came along, who had much experience in doing calculations for the Army. And she flunked his test, so nobody wanted to hire her. Then he said, "This is ridiculous. This just proves to me that the test is ridiculous. We know that she is going to do a good job," and in fact [we hired her] and she retired from UNIVAC [in the 1980s]. So the truth is we did it by the seat of our pants, and I personally did it if I liked the person.[134]

Whatever the evaluation scheme, an effective group was assembled at EMCC.

The applications group grew slowly between 1947 and 1950. M. Jacoby joined the firm in December 1947. Dr. Arthur Katz came to EMCC shortly thereafter, in February 1948, and Jean Bartik became an employee at the end of March 1948. Four more people joined in the second half of 1948 and early 1949—M. League, V. Hovsepian, Hubert M. Livingston, and Arthur J. Gehring. Besides the special studies noted above, Snyder worked closely with Mauchly on the early codes (instruction sets) for EDVAC II and BINAC, codes C-1 through C-5. The special studies involved work for the Army Map Service, Oak Ridge, and Glenn L. Martin Company, all completed by early 1949. Snyder worked on a floating decimal routine (at one point along with Katz), a reciprocal routine, double precision operations, and reciprocal square roots. Mauchly, while working with Snyder on the code, keeping contact with potential customers, and overseeing the programming group, worked with several people on such problems as the generation of random numbers, biharmonic problems, and programs for BINAC. Bartik spent most of her energies on test routines for BINAC. She even spent some time programming chess and gin rummy games.[135]

The programming activities fell into three categories. First, there were the requests of the customers for programs to accomplish their tasks of payroll, procedural flows, accounting, and purchasing. Mauchly was especially sensitive to the need to develop programs for business applications as inducements to obtain a UNIVAC. Grace Hopper summarized some of the issues under consideration in the applications group about this matter:

> Mathematicians, physicists, and engineers can usually arrange data quite readily. The businessman must receive data in a form adapted to the sales man, depositor, and the debtor, and satisfying law and custom. Mathematics problems follow a logical development. A commercial problem must frequently pass through arbitrary phases. Mr. Smith, a vice president, wants to know how many customers as well as the number of sales of item A.
>
> The part must be shipped from the nearest depot having an excess supply provided that this depot is not more than x miles away.
>
> The commercial problem, in general, remains far more complicated than any problem a mathematician or engineer can dream up.[136]

Second, other commercial research was undertaken by EMCC to enhance sales of computer systems: collation sorting, merging, editing, tabulated examples, and integrated systems for payroll. And third, EMCC engaged in engineering studies in collaboration with the engineering design group. Besides the logical design of BINAC and UNIVAC, they investigated the logical design of the UNITYPER, card-to-tape converter, supervisory control, speed comparisons of codes, error detection, and reliability.[137]

March 1947 was an important month in EMCC, as the groups made many decisions about basic design, which no doubt is the reason Snyder served as a consultant during this time and the applications group began to grow in the following summer. As noted above, March 11 and 12 were devoted to the design conference on the EDVAC II. In the context of programming development, it is worth revisiting the results of that conference. During this conference the staff discussed the basic activities of their design—sorting speed, conversion of data from tape to memory and back, instructions for operating the tape system, displaying the memory, instructions for moving from one point in a program to another, and starting and stopping. The give and take as reflected in summary minutes of the meeting resulted in some major decisions of how the storage system would be designed and operated.[138] Census problems would require significant sorting, and if the EDVAC II used binary sorting instead of decimal then gains over punch card systems would be offset making the two systems near equal for sorting. Moreover, in systems with a long latency period, sorting would be very time consuming. Times of recovery of data with tapes were estimated to be about ½ millisecond. "If mercury tanks holding 20 words are used, the average time lost in obtaining a word from such a memory is ½ millisec." This meant that the internal speed of discriminating was comparable with the speed of the input and output.[139] Calculation revealed that the gain in sorting using EDVAC II would be in the neighborhood of 2.5, a bad comparison when other tasks on the system showed gains of 100 to 1,000. Some adjustments would have to be made. First, EMCC could decrease the latency time by using ten-word tanks instead of twenty-word tanks. They could insert some parallelism by providing for simultaneous use of internal operations and tape reading and writing. Data could be transferred in blocks rather than individually. The discussion at the meeting was done under an assumption of a pulse rate of 1 megacycle. In further consideration of the input–output issues, the group evaluated doubling the pulse rate and returning to the twenty-word tanks, but this raised reliability questions. Further study seemed needed. Virtually all of these ideas would be tried over the next year.

Some of the instructions to accomplish these operations were obvious to the group, such as the arithmetic functions. Therefore, they spent time considering additional orders to transfer data in the most efficacious manner. "It is desirable to make the orders used for reading and writing on tapes as simple as possible for the operator to use, and as simple as possible to 'mechanize' in control equipment."[140] Of four tapes, the system could run two at a time, with provision for running forward and reverse and reading and writing on different tapes simultaneously. Several instructions were to be designed for this purpose.[141] Over the next six weeks, Mauchly and Snyder designed the first instruction set of twenty-six instructions, five of which would later be dropped.[142]

Between March 1947 and May 1949, the applications group developed and analyzed ten variations of the code, or instruction set, for EMCC designs and design changes. Many similarities exist across these codes, although there are some important differences. C-1 through C-4 were based on a 2 Mcy pulse repetition rate; the next four schemes involved a 4 Mcy rate. C-9 dropped back to 2 Mcy, and C-10 was to operate on 2.25 Mcy.[143] Word sizes varied from 52 pulses per word to 104, with C-10 ending at 91 pulses per word. C-1 called for 50 twenty-word mercury delay tanks, which in C-10 became 100 ten-word tanks. Block size climbed from twenty words initially to sixty at the end. As Snyder noted, the characteristics that remained fixed throughout the code definitions were:

The handling of decimal quantities

Using excess 3 addition

The handling of coded alphabetic data

Memory size from 1,000 to 100,000 words (4 digits)

Tape servos for input and output

Parallel read-write and compute

Buffer between input, output, and memory

12-character digit words

2 instructions per word

Directly connected typewriter[144]

Figure 4.2 shows a comparison of the features of the various Eckert-Mauchly designs compiled by Nancy Stern for her study of EMCC and the sources for the data.[145]

The applications group, especially Mauchly, identified a need to provide training for incoming programmers, engineers, customers, and sales personnel. As a result, several members of the group worked on a training manual and developed a course to be offered either at EMCC or at the customer's site. The Holberton papers at CBI contain outlines and some lectures from the course offered to EMCC engineers in early 1950, with lectures by Herbert Mitchell, Grace Hopper, and Betty Snyder. The course began with defining the operating code for UNIVAC and an introduction to programming in which several short examples of coded operations were presented. Subsequent lectures included description of flow charting, types of subroutines, collation, and matrix algebra. Students spent substantial time on specific examples to understand operations like floating point, round off, problems of tape wear, and so forth.[146]

While all this coding activity was going on Mauchly, as president of EMCC, was extremely busy visiting many customer and potential customer sites. For example, in the eighteen days between October 28, 1947, and November 14, Mauchly, alone and sometimes with others, hosted visitors or traveled to out-of-town sites, including two trips to New York City and one to Chicago. There were multiple visits with representatives from A. C. Nielsen, Northrop, and Prudential Insurance. He participated in drafting proposals for sales, interviewing candidates for positions at EMCC, conferences with staff on design questions, and oversaw the applications group.[147] EMCC at the time ran a six-day week, and often Eckert and Mauchly were in on Sundays. Eckert's days were an equally peculiar mix compounded by idiosyncratic work habits that sometimes had him staying around the clock.[148]

Returning to the discussion of applications efforts at EMCC, as the use of ENIAC and the other computer systems of the middle 1940s showed, there was a large class of engineering and scientific problems that could be attacked using electronic computers. Mauchly, with his interest in weather problems that led him to be interested in electronic computation methods, was in a good position to know this. Thus, it is no surprise, that among the applications group there were people thinking about the solution of such problems. The better posed problems involved partial differential equations that could be solvable using finite difference techniques. Betty Snyder and Hubert M. Livingston investigated a set of problems know as the plane potential problem. This pair published an article in January 1949 in which they presented a computer program for the UNIVAC to solve the Laplace boundary value problem.[149] They set up a two-dimensional space, and used a finite difference method originally proposed by H. Liebmann in 1918.[150] The article opened with a very brief description of the UNIVAC system, including a list of the instructions to be used in the solution of this problem. As is typical in the solution of such problems, the authors set up a region, in the example a rectangular space, though they argued how irregular spaces could be examined as well, with a mesh of horizontal and vertical lines, and set up the equations to calculate approximations into the partial differential equations that led to a set of difference equations. The number of equations resulting is equal to the number of interior mesh points. Either a direct or iterative method can be used to solve the linear system of equations. The authors discussed the availability of subroutines for use in these problems, and in a company document on the subject intended for circulation, discussed truncation errors, scale factors, and times of solution.[151] This problem is representative of the types of research going on in this group in the late 1940s.

In 1946 and 1947, EMCC devoted considerable time to study of various problems in commercial and government settings. They found substantial overlap in the computational methods needed for problem solution, leading the firm to the conclusion that a simple standard design would work across several settings. In a letter to Berkeley of the Prudential, Mauchly enumerated the setting and problems EMCC examined. They first focused on problems of the census, but then studied the problems of a marketing firm (Nielsen), the Social Security Administration, the Army Air Force concerning meteorological data, as well as needs in scientific computing. "These studies have convinced us of the importance of high input and output speeds, and so far as we know our own plans for the use of magnetic tape and our requirements for the tape control mechanism call for speeds which are higher than any being considered elsewhere." Thus, they saw magnetic tape as an enormous advantage "for almost every application."[152] IBM historian Emerson Pugh wrote, "An important insight of Eckert and Mauchly was that UNIVAC would be able to read into memory a sequence of information from magnetic tape, rearrange the information in memory, and then write the rearranged information on another tape."[153] And this assessment recalls us to the preparation for the demonstrations for NBS and the Prudential, which we will take up in chapter 4.

EMCC at the End of 1947

Unlike ERA, EMCC focused their efforts more tightly on the one system EDVAC II, later UNIVAC. They faced three problems with their company. First, given the range of opinions about what designers needed to incorporate into a system, Eckert and Mauchly needed to convince potential buyers that their system would satisfy the specified needs. As a result, EMCC designed a range of peripheral devices to meet the specifications. This design program took time and money. Second, some of the opinions resulted from potential users' lack of knowledge about how the computer systems could serve their needs. In 1947 EMCC set about to design applications to meet the needs and then to educate the customer in how the applications worked to enhance their business. Third, from the beginning, EMCC remained mired in financial difficulty. Throughout 1946 and 1947, Eckert and Mauchly added more contracts to acquire the funds to maintain the staff of EMCC. They were clever enough to make the requirements of these contracts converge. The central processing unit was the same for all. The BINAC, as we will see in chapter 4, served as the proving ground for the concept. They added new peripherals to satisfy the specifications of each customer. In this way, the company staved off bankruptcy until they had to sell to Remington Rand to maintain operations. Nevertheless, throughout this period, they continued to make progress on their design, repeatedly added functions in the company, such as an applications department in 1947, to develop areas that made the UNIVAC computer system more effective, thereby instilling confidence in their customers even though systems were a long time in coming to market. ERA in 1948 and 1949 faced some of the same problems encountered in this early period by EMCC. And it is to that situation we now turn our attention with an examination of how ERA became a full-fledged computer systems company.

3

Research on the Commercial Frontier of Computing Machinery: Engineering Research Associates, Inc.

At the end of the war, Naval Computing Machine Laboratory's principal R&D focus was with specifications for components in electronic data processing systems, as was indicated in chapter 1. The NCML focus on circuitry and storage techniques carried over to ERA in 1946. Moreover, the navy wanted to be kept informed of advances in other projects, which might enhance their own work. ERA received authorization for a survey of computing techniques, and since virtually all the other U.S. projects were funded by military agencies, other projects could be compelled to cooperate with ERA.

ERA personnel began their R&D projects in time-honored fashion by searching the available literature, especially on magnetics. They obtained access to captured German documents on wire and tape recording systems research. They received reports from the navy of activities in other companies, such as the work of the Brush Development Company in Cleveland, Ohio, on magnetics. All unfinished projects of the NCML were relocated to St. Paul after the war. Out of this ERA crafted an R&D program that was quite different than that of EMCC. To appreciate ERA's accomplishment and emphases, we must closely examine their work on circuits and magnetics before going on to their graduation into computer system design.

Each project's objective had an end user in mind. For EMCC, as we saw, it was the user with masses of data to process in a repeatable fashion—users like the Census Bureau and the Prudential Life Insurance Company. For IBM, it was the standard company already heavily involved with tabulating equipment for processing data, in most respects data not different from the interests of EMCC. Indeed, each saw the other as a competitor. For ERA, the client was the navy. The principal distinction between ERA and other firms in data processing, which has been emphasized repeatedly over the years, is that the navy's goal was the analysis of intelligence data. In the late 1940s, the analysis of intelligence data was a circumscribed problem. It was not obvious to the navy, or any one else for that matter, that the computer as a universal machine could be used for the solution of all these problems, including intelligence analysis. Researchers recognized this capacity, and combined scientific and business capability in the same machine, in the late 1950s. Hence, the focus on storage systems. ERA focused on three aspects of storage systems: (1) basic magnetic substrate on a disk or drum; (2) arrangement of data on the drum; and (3) read–write–erase circuits to handle data. While some attention was paid to other storage mechanisms, they were all rejected for reasons of speed and convertibility. ERA's approach, after consulting with the navy, was to select specifications for a system and then examine these three areas to achieve the goal. The projects each had three parts to reflect those areas.

Once they arrived at a storage system design and prototypes had been built, they sought for ways to use the system for other applications, such as airline reservation systems and inventory control. Following this, more consultations with the navy were held, and larger systems with more features were proposed. Thus, ERA proceeded from Orion, to Goldberg, to Atlas. Finally, they brought a complete computer to market: the ERA 1101, a close copy of the Atlas.

The Early Computer Projects

Negotiations for the computer project proposed to ORI dragged on into the late summer of 1946. By October, ORI had transformed into ONR and Mina Rees became head of the mathematics section. Rees traveled to many installations interested in funding for computing and other mathematical projects. On October 9, 1946, she and John Curtiss of NBS visited ERA and participated in a discussion with Tompkins and others. The discussion ranged widely over the various ERA ideas, ONR's interest in the establishment of a National Computing Center, possibly in the Midwest (at the University of Chicago), and construction of machinery for the NBS. The meeting included a visit to the University of Minnesota. With respect to the computing machine proposal, a summary of the meeting discussion reported the following:

> By reading this proposal and conversing at length with C. B. Tompkins, and at somewhat less length with J. H. Howard and L. R. Steinhardt, she [Rees] understood what ERA had in mind when the original proposal was submitted. She came to agree with the motives which led the Office of Naval Research to request

> that the first proposal be withdrawn and replaced by one more ambiguously worded, in which ERA was to serve ONR, among other ways, by furnishing the personnel services of ERA personnel where necessary to carry out a survey of the Navy's computing needs. . . . Doctor Rees was not anxious to specify very firmly other research projects to be attempted by ERA under this program. She has the reasonable attitude that a person engaged in research should choose his own program.[1]

Rees saw no reason why this more circumscribed contract would not be let, and that it would be beneficial to the field.

It seems appropriate while focusing on this memorandum to digress for a moment and report on the views of Curtiss at this time and Tompkins's perception of his influence on these views. Curtiss was on "a brief survey of outstanding institutions in the Middle West." He apparently gave the impression that he hoped that a National Computing Center could be established somewhere in the Chicago area. Tompkins, in his memorandum, listed other schools in a probability order as Michigan, Minnesota, Iowa State, and Ohio State. Besides containing equipment for use by personnel at these and other universities, "the center will supervise design and construction of a second machine to be housed at, and to be used by, the Bureau of the Census."[2] Curtiss went on to discuss the NBS program for construction, and described the intention of NBS to let a series of contracts to companies like ERA for design of a "high speed digital computer." Tompkins noted in his summary, "there seems little question of the possibility of ERA being able to obtain one of the first fifty-thousand dollar contracts."[3] The summary of the meeting contains an interesting coda concerning miscellaneous topics. "From the fact that many remarks made by Tompkins seemed to influence and change the thinking of Curtiss concerning [computing problems and computing techniques], it may be concluded that the field is still fairly fluid. . . . Generally, it is believed that both Curtiss and Rees left St. Paul with a cordial feeling toward ERA."[4] What seems not to have been revealed to the visitors was ERA's planning to interest a commercial firm in the support of ERA activity in the computer field.

Just the day before, Tompkins wrote a memorandum to William Norris about five probable sources of computing machine business. Besides ONR and NBS, he cited the U.S. Army, Prudential Life Insurance, and the University of Chicago.[5] This last university might have been on the list because Tompkins had had dinner with Edward Condon, Curtiss, and Rees in Chicago during the previous week.[6] In that conversation, Curtiss told Tompkins about the contract to Eckert and Mauchly. "He also said he believed that ERA would have no difficulty in getting a contract in this program provided they will waive patent rights to inventions produced under the program."[7] Strange, since Eckert and Mauchly did not accept this condition. By December, no contract had been awarded for the computing machine project, and Clifford drafted a letter for Parker to send to the secretary of the navy.[8] The letter was delivered to the navy on December 12.[9] In spite of the awarding of the ONR contract in August 1946, containing as it did requirements for a survey, services, and breadboard models, ERA continued trying to obtain a contract for a larger computing machine project.

Project B-3001

Early 1947 was an exciting time in the new field of digital computing devices. Several projects were reaching completion. A general conference, discussed in the previous chapter, was held in January at the Harvard Computation Laboratory. ONR was arranging for a number of new projects, and machine designs were in process at many locations. But the problem of storage still plagued these designers. It was at this time that ONR engaged with ERA to explore a commercial magnetic storage system along the lines of Goldberg. This project became part of project B-3001.[10] It served as the transition project in ERA from surveys to the deeply desired computer project.

During 1947 under the ONR contract to survey computer projects in the United States, Tompkins, Cohen, Hill, and others visited a number of installations to discuss the work of those projects and other subjects of mutual interest. For this work, in 1947 they visited MIT (Whirlwind), Brown University (the solid-state delay line work of Arenberg), the University of Pennsylvania (EDVAC), Harvard (Mark II and III), and knew about the development at the Institute for Advanced Study under von Neumann. In fact, on June 18, 1947, Goldstine sent a copy of the IAS programming reports to Tompkins.[11] Through NBS they obtained the instruction code for UNIVAC.[12] Tompkins, of course, was doing this in his capacity as consultant to ONR as well as an officer of ERA. However, ONR and NBS were distributing information about these projects (and others as they developed) to a broad group of people. So, it is difficult to sort out when people at ERA learned of designs and techniques and when they incorporated modifications of these in their own designs.

ERA personnel also visited a number of navy sites and concluded from their conversations there the following:

> [It] may be said that the bulk of the problems involving extensive computation now arising in the Navy may be solved in a reasonable time by a machine much slower than many presently contemplated. However, it is true that the personnel on the ranges, for example, are not experts in the design and operation of large, high speed digital computing equipment, and they do not care to become experts in this field; therefore, one of the chief requirements in any equipment developed for them is convenience. A chief corollary of this requirement seems to be a storage component fast enough to serve as a primary memory and large enough to obviate the need for secondary memory. Because of this, considerable attention is being paid to magnetic storage systems, and development of a system is being undertaken.[13]

What is of especial interest in B-3001 is the definition of the problem: the nature of the results and the possible knowledge to be gained from other projects while the work was going on. Like NBS, ONR seemed to want to proceed with computer development by stages. There are many similarities between the Goldberg project for CSAW and B-3001 for ONR. For example, they are both magnetic storage system developments: magnetic storage drums with several heads for reading and writing, with Teletype machines for input and output. However, B-3001 was to have more generality, and would result in better, denser magnetic storage methods. Many of the research aspects of magnetic recording in Goldberg were carried over into B-3001 and intensified. "The broad purpose of the program is (a) to determine the practical limits of high speed and small digital storage area, and (b) to investigate the factors influencing proper choice of technique wherever alternative possibilities exist. The results of such a study will provide the information needed to design a magnetic storage system meeting a specific set of requirements."[14]

This revised B-3001 project was starting at the same time that a contract was being let to construct the Goldberg system to analyze data of a "Teletype nature" at a rate of 20,000 pulses per second. The drum would contain 5,000 magnetized "spots." The goal of the system in B-3001 was to analyze data at 100,000 digits per second, data that would also be packed more densely. Under this requirement, a whole new range of problems with head design, recording media, and circuit and system needed to be investigated. In short, what the navy wanted was "a magnetic pulse recording system using maximum practicable speed and minimum practicable area of magnetic medium."[15] Tompkins in a memo to Cohen noted that five other organizations were working on magnetic pulse recording, but only Harvard among them had an interest in drums at the time.[16]

Tompkins and Engstrom were sensitive about the possible conflict of interest in doing work that could be competition to the surveyed projects, so they were careful to observe protocol whenever they wanted someone else from ERA to visit a facility. They were careful to arrange the visit through ONR and to tell the hosts that it was necessary to achieve the results required by ONR. Later in October 1947, Pendergrass of CSAW instructed ERA to use whatever was available in the way of designs and concepts at other facilities to accomplish faster their navy objectives on the new Atlas being designed simultaneously with B-3001.[17] As long as they worked on government contracts for government machines, this procedure seemed acceptable.

These early designers of electronic digital machines had to face several problems simultaneously. Foremost among them was the problem of storage. The ENIAC contained only twenty accumulators to store twenty "words." This was insufficient for doing calculations automatically using instructions inside the machine. Some new scheme was necessary. A second problem was how to provide quick access to the instructions and steps in the calculation or manipulation that were stored inside the machine. And a third major problem involved the input of needed data and the output of the results. On the ENIAC, the Mark I at Harvard, and the Bell Telephone Laboratories models, input and output were accomplished through the use of regular typewriters and punched card or paper tape units. This was seen to be the weakest link in the system, mainly because of the many mechanical parts involved, but it was put aside because of the need to solve the storage and access problems first. Greater storage was paramount in the search for a high-speed computing device.

Regardless of the type of storage system under discussion, the constraints on design in these early years were the same.[18] Designers were concerned about the distribution (or density) of the signals in or on the medium and the access time to retrieve the signals. If we let, using the drum system as example,

C number of cells

R (no. of cells/inch) (velocity of the cells in inches/sec)

H no. of reading elements

then

Access Time C/RH

The number of cells is a function of the circumference of the drum and the fineness of the readable magnetization, where the latter is related to the frequency of the signal in the writing head. The higher the frequency of the signal, the smaller the area of magnetization needed. So there is a maximum number of cells for a given circumference.

The constraints offered by this element, C, can be circumvented by increasing the velocity of the surface of the drum and the number of reading heads around the drum. However, these increases bring with them other constraints. The faster the velocity, the greater the discrimination problems in reading the magnetization flux on the drum. Increasing the number of reading heads requires increased complication in the reading head circuits to control the reading process from more heads. The control of these circuits decreases the effectiveness of the reading system. In effect, designers would trade some increase in access time for increased velocity and number of heads.

Why this is a problem can be seen from a simple analysis of the number of circuits needed for a drum storage system. Each of the cells has a unique address. A clock circuit provides an identifier for each location as it passes the reading head. This clock circuit also regulates the actions required. One circuit must know what location is in front of the read head; one circuit must know what location is in front of the write head; and one circuit must know what location is in front of any erase head used. Additional circuits are required to tell each head what to do. In addition, there was a need for a discriminating circuit to know where to put something, either something entered from input, moved within the system, or sent to an output system. Each circuit required modification if any changes in the basic relationships among the components of the system were made. These elements of the system were encountered in Goldberg, Demon, B-3001, and Atlas, hence the ERA emphasis on circuits. The number of circuits in this system was significantly larger than the number for Goldberg, but the problems were the same, so the two systems were pursued simultaneously.

Conferences for this revised B-3001 started toward the end of February 1947, apparently between Tompkins and ONR personnel. By March 10 Tompkins had met with Cohen and George Hardenbergh to discuss "the preparation of the list of components for computing machines . . . and to start additional researches concerning magnetic storage of pulses." Three groups would do the pulse work, led by Coombs, Rubens, and Gutterman, respectively. ERA wanted to redesign the reading and writing heads and use an electric signal in the head circuits that was referred to as a non-return-to-zero. Rather than return the current to zero, or make it go negative to reverse the magnetization on a site, a steady current was applied with positive and negative spikes to convey information. Determination of what steps to take to accomplish this design work was assigned to Cohen.[19]

Cohen responded in two weeks with a twelve-point program concerned with head, media, circuit, and system problems. Further work was to be done on head shape and size, lamination for improving the efficiency of high-frequency response, the size of gaps between the heads and the magnetic surface, and the materials out of which the head was made. Possible new research on media components would be balanced with research on placement of these components on drums. For example, ERA wanted to determine the properties of a drum with alternate segments of magnetic and nonmagnetic material. ERA would design circuits for different characteristics of signal, such as return-to-zero (RZ) and non-return-to-zero (NRZ), run tests on the feasibility of long-period recycling of data, and develop any special circuit equipment needed for the head and media program.

To accomplish this research, Cohen listed a number of pieces of equipment that would be needed. Among the list was a rolling mill for preparing lamination stock, a dry-hydrogen annealing furnace, two additional oscilloscopes ("at least one should be of the type having x, y, and z axis input, with single-sweep feature, for photography"), and "a device for generating signal patterns typical of NRZ."[20] The oscilloscope purchased at this time was a Dumont Type 348, which had a driven sweep and a z-axis amplifier.[21] The oscilloscopes were used to reveal the shape of signals at various points in the storage system.

A month elapsed before the steps proposed by Cohen in his March 24 memorandum became part of ERA activity. In mid-April, ERA and ONR agreed that the R&D aspects of magnetic storage in Problem 1-H from Goldberg be transferred to B-3001.[22] And on April 28, Cohen wrote to Gutterman and Rubens calling for a meeting on May 5 to discuss their outlines of work to be performed to satisfy the objectives stated in his March 24 memorandum. Following the May 5 meeting, meetings took place weekly.[23]

The company was astir. It was in early April that Coombs and Hill prepared their patent disclosure for a magnetic storage system and in the first week in May that Coombs sent a memorandum to Engstrom suggesting ERA build a model storage system for demonstration.[24] Their first storage system was about to be constructed. And most important, discussions had begun for the design and construction of a complete computer, the one to be known as Atlas. The group seemed to be assessing where they stood, and positioning themselves for the next steps.

At the May 5 meeting, the group divided the program into five phases:

I. Comparative analysis of systems

II. Development of circuits and a model system

III. Improvement of digital spacing and rate

IV. Erasure methods and noise

V. Narrow head and narrow track effects

The immediate goal suggested by the group "should be to produce a working model of a complete magnetic storage system." To accomplish this and put a report out as soon as feasible, the group wanted to pursue phases I, II, and III as "rapidly as possible."[25] Phases I and II would be under the control of Cohen and Hardenbergh, and the rest would be handled by the Magnetic Research Group under Rubens, with some help from the Research Instrumentation Group. They asserted in their research plan that "[t]echniques have been successfully developed by ERA for recording and reading binary digits at 0.02" per digit spacing and 20,000 digits per second counting rate [Goldberg]. The class of recording used was d-c erased, two-state, return-to-zero. The method is completely described and specified in Reports A and B (available June 1, 1947) of Project 1-H, Part II. It should be emphasized that circuits suitable for a computer storage system were not devised as part of this work.[26]

The Goldberg design became the starting point of this investigation. Examination of the photographs showing the Goldberg test facility and the B-3001 experimental setup shows an almost identical array of components.

Even though this activity was designed to produce a working machine, in many respects this was a research project. In Phase I, for example, Cohen set out to do a preliminary paper analysis of several magnetic recording storage systems, which would lead to Phase II, the building of a model storage system and component circuits. Following the model set by von Neumann in the EDVAC report and used by Burks, Goldstine, and von Neumann in their logical design study in 1946, Cohen wanted to develop a "block diagram of each type of storage system," complete with a definition of the properties of each block and a description of the probable contents of each block. This would be followed by a "list of relative advantages and disadvantages of the several types of system." During this development, he also intended to consider different types of recording states, using both return-to-zero and non-return-to-zero carrier techniques. From these two analyses, Cohen expected to make recommendations about the type of system to build, the circuit units that should be developed, and what magnetic and other information would be urgently needed to construct the recommended system.[27] A complete report would be drafted about Phase I.

Cohen expected to build the system in Phase II based on the results of phase I and assumed a rate of 100,000 cycles per second pulse rate. He wanted to test the operational features of the system "without delay." "This system will contain for demonstration purposes simple input and output devices, perhaps in the form of manually set input flip-flops, and output flip-flops, which operate neon indicators. A very simple form of drum is contemplated." Another report would be prepared about this second phase.[28]

The remaining three phases would contribute to the refinements appropriate to the system constructed in Phase II. Phase III, for example, was an attempt to increase the density of magnetic information on the drum. "Can binary digits be reliably recorded and reproduced at a spacing of 0.010" and a rate of 100kc?" The group wanted answers to such questions by October 1, 1947, "in order that the results may be applied to a model storage system." They confined their attention in this phase to d-c erase techniques with a return-to-zero carrier under the assumption that "non-return signals can be expected to reduce the effective digital spacing by perhaps 50%." Phase IV would examine a-c erase, and if it proved effective, suitable heads would be designed for the system. The track and head widths and intertrack spacing were to be analyzed in Phase V.[29]

B. H. T. Lindquist sent a copy of this research proposal to Tompkins, who replied on May 15 that "the program as outlined seems excellent." Tompkins requested some modifications due to recent information he received from Aiken at Harvard.

> At Harvard for the Mark III, Magnetic Drums have been developed. These drums have a hard nickel surface with 10 binary digits per inch. The drums are 20 inches in circumference and rotate at a speed of 72,000 rpm. A special head has been designed with 1-mil laminations. Professor Aiken was enthusiastic about this head design, and it is proposed that ERA experiments or research on head design be postponed until further information can be obtained from Professor Aiken. For reasons already stated it is believed that this information

> should not be obtained until we can furnish quantitative information in a report on our Magnetic Drum. In summary, then, it is requested that research on Magnetic Head design be deferred or abandoned, that a report with tabulated data concerning our Magnetic Drum be prepared, that a copy of this report be carried to Professor Aiken and that information concerning his head design be obtained at that time.[30]

Along with this recommendation came Tompkins's request that estimates of cost for this research program be prepared. Cohen responded on May 27 with a detailed list of costs and needed personnel. He estimated the program would take seven months and require the services of four research engineers (men like Cohen and Rubens), three assistant research engineers (men like Chaloux and Hardenbergh), three electronic technicians, and two mechanical technicians. There would also be modest time required of shop personnel.

While no evidence appears to survive that Aiken's evaluation was solicited, several ERA reports about magnetic system research were written at this time. There was the Coombs and Hill mid-June report on "Storage of Numbers on Magnetic Tape," which we used above to describe the nature of the Goldberg design, a draft of which was available as early as April 28.[31] This report would appear to be a summary of part of the Goldberg project. We know from Cohen's contemporary and later writings that the Goldberg design was the basis for the experimental work on "Selective Alteration."[32] The longest report, prepared by Rubens, contained an extended account of "Magnetic Recording of Pulses for the Storage of Digital Information." This report is also a part of the Goldberg project. The investigations on tape quality, reproducibility of signal, head design, maximum signal amplitude, tape velocity, head displacement, and so forth, were discussed at length. The maximum pulse rate considered was 70,000 pulses per second, reading signals at a drum velocity of 400 inches per second, with satisfactory pulse rates of 30,000.[33] The results of this work on Goldberg by Rubens became the launching pad for his efforts on B-3001, when Problem 1-H was transferred.

Cohen wrote a report on "Internal Storage by Magnetic Recording," dated June 30, which can be taken as his analysis of the above two reports and their applicability to B-3001. Some overlap with the Coombs and Hill report exists in this study. But the bulk of the report is devoted to discussion of the nature of the signals generated in the circuit when dynamic recording using different types of signal carriers occurs. "The specific manner in which digits are transferred to and from tracks on a storage drum is subject to a certain degree of choice"—the first reference to selective marking, what would become in the next few months selective alteration.[34] Conclusions about the shape and design of heads, along lines noted by Rubens in his report, suggested the research program of the next few months. A striking part of this report is an attached extensive bibliography on magnetic recording, including most if not all of the important publications and reports on magnetic recording of speech and music from around the world done between 1937 and 1947. The information from these and other reports was included later in the *High-Speed Computing Devices* report and volume.[35]

George Hardenbergh prepared a last and less well-known study from this same month on input and output media. Hardenbergh considered the problem of converting data on paper tape, punched cards and magnetic tape and wire to signals that could be read into (and of course out of) storage. He dealt with the problem of synchronization between input–output and internal storage that is inherent in the use of delay line storage, a problem that does not exist in electrostatic storage tubes. In the latter case, there is an upper limit of input speed, "determined by the accessibility time of the storage system." He noted that floating-point decimal and binary arithmetic circuits had different influences on computer design. And the type of problems to be solved on the machine permit simplification of the input–output equipment in some cases. Toward the end of the report, Hardenbergh briefly analyzed the nature of the problem of using magnetic recording equipment for input and output and what forms of equipment would facilitate maintenance. His references included the Burks, Goldstine, von Neumann discussion of the logical design of computers, the manual of operation of the ASCC at Harvard, and Wallace Eckert's *Punched Card Methods*, among others on machines in use such as ENIAC and the Bell Labs models.[36]

These conclusions about the purpose of the various reports is confirmed by the content of the bimonthly progress report for the period May 1 to July 1 to ONR for contract 240. Two projects were described: the computer survey and design of machines. For the design project, B-3001, Cohen reviewed the work on non-return-to-zero and selective mark insertion. Construction of the experimental system was under way. He noted "the order of magnitude of the goal sought is 100 digits per inch, at 100,000 digits per second." An appendix to the report summarized the work done in studying the effectiveness of several types of recording and reproducing heads.[37] Using a generator made by the Measurements Corporation, Boonton, New Jersey, Rubens tested a number of heads acquired from Brush, manufactured for sound reproduction, and heads made at ERA. The ERA ring design proved to have better response curves at high pulse frequencies than the Brush heads. The ring heads seemed to be very promising and were used during work over the next two months.

Designing Circuits

Following the assessment of the Goldberg work and establishing a work agenda for the remainder of the B-3001 project, the group at the beginning of July 1947 began in earnest to design circuits and improve the heads. We can pick up the threads of these activities in the logbooks of Cohen and William Keye. Keye had a bachelor of electrical engineering from the University of Minnesota, and had previous experience at the Airborne Instruments Laboratory during the war and at RCA as an applications engineer for two years after the war. Keye opened his notebook on July 22, 1947, noting that "the writing in and out of signals in the selective mark insertion system seems to be a problem of major importance. I have therefore been working on a system suggested by Arnold Cohen."[38] Starting with a basic pulse generator driving one of the screens of a 2D21, the plate of the tube is connected to one side of the writing head and a 0.003 microfarad condenser connected to the other. Discharge of the condenser and a pulse to the grid of the tube sent a current through the head. The resistance was kept low by using only thirty turns of wire on the writing head. The results were not successful. Several changes were tried, including replacing the head with a small air core high Q inductor to check the wave form, as well as returning to the original circuit and putting a 100 ohm resistor in series with the coil. Since the resulting wave form was not symmetrical about its midpoint, the circuit was deemed unsuitable.

Besides the problem with the pulse shape, the Q of the writing head would need to be adjusted to employ more than 30 turns of wire. In fact, the heads would need 200 or more turns to accommodate the frequencies contemplated. Keye tried to modify the circuit to make more turns possible and still preserve the waveform. But this circuit inverted the polarity of the pulse from positive to negative. He concluded, "The easiest and quickest way for test purposes is to add another amplifier stage which will reverse the polarity of the pulse."[39] This led him to consider the possibility of generating a sinusoidal pulse through the 200-turn writing head using a blocking oscillator and a high Q resonant circuit. A 6AQ5 driving the writing head would "probably be satisfactory." Keye constructed a Hartley oscillator using a 6J5 tube, but it was not possible to make the oscillator block on one pulse. Instead, it would block after a train of pulses, which was unsatisfactory. By making the output of the pulse generator drive the oscillator tube grid position, the blocking was correct but the pulse shape was governed by the pulse rather than the constants of the circuit. Further modifications were called for.

By the end of his first week on the problem, Keye had adopted a logical lineup of elements in the circuit. The power amplifier used the 6AQ5 as the output tube. Employing a gating amplifier meant that they could continue to use the Keye modified circuit and the gating circuit would reverse the pulse from negative to positive. The tube chosen for this gating circuit was the 6AS6.

Testing of this circuit revealed problems. The gating pulse of the 6AS6 changed the plate current pulse and would not allow the signal to be amplified by the 6AS6. The change in the plate current at the beginning and end of the gating pulse produced a signal on the grid of the 6AQ5 amplifier causing an extraneous writing pulse. "This circuit was then abandoned."

Arnold Hendrickson suggested another modified circuit, using a multivibrator. Keye recognized that this circuit would not perform all the necessary functions; the coincidence circuit would write too many pulses on the magnetic tape. But consideration of this circuit, and its failure to serve the purpose, led him to the design of the final writing circuit. "It was then thought that the solution would be to put a flip-flop circuit after the (6J6/2) gating amplifier. Since the output of the (6J6/2) gating amplifier are [sic] positive pulses the flip-flop would flip once and would have to be manually reset. This did not work because of the time lag in the flip-flop. Before the gating pulse came along the pulse was over."[40] In the final circuit, the current amplifier was modified to use two 6L6s in place of one 6AQ5, and some minor modifications were made in the pulse forming circuit in the connections of the 2D21.

It is instructive to note that the Harvard designers of the Mark III magnetic drum storage computer used essentially the same design. "The input voltage is delivered to a pair of mutually inverted gates [using 6AS6s]. A record pulse applied to the suppressor grid of the pentodes is gated to one of the inverters in the 2C51 envelope, which in turn drives the grid of the corresponding power tube. . . . A damping resistor is provided in parallel with each recording coil, to reduce the oscillations which occur when the power tube is suddenly cut off." The current amplifier used the same 6L6s as employed by ERA.[41]

This description illustrates the intensive R&D process in ERA to design the circuits to control and activate the read–write head circuits. The Harvard example shows other groups involved with drums grappling with the same type of problems. The circuits for other storage systems are somewhat similar. It is not unreasonable to ask, then, whether any of the other projects influenced design at ERA.

In several interviews with ERA personnel long after the events, many of them when asked about their knowledge in 1947 of other simultaneous projects, referred to the work at IAS and MIT as influential on ERA developments.[42] There are contemporary references at ERA to the Burks, Goldstine, von Neumann June 1946 paper, "Preliminary Discussion of the Logical Design of an Electronic Computing Instrument."[43] The second report from IAS by Goldstine and von Neumann on "Planning and Coding Problems . . ." was dated April 1, 1947, and reached ERA only in June, as we noted above. Moreover, when it was received, it would have been useful in Cohen's logical work, not in circuit design. We can conclude that the most substantial influence would not have been these reports from IAS, but the "First Draft of a Report on the EDVAC."

What information did the ERA engineers have about the work at MIT? To ascertain this, we need to appreciate where the Whirlwind project stood on say January 1, 1947. Redmond and Smith report that in early 1946, Forrester set up ten working divisions, seven to carry out technical work on block diagrams, computing circuits, mathematics, storage tube research, mercury delay lines, and mechanical elements. "The task of the Block Diagram Group, as described by its head, Robert Everett, was 'in general, to devise a complete computer system, including definitions of all components, interconnections of these components, [and the] sequence of operations.' At the same time that the Mathematics Group would be a source of information about computer requirements, the Block Diagram Group would be ascertaining machine computing techniques, programming techniques, and component designs for accomplishing computing, storing, switching, and programming." Using the information in the ENIAC and EDVAC reports, "the young engineers under Forrester's direction spent the year of 1946 exploring possibilities, selecting from these the arrangements, designs, requirements, practical limits, characteristics, theoretical models, and bench-test items they found promising. Some worked on hardware designs. Some worked on mathematical procedures that would be amenable to machine handling and machine solution. Some worked on the problems peculiar to creating a machine—the analyzer and its computer—that, to work properly, must consist of an integrated system of component electronic and mechanical mechanisms and submechanisms." By the end of 1946, enough was known about the parts and their connections to confirm a view that a "pre-prototype" machine should be built. Forrester began planning for construction to begin in July 1947.[44]

During 1946 and 1947, the Whirlwind group released a series of reports, known as conference notes, engineering notes, and memoranda. The substance of these reports varied over these two years, but for our purposes two of the memoranda issued in early April 1947 have special significance. Memorandum No. M-66 on "High-Speed Digital-Computer Circuits" contained a section on "Principles of Circuit Design."[45] The memorandum asserted, "All computer circuits can be constructed with flip-flops, gate tubes, crystal rectifiers, and delay lines as the building blocks. Also, buffer, or power, amplifiers, inverters, and pulse reshapers will be necessary."[46] For these circuits, "conventional types of tubes should be used." These plus a knowledge of the number of pulse intervals needed, to determine the pulse repetition rate, and the physical size of the circuits will allow one to estimate the characteristics of the circuits. From their calculations, the pulse amplitude for the Whirlwind I computer was selected on the basis of the transfer characteristics of the 6AS6. There followed an analysis of the use of this tube in gate circuits.

Different ways of driving the grid were described to achieve fast rise and fall times of each pulse. For example, if the grid is driven positive and a clipping resistor is used in the circuit, the rise and fall times introduced will be appreciable. To achieve short rise and fall times, load resistors must be kept small. While much of the discussion in the memorandum centered on the use of such circuits in accumulators, the information was circulated at a time when ERA was considering these same problems. Yet I have found no evidence that anyone at ERA received these reports at this time.

What we do know is that Cohen visited Forrester at MIT on March 6, 1947, just before his March 10 conference with Tompkins on the nature of the B-3001 project and his March 24 memorandum outlining the research program for B-3001. Cohen made four pages of notes at that meeting.[47] Forrester began by describing the electrostatic storage tube contemplated for use in Whirlwind. Then they turned to a discussion of the storage system using flip-flops. Forrester described pulse widths and shapes, and talked about their project's desire to shorten the pulse width. One note by Cohen concerns the use of 6AG7s and the need to "stick to pentodes for high speed work." Using these tubes as gates required that the suppressor grid should be driven positive. Cohen noted that reports would be forthcoming on circuits, flip-flops, and clocks.[48] He must have been referring to Memorandum No. M-66. The review above of this memorandum, however, showed that it did not contain the range of information developed by Cohen, Keye, and the others in the spring of 1947. This is not to degrade the efforts of MIT, but to show the robustness of the research and development efforts at ERA.

With this in mind, let us pick up the thread of Cohen's own work in the summer of 1947. In a logbook entry of July 7, Cohen summarized the objectives of this project, referring to a letter sent by Coombs to Tompkins dated June 25, 1947, and his own end of June progress report to ONR, which we cited above, on magnetic recording storage prepared for the component survey.[49] He reported that non-return-to-zero (NRZ), two-level signals would be included and selective mark insertion, as opposed to continuous erasure and rewriting, would be used. He noted that "[t]he earliest application foreseen for the techniques worked out under this program is a low-grade computer, which will possess reasonably large storage capacity but will not impose very great requirements on the speed of accessibility. C. B. Tompkins visualizes 100 milliseconds as adequate accessibility time."[50] The reason cited for choosing NRZ is that twice as many digits can be placed on the tape as happens with RZ carriers. This result had already been reported to ONR in the July 1, 1947, bimonthly report. Selective mark insertion (SMI), later to be called selective alteration, presented two "outstanding" features.

1. Stored data are *non-volatile,* i.e., do not vanish on failure of power or of an electrical component. Magnetic recording with SMI appears to be the only method of storage, which is *both* erasable and nonvolatile.

2. Eliminates the necessity for writing sequentially with each successive cell. Writing can be done on a "duty-cycle" basis.[51]

There followed some consideration on the way in which the timing track would operate and some of the limitations of the system.

For the next week Cohen thought about the circuits necessary to accomplish these tasks. On July 14 he sketched in his logbook several block diagrams for the operation of a 64-cell storage unit, twice the size of the Goldberg experimental system. These diagrams were for the circuits governing the timing track reading head, the binary counting circuit with cell finders, the printing head (i.e., writing) circuit, and the reading head circuit. Within two days, he sketched a proposed pulse-printing circuit using thyratrons (2D21s), with diagrams of what the pulse shapes should resemble. With only a few modifications, this is the circuit that appears in Keye's logbook under the date July 22, 1947.[52] During the remainder of July, Cohen continued to concern himself with the pulse shapes in the various circuits. It is clear he was working closely with Keye during this time, because there is a close correlation between the information in the two logbooks. For example, on July 24 Cohen was speculating in his logbook on the shape of pulse needed in the writing circuit (referred to at this time as the printing circuit). He thought that this could be done with a pulse-forming network in the output circuit. Two days later, Keye's logbook shows a new block diagram for the writing circuit that includes the power amplifier he had been working on for a week and a new pulse-forming network.[53] However, while Keye in August continued to work on the writing circuit, Cohen shifted his interest to cell-locator circuit issues. The new ideas introduced by Cohen and exploited by Keye are consistent with those discussed between Cohen and Forrester in March. But they were not simple to implement, as the long experimental process at ERA shows. This is similar in many ways to the extended R&D program at EMCC. We can conclude that transfer of these ideas from one laboratory to another was not a simple process for either firm.

For the locator circuit, Cohen proposed to use a Rossi-type coincidence circuit to detect the occurrence of the desired pattern. The original Rossi circuit was developed in 1930 for counting coincidences from several Geiger counters.[54] The simplest gate after the war employed a 6SA7 or a 6L7, because of their multiple grid inputs allowing a single tube to be used in the circuit. In a computing circuit, however, it is desired to have the possibility to generate or not an output based on one or two signals. For this, a tube with two plates is needed.[55] Basically, Cohen wanted to use this Rossi-type circuit for the six-fold (2^6) binary counting circuit. He believed it would be satisfactory if the average delay per stage were very small. If all stages have the same delay, then it is possible to establish the delay time for a series of changes to occur. "The variable spacing of the cells this effect would produce becomes serious if the set-up time becomes an appreciable fraction of the pulse period."[56]

The group experimentally determined that tubes such as the 6SN7 and the 6J6 had various delay times between stages, in agreement with NDRC 1942 reports on electronic counters. Cohen thought that Forrester's "flip-flop using 6AG7s may be capable of delay times" of the right order of magnitude.[57] He concluded that a different approach to the problem of cell location "appears desirable." Cohen turned to ring counters,[58] and in ERA's report to ONR at the end of August, the circuit diagram included shows a Boonton pulse generator feeding a ring-of-ten counter.[59] This decision must have been made early in the month of August, because the final diagram of the storage system represented in Keye's logbook and used in subsequent experiments on head design and placement is dated August 8.[60] No further entries on the subject appear in Cohen's logbook, except the notation that "considerable detail is contained in a report on selective alteration of September 1, 1947." However, notes of a meeting between Coombs and Cohen on August 26 reveal that they were anxious to "make a convincing demonstration" that the principles used in designing these circuits were sound.

By the beginning of September, in all its essential features the work on the magnetic storage system was complete. Selective alteration using a non-return-to-zero carrier was recommended as the writing format. The report contrasted reading and writing data on the drum by a recirculating technique similar to those used in acoustic delay line memory systems with selective alteration. In a recirculating technique, separate heads are needed for reading, writing, and erasing. Signals from the reading head would be reshaped and fed to the recording head. Using selective alteration, the erasing head could be eliminated. The circuits were designed in such a way that when the new signal is written onto the magnetic drum the previous signal "is completely eradicated." The report went on to describe the physical features of the system by which this could be done.[61] ERA had achieved the objectives set out in the contract. However, the group still saw the system as somewhat experimental. "It was not intended, during this initial phase, to refine or simplify the various circuits beyond what was necessary to collect the desired performance data. Consequently many circuit units appear more cumbersome than might be desirable for computer applications. It is confidently felt, however, that efforts directed along these lines can produce the required refinements without great difficulty. Such efforts are appropriate to a later phase of this work."[62] The progress report stated that ERA had plans to continue the investigation of selective alteration and NRZ signals.[63] Incidentally, at the request of Mina Rees, copies of this report were forwarded in late September to Aiken at Harvard, Alexander at NBS, Bigelow at IAS, Crawford at ONR, and Weaver at Rockefeller. "No further distribution is planned at this time."[64]

Their perspective of the system as experimental is also clear from several other documents that survive from September 1947. On September 8, Coombs, Cohen and Keye met to discuss next steps. They agreed to “start immediately a design of a circuit to test the reliability of the system.” They wanted to complete this circuit by September 15 and “simultaneously start to improve present circuits.”[65] This was confirmed four days later in a memorandum from Coombs to Tompkins. “We are in quite complete agreement with your contention that some sort of long period reliability test should be devised and run in a selective alternation NRZ memory system. It must be emphasized, however, that the present experimental system requires considerable polishing and improvement before we can be satisfied, even on the basis of engineering judgment, that it is capable of reliable operation.”[66] One thought was to develop this test circuit in the context of another project, though no specific project was mentioned.

Besides some work on head design and the slight modifications of circuits, the project was finished.[67] The December 1, 1947, summary report by Cohen and Keye is little different from the September 1 document. Other projects for the navy were absorbing the time of the group members. One final note with regard to this project needs to be made. On October 17, Cohen sent a memorandum to Norris concerning items of possible patent interest from this project. Three items mentioned were “the application of non-return-to-zero to the magnetic recording of pulse-coded information; the combination of selective alteration with non-return-to-zero; and the use of a single-action pulse forming circuit.”[68] All three of these items were pursued and are included in a patent filing by ERA in March 1948.[69]

Cohen and Keye felt confident enough to request permission to present their findings on the data storage system at the March 1948 Institute of Radio Engineers national meeting in New York City. Permission was granted and a transcript of the presentation, which was taken from the December summary report, was circulated by the company after the meeting. There was a deliberate design in the company’s decision. In a memorandum by John Howard to Ralph Meader, Howard pointed out that “[w]hen A. A. Cohen and W. R. Keye give their paper at the National IRE Convention in a few weeks, a new vista will be opened to numerous people throughout the country—people who have been faced with problems, which can now be solved by the use of magnetic storage. These people are our potential customers, and are all competitors for patent protection in the specific application of magnetic storage to their problems." He recommended that:

> the IRE paper be slanted to serve as a come-on for potential customers . . . but that we do not reveal to the general public our techniques in so much detail that our customers have no further need of our services.
>
> ERA hold *immediately* a large-scale symposium for all personnel who might have ideas as to possible applications.
>
> ERA immediately set up a small staff whose total and undivided attention is given to:
>
> a. actual construction of a small unit with input, output, storage and computation features for use in practical demonstrations to customers and for patent purposes. Coombs has been proposing this for some time. . . .
>
> b. correlate all suggestions as to uses and techniques and advise management of their implications—both as to commercial use and patent protection.[70]

While this formal memorandum was sent to Meader on March 12, it had been composed on March 4. The ideas in the memorandum must have received quick acceptance from Meader, Tompkins, and Norris. Recommendations one and two of this set were acted on with dispatch. In fact, the symposium called for was held on the morning of March 5.

Seventeen members of the engineering staff attended the meeting. Coombs opened the meeting by describing the basic parameters of the magnetic drum storage system. Next, he described several possible uses, such as numbers and instructions for an automatic computer; use by Western Union to replace tapes at relay points, increase flexibility, and cut costs and maintenance in operations; replace punched cards; index information systems; and high-speed multiplexing over a radio link.[71] Most of the ideas for use offered by others at the meeting were not very much advanced over the first description of products circulated at the time of ERA's founding. They had to do with mass communication problems, as a consultant for wage rates in connection with punched card machines, storing credit information for quick reference, use in storing data for maps and weather, and rapid recording of experimental data. One of the most intriguing suggestions at the meeting by Howard was the coupling of the drum with an IBM machine. In the next few days, a number of the attendees submitted further ideas.[72]

Howard received so many suggestions at the meeting that he was able to assemble them into fourteen categories in a twelve-page memorandum to Meader prepared on March 8.[73] The categories seem to be ranked in order of importance. Seven ideas were grouped in a category on "sequence control applications." These ranged from automatic control of looms for pattern weaving and of machine tools to automatic control of guided missiles and airplanes. This latter idea was already part of the analysis by Tompkins of the needs of the various missile development groups of the navy as part of the components survey. In the "dynamic inventory applications category," we find airplane reservations systems, large-scale inventory problems, the census, and automatic accounting systems for banks. Over the next two years many of these ideas were presented by ERA to corporations and the government with some success.

On March 17, for example, J. H. Bigelow and M. Rubinoff of IAS visited ERA "to determine if ERA could supply a magnetic storage system for use with" "the machine under construction at Princeton."[74] Bigelow and Rubinoff witnessed a drum system in action and expressed an interest in acquiring one as an interim solution to their storage needs while the Selectron tube was in development. They desired a device "to store 1,000 binary numbers, each having 40 digits, with a maximum access time of 10 milliseconds." Coombs pointed out that to do this a drum with fifty magnetic tracks, of six-inch diameter, and a rotation period of 6,000 rpm would be required, at a time when ERA drums operated at speeds of 1,000 rpm. The IAS group was anxious to obtain a system, and agreed to accept only the drum and heads (50), if it could be done quickly. Bigelow and Rubinoff thought that a delivery time of three months was acceptable, but if it went to nine months or more, they preferred to wait for the Selectron.

The interest of IAS in a drum storage system is not surprising, because while Andrew Booth was at IAS in 1947, he designed a small drum for them. Booth described this design in his report "General Considerations in the Design of an all Purpose Electronic Digital Computer." Warren Weaver sent a copy of this report to Mina Rees, who wrote to Herman Goldstine for further information. Booth wrote, according to Rees:

> The magnetic tape or wire is fundamentally a serial memory of medium speed. There are several methods, however, of making a high speed, parallel operation memory on a magnetic basis. One of the best ideas is to record the data (in the form of magnetic pulses normal to the surface) on a cylinder capable of rotation at high speed (1,000 rev/sec). By having a number of pick up heads in each of the digital channels, and suitable switching arrangements, data could be recorded and read off at better than 10^{-4} sec. per complete number. This rate compares favorably with current ideas on electronic memory . . . and completely outclasses delay line memories of equivalent complexity.[75]

Rees remarked to Weaver, and then to Goldstine, that "these claims for magnetic memory seemed to me a bit optimistic." Weaver told her he thought the IAS group had achieved the performance reported, except "for the need of an electronic switch which would make it possible to get into a channel at each of several points, to reduce read-out time." Rees asked Goldstine for clarification, because it was her belief that no magnetic drum that could compete with electronic memory had yet been constructed. She finished her letter with the comment, "I am finding it very hard to separate fact from fancy in this field, for claims seem too often to be made only on the basis of unfulfilled hopes."

Goldstine responded on July 2 that he thought "Booth's statements regarding the magnetic memory may be capable of realization but are not so at the present time."[76] He continued "I believe the following is the state of the art at the present moment: Pulses can be put on wire certainly with a spacing of 50 pulses to the inch and probably safely with a spacing of 100 to the inch. With spacing of 50 pulses to the inch the wire can be read or written on at speeds up to 50 feet per second. These statements represent a very brief summary of engineering experience here." But he went further than this by speculating that "[i]t seems with the present types of reading heads that the upper limit on the frequency [sic] of pulses that can be read is the order of 30,000 cycles per second. This figure could undoubtedly be much increased if the heads were redesigned to lower the inductance of the coil associated with the head and also if certain capacities were reduced. So far as I know no work had been done in this direction." As we have seen, Cohen had reached the same conclusions at ERA and, within a few days of this, he embarked on a program to redesign circuits and requested that new heads be designed as well.

The Goldstine letter to Rees is remarkable because he went on to discuss the nature of the mechanical as well as magnetic problems associated with a drum storage system. The information could be used by the people at ONR to assess the accomplishments of ERA when the ERA reports arrived at ONR in July and September of that year. For example, Goldstine began with a hypothesis of a drum speed of 600 inches per second (ERA was using 400 at the time) and packing at 50 pulses per inch (ERA had achieved this in Goldberg and was trying for 100). Goldstine's hypothetical drum was 3.2 inches in diameter (10-inch circumference) with 40 channels width. The drum revolution period would be 60 rps, at a time when "commercial motors run at 1800, 3600 and 7200 rpm" (30, 60, 120 rps). On the hypothetical drum, the storage size would be 500 words.

At this size and speed of drum, it would take approximately eight milliseconds to access any given pulse on the perimeter. With eight pole pieces, access times of one millisecond were possible. "This is an order of magnitude lower than the results stated in Booth's paper but would require, I believe, very little engineering, i.e., the order of about three months. . . . The speeds indicated in Booth's paper are about an order of magnitude faster than the data I have given above. It would probably be much more difficult of achievement and might take possibly six months or a year to develop."[77] Goldstine did not believe any "work has been done in this direction," and IAS was not planning to develop such a magnetic memory.

As Goldstine pointed out, Booth was interested in magnetic drum developments, though at this time he seemed to be using wire rather than tape on his drum model, but IAS was not going to pursue it. Booth left as planned in the summer of 1947 for England. The Booth drum required that the drum's entire data had to be erased and renewed each time new data was written on the drum, making it a less effective device.[78]

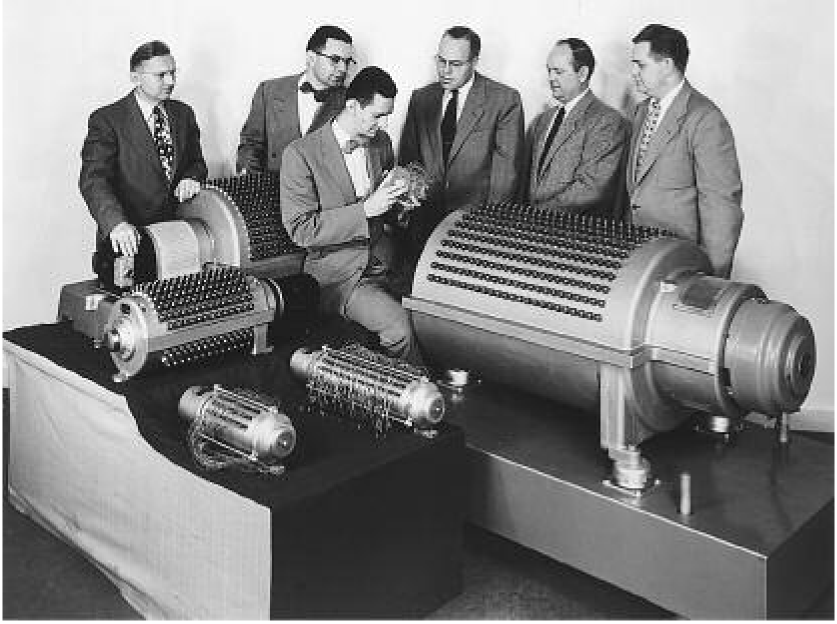


Figure 3.1
A selection of ERA drums for sale. Pictured from the left are ERA engineers John L. Hill, Arnold A. Cohen, Frank C. Mullaney, Robert L. Perkins, Arnold P. Hendrickson, and William R. Keye.
Courtesy of the Charles Babbage Institute.

The ERA selective writing and erasing technique circumvented this requirement of the Booth drum. Also according to Goldstine, he tried to interest NBS in doing or supporting magnetic drum development and learned that Alexander and others had already talked to General Electric. GE thought "they could build a drum to run at 120 revolutions per second with a packing of 100 pulses to the inch and with the separate channels located $\frac{1}{4}$ apart without too much development work."

Between this exchange of letters between Goldstine and Rees in mid-1947 and March 1948, IAS completed their work on the "arithmetic organ" spoken of by Goldstine as their emphasis in 1947 and were anxious to obtain a storage system to test it. Hence, their trip to ERA to assess ERA's accomplishment. ERA was prepared to sell, but Bigelow did not place an order.

In mid-May, NBS was considering buying drum storage equipment "for use in a small serial-digit computer which they are planning to build." Norris in reporting this enquiry to Meader requested he have cost and delivery date estimates made.[79]

Estimating the cost of such a drum system turned out not to be a simple task. In mid-June management assembled to discuss the problem.[80] Coombs stated that ERA did not have a firm design on a standard drum "to use as a basis for making a cost estimate." He believed the design drawing prints could be assembled in a week, but this drum design would probably not be satisfactory to NBS. "Mr. Norris then agreed to shelve this issue for the time being."

During the meeting, the group discussed the possibility of designing a standard storage system. They believed a number of customers besides NBS and IAS would be interested, companies such as Automatic Electric and Baird Associates. Coombs estimated that if the company were willing to invest between $3,000 and $5,000 in the task, an adequate design for estimating purposes could be prepared. Engstrom agreed to analyze the situation and report back to management.

Why not move aggressively on this design? By this time, ERA was heavily involved in completing the components survey for ONR, deeply immersed in a design of a major computing system for the navy, the system to be known as the ERA Atlas, and negotiating with NBS for design of yet another computer based on the needs of the U. S. Air Controller's office. These tasks precluded shifting personnel to an investment venture of the firm at the expense of assured contracts. Once again, ERA seemed to be shifting such venturesome activities to funded projects in the hope that eventually a more widely marketable product would emerge. In time this strategy would succeed with the design of the ERA Atlas.

The ERA Atlas

Navy personnel at CSAW did not stand still waiting for ERA to accomplish its assigned tasks. James Pendergrass took an active role in assessing navy needs. He was one of six navy personnel to attend the Moore School lectures in the summer of 1946, the only person from the intelligence group OP-20-G. Twenty-eight people in all registered for the course.[81] Pendergrass recognized that the machines being described in these lectures were more versatile than calculators, and they were suitable for analysis of intelligence data.[82] Pendergrass received such stimulation from the summer school he began to visit with persons active in the computer field, especially the Princeton IAS group. In October 1946, he prepared a report on the lectures and proposed a variation on the EDVAC machine (as described by von Neumann) with an instruction repertoire, an order code that would be useful in the cryptography business.[83] By January 1947, he was in a position to write another report, which contained a review of the problems of interest to navy intelligence and "programmed" them to demonstrate the possible versatility of his hypothetical machine.[84] These classified reports received a small circulation, which included ERA.

During the time he was working on B-3001, Arnold Cohen read these reports.[85] Cohen later characterized these reports by saying "the whole thing was a pretty good sales talk for the utility of a general purpose machine, compared with all of the special hardwired mechanical things that they had been using at that time." Cohen went on to say, "that was a good source of education for me."[86] But Cohen could not remember just when during the B-3001 project he read these reports. It could have been anytime between February and July, since the result of navy deliberations's about Pendergrass's ideas gelled into the Task 13 contracts to ERA that commenced on August 4, 1947.[87]

Negotiations for the Task 13 contract began as early as May 1947. On May 16, Tompkins met with Lt. Comdr. Blois of OP-20 to discuss the project.[88] Blois stated that this project would have "the highest priority" among all NCML projects, and so they discussed personnel available. Tompkins agreed to initiate thinking on the subject immediately and stated that the project would probably be in the hands of John Coombs because of his involvement with Goldberg. According to Blois, the military characteristics for the computer were already on their way to NCML in St. Paul. In fact, the project already had an account number in the navy (N-1500-G), and Tompkins thought it appropriate to begin expending time on the project.

The objective for the project as stated in various navy documents sent to ERA was to "perform research and investigations and conduct such tests as are necessary to permit the preparation of detailed engineering specifications for a special machine. Furnish BuShips with resulting specifications."[89] Once again, ERA was asked to design a system first. Tompkins's memorandum to Engstrom in May 1947 contains the initial thinking at ERA for this project.

> A storage facility required in the Military Characteristics can be met only by magnetic drum at present. I pointed out to Lt. Comdr. Blois that work on modifying a Goldberg drum for use in a computing machine is already proceeding under our ONR contract. . . . I suggested that no immediate steps would be taken to design computing circuits, for a complete report of the circuits designed for project Whirlwind by Forrester at MIT is expected fairly soon. If these circuits are not published in time for use in Atlas without delay we shall attempt to get them by hand from Forrester. If sequence rather than parallel computing circuits are decided upon it is suggested that we might be able to have the circuits built up for us by the Technitrol Engineering Company in Philadelphia. I believe that very strong consideration should be given to the use of parallel computation before it is abandoned. . . . It is suggested that the maximum efficiency in using magnetic storage for programming might be brought about by including the address of the next expected command in each command, rather than expecting commands to be followed in any particular sequence. Further, it may be true that more efficient utilization will result from use of more complicated commands than von-Neumann's system—for instance—a function of (x,y) might be specified with three addresses, one for x, one for y and one for the computed value (sum, difference, product, quotient, etc.). (Samuel Lubkin originally suggested this system, with the expected next command address, so far as I know.) It is further suggested that computing functions of the machine might be pretty well estimated from reports by Lt. Comdr. J. T. Pendergrass, one of which is held by USNCML, and one of which will be transmitted to USNCML shortly, and by reports of project Sweater (N-1500-A). Dr. J. J. Eachus intends to visit St. Paul in a couple of weeks; at that time he may want to discuss Atlas in some detail and to learn in any available detail ERA's plans.[90]

So, what were available to ERA toward the end of May were the first Pendergrass report and the military characteristics, and the second Pendergrass report. The MIT reports and IAS documents were still to come. We saw above that Cohen had visited MIT in March and discussed circuit design with Forrester. The MIT group issued a memorandum on high-speed, digital-computer circuits in April 1947, but when that reached ERA is not certain.[91]

The requirements for Atlas went through several iterations between May 1947 and April 1948 when a proposed set of Atlas characteristics was submitted by ERA. On July 31, 1947, Cohen and Coombs met and summarized what they understood to be the requirements at that time. The memory was to have a capacity of 2^{16} words of 22 binary digits. This equals 65,536 words (1,441,792 binary digits). The design should be such that storage tubes could replace the magnetic unit if and when available. If electrostatic storage was decided upon, the recovery time "must be" 100 microseconds, and preferably of the order of ten microseconds. Magnetic storage would have a recovery time of the order of one millisecond. It was clear that the Naval Communications Annex did not consider magnetic drum storage as high-speed storage, and expected this to come later from some other source. This attitude continued through the design of Atlas.[92]

The arithmetic unit had to be capable of a 1 Mc pulse rate and the addition and multiplication time had to be compatible with the storage recovery time of one millisecond. The navy desired the machine to have an accumulator for each 44 digits required. They hoped to increase this to eight each later. The plan called for a full memory input time of no more than thirty minutes. The media and equipment for input, such as cards and tape, should use types and techniques available at the time. And it must be able to print directly from the medium. The speed of the output should be greater than IBM typewriter speed.[93] Coombs assumed the role of project supervisor, with Cohen and A. W. Frick as project engineers.

It is useful to compare these characteristics with those planned for Whirlwind I at this time. Whirlwind I would have electrostatic storage of 2^{11} numbers, each of 16 binary digits; whereas Whirlwind II was planned to have 2^{14} numbers, each of 40 binary digits. If each of the electrostatic tubes stored between 2^8 and 2^{10} binary digits, Whirlwind II would require about 640 storage tubes. They expected to code 32 different operations in a command scheme similar to that proposed by Goldstine and von Neumann (Atlas would use 33 operations). The block diagrams associated with this design (August 1947) were essentially the same as those described by Goldstine and von Neumann. Tompkins, who had been present at a briefing on Whirlwind on August 5, 1947, communicated this information to ERA.[94]

By August 7, Cohen had formulated an "immediate program" to pursue this project while completing the designs for B-3001. As expected, there was an overlap between the Atlas design problems and those of B-3001. In another set of notes on the "immediate program," he outlined circuit, storage, and control problems.[95] He expected to use fast basic flip-flops with tubes such as 6AG7, 6AK6, and 12AU7. A fast binary counter must be capable of extension to sixteen stages and be preset from a flip-flop register. The circuits should be capable of subtracting or adding numbers of either sign.

Cohen proposed, as a first step, to construct a drum storage system of one-eighth the total contemplated capacity. One drum, 7-inch diameter by 24 inches long, would contain 88 tracks (4 groups of 22 each) with 2,048 digits/track (2^{11}). This drum would require a thirteen-digit address. Cohen wanted Rubens's people to continue magnetic head development toward increasing the number of tracks/inch and improving the high-frequency response. The problems of control called for a literature search first to ascertain the best approaches to sequence control of the basic circuits. Sometime during this period when there were many contacts between ERA and naval personnel, Pendergrass insisted that ERA "incorporate other people's circuit developments into our designs, wherever applicable."[96]

The military characteristics arrived and were evaluated in August. A conference took place at the CSAW site among Coombs, Cohen, Eachus, Howard Campaigne, and James Pendergrass on August 19 and 21, during which the specifications were discussed. They agreed that electrostatic storage tubes would not be available for at least six months, and so preliminary designs for a magnetic storage system were under consideration, consistent with Tompkins assessment in May. The ERA group expected to formulate a plan of attack during September. "The emphasis on this project will be less on developing improved circuits and more on obtaining the correct combination of existing circuits to achieve the optimum balance between speed and flexibility on the one hand, and cost and size on the other."[97] ERA was finally involved in the computer project they had sought for over a year.

In October, ERA completed its evaluation of the storage system components and tentatively decided to use the selective alteration NRZ technique developed under Project B-3001. Attached to their October report was a version of the selective alteration report of September 1, 1947, submitted for B-3001. The report also contained a preliminary design for a storage system, which went way beyond the design for B-3001, and a "tentative" design of an accumulator.

The design began with some basic assumptions about component limits. Designing the system for use later of an electrostatic storage system, ERA decided on a parallel recording system, that is, one in which all of the digits comprising a word are recorded simultaneously rather than in time sequence. The requirement of 22-digit words meant

22 parallel tracks would be needed. At a density of 100 cells per inch and a scanning rate of 100,000 cells per second and a desired capacity of 65,536 words, 14,418 linear inches were needed on the drum surface. With 22 parallel tracks, the circumference of the drum would be 655 inches (an 8-foot. radius). This drum would have an access time of 655 milliseconds, because a complete revolution of the drum is required to locate a particular cell. Increasing the number of heads could reduce this access time. The practical limit on such an increase in heads comes about from the number of vacuum tubes needed in each head circuit and the controlling circuits for the system, as we saw above. The storage system was to be limited to 1,500 vacuum tubes at most. The electrical circuits associated with each scanning head required about eight; this restricted the number of heads to 185. In fact, the dimensions decided upon ended up with 176 heads, determined by the size of memory and access times.

One other practical limit was the number of read–record heads in a track. Previous experiments at ERA showed this limit to be 8 heads. With 8 heads the access time reduced to 82 milliseconds. From this information—8 heads per track, 22 tracks per set, the diameter of the required drum could be decreased in size to a more practical limit. By dividing the system into 8 sets of tracks, 22 tracks per set, the drum could be reduced to 82-inch circumference, or 26-inch diameter. Now, of course, added control circuits had to be added to monitor the parallel activities of the drum.

Basically, the storage system is a more complicated B-3001 system, in that there are 8 sets of 22 tracks instead of one set along with the needed circuits to control the system. The reading and recording amplifiers in the early designs were the same as those in B-3001. The locating circuits needed to be more complicated and selection circuits had to be added to select the appropriate track set. More gates had to be added to accomplish this selection. But the overall design is the same, and the group used proven techniques to accomplish the desired results. To give an impression of the design at this time, we can examine the operation of the storage system by tracing activity in the locator, record, and read circuits, as was done in ERA's October 1947 monthly report.[98]

By October 1947, a 2-digit breadboard model had been built and operated satisfactorily. But to test the suitability of the carry-over circuits a larger model was needed. At the time of this report, a 22-digit breadboard model of the accumulator was under construction to permit the testing of the reliability of the various features of its operation.[99]

During November, four stages of this 22-digit model were completed and tested, which revealed several faults in the design. These problems were discussed with Pendergrass and Campaigne on November 17–18, and some modifications were agreed on for trial.[100] Details about what was decided are not available, but from notes of Pendergrass in Cohen's files, we know that there were lengthy discussions about whether to use 1s or 2s complements in arithmetic computations.[101] The Pendergrass notes emphasized 2s complements, but a memorandum from Campaigne three days later (November 21) stated "at the moment we are inclined to favor the one's complement."[102] How these discussions affected the hardware design is not clear. However, we do know from Pendergrass's notes that the various registers were to be changed to have a capacity of 48 digits. This led to the further conclusion that the basic operation would be subtraction; zero being defined as a number with positive sign, and complements on (2^{48}–1) being used for addition.[103]

More discussions with the Naval Communications Annex took place in December during a visit to Washington by Coombs and Cohen. And in this month, work on the arithmetic circuits was confined to accumulator and register circuits, to permit further testing. A simple control circuit had been built to test the adding and shifting facilities of the accumulator (this is consistent with the concerns reflected in the Pendergrass notes of the November conference). The circuit went through a series of changes during the testing, indeed, the accumulator circuit underwent considerable modification. The triode flip-flop circuits were found to be "excessively" unstable for operation at one megacycle, and they revised the circuit to use pentodes. "Satisfactory operation of a five digit accumulator has been obtained, with very critical adjustment of supply voltages and pulse amplitudes." They expected to be able to modify this circuit sufficiently to ensure stability and dependability. Work on the input–output in the form of a photoelectric reader had begun in December also. ERA still claimed that the specifications would be ready on March 1, 1948.[104]

By the beginning of the year, ERA was busily engaged in an assessment of the "arithmetic organ" and the development of a set of operation commands. The firm constructed an experimental drum storage system of four groups of storage tracks, of four tracks each, for test purposes. As they tested the accumulator and register circuits, they concluded that there was some indication that reliability of these circuits "might be improved considerably by a decrease in the basic pulse rate."[105] Tompkins had alerted them to the fact that the Whirlwind team were assessing the pulse rate for their machine and had reduced the rate from 5 Mc to 2 Mc.[106] The time of a complete carry slowed the machine down and ERA thought they should investigate the value in slowing the pulse rate to synchronize with this delay. A decision on this issue for the Atlas did not come until after the summary characteristics report of April 1948.

The size of the memory had been reduced by a factor of four to 2^{14} words of 24 digits each. The number of groups of tracks and the number of tracks in each group remained the same. This enabled them to reduce the size of the drum to 8.5 inches diameter and 26 inches in length. The scanning rate at a speed of 3,600 rpm would be 125,000 digits per second. Thus, the average access time became 8.5 milliseconds.[107]

Other concerns arose about the memory capacity and speed of access during the conference with CSAW. Not all problems apparently were of the same size. To search the entire drum when it was only partially filled seemed too extravagant to the navy personnel. ERA evaluated the claim by analyzing the changes in address circuits needed to speed access to date. They redesigned the address circuits to include a switch in a multiplex style circuit that would adjust the number of digits used in an address downward from 11 to 8. The data would be stored on the drum in eight places then and be read at the first place on the drum a head came to in response to the first 8 digits. This change increased the average writing time by a factor of 2, but decreased the average reading time by a factor of 8. This tradeoff between storage capacity, by repeated writing of the same information, and speed of problem solution seemed acceptable to the navy.[108]

Greater specificity was given to the arithmetic organ by this time. It was composed of three principal units: an accumulator and two registers. Certain properties of these units had been agreed to by this time, but the algorithms the organ would follow were yet to be specified. The accumulator was the same as described above: holds a 48-digit number; negative numbers expressed as complements on $(2^{48}-1)$; basically subtractive, with end-around borrow; able to shift its contents to left or right up to 24 digits. A Q-register (QR), 48 digits wide, would contain the multiplier during multiplication and the quotient would be formed in this register during division. A special property of QR was vector addition. The X-register (XR), also 48 digits wide, contained the multiplicand, the divisor, the addend, or the subtrahend in the corresponding operation. The X-register also served as the extraction register for the storage system.[109]

To clarify the many issues surrounding the choice of components and to decide on the choices available, Campaigne spent two weeks at ERA in February 1948. As a result of these conferences, decisions were reached on all of the fundamental machine properties. They modified the set of operation commands that had been submitted with the January progress report. Construction of the experimental test storage system continued, and because of the delays in this and the decisions involving choices, the date for submission of the design characteristics was extended forty-five days to April 15, 1948.[110] During March, the ERA staff, which had not changed much for Task 13 up to this time, continued the crafting of the proposed specifications and system diagrams. At the same time, they continued to do experiments on the drum memory, an input system for transferring data from a punched tape (read photoelectrically) to the computer memory, and on rapid arithmetic circuits.[111]

ERA submitted the Atlas characteristics on April 15, 1948, as planned. The report consisted of two volumes, volume one contained sixty-nine pages of text describing the system and how it would operate; volume two was composed of forty-seven figures showing circuits, flow diagrams, and functions, and twenty tables listing such things as operation commands, algorithms, and control pulse sequences.[112] The system as described in this report contained all the features developed in fall 1947 and winter 1948 that we described above. BuShips prepared a letter the day before this report was submitted that modified the Task 13 description. ERA was to prepare "detailed engineering specifications, and construct, test, and deliver two developmental models of a special machine."[113]

CSAW carefully evaluated the Atlas Characteristics report during the next two months. Meanwhile, ERA continued to work on the experimental magnetic drum memory, an input system for transferring data from a punched tape to the computer memory, arithmetic circuits, changed the pulse rate to 400 kilocycles, designed several standardized types of gate and flip-flop circuits, started a mechanical design for the final drum, considered changes in the head design to accommodate production runs, continued the mechanical assembly of an experimental tape reader, and began to investigate new methods for adhering the magnetic material directly to the drum surface rather than attaching magnetic tapes to the drum.[114]

Cohen and Hardenbergh were asked to attend a conference at CSAW during the last week of May. "An important result of the meeting was the decision to operate the control and arithmetic portions of the machine at a 400-Kilocycle pulse rate." They discussed modifying some of the commands, but agreed that this was not urgent. They agreed that an appropriate intermediate goal was the construction of a “small-scale laboratory model of a complete computer.”[115] For this model, the drum memory would have a storage capacity of 2^8 12-digit binary numbers, recorded on two groups of storage tracks with 12 tracks in each group. (This was down from the four groups with 8 tracks.) The limited storage required would allow ERA to test the multiplex storage principle while retaining the full 256-number storage capacity.[116] With only minor changes, all the other features of the model were to be the same as in the summary report.

Progress during June included the conclusion that nonmagnetic 18–8 stainless steel was an acceptable drum material; whereas cold rolled steel was not. Steel rather than aluminum permitted “the machining of a well-balanced drum and shaft unit from a single piece of stock.” Head design for production and experimental work on the photoelectric tape reader continued.[117] Slowly in June and July, the number of personnel on the project increased with the addition of several assistant engineers. And toward the end of the summer, as the designs of circuits and components were finalized, principal engineers like Cohen and Coombs reduced their time on the project starting in August, shifting to another computer design for NBS, and leaving the supervision of the project to John Boekhoff.[118] Even Keye was off the Atlas project by October 1948.

Research on Magnetic Materials

We must return briefly to a consideration of ERA research on magnetic materials. Work proceeded on construction of experimental models in a fairly routine fashion throughout the fall of 1948. One of the most important new developments, which was noted in chapter 1, occurred in September and October, when ERA worked with 3M Company on a magnetic material to spray on the surface of the drum. To pick up the thread of this work, we need to return to the Cohen research plan of March 24, 1947. In reviewing problems related to the medium on which the magnetic signal was to be recorded, Cohen noted that one problem needing study was “possible plated materials, as well as materials coated directly on drum surface.”[119] It seems that the attempt to obtain material for direct application to the drum was not discussed at the time. And except for an occasional contact with 3M to obtain magnetic tape for sticking to drums, nothing further was done to investigate this problem.

On March 9, 1948, Rubens reported to Engstrom that he had had a recent conversation with William W. Wetzel of 3M about the possibility of a joint research program on the "process of recording on magnetic tape with supersonic bias," a process that had not been adequately explained at the time.[120] The proposal was given serious consideration inside ERA. Wakelin, for example, commented to Engstrom on several aspects of the proposal.[121] Following his assessment of the main points of the proposed research, Wakelin went on to note that "with regard to the scientific merit of the proposal, I believe that such studies are of value and should be undertaken. The more fundamental information, which we can obtain for application to the magnetic storage device, the stronger our position, will be technically and commercially in this field." Wakelin worried about the possible jeopardizing of ERA's patent position through this work with 3M. "If this [ERA's patent position] were unequivocally strong at present, I would consider such an objection of a somewhat secondary character. However, the research program suggested by Dr. Rubens may produce important design improvements in both the magnetic material and the recording head design, which could be used to fortify the present claims now in process in the Patent Office." He described some other possible effects of Rubens's ideas, suggesting ERA work on a device in a ternary system as well.

The proposal was placed before the planning board, of which Wakelin was the chairman, at its March 30 meeting. The board believed that the Rubens proposal was too sketchy for them to recommend any action. Instead, they requested that Rubens prepare a definitive research program, including a program for accomplishing the results. They recommended that ERA consider in more detail the patent aspects of this program and explore other sponsorship, such as the government. Both these recommendations were energetically pursued.

Simultaneously with this consideration was evaluation of the patent prospects stimulated by Coombs and others in March 1948 described above. By June the patent department prepared a report recommending policies and procedures in connection with patent protection for ERA's magnetic storage techniques. The department report noted that there was no possibility for ERA to obtain basic or fundamental patent protection in the field of magnetic storage. Many ideas dated back to 1900 and the patents of Vladimir Poulsen of Denmark. Since that time there had been a continuous and extensive development. ERA did believe that patent rights could be obtained "on a large number of detailed items." The report listed these items.[122]

Four basic ideas were at the center of the patent concepts: selective alteration; non-return-to-zero; pulsing circuits; and reshaping circuits. “These four items represent what is probably the most significant advance of ERA practice over prior techniques and therefore form the nucleus of our patent molecule.” These four concepts had been the subject of two patent filings of March 25, 1948. Coombs and Tompkins described in their filing a rotating drum for storing data in magnetic units.[123] Cohen, Keye, and Tompkins described an entire system of drum and circuits using non-return-to-zero signals for recording the data on the magnetic rotating drum.[124]

Around this “nucleus” an array of other patents could be arranged. Attached to the report was a diagram showing this array. The specific applications were the subject of the Howard/Meader analysis of March 1948. Three applications were highlighted in the June 20 report: airlines space reservation system, air traffic control, and the temporary storage of messages in communications work. “All of this material regarding potential applications will be examined for possible patent implications. . . .” With regard to the airlines system, this work continued over the next few years.[125] At the end of this patent prospects report, there was a mention of the Rubens research program, noting that ERA “will begin active work upon receipt of suitable sponsorship.”

In the meantime, William J. Field, an engineer on Task 13, who came to ERA in 1947 from Honeywell, examined the possibility of spraying a magnetic oxide suspension onto the surface of the drum. By mid August, he had reduced the concept to practice on “a very small scale.”[126] This technique was mentioned in the September progress report and successful tests had been completed by the end of the year.[127]

By this time, the basic circuits had been agreed to, built, and tested, production head designs were finished, but head characteristics were still under investigation, and concern had not shifted to the reliability of component parts such as pulse and step-up transformers.[128] In September, also, a Raytheon QK-244 Electrostatic Storage Tube was received and ERA initiated preliminary studies of its characteristics. It took two months to build test equipment for the evaluation of this tube, but this was done by December and the initial tests “indicating satisfactory writing, erasing and holding.”[129] But shortly after the beginning of the year, it was clear that the two tubes sent would not be suitable for operation “at the vendor’s maximum ratings, due to leakage, arcing, and gas in the tube.”[130] In the spring, ERA turned to a consideration of the William’s tube.

Also in the winter of 1949, ERA crafted production discs and molds for the production of magnetic heads. "Preliminary electrical tests of these heads indicate improved performance over the previous laboratory produced specimens."[131] Many of the circuits were in modular form by this time. The locating system for the twelve-digit pilot machine had been completed and tested. And a final mechanical design of the photoelectric tape reader was completed, built, and tested by summer. There were some delays in procurement of parts, such as satisfactory pulse transformers, which limited the size of the complete storage system that they planned to test in spring 1949.

Endurance runs on the system, restricted to a six-digit storage system, were performed in June 1949.

> The procedure was to write a selected six digit binary number into cell No. 1, read it from cell 1 to a register and write from the register into cell No. 2. This process was continued cell-by-cell until the number read from cell 255 was written into cell 256. Then the "one's" complement of the number read from cell 256 was written into cell No. 1. This number was then transferred cell by cell through the complete storage system and its complement (which is the original number) again reappeared to be written into cell No. 1. This cycle consists of 512 reading and 512 writing operations or 2 readings and writings per cell and exercises every tube in the system at least 128 times.

Two endurance tests were reported for this trial. The first accomplished 4,900 cycles (5,040,000 coincidence detector operations) in 15.5 hours' continuous operation. The second ran for 55.5 hours and accomplished 17,600 cycles. The tests were run in nonworking hours. "Both runs failed because of abnormal power supply transients caused by laboratory 'accidents' on the resumption of work the following morning."[132]

In the next monthly report, ERA noted that the system had been expanded to twelve digits and "tested without incident."[133] No explanation was offered about why this form of the system worked better than the six-digit system. During July, ERA and CSAW agreed on a final set of command operations.

ERA continued to build and test heads, pulse transformers, and various switches for the rest of 1949.[134] Many small problems were investigated. For example, the circuitry for the Group Selector Switch was reworked in September to lower the impedance level at which the germanium diodes operated to enhance its reliability. As late as September 1, there was no successful typewriter and punch control system. In fact, over the next few months, a number of problems developed with the input system. Discrepancy in the performance of the accumulators required that an additional amplifier be put into the system "having the exclusive purpose of compensating for attenuation of the stored borrow pulse in the Borrow Storage Delay Line." All of these small problems took time to correct, and testing was delayed until the end of the year. During all these months, there were still only sixteen people working on the project, a quarter of them parttime. Of course, this does not include shop people called upon to make parts.

In August, ERA's plans called for complete debugging tests on the pilot system by November 1, 1949. Sample problems supplied by CSAW were to be run in November and corrective modifications called for by these runs would be made by December 15. The winter of 1950 would be occupied with constructing the final machine. After final tests beginning in mid-April, the machine was to be delivered by June 15, 1950. In the event, problem runs were delayed until December 1949,[135] and, as a result, the first Atlas was not completed until fall 1950 and delivered in December 1950.

In 1947 Pendergrass had been influenced initially by the design work at IAS, and he proposed a system with instructions of the one-address type and parallel operation and a Selectron for internal high-speed memory. Over the course of the next year, neither the Selectron nor the IAS machine had advanced to practical use for construction at ERA. As we have seen, ERA substituted a magnetic drum storage system and performed the work needed to modify circuits and performance of the read/write heads. They greatly improved the access time of Atlas over Demon (down from 250 milliseconds to 17). Modifications in circuit functioning after delivery of the Atlas I to NSA (now responsible for intelligence communications) further reduced the access time.[136] ERA delivered a second Atlas I in March 1953. The sales prices later quoted by Remington Rand for these two Atlas Is were $997,808 for the first copy and $287,600 for the second copy. These were surely the contract amounts and not sales prices.

Even before delivery of Atlas I, CSAW ordered an Atlas II from ERA with a new design. The delivered system, in March 1953, sported two-address instructions, high-speed memory composed of electrostatic tubes, and a medium-speed drum memory similar to that of Atlas I. After this, NSA turned to other companies, particularly IBM, for new systems.[137]

The ERA 1101

The ERA 1101, in most respects a duplicate of their Atlas machine, was a single-address, binary-system parallel computer, with a magnetic drum memory. The drum capacity of 16,384 words, each 24 binary digits in

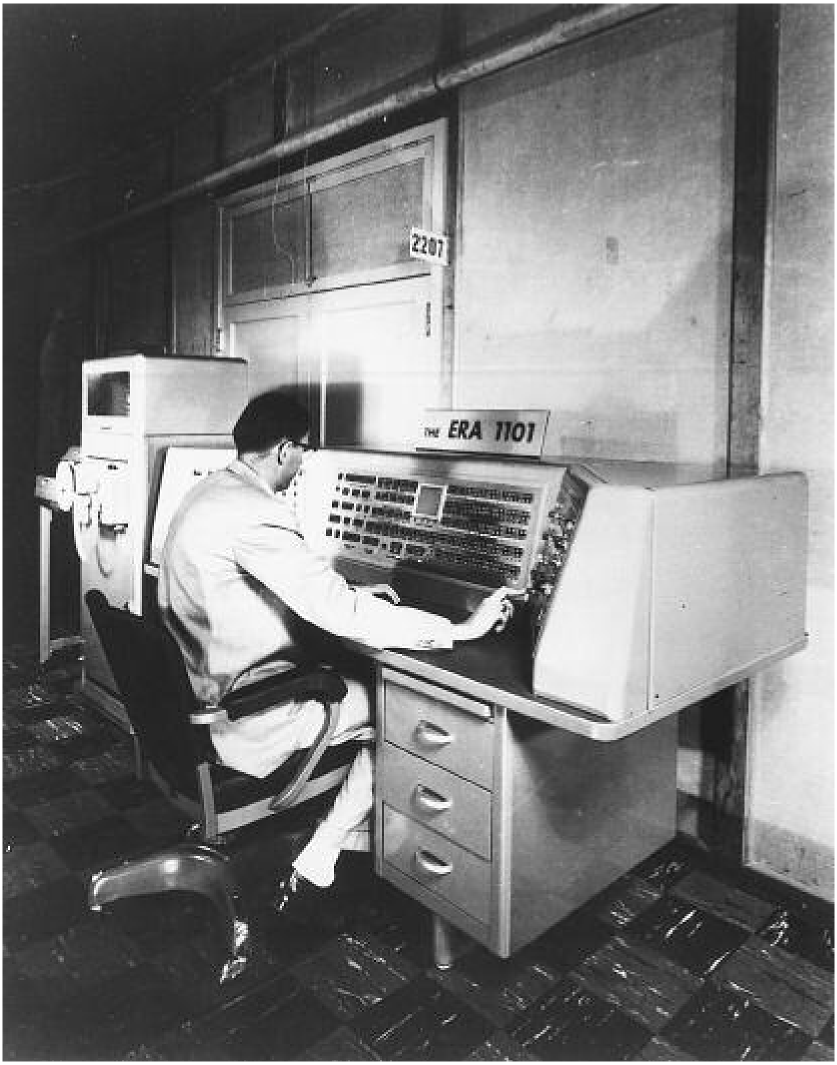


Figure 3.2
The ERA 1101 with ERA engineer Earl C. Joseph at the control panel. Courtesy of the Charles Babbage Institute.

length, stored data of 7 decimal digits plus a sign. The drum rotated at 3,500 rpm and was 8.5 inches in diameter, 26 inches in length, with 200 heads to store 400,000 or so bits. While the clock rate of the system was 400 kc (Atlas was 1 Mc), the pulse rate of this drum was 125 kc, yielding a random access time of 8 milliseconds. Optimization programming schemes could reduce this access time to around 1 millisecond by careful placement of orders and operands on the drum. On the surface of the drum, there were 192 tracks, where data was read to the track using the return-to-zero technique. The non-return-to-zero method, investigated so heavily by ERA during the Goldberg development project, became the standard for the locating (11) and timing (1) tracks.

This computer's arithmetic section contained an "X" and "Q" register and an accumulator. The "X" register functioned as the repository for multiplicand, divisor, augend, and subtrahend. The "Q" register contained the multiplier during multiplication and the quotient after a division, thus serving as a shifter. Both registers were 24 binary digits in length. The actual arithmetic was performed in the accumulator, the principal arithmetic register. Forty-eight binary digits in length, the accumulator also possessed subtracting and shifting properties. The time necessary for addition or subtraction was 96 microseconds. This time included fetching of the next instruction. The time for division was 415 microseconds and for multiplication 352 microseconds.

The ERA 1101 contained 38 operations in seven groups, with ten arithmetic operations, four transfer operations, two output operations, and three stops. The computation and control sections operated asynchronously with respect to memory. When main control initiated a storage reference, it suspended further activity until it received a "resume" command from the memory system. Control was further divided into a main sequence control and an arithmetic sequence control. The main sequence control received the operation code and issued the necessary operation pulses to perform the command. The arithmetic sequence control handled the more complex arithmetic operations such as shift, multiply, and divide. Lastly, the input system was a photoelectric tape reader, based on the earliest work in ERA, and the output machines consisted of an electric typewriter and a paper tape punch.[138]

In late 1951, ERA had finally achieved their long desired goal: marketing of a commercial computer system. The company's first 1101s became available, and the Bureau of Ships received the first two copies (really the Atlas Is). There were no further orders, and the third computer, a commercial system, was sent to their Washington, D.C., computing center, an

Figure 3.3
Frank C. Mullaney in his Control Data Corporation office around 1965. Courtesy of the Charles Babbage Institute.

Figure 3.4
Erwin Tomash (left) and Arnold A. Cohen at ERA in the late 1940s.
Courtesy of the Charles Babbage Institute.

operation designed to solicit business both for systems and for services.[139] Later ERA donated this third system to the Georgia Institute of Technology in October 1954. Perhaps the lack of additional orders is not surprising, considering how fast the market was moving at the time. In response to a contract from the U.S. Air Force, ERA began to design the 1102, and the navy ordered a new task to design a more powerful Atlas, which became the Atlas II and the commercial 1103. ERA produced only three copies of the 1102 for air force's Arnold Engineering Center in Tennessee. The 1103 did somewhat better. The navy bought the first two for a combined price of $1,974,997. Unit 1, as it was called, the third copy, was rented to Convair. In October 1955, John Parker's Sales Office of Remington Rand reported a total of fourteen 1103 computer systems in use or on order. Remington Rand later noted that nineteen 1103 and

1103A computer systems were sold.[140] But, in 1951, ERA was already running into an obstacle, which made the accumulation of inventory to produce these systems difficult. John Parker could not see his way to financing the increasing needs of the company, and he began to seek for a purchaser that would have the resources to help the company gain market share with the 1100 series.[141]

The Sale of ERA

A quick glance at the financial position of ERA in October 1951, the end of another fiscal year for ERA and the opening of the period for negotiations to sell the company, suggests ERA was in a strong position and just might be on the verge of substantial success. In current assets, the company had cash of almost $100,000, accounts receivable of just over one million dollars (virtually all from the U.S. government), and an inventory amounting to $132,000. Earnings to be retained for the business came to $260,000, an increase of $70,000 in the current year. The net income per share was $0.35, just double that of the previous year.[142] Contracts with the federal government and commercial enterprises had also been rising.[143]

	Government	Commercial
1947	$ 1,215,058	$ 288,220
1948	3,650,594	89,753
1949	3,154,742	66,148
1950	2,388,710	154,691
1951	4,154,672	295,010

The 1950 numbers represent the results of a decline in military spending, while the 1951 numbers reflect the police action in Korea and the military buildup at the end of the Truman years, as well as the sale of the two ERA 1101s to the Bureau of Ships. Furthermore, Parker and ERA had flirted with IBM, shown in the increase in commercial numbers in the list. Why then the desire to sell the company? ERA still did contract work for firms interested in customized equipment, namely the transportation industry (airlines and railroads). Much of the commercial business profits came from these endeavors. They had done several contracts for IBM. In fact, IBM engaged in an exercise with ERA on the production of magnetic drums, during which IBM evaluated their own engineers' designs and the company's production standards. In the end, IBM decided to manufacture their own drums rather than buy drums from ERA.[144] The contract provided for transfer of many patents on drum design to IBM, which caused many engineers to view this as a sellout by Parker. But Parker's motives in accepting a contract that would be very generous to IBM are not easy to sort out.The most charitable view is that he was trying to buy favor from IBM in the hope this would enhance ERA's chances in the market.

Parker was disappointed both with the IBM decision to manufacture their own magnetic storage drums, rather than buy drums from ERA, and the overall profit performance of the company. Parker still had much of his own money tied up in the firm, money he expected to be repaid in January 1953. The low profitability of the firm made the hope of early payment questionable. Parker came to believe that the only way he could extract his money, yet give the firm the higher level of funds it needed to succeed with products like the ERA 1101, was to sell the firm to a large corporation with ample resources to fund research and development and inventory. Sale of computers like the ERA 1101, similar to UNIVAC, required more capital than ERA had access to at the time.

What choice did ERA have? Parker considered one option to be taking the company public and advancing in small steps. Some money to finance inventory and other needs could be obtained through a stock sale. This direction presented a problem. To go public required open disclosure to the Securities and Exchange Commission of the company's activities, but ERA security work precluded that path. Another option would be to sell to a larger company that had the resources to bankroll gearing up in the computer market. Parker saw the latter as the only feasible choice.[145]

Unlike the EMCC case, the surviving records do not reveal the steps that led to Remington Rand's interest in ERA. A series of visits to ERA by Remington Rand personnel occurred at the end of 1951 and the beginning of 1952. Remington Rand obtained the services of EMCC's principal attorney George V. Eltgroth when they acquired the small firm, and Remington Rand used him to evaluate ERA. At the end of December 1951, a team of Remington Rand personnel visited their prospective acquisition. Eltgroth, along with Earl Olofson and Hugh Duncan, both former ERA employees, Jim Weiner and Ted Bonn, veteran EMCC engineers, visited ERA to discuss its organization, operation, past engineering achievements, and the current engineering activity. Security restrictions, however, prevented ERA from disclosing the major portion of their work to the Remington Rand team. Among the engineers of ERA at the meeting were Engstrom, director of research, Coombs, director of engineering, Cohen, and Mullaney, both supervisors in the engineering department. Eltgroth reported that ERA "is predominantly of an engineering character with neither facilities nor personnel for large-scale production." He believed that the reason they were considering a sale to Remington Rand came from this "unfavorable situation." The company employed some 158 graduate engineers, 60 draftsmen, and a number of electronic technicians at the time. Eltgroth criticized ERA for letting patentable ideas fall into the public domain "by failing to file applications within the statutory period of one year after the death of the first sale." He also came to appreciate that naval personnel rotations resulted in navy personnel acting in liaison with ERA without the close relationship of ERA's early years. He believed this worked disadvantageously for ERA. "It is believed that this gradual change in relationships has contributed to placing ERA in a position where they are considering merging with a larger parent corporation," though he did not indicate whether it was he who believed this or some group of people in ERA. ERA's situation with the navy was clear, however; the company was now just one among a number of suppliers. Eltgroth's conclusion:

> [I]t appears to the writer that ERA has much to contribute to the organization in the field of magnetic information storage and the processing of information so stored. They do not seem to be unusually advanced in producing a high-speed printing device. ERA is also presently investigating several alternative forms of information storage, including the ferroelectric phenomenon, the electrostatic cathode-ray tube, and concatenated magnetic memories of the type developed by Way Dong Woo. They have on the premises a breadboard model of a binary type logistics computer. It was noted that much of their construction technique is quite similar to that employed at Philadelphia and is of a type which will infringe patents now allowed and scheduled to issue within the next nine months.[146]

Two things still remained before agreement could be reached. One was access by Remington Rand to more information about the classified activity in ERA. The Remington Rand group met with the head of the navy unit at St. Paul, Captain Earl Hawk, to learn if anything could be done about this. Hawk, after expressing the dismay of himself and his superiors in Washington for not being brought into the discussions sooner, thought it might be possible to provide access to information to up to six Remington Rand representatives. They agreed that Engstrom would prepare a formal request to the navy for access, which request would detail the circumstances of the proposed sale of ERA.

The second thing was to obtain, through the Bureau of Antimonopoly of the Federal Trade Commission, approval from the Department of Commerce to the proposed sale. The Bureau of Antimonopoly was part of the Theodore Roosevelt administration's program to monitor the merger activity of companies as part of its antitrust campaign, and continued to function in the post–World War II era. In a letter from Parker to the head of the bureau, we are offered a view of the company by its president at the time of the sale to Remington Rand. First, on the distribution of effort: "The company's projects generally are of an engineering nature which primarily involve both research and development."[147] His estimates of these activities were: 10 percent research, 75 percent development, and 15 percent manufacturing. The products produced were for specific and, in general, "non-recurring users." "There are therefore no product lines." The company did offer five products for sale at the time, with varying degrees of success. In the ERA 1951 fiscal year (ended October 31, 1951), the magnetic drum storage equipment brought in $59,000. A magnetic accelerometer for measuring acceleration raised $73,000 from government, telephone equipment manufacturers, and aircraft manufacturers. One company, Consulting Engineering Co., purchased $49,000 worth of a device for converting shaft positions to electrical pulses for analog devices. The company also produced a small number of pulse transformers and electro-mechanical counters ($12,000 total). As we noted above, this commercial business constituted only a small percentage of ERA's business at the time (approximately 7 percent).

Because of this disparity between government contracts for one or a few similar devices each and the commercial product line offered for sale, ERA did not see itself as competition for any other firm in the electronics and electrical engineering industry, let alone the computer industry. No mention was made of the recently delivered Atlas computer as a product, and only a glancing reference was made to the forthcoming ERA 1101. Parker noted that only one 1101 had been built to date and they were not manufacturing additional copies. "Our plans for the immediate future are unknown in this regard because to date we have not received an order from any source." The peripheral equipment that could be used with this machine could be acquired from a number of firms, and practically all supplies used in their equipment were purchased on the open market. Parker did hedge, however. "The requirements of military security so cloak the activities of the various organizations in this field that it is impossible to estimate the relative position of ERA." To justify these two assertions, ERA submitted a copy of the June 1951 issue of *Electronics, The Annual Buyers' Guide* to show that there were "hundreds" of suppliers of generally similar products.

Parker also offered yearly estimates of development expenditures, which must have offered a rather remarkable perspective to Remington Rand management about the cost of such equipment. To wit:

1946	$ 200,000	1949	$ 2,230,000
1947	1,017,000	1950	1,650,000
1948	2,500,000	1951	2,206,000

And the estimates for 1952 and 1953 were each $2,400,000. Parker then went on to describe what he believed to be the minimum capitalization necessary for a company to make and sell electronic computers: "$10 million." The basis for this estimate, while not definitive in character, is an

> accumulation of the estimates made by other important organizations in this industry, the published costs by governmental agencies of monies spent for various machines either now in use or being developed, and our own experience of cost, both in development and reproduction of the ERA 1101 computer. The estimated development costs of various computers range from a few millions to as much as the reported 13 millions already spent at Massachusetts Institute of Technology. Each of our 1101 computers will cost over $300,000 for reproduction, in lots of 10. It would seem reasonable to assume that at least this number would be required to successfully enter the electronic computer machine business. It would require, in my opinion, the completion of at least 10 electronic computers in the first year's operation for a successful enterprise in this field.[148]

Remington Rand, which received a copy of this letter, could not say they entered the arrangement ignorant of what the participants believed the ante to be. Later in the letter, Parker noted that the proposed acquisition by Remington Rand of ERA would enable ERA to pursue its planned course with adequate financing, financing unavailable through "any other means." As if to placate the navy, he stated that acquisition would not change ERA as a corporate entity. "ERA will continue to carry out the purpose for which it was originally formed; namely, to provide engineering services and to develop equipment in the field of utmost importance to the national defense. . . ." The financial stability available through Remington Rand would only enhance this role. Indeed, new financing would allow ERA to begin to compete with IBM, GE, NCR, RCA, and Burroughs, according to Parker, in a market severely limiting because of the cost and application of large computing machines like the ERA 1101. Moreover, Parker worried about what would happen if ERA could not find the financing needed and the talented team of engineers and technicians disbanded. He believed this would be a great loss to the country and not in the national interest.

The letter was presented to the Bureau of Antimonopoly at a meeting in Washington, held on February 4. Parker and Engstrom represented ERA at the meeting. Discussion focused on three areas: ERA's competitive position in the electronic computer market, minimum capitalization needs, and the relative position of other companies in this market. The concern of the bureau seemed to be whether Remington Rand, which already owned EMCC and marketed the UNIVAC, really needed products like the ERA 1101, and did ERA previously consider EMCC a competitor. Engstrom responded in the negative on competition, because UNIVAC and the ERA 1101 performed different functions. Parker added that the 1101 could in no sense satisfy commercial needs. But Dr. Barnes of the bureau was not satisfied. He wondered if the addition of certain peripherals might make the 1101 more competitive with the UNIVAC. We can assume that the thrust of these questions was to learn if ERA could satisfactorily compete with Remington Rand if financing came from another source. No, Engstrom responded, to make the 1101 competitive would require "profound modification," which could only come about though "a great deal of reengineering and further development."[149]

Considerable discussion took place concerning Parker's estimate of $10 million as minimum capitalization to pursue the computer market. Asked if this figure applied to a new startup or an established company like ERA, Parker responded that he did not consider the question relevant, considering that the 1101 had been developed for a specific customer and would need more thought and development before he could consider it a commercial product. He admitted that the figure of $10 million came from estimates of expenditures by Burroughs in their ongoing development of a machine they expected to have on the market in about ten years. Parker estimated they were spending from $1 million to $2 million a year in development.[150] This argument was slightly more germane to the issue than the numbers he had given in his letter.

Engstrom offered an opinion on the relative position of various companies in the computer business, but with several caveats about his limited knowledge. Based on quantity of orders, effort, and expenditures, he thought IBM was "by far in first position." Considerably lower than IBM was a second group of companies, which consisted of Remington Rand, Burroughs, Bell Laboratories, NCR, Hughes Aircraft, GE, and RCA. His third rank of mainly small companies contained Computer Research

Corporation, North American Aviation, Northrop, Raytheon, and ERA. Engstrom made reference to a fourth group of small companies, such as Technitrol and Southwest Research, but without elaboration on what they were involved in in the field. Last, he offered some comments about the extremely active group of universities and government laboratories, which should be considered if one was interested in actual expenditures in development. Parker, in response to a question, opined that none of these companies would object to ERA's acquisition by Remington Rand.[151]

Even though Remington Rand and ERA did not need the approval of the bureau for the sale of ERA, they continued to supply information to the Bureau to obtain their approval. Two days after the above meeting, Engstrom sent another letter detailing technical information on drum production and capability, a list of companies in the United States thought to be producing or planning to produce drums (sixteen), and similar information for the other four products ERA offered for sale.[152] Another two months passed with no action.

Parker and Engstrom requested another meeting with bureau personnel. Held on April 8, Engstrom opened the discussion in a tone of dismay. The delay was having serious consequences on the morale of the technical personnel of ERA (engineers were beginning to leave, for example, John Coombs left for IBM) and future planning was held up putting the company at a disadvantage. Norris, also at this meeting, pointed out that ERA depended on some twenty-four key technical people, and even the loss of a small number of them had serious consequences. Such an event was not hypothetical only, as IBM, RCA, Hughes, and Consolidated Engineering were actively recruiting in St. Paul. Barnes may have taken offense to the tone of the ERA people, because he began to hide behind a bureaucratic smoke screen of too little staff for the job required, especially when evaluating a new industry, and a Congress reluctant to increase the bureau's budget. Parker did not back down, emphasizing the ERA was "imperiled."

Tension heightened when Barnes challenged some of ERA's arguments. For example, the successful operation of the UNIVAC, the only commercial machine on the market, suggested to him that Remington Rand was in the lead, and that there were relatively few important companies in the field as competition. To him, there seemed to be only four or five important companies, and ERA was one of them, placing it higher on his scale than Engstrom had at the earlier meeting. According to Barnes, acquisition of ERA by Remington Rand would lessen competition, and because of their leading position, Remington Rand did not need ERA. Engstrom took strong exception to these remarks by Barnes, and both he and Parker played the national defense card. Parker said he would have to notify the Department of Defense that the bureau imperiled ERA, apparently because of the lack of action. Barnes was not intimidated. "[My job is] to analyze the transaction from the point of view of the future development of the industry and the Department of Defense would have no influence" on his opinion.[153] Both sides backpedaled at the end of the meeting, Barnes saying he wanted to do nothing to harm ERA and Parker saying both their motives were to achieve the same ends for industry and defense. Barnes stated he would have a report in a short time. Eventually, a rather noncommittal letter arrived allowing the merger to proceed, but reserving the right to intervene later if it seemed appropriate. With this obstacle overcome, Remington Rand set about acquiring all the outstanding stock of ERA. Remington Rand established it as one of its subsidiaries.

Good R&D Was Not Enough

As 1950 proceeded, ERA's need for capital to support inventory needs approached a level simply outside the financial capability of Parker and his backers. The Atlas I would have to be converted to a more useful commercial system, including the need for software development, something ERA had not expanded beyond the basic instruction set design needs. Even Parker could see the company's limitations. ERA's good R&D work in system design simply was not enough to ensure a golden future. No doubt, Parker and others saw the advances at EMCC and IBM as similar to their own. ERA, after all, was a strong technical company. But IBM's resources outstripped those of ERA. No group stepped forward to help ERA. As we shall see in the case of EMCC also, no individual or small company could advance the amount of money needed to finance large-scale expansion of either firm. In one sense—the commercial sense—EMCC was ahead of ERA. Still, it could not maintain a market position due to lack of funds. We turn now to a consideration of EMCC's activities in this same period (1947–50) to learn the details of their remarkable struggle to succeed and deliver a quality product to market and the factors behind their decision to relinquish control to Remington Rand.

4

Always a Dollar Short and a Day Late

EMCC Strives to Succeed

The new contracts meant that EMCC required more personnel. One of the new people hired in August 1947 was Herman Lukoff, an electrical engineering graduate of the University of Pennsylvania who had worked on the ENIAC project before entering the navy. In his idiosyncratic autobiographical memoir *From Dits to Bits,* Lukoff reported that when he arrived at EMCC there were only a handful of professionals and a small technicians' group. After his arrival, the company grew "by leaps and bounds." The number of professionals in September 1947 was around twelve. Lukoff wrote that his first assignment on September 1 was to join the small group designing a "mercury tank memory demonstration system," in collaboration with Gerry Smoliar, a former Signal Corps employee, and Bradford Sheppard, recruited from the ENIAC group.[1] Another new employee who started work on September 1, Ted Bonn, was assigned to the tape-transport demonstration project. Lukoff noted that "the tapes and magnetic heads couldn't provide the high frequency response or reliability required, and the transports couldn't stop and start fast enough." So, even though the NBS contract called for these demonstrations to occur on August 15, in September the demonstrations were still to take place.[2]

In fact, on September 18, Mauchly wrote the Nielsen Company that "Pres Eckert and I are still finding most of our time absorbed in preparing a final design report for the Bureau of Standards and in getting certain demonstration apparatus built." He went on to report that "in spite of the pressure of this work, we are trying to formulate a new proposal for a contract with your company."[3] At the end of October, a complete report had not been submitted yet to NBS.[4]

This is not to say that the group had not been extremely busy. As Lukoff noted, a flurry of activity in EMCC required the hiring of more personnel. From about a dozen professionals in mid-1947, the number tripled by the end of the year to thirty-six.[5] Another impression of the increase in activity can be seen in a report Berkeley delivered to the Prudential on progress during the period August through mid-October. As he put it, in this period EMCC "crossed several scientific frontiers."

(1) They had recorded on magnetic tape 200 magnetized spots to an inch of length;

(2) They had recorded on magnetic tape 6 channels in ($\frac{1}{4}$) inch of width;

(3) They had devised a method for showing the magnetized spots on motionless magnetic tape, by dusting it with magnetic powder, which clusters on the magnetized spots, and then picking off the powder with cellophane tape;

(4) They had devised a holder to vibrate a section of stationary magnetized tape opposite a reading head, so that the pulses on the tape are thereby read.[6]

The reports required under the contract on the collation process and preparation and checking of magnetic tape had been submitted. There was only the status of the demonstrations at issue.

After reporting on the status on the eight required demonstrations, Berkeley recommended that EMCC not be held to specific dates for the demonstrations. Instead, an estimated date for completion of the first part of the contract should be presented by EMCC and either approved or modified by the Prudential. As the development proceeded at EMCC and as new information came from the Prudential's analysis of its problems, new engineering possibilities needed to be built into the design, slowing down the design process. According to Berkeley, it was in the best interests of the company to let this process continue, because a better machine would be the result. "No one can cross a scientific frontier by setting a date to do it, or by putting heavy pressure on people. It takes time, and a favorable environment. Too vigorous a timetable destroys this favorable environment and makes for less thorough and less worthwhile work."[7] EMCC requested a change in the wording of the contract to allow for a monthly schedule for reporting progress and to shift the demonstrations' dates all to the end of 1947.[8]

While all this work on hardware proceeded, Mauchly and Betty Snyder tried to perfect and extend the capabilities of the code used in EDVAC II.

In memoranda prepared for Berkeley by Prudential staff, we learn of the transmission of several new codes—C4 and C5, and of a number of visits by Prudential people to EMCC to discuss various ways to code problems and to convert punched card data to magnetic tape.[9] It is not my purpose here to describe the many problems faced by the Prudential in setting up an organization of data in response to the needs of an automatic machine, but these documents reveal that the company had to generate an index to data that would enhance retrieval. Many punched card files had to be given new names to make their meaning explicit. The new codes contained one or two added instructions to help with customer needs.

The design of a complete system was turning out not to be as simple as envisioned, and by January 1948 the group of demonstrations required by the NBS and Prudential contracts had not been done. At that point, the Prudential could have insisted that half of their $20,000 be returned. They did not, and the contract dragged on. Mauchly did write Cannon at NBS toward the end of the year to arrange for a visit to view demonstrations on the mercury memory, the binary adder, and the tape-operated typewriter.[10]

The visit was scheduled for January 12–13. About twelve people from the Census Bureau were expected at EMCC. James McPherson requested that a special presentation be given to the director and two assistant directors of the bureau and to a representative of the Bureau of the Budget. This was to be a short description of the logical organization of the EDVAC II to make the demonstration more intelligible to them.[11] Some slippage occurred in the date at which the major figures from the census could view the system, and they came on January 26 instead.[12] Representatives of NBS also visited the company during this time, no doubt among the number of people from the census.[13] Incidentally, a visit was also made at this time by NBS to Raytheon to discuss their design.[14]

These delays, the addition of staff, the acquisition of new and larger space, and the slowness with which new contracts were likely to be arranged, produced another in a series of financial storms for the company. In an effort to attract new investors, Eckert and Mauchly formed the Eckert-Mauchly Computer Corporation (EMCC) in late December 1947, which acquired the assets of the Eckert and Mauchly partnership, namely Electronic Control Company. The agreement of sale showed assets of almost $27,000 with liabilities of a little over $13,000, leaving about $13,500. The new corporation was organized with an authorized capital of $15,000, consisting of 15,000 shares of capital stock of par value $1 per share. In return for the excess assets, the Eckert and Mauchly partnership, which was not dissolved, received 13,500 shares in the new corporation.[15] The search for new sources of funds was becoming acute, because the NBS had decided that an evaluation of the results of the various plans to build machines that NBS was supporting was needed, and the outlook for continued funding from them did not look promising.

In April 1947, Curtiss asked the National Research Council (NRC) to appoint a committee to evaluate the computing machine project reports expected soon at NBS, and to offer NBS advice on how these machine designs compare with the range of machines being designed. While this was not stated as such, in a letter to EMCC Cannon described the hopes of NBS: "The designs evaluated will probably include the EDVAC, the IAS machine, and the computer designed by the Servomechanisms Laboratory, MIT, in addition to the UNIVAC and the Raytheon machine. . . ."[16] Cannon saw that this evaluation might seem to be a competition, but he hoped to avoid this by not referring to it as such. He also went on to allay the possible fears of EMCC about patent matters. In discussions with the Patent Office attorneys, he learned that this evaluation would not be construed as publication.[17]

What the NBS hoped for they did not get. The NRC committee, composed of Howard Aiken, Samuel Caldwell, John von Neumann, and George Stibitz, interpreted their role more narrowly. In their report, not issued until March 16, 1948, they evaluated only the EMCC, Raytheon, and Moore School designs, and made no attempt to compare them with other machines. The committee decided that "a detailed technical discussion of these reports at this place is not what is primarily called for . . . since the mathematical and logical bases for machines in the speed and capacity range involved have already been extensively discussed in technical meetings and in the generally accessible literature . . . a considerable body of reasonably homogeneous scientific and technical 'public opinion' on many of the major questions that are involved is already in existence."[18]

As Stern noted, "the underlying message of the NRC report was that the three machines did not merit an extensive technical analysis since the design principles were part of the standard literature."[19] The NRC report claimed that the designs were essentially all the same. "It would seem that these three proposals do not represent three really different and independent intellectual risks but that all are predicated on essentially the same estimation of what the most promising engineering approach is."[20]

Thus, according to the committee, a choice on technical grounds was not possible. Since they were all based on the EDVAC design, this is not a surprising conclusion to us now. In effect, the report was of little use to the NBS. However, the NRC committee did recommend that no more than one machine of each type—EDVAC, Whirlwind, IAS, and so forth—be built at that time. This recommendation would seem to leave out the designs of EMCC and Raytheon. Eight months had gone by, a more serious result as far as EMCC was concerned.

NBS did their own evaluation, while waiting for the NRC report. As a result, Curtiss posed a set of questions to Mauchly on January 20. He asked for a cost figure on the preparation of a set of complete detailed manufacturing specifications; how much of the projected cost would result from the engineering development necessary to present manufacturing specifications; what would be the cost of each of n machines, starting with n 1 and going on to 2, 3, and so forth; what time would be needed to build machines beyond n 1.[21] Curtiss requested the information be submitted within two weeks. It took Mauchly seven weeks.

Mauchly sent his response on March 13, with the terse comment that the questions required "only a certain number of man-hours devoted to estimating." He noted that to be in a position to build more than one or two machines the firm had to acquire new space and new staff, both of which were in process. Independent estimates were made by several members of the EMCC staff, including James Weiner, who had recently joined them from Raytheon, where he had done similar planning for the computer project there. So as to keep a focus on the complexity of the UNIVAC, Mauchly emphasized again that Curtiss's questions referred to "a 'machine,' whereas we have designed a 'system' consisting of a UNIVAC computer and auxiliary units which provide greater flexibility for meeting the requirements of different applications. In those questions dealing with the 1,000-word memory, the figures which we have given included what might be termed a 'basic set' of auxiliary equipment. More equipment than this would be desired for many statistical and commercial applications, but for purposes of comparison here, such a group is very useful."

With perhaps minor differences, the prices quoted by EMCC at this time were in the same range as those presented to the Prudential ten months before. The differences could have resulted from variations in the type and quantity of auxiliary equipment. Mauchly expected to build "five or six" machines simultaneously, with independent testing. The number to be built over the following eighteen months was five. An amount of the order of $85,000 was still needed to prepare manufacturing drawings and designs, $25,000 of which was in the development category not counting $50,000 to $100,000 for any high-speed printing equipment design. Since they expected to build machines with increments of 500-word memory units, Mauchly gave construction estimates for several size basic machines (not counting auxiliary devices whose price was not machine-size sensitive). He opined that the large, 4,000-word machine would not be in great demand, but more likely standard problems would need a 2,000-word capacity. He concluded his letter with a brief statement of progress in tape speed and internal pulse rates of operation, twice and four times as fast as called for in the original contract for the census machine design. This, in his mind, justified acceptance of the 2,000-word machine with its cost savings over the larger memory.[22]

Meanwhile, at NBS $172,000 of the original $300,000 remained of the funds transferred by the Census Bureau. In minutes of a meeting held at the Census Bureau on April 7 following the NRC report to NBS, they reported discussions of estimated construction costs for the UNIVAC and Raytheon machines at $156,000 and $400,000–$600,000, respectively.[23] NBS, rejecting the advice of the NRC, had recommended on March 22 the purchase of three UNIVACs, one for the census and two for the armed forces. Furthermore, the minutes record that three commercial firms intended to purchase UNIVACs as well: Prudential, Nielsen, and Fairchild Engine Company. EMCC had a purchase order from Fairchild;[24] Nielsen was about ready to sign a contract; the Prudential contract called for demonstration of components, as we have seen. The committee "agreed unanimously" that the recommendation of NBS that the Census Bureau acquire a UNIVAC should be accepted.

This should have settled the matter. It did not. The NRC deliberations and those that followed them in the agencies of interest were not the only matters that slowed down further contracting with EMCC by NBS. First, there was a security matter raised by the navy, which had been examining the possibility of contracting for a UNIVAC. On the basis of a classified report, the navy unit in question rejected the idea of a contract with EMCC. Nancy Stern, using information obtained in an interview with Mauchly, attributed this matter to attendance at a prewar meeting by Mauchly of an organization that had a Communist affiliation, unknown to Mauchly.[25] Several members of the EMCC staff were accused of "Communist leanings or alleged associations with Communists." The navy reported their decision to NBS and other agencies of the government involved with EMCC. NBS conveyed the information to the census, and after consideration by the Census Bureau's Committee on the Use of Mechanical Equipment, they decided to go ahead with the purchase of UNIVACs, in spite of the navy's view that EMCC might be a security risk, but other groups, such as Oak Ridge Laboratory working on a nuclear powered aircraft, supported other computer projects.[26]

Second, there was still the problem of how to contract with EMCC. EMCC wanted and needed a payment at the front of the contract; they asked for 20 percent of the total amount. NBS lawyers, according to a letter from Harry Huskey, believed that it was necessary to write a contract by which payments could be made after certain steps had been completed. "There will be some delay involved in committing our National Defense funds so we propose to write a contract for one UNIVAC with options for two more. This contract will be written as if the financial situation [of EMCC] is satisfactory and may contain a cancellation clause to cover us in case the financial situation is not clarified."[27] Huskey knew on other grounds that there were some questions about adequate financing of the company.

The lack of success in overcoming the financial stringencies of the company was not for lack of trying. Mauchly sent a memorandum to the company's leaders in mid-January detailing the range of prospects then being courted. Three groups of twenty-two prospects were listed. The first group contained their four solid prospects: Prudential, Nielsen, Census, Army Map Service, and a fifth, Fairchild. The second group contained a list of seven organizations with which some contact had yielded a positive feeling. It contained organizations such as ONR, Project Rand, and Presidency College, Calcutta. The last group of ten was more difficult to assess, because "we have been unable to spend much time in contacting them." More government agencies and several banks were listed in this group. If enough of these contracts could be landed, however, the future of the company seemed bright.[28]

So bright in fact, other technical designs were under investigation. Also in mid-January, EMCC filed a disclosure notice for an electrostatic memory system designed by Herman Lukoff. This was part of Eckert's plan to investigate as many methods for memory as possible. As Lukoff remembered about his second assignment, "I designed a simple test setup for the [cathode ray tube]. My objective was to study the basic fundamentals of charge storage, examine the playback signals, determine the best means of storing a 1 and a 0, and learn what factors disturbed the charge. How close together could charges be stored? How long before they deteriorated? . . . Also, I wanted to try different types of CRTs because of the advantage in space savings when many have to be utilized in a memory system."[29]

Small tubes were obtained from a Philadelphia firm, Waterman Products, which made portable oscilloscopes. The system Lukoff designed contained the CRT, timing and deflection circuits, a regeneration unit for memory operation, and power supplies. By mid-January, the system worked with 216 spots on the screen. "Tests show that 1024 spot operation is possible as soon as a few unwanted variations are removed."[30] The spots were placed on the screen either manually through switches or by increasing the gain of the amplifier. Reading was either visual or through a flip-flop circuit.

Mauchly commented on this disclosure to George Eltgroth, EMCC's patent attorney, at some length three weeks later. The memorandum of several discussions about the storage technique included comments on possible financing, what novel features might be in the design, and a background statement on similar projects of the recent past and present. Mauchly noted that he had been told that no other group working on electrostatic memory had the kind of test apparatus available at EMCC. "Inasmuch as we believe that such apparatus is necessary to our own development, this indicates that our own development is in advance of that elsewhere."[31] This seemed adequate to him to assume that some novel features and circuits were part of their design. This memorandum was prepared to offer the kind of background needed to decide on a patent filing.

Mauchly stated that electrostatic storage could not be claimed as novel; it had been one of the memory techniques discussed during the ENIAC project and included in the design proposal for EDVAC. Eckert, according to Mauchly, "had already worked out circuits for the accurate deflection of beam tubes when, at Dr. Goldstine's request, Dr. von Neumann came to the University of Pennsylvania for a series of conferences on computer design and application."[32] The memories of the conferences with von Neumann and Zworykin of RCA by Eckert were that he had stated to them that the problem was a practical one, which they remembered von Neumann as questioning, and that he had a working circuit for the deflection control.

Last, Mauchly summarized the contents of an article that had appeared in the September 1947 issue of *Electronics,* by Andrew Haeffe of the Naval Research Laboratory. Haeffe described a new type of memory tube, which had been developed during the war. The tube rapidly recorded electrical signals, stored them for any desired period, and simultaneously multiply reproduced the recorded signals. It employed three electron beams of different energies to scan the dielectric target. One beam wrote or painted; another beam held the recorded information, and the last beam read from the target. Charges deposited on the surface of a good insulator could be retained for a long period.[33] (The images presented in the article were of complete items, an alphabet letter, an object. It does not appear that random reading and writing was possible with this system.) According to Mauchly, a contract was then given to Raytheon by NBS for the development of this type of tube. Further, he noted that the Haeffe tube used the same kind of regeneration circuit as Zworykin employed in the selectron. The differences between the Haeffe tube and the EMCC design, according to Mauchly, made the EMCC design superior and patentable.

But they were not prepared at this point to cast aside the acoustic delay line memory for the electrostatic system. Indeed, in a promotional description of the UNIVAC system prepared in March 1948 for delivery at the IRE meeting (the same meeting where Cohen and Keye of ERA presented their paper on magnetic recording[34]), the delay line designed by "Mr. Eckert and this author [Mauchly]" was prominently featured. The system design described by Mauchly was complete, and he reported that all the component parts had been developed and tested. What he did not say was whether the units had been tested as a system at this time; we know that integration of units was to cause considerable delay over the next year. Instead, he stated that "manufacture of UNIVAC equipment is now being undertaken by the Eckert-Mauchly Computer Corporation, and a number of these standard UNIVAC Systems will be in use next year."[35]

Some six months later, Lukoff, after some design work on the BINAC input–output system, returned to the electrostatic memory design.[36] Lukoff set about designing a "more sophisticated test equipment," a CRT memory with sufficient flexibility in its modes of operation. The face of the screen was to have a 32 32 array, 1,024 positions. The beam could alternate between positions selected by switches and advance through each one of the positions. He designed the possibility for varying duty cycles, clock rates, spacing between positions, and accelerator and grid voltages. As was important in the magnetic read–write situation, he explored various means of achieving usable signal-to-noise ratios to store 1s and 0s. First, he tried to store the data as large and small dots, but later replaced this with a dot and a ring. Within a few more months, Lukoff achieved satisfactory results of the design as a memory. Data would stay stored for hours.[37] But there were still problems with the unit. "The high voltages used in the circuitry caused peculiar problems. Silver used on contacts would migrate across the phenolic component mounting boards and cause short circuit 'splats.' Signal–to-noise ratios were marginal for some memory positions. We concluded that electrostatic memory was not reliable enough to use in a computer system."[38] By the time of this decision, however, it was almost the middle of 1949.

In early 1948, while EMCC continued to work on the demonstration equipment and the NRC committee deliberated about its report, NBS proceeded with its own analysis. Chester H. Page, Edward Cannon, and John Curtiss held a conference on January 10 to consider their own position. They agreed that an NBS evaluation of the EMCC and Raytheon proposed design specifications from an engineering point of view would be helpful. Also a survey of EMCC's cost estimates for the UNIVAC machine would be useful to compare with Raytheon's estimates, and "to evaluate the accuracy" of the EMCC estimates.[39]

Page responded to this memorandum with his evaluation on February 2. The proposed designs, according to NBS engineers, "look reasonable" and are "feasible." Both companies had assembled demonstration memory units that could be operated manually. "In each case, there are two or more signal channels operating in a common mercury pool without interference." EMCC had demonstrated its high-speed binary adder. Page believed that considerable engineering remained before a detailed design of a complete machine would be available. "This additional work is predominately engineering design with known techniques which a competent engineering staff will be able to handle. The quantity and nature of this further work are such that it is impossible to accurately estimate the expenditure of time and money necessary for completion of the program." In other words, they had no way of assessing which cost estimates were more reasonable. "One engineering staff is apparently being ultra-conservative in its approach to this new field; the other staff tends toward the opposite extreme. There is no *a priori* method of determining sufficiency in design; experience is necessary. In view of the divergence of the two proposed designs, and the present fluid state of the art, it would be very worthwhile to construct one machine of each type for practical evaluation of the proper compromise."[40] This was a compromise that was to be accepted.

Harry Diamond wrote to Curtiss a month later agreeing to Curtiss's suggestion that Diamond's division (13) assume control of the procurement of the machines. He referred to Page's memorandum, but noted that neither complete designs nor specifications "have been offered," and that some vital parts of the designs had not been constructed and tested. Thus, launching the second phase of the program, "i.e., the completion of design and actual construction, presents a complex problem." Development contracts were no longer in order, and instead, he recommended that the machines be purchased on the basis of general performance and reliability specifications. To achieve this, construction contracts should be made with provisions for partial acceptance at several stages of completion.[41] (The use of elements constructed to satisfy requirements of the BINAC contract for satisfying the NBS contract also was to cause difficulty with Northrop later.[42]) Diamond called for close liaison between NBS and EMCC personnel and recommended that several people actually be transferred to Philadelphia. Prototypes would be sent to NBS for evaluation and testing as they became available.

The Applied Mathematics Executive Council composed of members of NBS, the Census Bureau, ONR, AEC, Bureau of the Budget, the Weather Bureau, the air force and the army, met at NBS on March 22 to discuss the various evaluations of the proposals, their own and the report of NRC. The group first discussed the NRC recommendations and concluded that the NRC view that only components should be contracted for at this time was too pessimistic about "the present situation." The fact that several commercial firms and universities were placing contracts for complete machines was evidence against the NRC evaluation and such contracts would be detrimental to the NBS program, because other organizations were placing orders for complete machines and would obtain an advantage over NBS.[43]

The group next turned to financial considerations. Comparisons were made among the EMCC, Raytheon, and ERA cost estimates, all of which submitted bids. We have seen above that the EMCC estimate was around $150,000 for the first machine and Raytheon's estimate was $595,000. The Raytheon estimate would have been lower by $170,000 if they had received a contract from the Nielsen company, then under consideration. ERA made a proposal for a delay-line memory machine, using the EMCC and Raytheon reports as a basis for their own design, whose cost would be in the neighborhood of $490,000. The work at ERA would be divided into three phases and would take about two years to complete, a time similar to Raytheon's estimate. All three machines would have memories of 1,000 words, although the Raytheon machine would contain the possibility of 4,000 words with appropriate switching. There followed some discussion about the ERA proposal with respect to expandability and possible substitution of an electrostatic memory unit. Some decisions would need to be made by NBS, because they noted that the money available would not be enough to build five machines.[44]

Curtiss proposed that a contract be made with EMCC for three machines, with conditions consistent to those proposed at the beginning of the month by Diamond. He also proposed a postponement in any decision about the Raytheon design due to the unfavorable cost estimates, thereby delaying delivery of machines to the NBS Eastern Laboratory and the Air Comptroller's Office, but that a contract be made with ERA for the phase one they proposed, to wit: "integration of the Raytheon and Eckert-Mauchly proposals to produce an optimum design and to estimate the cost" of a development contract accurately (the B-3008 project in ERA).[45] There were later objections to this series of recommendations, especially from the representatives of the Air Comptroller's Office. In the event of no machine being delivered to them, they requested and obtained agreement on priority of use of whatever machines were released by NBS for use in the Washington, D.C., area. For example, the first machine to be available would be reserved 50 percent time for census work and 50 percent time for "logistic planning problems of the Department of National Defense."[46]

The desirability of diversification of suppliers gave rise to the concern about the concentration of effort in EMCC. Government agencies buying new computer systems wanted to be perceived as fair in the competition and thoughtful about future needs if systems proved less than reliable and only one manufacturer was in business. "Only budgetary considerations and the apparent general excellence of the Eckert-Mauchly machine could justify such a concentration of the program."[47] Thus, the two remaining machines should be designed with more flexibility, and this could be done through a contract with ERA. This led to discussion about the rotating drum type machine. While the minutes do not describe final actions authorized by the group, the results can be implied from contracts let in the next few months with EMCC and ERA for the purposes specified in the minutes.

During April 1948, a decision was made to contract with EMCC for the final design and construction of one UNIVAC machine with an option for two more. Since two of the machines were destined for military organizations, this would circumvent the problem of committing national defense funds while the navy pursued its security investigation of EMCC. NBS entered negotiation with EMCC right away. On May 7, a group from EMCC met with several of the NBS and Census Bureau people at a meeting conducted by Harry Huskey.[48] During the meeting, contract provisions and a list of checkpoints were agreed to by the group. With this contract containing a provision for a 20 percent down payment, that is, about $32,000, forthcoming, EMCC could turn its attention back to BINAC and to further development of the UNIVAC. The preparatory period was over. While the context had been set and success appeared imminent, the preparations would prove not to be enough.

EMCC had been very successful soliciting contracts, which, at least in principle, would stave off crippling financial crises. In November 1948, the contract committee prepared a list of the company's commitments by date. The commitments began in October 1949 to satisfy the Nielsen contract, with a central computing element to be delivered toward the end of December 1949. The Bureau of Standards deliveries were to begin in February 1950, with monthly requirements for the rest of the year. EMCC planned to deliver a complete system to Prudential in June 1950.[49] This was a very ambitious schedule, and Eckert and Mauchly, as well as others in the firm, knew by mid-1949 that it could not be met. Toward the end of the year, they began looking for a partner to help them.

The BINAC

In 1947, Northrop Aircraft agreed with the air force to develop a long-range guided missile named the Snark. The guidance system for the Snark required some form of in-flight navigational control. It was to determine if electronic digital equipment could serve this purpose that Northrop turned to Mauchly for the consulting advice described above. Based on Mauchly's analysis and recommendations, Northrop became convinced of the feasibility of having EMCC design and construct a computer, to be called the Binary Automatic Computer (BINAC).[50] Robert Rawlins, the liaison for Northrop, in a letter to EMCC cited the specifications for the machine. "The experimental computer is needed in order to prove the feasibility of a particular method of navigation. It should be less than twenty cubic feet in volume, and weigh 700 lbs. or less, and be capable of operating from 117 volts, 60 or 400 cycles. Ultimately, a compact, airborne computer will be wanted."[51] EMCC sent a proposal in response to Rawlin's letter, which indicated EMCC's intention to meet these specifications. At the same time, Eckert and Mauchly intended the BINAC to serve as a prototype for the general-purpose UNIVAC, although Eckert was later to say that this was for the circuits portion only, not the logic portion.[52] As we saw above, the contract was let on October 9, 1947, with an expected completion date of May 15, 1948. Eighty thousand dollars was paid upfront and another $20,000 would be tendered on completion.[53]

Northrop desired a binary machine, whereas EMCC's objective was to build a decimal machine. Binary, they believed, would be a detriment in the business community, because of the need to have a binary-to-decimal converter. Circuit designs would be essentially the same for both designs,[54] but the architectural concepts would be slightly different, requiring time to design the different system. Since germanium semiconductor diodes had become more reliable and inexpensive, Eckert and the other major CPU designers—Lou Wilson, Al Auerbach, Jim Weiner, and Bob Shaw—decided to employ them in the logic circuits. EMCC organized circuit design groups to prepare circuits for logic, gating, pulse formers, and delay line registers.[55] They decided to strive for a 4 MHz clock rate to give the highest circuit speed possible. In the end this clock speed proved to be impractical and the speed was reduced to 2.5 MHz. Mercury delay lines would serve as the memory for BINAC. Sixteen columns would occupy a common mercury pool and form a 512-word memory, each word consisting of 31 binary digits. One engineering problem here was the necessity to machine the quartz crystal transducers for these columns with greater precision than for the earlier EMCC demonstration memory so that the channels were accurately in line. And crosstalk resulting from the channels operating in parallel had to be eliminated.[56]

Work on BINAC began in earnest in the late spring of 1948. Delivery had been specified in the contract as May 15, 1948. Toward the end of May, Al Auerbach had prepared an internal memorandum of progress on this project. He reported that the designs of the computer, memory, power supply, and control box were each 90 percent to 100 percent complete. Only the computer and the memory drafting had been done and most of the material for construction of these units had been acquired. Each was about half constructed. Nothing else had been done on the other units besides design.[57]

Lukoff reported that most of the engineers were assigned to the BINAC project at this time. Wilson, A. Auerbach, Weiner, and Shaw were the major designers of the CPU. Eckert was everywhere helping with design decisions.[58]

Brad Sheppard and Lukoff designed a tape loader input device for loading the program to memory, and recording data. The input/output was achieved by a typewriter keyboard and a character printer, or an encoded magnetic tape. Nancy Stern pointed out that even though these magnetic tapes were "somewhat" unreliable, "they represented a revolutionary first step in the use of magnetic tape as a high-speed input-output medium."[59] Data going in or coming out did so via a special register that communicated with the main memory.

BINAC had two processing units, capable of performing 3,500 additions or subtractions or 1,000 multiplications or divisions per second. The machine performed operations in binary and displayed the results in octal notation. Conversion to octal was easier and faster than from binary to decimal. There was no provision for alphabetic characters, making BINAC more suitable for scientific than commercial operation.

The final dimensions of BINAC were twenty cubic feet for the arithmetic and control units, with the memory (2), power supplies (2), converter unit, and input console taking up an additional 110 cubic feet. If the original contract specification of twenty cubic feet meant the entire volume, EMCC had gone way beyond that by a factor of 6.5! Yet, in comparison to ENIAC, it was very, very much smaller.

As noted by Stern, BINAC had two distinctive operational features. First, BINAC was a stored-program computer, indeed the first one completed in the United States, capable of solving numerous types of mathematical problems, way beyond the special purpose for which it was designed. "It had arithmetic, data transfer, and logical control commands similar to other computers being built at the time." Second, designed to minimize computer errors, it had two processors capable of checking each other.[60] Each machine performed a given calculation and checked the results against the other. Matching results allowed the machines to continue problem execution; a mismatch caused the BINAC to halt. Since the risk of similar errors occurring in two calculations of the same quantity is very small, the built-in duplication ensured the high probability of the accuracy of the results.[61]

The completion date of May 15, 1948, came and went; even the design phase was incomplete at this time. Construction actually began in the summer of 1948,[62] and the system was ready for delivery in August 1949. Testing consisted of laboriously following signals through each of its logic paths. Thousands of points had to be examined with an oscilloscope.

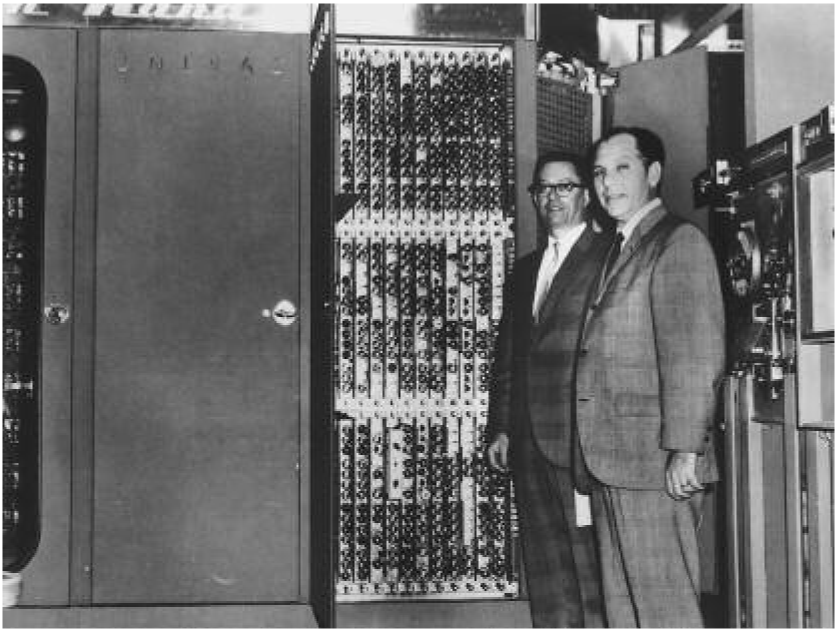


Figure 4.1
Herman Lukoff, director of research and advanced technology of Sperry Rand UNIVAC (left), and Nat Brisgone, data processing operations manager, standing in front of a first generation UNIVAC II computer recently retired (late 1960s). Courtesy of the Charles Babbage Institute.

According to Lukoff, one of the test engineers, "The challenges were great. The pulse former, which was supposed to restore the pulse shape after a number of logic gating transactions, proved to be tricky to adjust. Unfortunately, it had too many tuned circuits that had to be adjusted, resulting in endless 'didling.'"[63]

In the middle of the testing process, Eckert and Mauchly decided the company's facilities were too small for producing UNIVACs when the time came, which they hoped was soon. The new quarters they acquired in North Philadelphia were much larger than the early headquarters, and the move took place with relative ease. BINAC was delivered in trucks open to the air. Even though the day was clear, Eckert was furious that the move managers for EMCC had taken the risk.[64]

In general, the Northrop people were satisfied with the design and construction, if not with EMCC's inability to complete the contract somewhere close to the date promised. One of Northrop's engineers, Richard Baker, was even resident in Philadelphia for the last eight months of the project. After four months there, he was sending negative reports back to California about the performance of BINAC. He was distressed with the many changes required, some unreliability in the memory units, the very little time per week ("about one hour") BINAC operated, and some economizing leading to what Baker saw as "poor workmanship."[65]

The BINAC worked satisfactorily in Philadelphia as far as Eckert and his team were concerned. So the system was presented to Northrop as functioning and suitable for use. When BINAC was programmed to solve Poisson equations as part of the acceptance tests in Philadelphia, in a little more than three hours the BINAC obtained twenty-six solutions. "For each solution, the computer performed in a period of approximately five minutes 500,000 additions, 200,000 multiplications, and 300,000 transfers of control."[66] The full test ran for over seven hours, with only forty minutes of downtime for maintenance. On this basis Northrop officials accepted the machine and took responsibility for moving it. EMCC's role was completed.

When it was reassembled in California, it did not meet the expectations of many at Northrop. As Nancy Stern pointed out, the reasons for this dissatisfaction were many and diverse. Northrop engineers concluded that the machine was unreliable and insensitive due to the deplorable condition of the BINAC when they received it. After five months of use, Northrop listed twenty-eight serious deficiencies related to design, replacement features instead of the original elements agreed on, work never completed that affected reliability, and some unsatisfactory circuits, some even where the wiring was incomplete.[67] The comments by Northrop personnel and others present at the dedication cited by Stern make it sound as if the machine in Philadelphia was really an experimental device, too delicate to dismantle, ship, and reassemble. To deliver a market-ready machine would have required a complete refitting, with perhaps some redesign, to make it a device to put into the hands of users unfamiliar with such an artifact, as we saw also argued by Engstrom for the Atlas to the Bureau of Antimonopoly. Such a redesign would have cost EMCC even more money, and they had no resources for that.

The machine never worked to the full satisfaction of Northrop, and EMCC was in no financial position to fix that. They were facing insolvency. EMCC delivered the BINAC to Northrop in September 1949 and were paid the remaining $20,000 owed on the contract. Regrettably, the machine project cost EMCC $278,000, a loss of $178,000, which EMCC could ill afford to absorb. It was not a company with a profitable line of products that could afford R&D, nor were Eckert and Mauchly interested in giving up their interest in the firm to obtain the needed capital. They continued to juggle contracts and loans. One thing that helped was the testing of the BINAC memory units in January 1949 for NBS, which satisfied another milestone in the NBS contract, and they received another installment payment from them.

With the reluctant agreement of Northrop, EMCC publicly demonstrated BINAC for members of the industry and media on August 19, 1949. James W. Birkenstock, Steven Dunwell, and Byron Phelps attended from IBM and submitted reports on their return to the company. W. H. Reid summarized these reports in a memorandum to Thomas J. Watson, Jr. After a recap of the technical specifications of the system, Reid pointed out "it is conceivable that the competitive machine might replace our 603-405 for certain engineering computations." "The information which we now have indicates that the Eckert-Mauchly Corporation is a potentially important competitor in the electronic business machine field." His justification for this assertion cited not just the successful running of BINAC, but the fact that EMCC was in the process of building six UNIVACs, had a group of ten to twelve people studying business applications, and supported a broad development program "which may be on a scale comparable to our own electronic programs," and he listed nine areas of R&D. Among them were storage systems (acoustic delay lines, electrostatic storage, and magnetic drums), tape systems (plated steel tapes, servo mechanisms, photographic recording, and tape sorting and collating), and what would later come to be called systems software.[68]

There is one important footnote to the BINAC story. As BINAC construction began in August 1948 one year before delivery to Northrop, Mauchly prepared a memorandum for the executive committee on the subject of "What are we going to sell?" In the preceding few months, Isaac Auerbach had advocated production of BINACs for sale within six months. Mauchly thought that production of these machines would not interfere with production of UNIVACs, which would start soon as well. A significant amount of effort would be needed to increase the reliability of future BINACs, which would be outside a research environment, and EMCC would need to develop applications. These efforts might even enhance the UNIVAC program. "Any modification in the original design, however, requires engineering time." This could only be done if it did not interfere with the UNIVAC program. He went on to list possible organizations that could be interested in a BINAC, followed by a list of suggested modifications. Only one of the organizations might conflict with a sale of a UNIVAC.[69] Virtually all of the modifications were for simpler input–output devices and applications software to make the commercial BINAC more attractive to nonengineering personnel. The subject was to be put to the board of directors at its next meeting scheduled for August 24.[70]

Discussion by the board turned unfavorable. Eckert believed that engineering attention to the suggested modifications would consume too much time and lead to confusion between the development of BINAC and UNIVAC. Additional personnel would have to be hired, and this would not necessarily lead to efficient use of personnel. There would be insufficient safety factors in UNIVAC completion. A majority of the board was not in favor, but no definitive action was taken at the meeting. Instead they let the problem drift. Mauchly pushed for a final decision in a few days. No decision was forthcoming, but neither did EMCC build any other BINACs.[71]

Operating experience with the BINAC did suggest some modifications for UNIVAC. Circuit designs and interfaces were modified that resulted in increasing the number of tubes in UNIVAC from 2,000 to 5,000, which increased the size and power consumption of the system. Mauchly and his applications group also suggested changes in the code.[72]

The UNIVAC

The UNIVAC system description brochure, prepared in 1948 almost a year before the completion of BINAC, began with questions about a user's problem. "Is it the *tedious record-keeping* and the *arduous figure-work* of commerce and industry? Or is it the *intricate mathematics* of science? Perhaps your problem is now considered *impossible* because of prohibitive costs associated with conventional methods of solution."[73] EMCC asserted that the UNIVAC system could perform applications "as diverse as air traffic control, census tabulations, market research studies, insurance records, aerodynamic design, oil prospecting, searching chemical literature and economic planning,"[74] all of which examples were under study by the Applications Group under Mauchly. The emphasis at the beginning of the brochure was on what UNIVAC could do, not how it was designed or functioned. The latter description came later in the brochure. Mauchly, who drafted the brochure, described the advantages of using electronic equipment, stressed the automatic operation of UNIVAC, and claimed that the system would have low maintenance and high reliability. The high reliability would result not from known elements in the design, but from the experience of Eckert and Mauchly and the others in designing ENIAC, BINAC, and EDVAC. Another striking element of the brochure is that the system is described around what it can do rather than the makeup of its components. UNIVAC I is "truly automatic"; it uses newly developed tape operation to speed input and output; it performs automatic printing; it can store "voluminous records"; everything happens in the system in microseconds; an important feature of UNIVAC is its ability to automatically set up programs; and control of the system is simplified over earlier calculating techniques. A minimum system would consist of a

UNIVAC (the fundamental component of the system containing the CPU)

UNITAPES (input and output devices)

Supervisory control unit (handled automatic activity of the system)

Unitypers (for input from a typewriter)

Uniprinters

Reproducers

None of this was available in late 1948, but design had advanced far enough that the brochure touted the minimum specifications of the future system, and asserted that "actual performance will exceed the values given."[75] The input–output rate would be at 10,000 decimal digits per second. The system would handle up to twelve tape units. "Two UNITAPES may operate simultaneously, provided one is input and the other is output." Words would consist of twelve decimal digits each, with the possibility of using alphabetic and special signs. All the types of transfers, including conditional and unconditional, were listed, and "average" times were given for arithmetic operations. The physical characteristics and power requirements of the central unit were also provided. The brochure contained similar information for the peripheral components.

The back page described the accomplishments of the company, and they are worth quoting in full.

> The new important additional developments [that] make the UNIVAC a practical and reliable commercial device are not merely paper designs or laboratory curiosities, they are tested devices already incorporated into the BINAC design. Although the BINAC is not a decimal computer, nevertheless, the same principles of electronic design and the same basic electronic circuits and components,

including the mercury delay line memory and four-megacycle computing and control circuits, are used in its design and construction. The BINAC, although not intended as a general-purpose computer, is a practical commercial application of the same devices [that] are used in UNIVAC.

The UNIVAC is the only electronic computer [that] has been designed by an engineering staff who have successfully produced other computers employing the same electronic techniques. The UNIVAC is the only decimal electronic computer now under construction.[76]

This brochure is an important benchmark illustrating the progress made by EMCC in designing the UNIVAC. By the time Mauchly prepared the brochure in early 1948, summarizing the design characteristics, the design was essentially complete. By and large, this became a frozen design and most activity after January 1949 focused on the production of the system, giving allowance for the heart-wrenching experience of having to sell the company in 1950. Figure 4.2 shows a comparison of the characteristics of the various Eckert and Mauchly designed systems in order to provide information on the set and to show how close the characteristics of the first UNIVAC I were to the paper system described in the 1948 brochure.

During the BINAC project, EMCC tested the operation of the various circuit components they intended to use on UNIVAC. The engineers gathered data about the reliability of circuits, components, and tubes. Indeed, the EMCC program on the reliability and life of tubes, crystals, resistors, condensers, and basic circuits had been proceeding since at least the end of 1946. With the completion of BINAC, further development of the UNIVAC was divided into seven project areas in the Electronic Equipment Section of the company:

Logical design

Arithmetic element

Input-output equipment

Main function table and associated equipment

Central control and supervisory control

Mercury memory

Power supply

Weiner, head of the section, expected that his group would complete production design on UNIVAC by the end of 1949, and testing of the central computer would start shortly before the first of the year 1950.[77]

A COMPARISON OF ARCHITECTURE, PERFORMANCE, & PHYSICAL CHARACTERISTICS OF THE ECKERT-MAUCHLY COMPUTERS			
	EDVAC	BINAC	UNIVAC
ARCHITECTURE			
Programming	Stored program	Stored program	Stored program
Data Transmission	Serial	Serial	Serial
Number representation	Binary	Binary	Decimal
Word Length	44 bits	31 bits	11 digits − sign
Other data types	-	-	12 characters/words
Instruction length	44 bits	14 bits	6 characters
Instruction format	4-address	1-address	1-address
Instruction set size*	12(16)	25(32)	45(63)
Accumulators/programmable registers	4	2	4
Main memory size	1,024 words	512 words	1,000 words
Main memory type	Delay line	Delay line	Delay line
Secondary memory	Magnetic drum	Magnetic tape	Magnetic tape
Other I/O devices	Cards, paper tape	Typewriter	Typewriter, cards, paper tape
Error detection	Redundant CPUs	Redundant CPUs	Redundancy, parity
PERFORMANCE			
Clock rate	1 MHz	4 MHz‡	2.25 MHz
Add time	0.864 ms†	0.285 ms†	0.525 ms†
Multiply time	2.9 ms†	0.654 ms†	2.15 ms†
Divide Time	2.9 ms†	0.633 ms†	3.89 ms†
PHYSICAL CHARACTERISTICS (approx. measurements)			
Vacuum tube count	3,600	1,400	5,400
Diode count	12,000	N/A	18,000
Power consumption	50 kW	13 kW	81 kW
Floor space of computer only	490 sq. ft.	N/A	352 sq. ft.

Adapted from Nancy Stern, *From Eniac to UNIVAC: An Appraisal of the Eckert-Mauchly Computers* (Bedford, Mass.: Digital Press, 1981).

KEY:

N/A data not available.
*—number of instructions used (number encoded).
†—includes memory access time for instructions and operands.
‡—later reduced to 2.5 MHz

Figure 4.2
A comparison of the architectural characteristics of several computer systems designed by J. Presper Eckert, Jr., John W. Mauchly, and others.

Peripheral equipment was under the charge of the Electro-Mechanical Section, led by Frazer Welsh. He, too, expected the final design on the

Unityper

Uniprinter

Uniservo

Card-to-tape converter, and

Tape plater

and the logical and detailed design of components intermediate to the Uniservo and the computer proper—synchronizer, processor, interlocks—to be completed soon after September 30, 1949.[78]

UNIVAC employed a newly developed magnetic tape recording system for input and output. The Unityper produced tapes with over one million decimal digits. The reels were 7-inches in diameter with 1,000 feet of tape 8 millimeters wide and 0.002 inches thick. The magnetic material was affixed to a metal base. Data could be read at 10,000 decimal digits per second. UNIVAC could read from one tape while writing on another. Data was entered on the tape by magnetic pulses 100 to the inch in five parallel channels.

The computer's memory stored 1,000 words of 12 digits each in mercury delay lines for an internal memory capacity of 12,000 decimal digits. Accurately timed pulses, one quarter of one millionth of a second apart, enabled the computer system components to be synchronized for reliable and fast input and output of data. The system's circuits operated in add or subtract mode at one million decimal digits per second. Instructions entered the machine in the same way as data, telling the computer what to do. The instructions were transferred automatically, and tapes with the programs could be stored and used repeatedly for the same problem.

The UNIVAC design, Eckert reported, consisted of 559 standard plug-in chassis, divided into two types. The rather complicated computer circuits, the majority of which were different, made up 362 of the chassis. The second type chassis, 197 in number, were more routine and common to each other. At that time, 90 percent of the computer circuits were available and tested successfully; only a few of the second type plug-ins had been tested, and Eckert saw this as a potential serious delay. Two memory tanks had been assembled and tested with the available memory chassis. Funds from the sale to Remington Rand made it possible in 1950 to proceed with construction of UNIVAC. Over the next few months, EMCC successfully assembled the first UNIVAC and notified the Census Bureau that they were ready to demonstrate the system's capability. They prepared to run acceptance tests on the system in March 1951. The tests demonstrated that the system could do what had been promised.

Rather than move the UNIVAC I directly to Washington after the satisfactory acceptance tests, the Census Bureau decided to lease space from EMCC and leave the computer in Philadelphia. According to Lukoff, Eckert had made a recommendation along these lines earlier. EMCC agreed to maintain the system during the lease period. As the bureau personnel had only experience with punched card equipment, Harold Sweeney, Richard Malaby, and James McGarvey of EMCC assumed the task of training. The next few months amounted to a training period for the bureau people. The bureau looked to EMCC for continuous operation of UNIVAC I. Out of a week of 168 hours, EMCC used 32 for scheduled maintenance, about 20 percent. EMCC programmers quickly acquired any time left over from the regular operation of the system, usually on the third

Figure 4.3
The first UNIVAC I soon after its acceptance by the U.S. Census Bureau still in Philadelphia.
Courtesy of the Charles Babbage Institute.

shift. Weiner assigned Lukoff the maintenance task, including oversight of all UNIVAC I systems under construction. “The responsibility for the continuing engineering, testing, and installation of the UNIVAC I computer for the next several years was in my hands.”[79]

At the time, Lukoff had charge of three machines, serial numbers 1, 2, and 3, the latter two having gone into production. Serial 2 required substantial testing effort at this time as it was in the final stages of construction and Serial 3 was being assembled and sections required testing. Meanwhile, Lukoff and his meager staff were responsible for preventive maintenance shifts for Serial 1 and emergency maintenance on a priority basis. Since the newly hired EMCC maintenance engineers were still learning about the computer system, Lukoff, in the first few months, by default handled all the emergency calls, many of which came at night.[80]

Even though UNIVAC I performed well during the acceptance tests, “it was far from being reliable.”[81] Several details required attention. For example, the Uniservo tape handlers introduced a new source of error as tapes developed folds resulting in unrecoverable data. As Lukoff later wrote, in order not to convey EMCC’s concern about the problem, they gave it a new name, “dolf,” fold spelled backward. The team developed transparent plastic tapes to observe the tape continuously. The folding problem became apparent and cutting back on the oil lubricant on the tape and the power to the reel motors contained the problem. In another example, fuses blew and when replaced the system refused to work. Lukoff traced the signal through the logic path with an oscilloscope. When he traced the fault to an oscillating cathode follower, he initiated an engineering design change. This task consumed four hours in the middle of the night. At another time, the A register did not respond to instructions. Using the same signal tracing procedure, he found a loose plug in one of the bays. However, fixing that connection revealed another problem in reading from the instruction tape. Continuing his diagnostic routines, he found a tube with an open heater. These problems were solved in only five and a half hours.[82]

Gradually, Lukoff hired a team of engineers to help with maintenance, all of them young and inexperienced. But under his careful guidance, they learned their role quickly. Eventually, Lukoff decided that their heroic efforts deserved a raise in salary, and Lukoff and Philip Vincent designed a new pay scale to compensate them for emergency calls in the middle of the night. Handling these and other problems resulted in over 100 engineering change orders, which helped to remove latent defects.[83] In its first six months of operation, the bureau’s UNIVAC I averaged 21 percent time devoted to scheduled maintenance and 17 percent unscheduled downtime, leaving 62 percent for effective operation on census calculations.[84] Lukoff found this insufficient performance and designed checking routines to uncover equipment problems before they erupted into major delays. By Serial 9, slated for the Metropolitan Life Insurance Company, the UNIVAC I performance percentage was considerably improved.

Programming at EMCC

At various points above, we mentioned the programming efforts at EMCC, efforts not lost on potential customers, such as Prudential, and other visitors. For example, an IBM team attended the BINAC demonstration in August 1949, and in their report on the visit and demonstration, they referred to the attempt by EMCC to develop business applications for the forthcoming UNIVAC. The author W. H. Reid concluded that when successful, EMCC "is a potentially important competitor in the electronic business machine field."[85] To continue effectively their work on programming, EMCC needed to expand the applications group.

Grace Murray Hopper joined EMCC in July 1949, with substantial training in mathematics and experience in computer development and coding. She studied math at Vassar College in the 1920s, and in 1934 received a Ph.D. in mathematics from Yale. Hopper was elected to Phi Beta Kappa and Sigma Xi for her accomplishments. For a spell in the 1930s, she taught mathematics at Vassar and held a postdoctoral fellowship award from Vassar, which she used at New York University in 1941. She entered the U.S. Navy in 1943, and, after training, was posted to the Bureau of Ordnance Computation Project at Harvard University. Working with Howard Aiken on the Mark I and Mark II, she developed several programs, and served as coauthor of the Mark I and Mark II computer manuals.[86] Hopper joined the Harvard staff as a research fellow in 1946, continuing to work on Mark II and Mark III for the navy. From this position, she moved to EMCC.

Rounding out the applications group in July 1949, Herbert F. Mitchell joined EMCC and became head of the new Laboratory for Computational Analysis. Mitchell received a Ph.D. from Harvard in 1948, where his dissertation advisor was Howard Aiken. Both these new hires played major roles in a programming course developed in July 1949 for Northrop employees who were to work with the BINAC.[87] Most of the topics in the course referred to any computing machine—simple coding routines, numerical analysis, octal arithmetic, flow diagrams, conversion routines,

Figure 4.4
Grace Murray Hopper as a U.S. Navy rear admiral around 1985.
Courtesy of the Charles Babbage Institute.

and so forth, so Hopper, Mitchell, Katz, Livingston, and others in the applications group could easily present lectures on these topics on short notice.

Over the next few years, coding or programming became a burgeoning area of activity in university computer projects and in the few companies focused on machine developments. As Knuth and Pardo summarized in 1977, the first important programming tools were developed, focused initially on "general-purpose subroutines for such commonly needed processes as input-output conversions, floating-point arithmetic, and transcendental functions." [88] In their brief summary of the history of compilers, Knuth and Pardo drew attention to two developments of the early 1950s: assembly routines and interpretive routines.[89] The publication of the Wilkes, Wheeler, and Gill volume on programming in 1951 became a classic in the training of programmers over the next decade at least.[90] An early version of the book reached programmers around the world in September 1950. Over the next few years, a range of interpretive routines appeared, perhaps the most notable for its influence being John Backus's IBM 701 Speedcoding System, published in 1954.

As we saw above, the EMCC group investigated the development of assembly routines for use with BINAC and UNIVAC in the late 1940s. Indeed, Knuth and Pardo credited Mauchly with development of the first "high-level" programming language that he implemented in a program called Short Code,[91] a program that could accept algebraic equations as written and the program would perform the indicated operations. William F. Schmitt coded this type of problem for BINAC. In 1950, he and Albert B. Tonik recoded the program for UNIVAC I, and in 1951 Robert Logan took the task a step further.[92] In this program, the twelve-digit word was broken into six two-digit packets. This can be illustrated with a simple example.

Evaluate	x a b
In Short Code:	00 S0 03 S1 07 S2

S0, S1, and S2 represent the memory locations of the quantities x, a, and b, and 03 stands for the operation of equality and 07 for addition. Read from right to left S2 is added to S1, which is placed in S0. Thirty operations were provided, including bracket indicators for evaluation of expressions, floating point arithmetic operations, finding integral roots, the basic mathematical functions, use of routines from a library, such as trigonometric and logarithm calculations, and input–output operations.[93] This program was an effort to introduce more flexibility into problem solving. And as long as the problems were small scale in which computer time was efficiently used, the code worked well. As the scale of problems grew, a point of diminishing returns arose where it was more efficient to code in the regular way.

From 1947 on, coders at EMCC developed a number of subroutines for both mathematical and business use. By 1951, this number had increased to the point where they needed to put some order into them to increase efficiency of use. Hopper took on this task in October 1951, and between then and May 1952 she and her associates wrote the first Remington Rand A-0 Compiler.[94] While the other members of the applications department continued their work on programs and routines, including diagnostic routines for UNIVAC I, Hopper assumed an interest in what she called "automatic programming." She attempted to meld the operations of the computer system and its programs with the use of subroutines. This idea of subroutines was exploited at EMCC before she arrived, as we saw above in the work of Betty Snyder. Hopper's contribution was to make it possible not just to call up a routine from memory, but, if necessary, actually construct a subroutine program from basic mathematical information supplied to the system by a mathematician or programmer, insert it into a program, and carry out the computation of the needed values of the function. After the needed information was inserted into memory, it could be delivered at any later time directly by UNIVAC. UNIVAC delivered the information necessary to program the computation of a function and its derivatives or values. The actual derivation of the function was done by the computer system, not by the programmer as before. Thus, the UNIVAC became capable of developing a completed program.[95] The process of translating a subroutine into a program received the name "compiler."

As Jean Sammet pointed out, "a compiler must perform at least the following functions: analysis of the source code, retrieval of appropriate routines from a library, storage allocation, and creation of actual machine code."[96] A-0, developed for UNIVAC I did exactly this, and in Sammet's sense, A-0 is the first compiler. Hopper, speaking in 1978, commented on A-0 in the following way: "It wasn't what you'd call [a compiler] today, and it wasn't what you'd call a 'language' today. It was a series of specifications. For each subroutine you wrote some specs. The reason it got called a compiler was that each subroutine was given a 'call word,' because the subroutines were in a library, and when you pull stuff out of a library you compile things. It's as simple as that."[97] When coding the compiling routine A-0 (and A-1), the coder needed to keep in mind three sets of memory locations:[98]

(1) those locations used by the compiler, concerned with compilation, input of information and subroutines, and output of running tape and record

(2) those locations used by the running tape, concerned with numerical computation, input of numerical data, and output of results

(3) those locations of the individual subroutines

Thus, at any given instant during compilation, a particular word usually had at least three addresses associated with it. For a given problem, it was assumed there would be four tapes (Uniservos) available. Tape 1 contained the instructions for compilation and data handling; 2 held the input data; 3 contained the data called for by specific subroutines; and 4 received the output data. Along with memory segments, say 000–059 for the initial read, for input, working storage, program, constants, and output blocks, the compiler had an area called the "neutral corner." The neutral corner contained certain transfer instructions. The concept of the neutral corner arose because Hopper quickly encountered the problem that in some cases the program needed to jump back for something previously processed and at other times the need was to jump forward to a section of the program still unknown, therefore whose location was unknown. That is, there were two types of jumps to be coped with. Jumping back was simple; jumping forward was impossible. The telling of her solution to this problem bears presenting completely in her own words.

And here comes in the curious fact that sometimes something totally extraneous to what you are doing will lead you to an answer. It so happened that when I was an undergraduate at college I played basketball under the old women's rules which divided the court into two halves, and there were six on a team; we had both a center and a side center, and I was the side center. Under the rules, you could dribble only once and you couldn't take a step while you had the ball in your hands. Therefore, if you got the ball and you wanted to get down there under the basket, you used what we called a "forward pass." You looked for a member of your team, threw the ball over, ran like the dickens up ahead, and she threw the ball back to you. So it seemed to me that this was an appropriate way of solving the problem I was facing of the forward jumps! I tucked a little section down at the end of the memory which I called the "neutral corner." At the time I wanted to jump forward from the routine I was working on, I jumped to a spot in the "neutral corner." I then set up a flag for the [forward operation] which said, "I've got a message for you." This meant that each routine, as I processed it, had

> to look and see if it had a flag; if it did, it put a second jump from the neutral corner to the beginning of the routine, and it was possible to make a single-pass compiler and the concept did come from playing basketball.[99]

A-0, however, was the only single-pass compiler built. Hopper believed A-0 should be a one-pass compiler. The information defining a problem came from one tape unit and the program was written on another because UNIVAC I had only 1,000 words of storage, leaving little room for anything but the basic steps of the compiling process.

In the technical language of the instruction manual, the neutral corner was described thus:

> When the compiler, processing operation a, is informed that one of the exits of operation a must transfer control to operation a b (b 1), a "forward pass" is required [fig. 4.5]. The compiler inserts in the exit line of operation a, an instruction transferring control to memory location g in the neutral corner. The compiler then records the fact that, the neutral corner has in storage a forward pass destined for operation a b. As each successive operation is treated, the compiler looks to see whether or not a forward pass has been tossed to that operation. Hence, it will find a pass to operation a b. The instruction transferring control to operation a b is generated and delivered to position g in the neutral corner.[100]

All of this was on the running or program tape, tape 2.

Similarly, for the compiling tape, tape 1, it was assumed that four Uniservos were available. These tapes were for the compiler, information

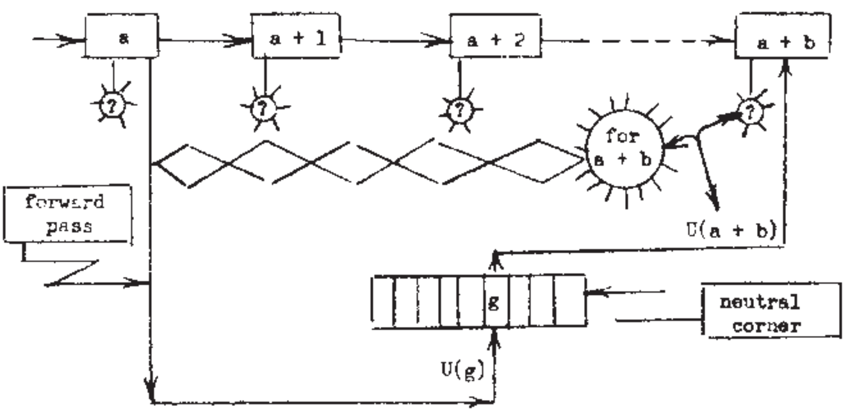


Figure 4.5

Grace Hopper's Neutral Corner diagram illustrating its use in the Remington Rand A-0 Compiler. Taken from the *A-0 Compiler Manual* in the Computer Products Manuals Collection of the Charles Babbage Institute.

defining the problem, the subroutine library, and the running tape. The memory sections were broken down in the same way on this tape, though each section might contain different kinds of information than on the running tape. The information defining the problem consisted of a set of operations, each defined by three or more words (fig. 4.6). The information contained the "call number" of the operation and subroutine, one or more "argument words" identifying quantities entering the operation, "control words" if the normal exit to the next operation was to be altered or if the subroutine had more than one exit, and, last, one or more "result words" identifying the results produced by the operation. The subroutines in the library were in alphabetical order. As each subroutine was entered in the running program, a record was kept by the computer, including its call number, the number of the operation, and the memory location in running memory at which the subroutine began.

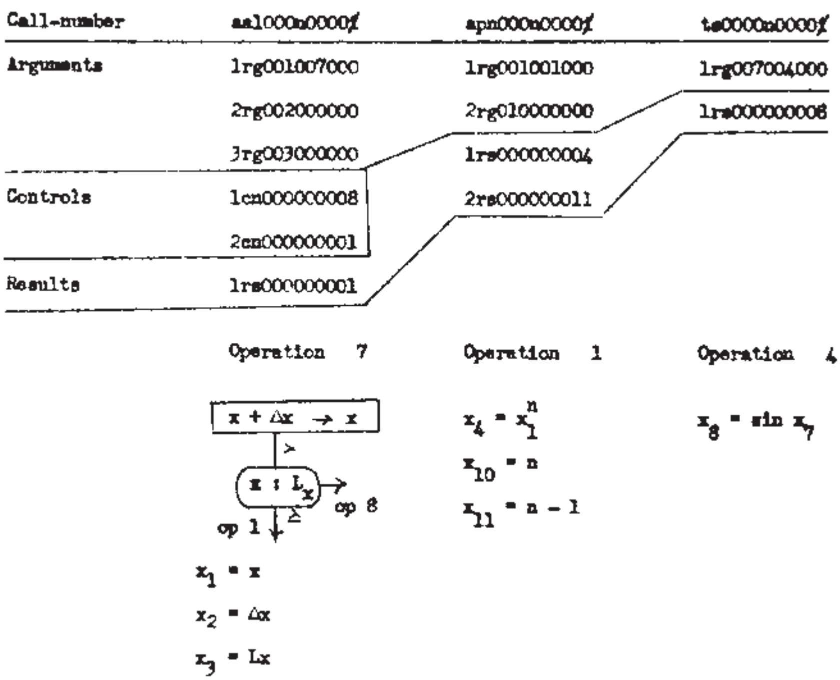


Figure 4.6
A diagram showing the compiling operations of the A-0 Compiler. Taken from the *A-0 Compiler Manual* in the Computer Products Manuals Collection of the Charles Babbage Institute.

The compiling tape was constructed in blocks from 1 to 13, where blocks 1 to 4 contained the data and instructions for the compilation and blocks 5 through 13 contained the compiling program. The A-1 compiler was more extensive than A-0, and provided for longer programs, a larger number of transfers of control to the neutral corner, and more working storage.

Hopper presented the compiler at the ACM meeting in Pittsburgh in May 1952. She carried 200 copies of her presentation to the meeting, and returned with 100 copies to Philadelphia.[101] Ridgway, in a paper delivered in September 1952, offered some comparison data for the use of A-0 acquired around the time of Hopper's talk. The group compared the calculation of the problem discussed above using the conventional method of program development and running and using the compiler. In the conventional method, Ridgway reported, 740 minutes were needed of the programmer's time, 105 minutes for auxiliary manpower and equipment, and 35 minutes to run the problem on UNIVAC. The equivalent numbers using the compiler were 20, 20, and 8.5 minutes, respectively. Thus, problem solution required 880 minutes conventionally and 48.5 minutes using a compiler.[102] In spite of this reported advantage in time, the A-0 compiler did not come into general use, for as we will see below, EMCC was in the process of increasing its generality to a complier called A-1 (January 1953), and then developed the even more effective compiler A-2 in mid-1953.

This time specified for programmer minutes in a given problem is only useful in this comparison. The time translates into only about an hour-and-a-half. A more detailed analysis of the conventional method for UNIVAC would show that the problem setup could sometimes take weeks, especially with a new problem. Consider the four stages in addressing problem analysis in the EMCC programming group. Lloyd Stowe noted in early 1951 that the programmer's task could be divided into four parts: analysis of the problem; preparation of block diagrams and flow charts; coding, checking, and preparation of time estimates; and, if needed, running of sample problems through the code; and "bookkeeping."[103] He noted that in one case he spent seven weeks on preparation of a problem. After the first preparation, he received more information about the problem. And after a second preparation, more information came that the people with the problem had not recognized before as needed. So a third effort was required. This example is reminiscent of the later problem in the 1960s of trying to obtain an expert's knowledge for developing an expert system.[104] Understanding a problem requires consultation with the proposers of the problem and analysis of the information provided. Since Stowe concentrated on commercial problems, he was particularly interested in the nature and amount of input data. The Census Bureau data, which Stowe, Snyder, and Gilpin were working on at this time,[105] expected an input of 151,000,000 punched cards.[106]

Programmers asked themselves such questions as: What form does the data have? What is the required form and volume of the output data? How will the output be used? Will the output be reused? and so forth. From this, the programmer could craft a block diagram or flow chart of the problem, in classic von Neumann style. The block diagrams helped Stowe, and presumably other programmers, to identify omissions, inconsistencies, and errors. The general order of problem solution was set down, sometimes in great detail: "take this number, add it to that one, divide it by two, and get a percentage."[107] Next came the flow chart procedure.

The most laborious part of the process followed. The flow charts had to be translated into the language of the machine, a process the compiler was designed to circumvent. To accomplish the simple task of adding two numbers, a significant number of lines of code were written. "The programmer must instruct the machine in its particular code to bring one number from the storage. He must tell it in another operation to add another number from the storage and must further instruct it to take the sum and send it back to storage. These three operations for the computer are implied by one operation in the flow chart. It is frequently difficult to look at the flow chart and say it is going to need 752 lines of coding; it is almost impossible without experience with the particular type of problem. Some of the most innocuous looking boxes on the flow chart may take lines and lines of coding."[108] It was at this point in the process that a decision could be made between two possible solutions, if multiple possibilities were under investigation.

After coding, an independent programmer checked the entire program. At EMCC, the coders tried to have at least two independent checks made of the code at this point. (In the event the problem needed to be put aside for a higher priority concern, Stowe tried to write a report on the work to this point so that when he returned to the problem he would not have to start anew.) Then came specific operating instructions. These instructed the operator what to do if something went wrong with the routine, how the tapes were to be mounted, how long was the expected run. Even these instructions were occasionally not enough. Sometimes, the programmer actually accompanied the operator during the program run to be able to handle programming errors if they turned up.

In his talk to the seminar, Stowe emphasized the need for training of coders and programmers, a point stressed by Mauchly to Remington Rand management at this time also as we shall see below. At this time, the programmer needed to be familiar with the logic of the computer system. People did not need to be computer designers. They could be taught programming. A background in particular problems would be a decided advantage. He stopped short of calling for a training program. If nothing else, Stowe's presentation illustrated the attitude of EMCC programming people of the need and desire for more sophisticated programming tools. The Hopper group's work on A-0 was designed to meet this need. But in 1951 A-0 did not go far enough.

Hopper realized that even writing the input specifications for the A-0 compiler was long and cumbersome. She and her group[109] adopted a three-address code for the twelve alpha-decimal characters. They imposed this on top of A-0, and wrote a translator to put on the front end of A-0. Thus, the A-2 compiler came to be.[110] In the previous compilers (A-0 and A-1), the problem analyst prepared the problem for solution and submitted the steps to a coder for preparation, just as was done in coding any problem. In A-2, the analyst circumvented this step through the use of a "pseudo-code." The pseudo-code instructions were recorded on tape and read into the computer. The compiler read these instructions and assembled the entire program for running. By this time, the C-10 code was in use on the UNIVAC.

The structure of this compiler resembled the earlier compilers with the added feature of the pseudo-code.[111] The set of easily accessible subroutines were contained in a library in alphabetical order. Information from tape was read in the same sixty word units, called blocks. Arithmetic was done in floating point. Data was expressed in "two-word" form, which represented the complete numeric quantity to be expressed. The first word contained a numeric quantity without the decimal point and the second word gave the information for the placement of the decimal point. The data and instructions occupied the same block locations as in the previous compilers.

In solving a problem such as:

$$y \quad e^{x^2} \sin cx$$

Where x ranged between 0.99 and 0.99 in increments of x 0.01, y needed to be determined for each of 199 values of x throughout the range. Consider only one such calculation in the set to appreciate the flavor of the pseudo-code. One operation was to increase x by the increment

Δx and test to determine if all the values of x throughout the range have been used to calculate the y result required. The description of this operation is "ADD to A LIMIT." Three lines were needed, expressed in a three-address code.

1 2 3 4 5 6 7 8 9 10 11 12

AAL (x_i) (x) (Lx)

1CN 0 0 0 0 (OPN #)

2CN 0 0 0 0 (OPN #)

The first line required three relative working storage addresses. The values needed were x, Δx, and Lx, the last being the limit of the range of x. X for this problem was known to be in 000, Δx was in 002, and Lx was in 004. Thus, the first line was expressed

AAL 000 002 004

On the basis of this instruction, the routine would add x (in 000) to x (in 002) and place the sum (the new x) back in 000. This new x would then be tested against the limit of x (Lx in 004) to determine whether or not the limit had been reached. All the coder was required to do was send "control" back to the beginning and calculate the next y with the new value of x. This was the purpose of the 1CN line. The symbols OPN # meant that if the new x was not equal to the limit, control would be transferred to the operation number (OPN #) placed here. Since actual calculation began with operation 1, this line would read

1CN 000 0 00001

Five digits were allocated to the operation number because the compiler could handle up to 99,999 operations. When the limit for this problem was reached, control went to the next operation, in this case operation 11.

2CN 000 0 00011

In all, there were 35 pseudo-code instructions, including an end coding instruction. See figure 4.7. In response to requests of the sales staff, later compilers for business program compilation received names, Math-Matic (originally known as B-0) and Flow-Matic. Flow-Matic allowed the user to write instructions in English pseudo-code, which UNIVAC I could translate and use to generate the program. Figure 4.8 shows the set of instructions for Flow-Matic.

A-2 INSTRUCTIONS

NOTE	1	2	3	PSEUDO-INSTRUCTIONS 4–12	DESCRIPTION
1,2	G	M	I	0 (t) ( ) 0 (S) (m)	INPUT GENERATOR
1	G	M	M	(m_1 abs.) 0 (n) (m_2 abs)	MOVE GENERATOR
1	M	V	0	[m_1) (n) (m_2)	MOVE FL. DEC. NUMBERS
1,2	G	M	O	0 (t) X (H L) (S) (m)	OUTPUT GENERATOR
3	G	Z	Z	0 (S) 0 (Z E) 0 (H L) 0 (t)	ENDING SENTINEL GENERATOR
1	A	A	0	(A) (B) (C)	ADD
1	A	S	0	(A) (B) (C)	SUBTRACT
1	A	M	0	(A) (B) (C)	MULTIPLY
1	A	D	0	(A) (B) (C)	DIVIDE
1	A	N	1	(A) 0 0 0 (B)	CHANGE SIGN
1,4	A	P	N	(A) (N) (B)	RAISE TO A WHOLE POWER
1,5	X	+	A	(N) (LOG_{10} A) (B)	RAISE TO A FRACT.POWER
1	S	Q	R	(A) 0 0 0 (B)	SQUARE ROOT
1,6	R	N	A	(A) (N) (B)	ROOT
1,7	L	A	U	(A) (LOG_{10} B) (C)	LOGARITHM
1,8	S	U	M	(x_0) (n) (Σx)	SUM
1,9	P	O	L	(x^λ) (C_n) (P)	POLYNOMIAL SUM
1,10	T	S	0	(A) (0 0 0 (B)	SINE
1,10	T	C	0	(A) 0 0 0 (B)	COSINE
1,10	T	A	T	(A) 0 0 0 (B)	ARCTAN
1,11	A	A	L	(x_i) (Δx) (Lx)	ADD TO A LIMIT
	1	C	N	0 0 0 0 (≠ OPN #)	
	2	C	N	0 0 0 0 (= OPN #)	
1	Q	U	0	(A) (B) 0 0 0	EQUALITY TEST
	1	C	N	0 0 0 0 (= OPN #)	(ALGEBRAIC)
1	Q	U	A	(|A|) (|B|) 0 0 0	EQUALITY TEST
	1	C	N	0 0 0 0 (= OPN #)	(ABSOLUTE)
1	Q	T	0	(A) (B) 0 0 0	GREATER THAN TEST
	1	C	N	0 0 0 0 (> OPN #)	(ALGEBRAIC)
1	Q	T	A	(|A|) (|B|) 0 0 0	GREATER THAN TEST
	1	C	N	0 0 0 0 (> OPN #)	(ABSOLUTE)
	U	0	0	0 0 0 0 0 0 0 0 0	UNCONDITIONAL
	1	C	N	0 0 0 0 (to OPN #)	TRANSFER
1	Q	Z	0	(m) 0 0 0 0 0 0	SENTINEL TEST
	1	C	N	0 0 0 0 (≠ OPN #)	
	2	C	N	0 0 0 0 (= OPN #)	
	C	S	T	0 0 0 0 0 0 0 0 0	OPERATION REPEATER
	1	C	N	0 0 0 0 (from OPN #)	
	2	C	N	0 0 0 0 (up to OPN #)	
	3	C	N	0 0 0 0 (go to OPN #)	
1	B	T	I	(m_a) (m_b) 0 0 0	TYPE IN
1	Y	T	O	(m_a) (m_b) 0 0 0	PRINT OUT
1,12	E	D	F	(m_1) 0 (n) (m_2)	LARGE OUTPUT EXPONENTIAL EDIT
1,13	E	D	U	(m_1) (c) (n) (m_2)	SMALL OUTPUT EXPONENTIAL EDIT
1,14	E	D	T	(m_1) 0 (n) (m_2)	LARGE OUTPUT CONVERSION & EDIT
	R	W	S	(tape nos. in order)	REWIND TAPES AND STOP
	S	E	G	M E N T Δ Δ Δ Δ Δ	SEGMENT
	E	N	D	Δ C O D I N G Δ Δ	END OF INFORMATION
	1	2	3	4 5 6 7 8 9 10 11 12	

Figure 4.7

A page of pseudo-instructions for the A-2 compiler. Taken from the *A-2 Compiler Manual* in the Francis Holberton Collection, Charles Babbage Institute.

Flow – Matic Code

```
(0) INPUT INVENTORY FILE-A PRICE FILE-B; OUTPUT PRICED-
    INV FILE-C UNPRICED-INV FILE-D; HSP D.
(1) COMPARE PRODUCT-NO(A) WITH PRODUCT-NO(B); IF
    GREATER GOT TO OPERATION 10; IF EQUAL GO TO
    OPERATION 5; OTHERWISE GO TO OPERATION 2.
(2) TRANSFER A TO D.
(3) WRITE-ITEM D.
(4) JUMP TO OPERATION 8.
(5) TRANSFER A TO C.
(6) MOVE UNIT-PRICE(B) TO UNIT-PRICE(C).
(7) WRITE-ITEM C.
(8) READ-ITEM a; IF END OF DATA GO TO OPERATION 14.
(9) JUMP TO OPERATION 1.
(10)    READ-ITEM B; IF END OF DATA GO TO OPERATION 12.
(11)    JUMP TO OPERATION 1.
(12)    SET OPERATION 9 TO GO TO OPERATION 2.
(13)    JUMP TO OPERATION 2.
(14)    TEST PRODUCT-NO(B) AGAINST ZZZZZZZZZZZZ; IF
    EQUAL GO TO OPERATION 16; OTHERWISE GO TO
    OPERATION 15.
(15)    REWIND B.
(16)    CLOSE-OUT FILES C,D.
(17)    STOP. (END)
```

Figure 4.8
A sample program from the Flow-Matic system developed by Hopper and others at the Remington Rand EMCC Subsidiary.

Dupont was the first company to use A-0. From there, it spread to the David Taylor Model Basin, where Betty Snyder now resided, to the Army Map Service, and the Census Bureau, all purchasers of UNIVAC Is.[112]

The Mauchly group determinedly tried to convince the community to use these techniques. There was the Pittsburgh meeting mentioned above where Hopper spoke on A-0. Mauchly repeatedly addressed groups in various professional settings. Not surprisingly, he participated in the symposium on large-scale digital calculating machinery at Harvard in 1947, where he spoke about “Preparation of Problems for Edvac-type Machines.”[113] In September 1949, he presented details about the UNIVAC system to the American Chemical Society. Mauchly was invited to address the Chesapeake Section of the Society of Naval Architects and Marine Engineers in January 1951 on the subject of the computer's value in various engineering problems of interest to the society. Before the American Gas Association–Edison Electric Institute Joint Accounting Conference in April 1953, Mauchly focused on the system's usefulness to business and noted a new training program offered by Remington Rand.[114]

Hopper was on the lecture circuit at least as much as Mauchly. In May 1952 as noted above, she spoke to the Association for Computing Machinery (ACM) on "The Education of a Computer," a title she used often but with slightly revised text each time to keep up with developments in EMCC. For example, one talk was to the Symposium on Industrial Application for Automatic Computing Equipment held in Kansas City, Missouri, by the Midwest Research Institute in January 1953. Richard Ridgway delivered a paper on "Compiling Routines" to a meeting of the ACM in September 1952 in which he did a detailed analysis of EMCC compilers. The Census Bureau organized a workshop on coding and programming for July 1953, attended by several Remington Rand applications personnel. In September 1955, Mary K. Hawes, supervisor of commercial programming of Remington Rand, presented a talk entitled "Automatic Routines for Commercial Installations" at a meeting of the ACM. After 1955, attendance at meetings by Remington Rand employees became too numerous to catalog here for any useful purpose.

All of these examples of codes, compilers, and outreach indicate the high level of software activity within EMCC and later Remington Rand, as well as being illustrations of the similarities with and differences from programming developments elsewhere. The company assembled a group of highly effective programmers to provide programs that would make the UNIVAC more attractive to potential customers and to attach customers to EMCC, and later Remington Rand. The group was effective, and after the sales force received education about the use of computers, sales began to rise, such that the late 1950s and 1960s ensured the future of Sperry Rand in the computer field. But what about EMCC?

The Light Dims and EMCC Is Sold

Even as they began to organize assembly of systems and to plan deliveries, Eckert and Mauchly began to realize in the fall of 1949 that they might not be able to do either of these two things without some more outside help. They had contracts with the Census Bureau (through

NBS), A. C. Nielsen, the Prudential Insurance Company, and also through NBS with the Army Map Service and the Air Material Command, contracts totaling over $1,200,000. Some contracts allowed for upfront cash payments, other contracts did not. They lost a substantial sum on the BINAC. Notes payable to American Totalisator in the amount of $112,000 were due in January 1950. After the death of Henry Straus, their supporter at Totalisator, the company notified EMCC that they would not purchase any EMCC stock as earlier agreed.[115] American Totalizator withdrew further support, and desired to sever their operating and managerial relationship with EMCC. They contacted Alexander Brown and Company, a Baltimore banking and investment house. There was no interest. They approached another firm, Merganthaler Company, manufacturers of linotypes, which expressed an interest, but later declined.[116] At the November 9, 1949, board of directors' meeting, the assembled members agreed that "new financing is essential" and not later than January 1, 1950. Funds were needed for the two objectives of "carrying out the UNIVAC contracted production program," and R&D work on other projects "considered necessary to realize the full potentialities of the UNIVAC System." Shortly after this meeting, George Eltgroth prepared a memorandum of prospects for financial reorganization.[117] At the December 15 annual meeting, Mauchly stated "that the Corporation's financial position was critical and that it had been a great disappointment to have failed to meet the originally projected production and delivery schedules by several months. He stated that the management had established contact with several potential sources of capital, both governmental and private, and that negotiations with these organizations were being pursued."[118]

While EMCC staff heroically worked to design and construct UNIVAC, financial problems continued to mount, until, at the end of 1949, they could no longer be solved with yet more contracts. There was cause for hope, however. By the end of 1949, the company and its products were well known. Through a variety of demonstrations, visitors came to know the strengths and weaknesses of the various EMCC components and completed systems. For each of the demonstrations, EMCC issued press releases and invitations to the showings. In hindsight, we might believe that one of these companies would come to the rescue.

Various members of EMCC established contact with a number of firms. In November alone, EMCC had contact with Bendix Aviation Corporation, Hazeltine Electronics Corporation, International Telephone and Telegraph, General Motors, NCR, Zenith, Remington Rand, Westinghouse, Addressograph-Multigraph Corporation, Hughes Aircraft, and IBM. IBM refused outright; Bendix wanted complete control, something Eckert and Mauchly were yet unwilling to give; Hazeltine and ITT declined. Westinghouse wanted to evaluate the potential market first, and later decided they would have to outcompete IBM, so declined. Philco Corporation evinced an interest, because of its developments in industrial electronics, for example, the possibility of transmitting business data to computers over unused television lines.[119] And on behalf of EMCC, the Nielsen Corporation had approached some private investors in Chicago as a possibility also.[120]

EMCC sought help from the R&D advisory board of the Department of Defense, for a reconsideration of further funds on BINAC because of EMCC's losses. Nothing came of this, although many discussions took place. The census people advised EMCC to seek funds from the Reconstruction Finance Corporation (RFC), an agency of the federal government. When EMCC filed an application, McPherson and Lockeray of the census met with Clifford Hahn, the regional director of the RFC.[121] Early in January 1950, RFC decided to decline the loan application, based primarily "on a lack of tangible collateral to support the loan."[122] In the same period, NBS director Edward Condon sent a letter to the director of the Office of Domestic Commerce of the Department of Commerce explaining the government's interest in the stability of EMCC and the need for the government to provide sufficient financial assistance.[123] Nothing came of this plea.

After visits by one or more of the companies noted above, only Remington Rand continued its interest.[124] Remington Rand seemed the best prospect. EMCC employed Remington Rand electric typewriters as one alternative component of the BINAC and UNIVAC systems. Consequently, there were occasional visits by Remington Rand Norwalk personnel to EMCC. For example, Arthur Draper came to EMCC in the summer of 1949 "ostensibly to assist in correcting faults of the Remington Rand electric typewriter."[125] General Leslie Groves, vice president for research, Draper, and several engineers from Remington Rand had attended the BINAC demonstration on August 22, 1949, "displaying considerable interest." Wistar Brown reported that during a September 1949 visit he made to Remington Rand about a gang printer for use in the UNIVAC system, Groves "obliquely hinted" Remington was desirous of some sort of alliance between the two firms.[126] EMCC asked Drexel and Company, the Philadelphia investment banker, to obtain a clear statement from Remington.[127] Groves requested EMCC present a brief written history and status of the corporation for Mr. James H. Rand. Two weeks later on September 17, another meeting occurred, during which Groves and Draper pressed Eckert and Brown for more information on the company's plans, projected financial requirements, and potential markets. With a chart in hand detailing rough expenditures and starting dates for UNIVAC production and specific development projects, the group met with James Rand and Albert M. Ross, senior vice president for engineering. Draper agreed to prepare documents about the situation in Remington Rand management style and asked the EMCC representatives if an exchange of stock appeared to be a reasonable method for handling a purchase.[128] The two men outlined for their colleagues the necessary future steps to continue negotiations. A week after the meeting with Draper and Groves, Brown telephoned Draper to tell him that EMCC would need about $280,000 per quarter to meet expenditures.[129]

Remington Rand acquired EMCC on March 1, 1950, through purchase of approximately 95 percent of EMCC stock, thereby taking over the basic development in electronic computing. EMCC would be operated as a subsidiary of Remington Rand, augmenting the research and development already under way in Remington Rand. This subject is a major focus of the following chapter. The company's press release noted that, "the addition of the new electronic computer [UNIVAC] to Remington Rand's widely diversified line of business recording machines places the company in an outstanding position in the application of electronics principles to scientific research and the calculating-recording field."[130]

We can reasonably conclude that if Remington Rand had not come to the aid of EMCC, had not assumed the mounting EMCC debt, had not agreed to provide the funds needed to acquire inventory to assemble the UNIVAC Is on order and salaries for staff, EMCC would have been crippled. No doubt Eckert and Mauchly would have continued to struggle, but with rapidly deteriorating conditions until it was necessary to close the firm and sell any marketable assets. Remington Rand would not have gained a foothold in the commercial computer industry without EMCC or another firm as advanced as it was in 1950. IBM would have had a somewhat easier time, but may themselves have stagnated without the competition of EMCC, a leading designer of computer systems. Other firms would have tried to provide the competition, but with less success. The emerging computer industry was better prepared because Remington Rand acquired EMCC, and later ERA. Nevertheless, we must recognize that Remington Rand stumbled badly when they approached the computer market, a subject we will address in the next chapter.

5

Remington Rand Computing: Integrating EMCC and ERA into the Parent Company

In 1950, Remington Rand was one of the two major calculating machine companies in the United States, but it had already fallen severely behind. Its share of the tabulator market hovered at 17 percent, while IBM's share stood out at 83 percent.[1] IBM entered the electronic market just after World War II, by redesigning its 603 tabulator to use vacuum tubes and issuing the IBM 604. Moreover, IBM indulged in the computer area through its design and construction of the Selective Sequence Electronic Calculator, the SSEC. At the time, Remington Rand had no advanced products under design. In 1946, the company established the Advanced Research Laboratory in Norwalk, Connecticut, as a research and development facility to introduce electronics into its line of tabulating machines. James Rand and others in the firm recognized the need to position the firm in the new technology. Even with the founding of the new laboratory, management still chose to extend its reach into the new area in its time-honored way of acquisition rather then building capability from within, as IBM did.

Remington Rand incorporated in 1927 as a combination of Remington Typewriter Company and the Rand Kardex Corporation, and very quickly thereafter added the Dalton Adding Machine Company, originators in 1903 of the first ten-key adding machine, the Baker-Vawter company, which introduced the first loose-leaf ledger in 1886, and the Powers Accounting Machine Corporation, principal competitor to Hollerith/IBM in tabulators. The typewriter firm dated from 1873, when Christopher Sholes developed the first practical typewriter and convinced the sewing machine manufacturer E. Remington & Sons to produce it.[2] E. Remington became Remington Typewriter in 1913. Rand Ledger Company was the design of James H. Rand, Sr., who set out to rationalize American business offices through the development of a visible index system. His son, J. H. Rand, Jr., chaffing in the company under his father's authority, developed his own invention, the Kardex Visible Record Control system, and began his own company. Father and son combined their firms in 1925 into the Rand Kardex Corporation, also a combination with other firms, such as the Safe-Cabinet Company and the Library Bureau. Powers dates to 1911, when it was established by James Powers to compete in the tabulator market with IBM's predecessor C-T-R. Although limited in the use of electrical technology in tabulators by IBM's strong patent position, Powers had developed several good sorters, tabulators, and printers, which competed in markets shared with Burroughs and National Cash Register (NCR). This pattern of acquisition by Remington Rand continued in the 1930s and the 1950s. When Remington Rand merged with Sperry Gyroscope, which also had a history of acquisition, in 1955, the new firm, Sperry Rand, continued to acquire other companies related to its core businesses.

By the end of 1928, Remington Rand had sales of $59.6 million, making it first among all business machine companies, followed by NCR and Burroughs. In 1931, Remington Rand remained in first place, but IBM had vaulted into second place, and by 1945 IBM had achieved first place.[3] When acquired, Remington Rand left Powers to function as a subsidiary, and only later integrated it more into the firm.[4] As James Cortada pointed out, Remington Rand entered the late 1940s "in a good position to take advantage of computers and to become a giant in that fledging industry. It had a sales force and a broad set of loyal business customers, not to mention good penetration within the government, especially the military. The company also had considerable expertise with electromechanical unit record card equipment."[5]

Evaluating this agglomeration, Cortada pessimistically noted that Remington Rand faced several kinds of problems that were to plague it over the second half of the twentieth century. Principal among these was Remington Rand's offering of multiple product lines with redundant goods, services, and expenses. In addition, personnel faced internal competition for resources and a split focus from senior management.[6]

Repeatedly, analysts and other observers of the business machines industry greeted mergers and other changes in Remington Rand with optimism. In 1927 with the merger of Rand Kardex and the newly acquired Powers Accounting Machine Company, observers viewed the new Remington Rand as a major force in the industry, a worthy competitor to Burroughs, NCR, and the smaller International Business Machines. As noted above, in 1946 Remington established a laboratory to pursue research into new electronic products to advance the company's standing in the tabulator market. One of its first products was an electronic version of the Powers tabulator, which reached the market in 1951 just as the company embarked in a new direction. Remington Rand's purchase of Eckert-Mauchly caused it to be viewed as the potentially dominating force in electronic digital computing at the opening of the 1950s. "The deal is earthshaking news to the office-machine industry." "This deal might well put it out in front of both IBM and its other competitors."[7] And when Remington Rand and Sperry Gyroscope merged to become Sperry Rand, *Fortune* noted that in the business-machines market "its potential is tremendous."[8] However, each of these changes seemed to produce organizational disturbance, some have said chaos, that delayed entry of new products to the market until it was often too late, which made it difficult to realize the potential. Readjustment of reporting lines often limited the effectiveness of personnel. Since such circumstances did not arise for its competitor IBM, IBM smoothly captured the market for computers in the 1950s. Perhaps a longer time for penetration of the market might have favored Remington Rand, but they never had that luxury. Moreover, some of the personalities in Remington Rand's computer area, while possessing vision about computing systems, lacked the personal modesty that would allow teamwork to enhance product development and rapid solidification of design to deliver products quickly. Cortada summarized the reasons offered by historians for Remington Rand's stumbles in the computer market.

Remington Rand failed to develop marketing strategies or a knowledgeable sales force to sell computers.

It failed to educate customers on why they needed computers and how to use them.

It had inadequate product development.

There was too much labor force turnover due to disenchantment with the firm.

The acquired computer firms were never integrated into the company until it was too late.

Weak management crippled the firm's ability to commit to the new industry.[9]

Citing these reasons does not offer an explanation of why Remington Rand performed in this way. Was it inadequate vision? Was it a case of too large a challenge in the mergers without adequate thought of what was at stake? Were there people in the firm who offered policies and tactics to meet market challenges but were ignored? Was Remington Rand risk averse? What does it mean to say that Remington Rand had weak management? After all, it was a profitable company overall; it simply failed to meet the challenges in one area of the market, albeit an important future area in which they possessed great talent at the outset.[10] And because of this, we need to caution ourselves in measuring what went on inside Remington Rand by the yardstick of IBM's accomplishments in the same period when it had only one focus, and Remington Rand had many to consider when viewing the marketplace. In the competition for resources inside a firm, foresight is not always crystal clear, where hindsight is a better teacher. It seems that Remington Rand had to learn an important lesson as pointed out more generally by Pugh and Aspray: "In a market characterized by rapidly changing technologies and customer requirements, suppliers capable of meeting the needs of several types of customers had the greatest chance for survival."[11] Remington Rand tried to meet the needs of several markets and its success, limited as it might have been in some of these markets, kept them in the industry down to the present. Remington Rand merged with Sperry Gyroscope in 1955 to form Sperry Rand. In 1986, Sperry Rand merged with Burroughs Corporation to form today's Unisys. Sperry Rand abandoned many of the earlier markets to focus primarily on systems involving computers.

Besides the array of office machine products—punched-card tabulators, calculators, adding machines, and typewriters—Remington Rand manufactured electrically operated filing devices, Kardex Visible Systems and Services, office and library equipment such as filing cabinets and loose-leaf accounting systems, cameras, shavers, and industrial television cameras. Manufacturing plants were distributed across the United States and three other continents. Remington Rand's gross sales for fiscal year 1952, which ended on March 31, 1952, were $227 million (slightly less than IBM's $267 million) with a net income before taxes of $34 million (only half of IBM's $77 million).[12]

Remington Rand showed great pride in its new high technology activity. In the company's 1952 annual report (the fiscal year ended March 31, 1952), the following assessment appeared. "The acquisition of Engineering Research Associates places Remington Rand in the forefront of the three phases of electronic computer development: the world-famous Remington Rand UNIVAC, the fastest and most advanced all-purpose electronic computer now in use; the ERA '1101' electronic computer for scientific work; and the office-size '409' electronic computer for commercial application developed at the Remington Rand

Laboratory."[13] This statement made it appear that the three areas were quite separate. Within a year, Eckert and Norris would come to know differently.

After World War II, James Rand, like many another chief executive in high technology companies, wanted to have his company engage in pioneering research. First, he established the Norwalk Laboratory. Second, he purchased EMCC and then ERA. As early as mid-1947, Rand approached General Leslie Groves, military director of the Manhattan Project that developed the first atomic bombs, to discuss the possibility of Groves's joining Remington Rand as director of research. Groves put him off. In January 1948, Groves had an unpleasant conversation with Chief of Staff Eisenhower and he decided to leave the army. He contacted Rand and they agreed that Groves would become vice president for research and development of office equipment at the laboratory as of March 1, 1948.[14] Groves became instrumental in the acquisition of both EMCC and ERA, and as a director of the company (after 1952) and director of research, he was a principal spokesman for Remington Rand on computer matters.

This chapter focuses on only three aspects of the history of the two newly acquired firms within Remington Rand. As two of the aspects, we analyze the independent activities in each subsidiary. In many ways, the subsidiaries continued to function in ways similar to their operations as independent firms. But they were sometimes constrained by policies and practices of the parent firm, and these constraints will be described through examples. The third aspect involves examination of Remington Rand with respect to the subsidiaries. In following its historical practices, the parent firm failed to understand fully the nature of the activities in the subsidiaries, the different approaches of the two subsidiaries, and how to coordinate these approaches to develop effective R&D and sales programs. It was not until the merger of Remington Rand with Sperry in 1955 that the firm embarked on coordination, but in a somewhat clumsy way, such that they almost lost the market. Indeed, their market share in 1960 was very much reduced from its promise of the early 1950s. Sperry Rand did develop a market strategy that saved its future, but by this time it had lost many of the talented engineers and designers who left Sperry Rand to join other firms or found their own firms. We leave the story of Sperry Rand at the point of this diaspora in 1957 when the ERA baton in Minnesota passed to the new firm Control Data Corporation.

EMCC in Remington Rand

While still independent, the EMCC group had developed a set of possible scenarios for operation in a new context. Remington Rand's offer fit one of these scenarios, one that gave them the most control, leaving EMCC to act as a subsidiary, retaining its original name. The board of directors, led by James Rand, endorsed the sale and authorized Remington Rand to assume (that is, pay off) EMCC's debt to American Totalizator. In addition, the board agreed in early February 1950 to supply EMCC with funds for operations.[15] Little was done in the beginning to alter the method of UNIVAC construction, to integrate manufacturing activities where possible, or to redesign the management structure of the new subsidiary. Indeed, Eckert, as vice president of Remington Rand and head of the subsidiary, reported directly to James Rand for the next several years. One change was made in the handling of legal matters. George Eltgroth, attorney for EMCC, began to report to the Remington Rand attorney Francis McNamara. Eventually, R&D reported to Groves, as did the Norwalk Laboratory of Remington Rand, which still attended to tabulator equipment.

Remington Rand officers believed that they understood the Eckert-Mauchly business. After all, UNIVAC was just another business calculating system, albeit larger than they were used to selling. The problems UNIVAC sought to solve were the same; potential customers for the UNIVAC were companies Remington Rand had done business with for decades. So the effort to meld EMCC into Remington Rand did not seem to be large. The man the Remington Rand officers assigned the task of integrating EMCC into Remington Rand was Arthur F. Draper. A graduate of Yale (B.S., 1931), Draper had been a supervisor for the test and inspection department of Philco, in charge of engineering at Langley Aviation Corporation and technical director of Andover Kent Aviation. He joined Remington Rand in 1946 and became involved with analysis, promotion, and supervision of new products. He became a special assistant to James Rand, and Draper became the operations/general manager of EMCC as it fit into the daily operations of Remington Rand.[16] He had apparently been influential in interesting Remington Rand in EMCC.[17] Some of Draper's influence on EMCC can be seen in the approach to sales initiated in EMCC as early as February 1950. Wistar Brown of EMCC listed some of the decisions needed to mount an intelligent sales effort. At this point EMCC had no detailed price schedule, and Brown recommended they develop one along with a delivery schedule. Delivery of the first UNIVAC was still a year away, yet he and others in the firm were thinking about equipment maintenance in the field and applications assistance. In 1950, he suggested that rates be established, making the services optional to the buyers. No doubt at the urging of Draper and others in Remington Rand, a recommendation for development of standard contracts was also included among his suggestions. Though he did not recommend explicitly that a programming group be authorized to develop new applications, it was there implicitly. He did explicitly state that there should be "a high degree of cooperation and coordination between the sales and applications departments. . . . It is doubtful if many UNIVAC installations will be sold . . . without thorough and intelligent systems and programming analysis which is expressed in the terms of processing of time requirements and dollar cost."[18] Over the next few months, EMCC invested substantial effort implementing these recommendations. It was during this time that they and Remington Rand renegotiated the various UNIVAC system contracts with government and business so as not to lose more money than necessary in the construction of UNIVACs.

Eckert and Draper's reporting to James Rand in the early years had its advantages. EMCC's position in the corporate structure meant that Eckert could make a direct appeal for needed R&D funds and offer suggestions for new and modified products. Decisions by high-level management about most of his and Mauchly's requests seem to have been negative as the records show, and board attention to computing matters was almost nonexistent.[19] However, Eckert did try to influence decisions about electronic computers, with some success. For example, in September 1952, Eckert argued for small UNIVAC machines "as essential to Remington Rand's future electronic success."[20] From consideration of this suggestion, Remington Rand developed the UNIVAC 60 and UNIVAC 120. Two years later, in November 1954, Eckert presented a proposal for a major computer development program, including super UNIVACs with all the peripheral equipment needed for them and very small UNIVAC systems.[21] The proposal for a super UNIVAC would become the starting point for the later LARC proposal made to the Livermore Atomic Laboratory facility. In order to carry out the Remington Rand/EMCC program over the first eighteen months Remington Rand owned EMCC, it financed a fourfold expansion in personnel.[22]

Several issues required early clarification. First, EMCC needed to deliver a UNIVAC system to the Census Bureau. Doing so would incur a major loss, as the cost of construction even exceeded the contract

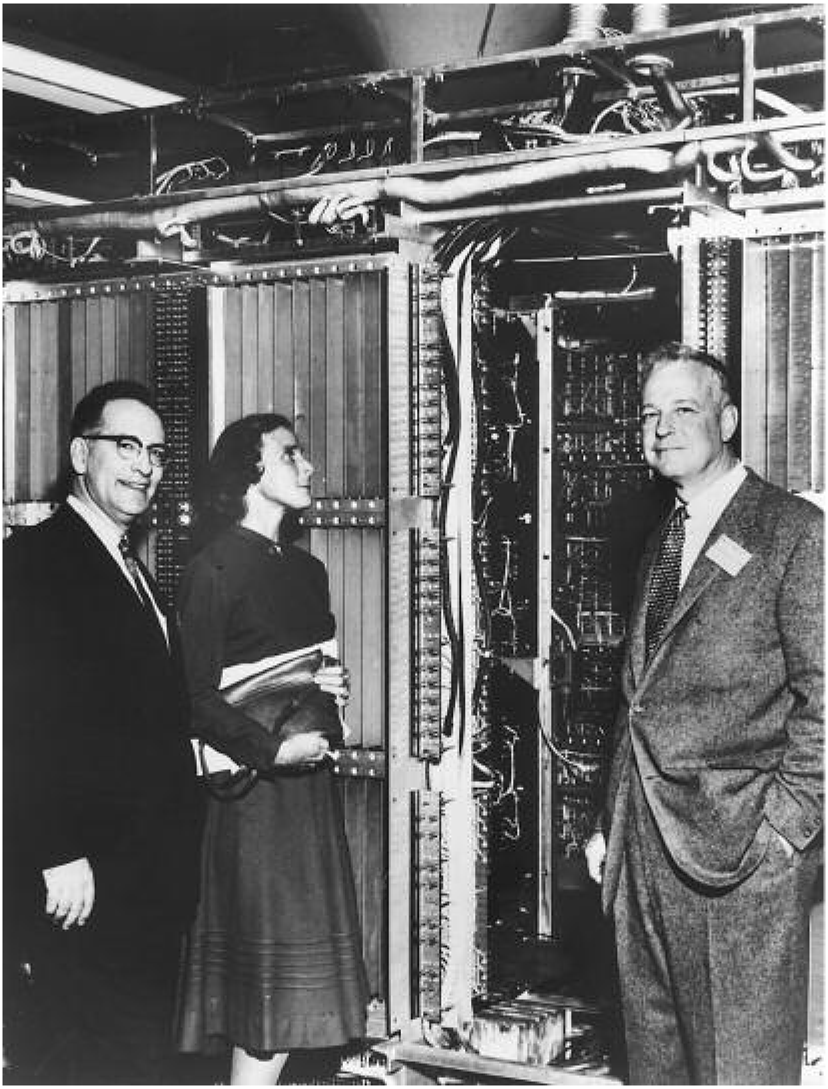


Figure 5.1
John W. Mauchly (left), Kathleen McNulty Mauchly (Antonelli), and Arthur F. Draper standing before the Livermore Automatic Research Computer (LARC) at Livermore, California, in 1960.

Courtesy of the Charles Babbage Institute.

amount with NBS on behalf of the Census Bureau. The Remington Rand legal department approached NBS and the Census Bureau requesting a supplement to the contract with EMCC. After lengthy negotiation, census agreed to an increase of $265,000 for three systems, but the contract was still far from the real cost. No blame should be attached to the Census Bureau's decision. Congressional committees repeatedly asked the Census Bureau about progress with UNIVAC and when it would be delivered. In the end, UNIVAC I, as it came to be known, was not used for the basic census data analysis. Congressmen seemed to focus attention on UNIVAC and associate all the money appropriated for computing at NBS and the Census Bureau to have been spent on this machine, a faulty assumption the Census Bureau went to great pains to overcome.[23] As discussed in the previous chapter, EMCC delivered UNIVAC I to the Census Bureau on the last day of March 1951. The system remained in Philadelphia under the jurisdiction of the Census Bureau for another year, when it was dismantled and shipped to Washington, D.C. During EMCC's first year as a subsidiary, the serial one UNIVAC I served as the major focus of activity. Machines 2, 3, and 4 were authorized and the company began construction. EMCC used all four of these machines to develop applications programs for various industries and government agencies in an effort to sell more UNIVACs.[24]

ERA in Remington Rand

The completion of the purchase of ERA occurred on April 28, 1952, when the Federal Trade Commission reported that they saw no reason to prohibit the transfer of stock from ERA to Remington Rand.[25] With this issue apparently settled, R&D management set about to evaluate ERA and compare work at ERA with work at the other Remington Rand R&D facilities at Philadelphia and Norwalk. Groves arranged a meeting of all three units—EMCC, ERA, and the Norwalk Laboratory—for May 27 and 28 at Norwalk.

Groves distributed an agenda in advance of the meeting, held at Norwalk. Consisting of two sets of topics, Groves believed the first set, focusing on use of components such as transistors, magnetic amplifiers, and plugboards, could be discussed in small groups in separate meetings. A second set of general topics contained tape handling problems, high-speed printing, memories, potential tube substitutes, and anything else of significance not on the list. Engstrom, Sidney Rubens, Erwin Tomash, and Gordon Welchman attended for ERA; Eckert and R. S. Vincent for Philadelphia; fourteen people from Norwalk, many of whom (such as Chaloux, Duncan, and Olofson) were originally at ERA but left some time before the sale. Groves stated at the outset that his objective was to ensure that no unnecessary duplication of work occurred at the three branches. Apparently this emphasis was at odds with what ERA had been told before the meeting. ERA staff prepared themselves to discuss magnetic core storage and high-speed printers.[26] In what appear to be official minutes of the meeting, Groves is reported to have "stated that the object of the meeting was to determine the extent of the research done by ERA along certain lines to be discussed."[27] Groves believed it necessary to understand what ERA had done because of its possible effect on projects under consideration by Remington Rand. The meeting, then, would evaluate the approximate arrangement of projects among the three divisions.

Engstrom noted that ERA had done very little on design of magnetic tape. ERA employed Raytheon equipment, which used 3M plastic tapes. Similarly, Raytheon furnished amplifiers. Engstrom went so far as to say that since ERA had done no design work of this kind, "it may be necessary to call upon Eckert-Mauchly for assistance and for tape handling equipment in the event Raytheon promises are not fulfilled."[28] Eckert then took the opportunity to discuss what his division had done. Tomash next described the photoelectric tape reader used on the 1101. Since the speed of these readers was quite fast, they exceeded the needs of the Norwalk Laboratories machines.[29]

Eckert, in an analysis of the Raytheon units, suggested they might be ineffective. He pointed to undue tension on the reels causing jamming under the reading head, and some skewing because of the guiding system. This equipment could not use the Eckert-Mauchly metal tape, and empty channels on Raytheon tape made it inefficient. "The general conclusion . . . was that Eckert-Mauchly was probably in a better position to help ERA,"[30] though this conclusion was not mentioned in the trip report of Tomash and Rubens to ERA management.[31] Groves ended the conversation by asserting that if ERA wished to acquire Eckert-Mauchly Division Uniservos, a request would need to be made about a year in advance.

One further example will serve to illustrate the tenor of the meeting. Three types of memory system came under discussion: magnetic, electrostatic, and delay line. The group seemed to defer to ERA on magnetic drums, although Eckert mentioned Eckert-Mauchly experiments with a two-inch diameter drum rotating at 100,000 rpm. The results were less than promising. At the time, ERA's 8.5-inch diameter drum on the 1101 ran at 3,500 rpm.[32] ERA described its efforts on electrostatic memory, which they were employing as part of Atlas. Eckert-Mauchly was not involved with electrostatic memories at the time. The group discussed magnetic amplifiers (developed at Eckert-Mauchly and ERA separately) and transistors as possible components. The unreliability of transistors at this date led to their rejection. Engstrom suggested that Eckert-Mauchly and Norwalk pursue the magnetic amplifier work "with all possible dispatch" because it would have an effect on the designs of all three groups.[33]

At the end of the first day, Groves indicated his disappointment with the reports by ERA, and he concluded that ERA "would not be able to contribute" to the Remington Rand program.[34] Security clearances were a clear impediment, but more significantly, he had believed that ERA was a research organization. What he heard suggested it was a "custom engineering company." Remarkably, Engstrom "assented to this latter conclusion."[35] These comments were not part of the "official" minutes. Instead, the minutes contained the following remark: "General Groves stated that ERA can be of great help in providing the Laboratory and Eckert-Mauchly with reports and information now classified which the Laboratory does not have access to at present, especially on magnetic storage."[36]

The following morning Engstrom reported that the ERA representatives "felt a mutual disappointment with the results of the meeting of the previous day."[37] ERA had obtained no useful information to help them meet their near-term commitments. After the smaller group meetings, the group reassembled for a further discussion on magnetic storage. In a brainstorming session, a number of ideas for new storage media emerged especially from Eckert at Groves's invitation, and Groves requested ERA to consider the list and make recommendations about possible further study by one or more divisions.[38] Groves ended the meeting on a positive note with his comment, as noted above, that ERA could be of great help by providing classified reports. He asked that ERA evaluate and advise on the type of memories of interest to ERA. ERA was asked to rank their reports on a spectrum from those concepts that required fundamental research to those where there was readily available knowledge, especially noting those topics of no interest at the end of their rankings.

After the meeting, Tomash and Rubens observed that "[t]he program at Remington Rand [the Laboratory] does not seem to differentiate and delineate between basic exploratory research, applied research[,] and development engineering. The program at Remington Rand and Eckert-Mauchly for future computing component development seems aimed almost exclusively at the possibility of magnetic cores used in conjunction with crystal diodes to the exclusion of transistors. This seems to be a premature decision in view of the indecisive status at present of both cores and transistors."[39]

Two more trips to the East Coast for meetings occurred in quick succession. As evidence that ERA wanted to make use of Remington Rand products in their systems, Jack Hill toured several Remington Rand facilities between June 10 and 14, 1952. He visited the laboratory at Norwalk, the manufacturing facility at Elmira, New York (typewriters and adding machines), and the Eckert-Mauchly Division. From his report, it seems he sought information about products that ERA could use as part of its storage and computer systems. Among other things, he examined the plug boards for the 409-2 calculator, typewriters, the newly designed Unitypers and Uniprinters, a new card-to-tape machine designed at Philadelphia, a high-speed printer design from Philadelphia (the one described by Tomash and Rubens in their report of the May meeting at Norwalk), and card reading and punching equipment. He noted the state of UNIVAC production—six in all, with number six assembly just begun. Hill was careful to describe the state of design and construction of each type of equipment he examined. One can appreciate his calculating engineering eye in the descriptions, and even though he does not offer recommendations, the implications about which are ready or could be for use by ERA are obvious. Except for the UNIVAC and 409 reports, all the other devices could be, and some eventually were, incorporated into ERA systems.

Meetings also took place to establish a place for ERA sales in the overall Remington Rand activity. On June 20, 1952, a major meeting of Remington Rand and ERA executives took place in the New York offices. Representatives from Eckert-Mauchly and the Remington Rand sales organization also participated. A. R. Rumbles, executive vice president for domestic sales, noted that the purpose of the meeting "was to discuss mutual interests in order that the sales of Remington Rand and ERA equipment might be promoted."[40] ERA was represented by Parker, Norris, and Engstrom, along with James Miles, Norris's assistant, and a mathematician in charge of programming, Alfred Roberts. Many attendees at the meeting wanted to find a way to use common input–output equipment on ERA 1101s, UNIVACs, and other Remington Rand systems, a point heartily agreed to by the senior Remington Rand executives at the meeting.[41] While the prime objective of the domestic sales office was to set up a communication channel between ERA and the sales department, much of the discussion at the meeting focused on the competitive aspects of the 1101 and the UNIVAC. A technical committee was assembled to compare the two systems. The members were H. Mitchell (Eckert-Mauchly), David Savidge (Remington Rand), and Miles and Tomash (ERA).[42] The meetings were to occur in Philadelphia and New York in ten days. "This will also permit us to review with Mr. Miles all of our pending commercial prospects for UNIVAC and minimize any possibility of duplicate effort or in turn, unify wherever desirable, our respective sales efforts against competition."[43] A similar analysis was to be made by the ERA people in Washington "in order that we might thoroughly integrate our respective interests and strengthen our unified sales position against competition."[44] Another meeting would take place to investigate the possibility of some common programming for the 1101 and UNIVAC.

The group believed that salespeople should attempt to sell the machine that best fit the users' needs, rather than compete between subsidiaries. Thus, ERA should help to sell UNIVACs, and vice versa for the Eckert-Mauchly group. Among the other topics covered at the meeting were pricing of ERA systems, labeling (all ERA materials should carry the designation "Engineering Research Associates, Inc., a Subsidiary of Remington Rand, Inc."), and the desirability of consistency in contract forms used by ERA. Besides the 1101, ERA people described three other products—the Speed Tally system, the Automatic Weighing Device, and the Microfilm Selector—and a possible combined maintenance program. For the latter purpose, Rumbles called for a comparison of the 1101 and the 409 computers, to determine whether the same maintenance staff could be used for both systems.

To complete the story of this initial round of contacts between Remington Rand, EMCC, and ERA, the committee reviewed a list of problems run on UNIVAC and identified those that seemed reasonable as 1101 applications. "Until such time as programming techniques are perfected for both the 1101 and UNIVAC on the same applications it is not possible to make detailed exact comparisons."[45] The Eckert-Mauchly staff did a review of such programs and their running times over the next six months.[46] The committee also discussed new sales materials for the 1101, a sales effort and plan, education outside Remington Rand, demonstrations of ERA equipment, and future development at ERA. ERA and Eckert-Mauchly's Computer Analysis Laboratory were to exchange one person each for programming training. Integration of ERA into Remington Rand seemed to be going smoothly.

The detailed analysis of program running time on the 1101 and the UNIVAC revealed some flaws in thinking and the results did not lead to definitive identification of problems suitable for each system, thereby providing little sales ammunition against the competition. The Eckert-Mauchly staff made sweeping claims for UNIVAC and relegated the 1101 to the scientific area, no doubt alienating ERA personnel. Here is a typical assessment.

> The UNIVAC is suitable for virtually any type of data processing or computing operation. The data used may be either numerical or alphabetic, and may require arbitrarily large quantities of input, output or intermediate storage.
>
> The ERA 1101 is suitable for numerical problems which can be handled within its internal memory and which require only a relatively small quantity of output.
>
> The two machines are comparable for problems in the general field of scientific computing. For such problems, the UNIVAC will be faster by a factor of from 3 to 6.[47]

I found no reaction by ERA to this kind of assessment. ERA was already involved in the modified machine 1101-2, the 1102, and a design for the 1103; they probably did not believe they needed to defend the 1101. By the end of the year, Mauchly's programming group provided a more detailed analysis of problem running times and effective comparisons. The general conclusion of this analysis was that "it is generally agreed that the UNIVAC system is as yet unmatched by any other computer" as measured by several criteria having to do with input and output facilities and magnetic tape handling.[48] There was no doubt that the 1101 could not match this assertion. The report went on to show that the programs designed by the UNIVAC programmers relied so heavily on the input–output and magnetic tape systems it was difficult to compare the running of these programs on the two systems. "Consequently, each group has difficulty in appraising the utility afforded by the computer characteristics most highly regarded by the other group."[49] Following a comparison of a range of problems and the efficacy of each system in running them, the report recommended that Remington Rand would be well advised to train a staff of specialists with capability in all three types of machines made by Remington Rand, so as to provide better service to its customers.[50]

As mentioned above, Remington Rand management seemed to know what they acquired when they bought EMCC. This was not the case for ERA, as evidenced by the range and substance of the meetings involving the various Remington Rand groups over the first year after acquiring

ERA. Over the years, ERA was profitable, but its cash flow was negative. In 1952, it was expanding and needed working capital. The Remington Rand Financial Policy Committee on June 26, 1952, "approved loaning ERA $750,000 on a demand note with interest at the rate of 5% per annum. This money is to be used as current working capital by ERA. In this connection, it is estimated that with the present programs being inaugurated by ERA it will be necessary to advance funds to that Company up to approximately $1,250,000 by December 31, 1952."[51] This number is similar to actual expenditures for engineering and research by EMCC in this period.

Certainly, ERA's position was not helped by the continual criticism coming from Eckert, and occasionally other members of EMCC. Indeed, as we will see below, during the first five years ERA was part of Remington Rand, two groups—EMCC and the Manufacturing Operation—tried to gain control of ERA's activities, producing significant tension for the new subsidiary. Often chaos resulted. In the end, this backbiting by EMCC and divisive office politics among Remington Rand managers with respect to ERA hurt all the computer activities in Remington Rand. It was not until the formation of the UNIVAC Division by Sperry Rand to contain all the computer development and design that this tension subsided. The new Sperry Rand took over five years to correct the situation, but in the process, many ERA engineers and managers left the company.

Development within Remington Rand

EMCC

After completion of UNIVAC I at the end of 1950 and its successful testing in early 1951, EMCC turned to new designs. The range of machines developed by the EMCC division immediately after the UNIVAC I focused on small users, both business and government (the UNIVAC 60 and the 120), those in need of a communications capability as part of their computer system (the 490), and the "super" user (the LARC). To address the small-scale market, EMCC developed the 60 and 120 systems. The UNIVAC Automatic Computer Model 60 was a biquinary, decimal, and alphabetic system. Designed to handle payroll, personnel statistics, stock accounting, cost accounting, and procurement accounting, the 60 was a business and scientific machine for the low-end user. A vacuum tube machine, digits per word varied from one to ten plus a sign and the six instructions of the system were of the three-address type. The 60 did not contain internal program capability, but was programmed through a plugboard developed at Norwalk, nor did it store anything internally. It contained only one arithmetic register, which had a capacity of 22 digits, and computation of each program step occurred in the accumulator. Input was by 90-column punched card, and output went to punched cards also. Basically, the 120 differed from the 60 in storage capacity, carrying twelve words instead of six, and in the fact that storage was part of the computing unit. This system, as well as the 120, resulted from cooperation between the EMCC and Norwalk groups. In the first eleven months of 1954 after introduction, Remington Rand sold or rented 42 Model 60s and 44 Model 120s. By 1960, Remington Rand reported that over 1,000 units of these two machines had been sold or rented, illustrating that there was still a market for hybrid machines.

Two other developments of the period after 1953 were the 490 and the UNIVAC Solid State 80/90, both delivered only in early 1961. EMCC designed the 490 for real-time use. In the late 1950s and later, several universities and companies developed computer systems that could keep track of changes in data as the changes were needed and to facilitate another's access to the latest data, such as in an airplane reservation system. The 490 computer system was an outgrowth of the Naval Tactical Data Systems project. The communications system provided instantaneous inventory and production control data to companies and government agencies having widely scattered offices, plants, and warehouses. The 490 received real-time data from a transaction source, processed the raw data and delivered the necessary answers in ample time to complete the original transaction. The storage system was by magnetic core, whose storage capacity was 16,384 words. A secondary storage magnetic drum could store between 327,680 and 786,432 words depending on the size of drum used. Preferably, input and output was by magnetic tape for speed, but could also be done by punched card. Circuit elements were composed of diodes and transistors. Sperry developed models of the 490 with greater memory and faster speeds. These were the 491 and the 492. Sperry produced sixty-one 490, 491, and 492 computer systems.[52]

A close follow-on system to the UNIVAC I, the UNIVAC Solid State 80/90 was designed as a general-purpose data processing system for use in general accounting, inventory, billing, budget control, sales analysis, statistics, railroad accounting, and revenue accounting. The Solid State used magnetic amplifiers they called Ferractors, developed at EMCC for the purpose, and transistors. The system consisted of a central processor, a read-punch unit, a high-speed card reader for either 80- or 90-column cards, and a high-speed printer. This system, too, was biquinary decimal coded with ten digits per word plus a sign. The system used one instruction per word, and 53 instructions. The system came with a library of approximately 60 routines. Storage was by magnetic drum of 4,000 words. Up to ten drums could be used with the system. Also, ten tape units could be employed on the system, if desired, for input and output. Punched cards for input and output were also an option. At the end of 1960, 190 units were in operation and Remington Rand reported orders of 300. The system was very versatile, with many parts of the system operating simultaneously, since the input–output components were buffered. The Solid State was completed in late 1956, but it, too, was delivered only in 1961. Lukoff asserted that this machine competed directly with the ERA Division File computer, so the Solid State was held back from the market until the summer of 1959, although it was sold in Europe earlier, and some 500 systems were sold.[53] The machine quickly became obsolete as transistors took over the market and magnetic amplifiers disappeared for this purpose.[54]

A little-commented-on system was derived from the Solid State 80/90: the UNIVAC Simple Transition Electronic Processing (STEP) system, a modular version of the 80/90. EMCC designed STEP to handle general accounting, inventory, billing, budget control, sales analysis, and statistics, in line with a number of their other machines of the 1950s. This system, too, was designed for the small-scale user. Ferractors, transistors, and diodes were employed in the CPU, and magnetic drums and magnetic tape units for secondary memory. Input–output could also be done with punched cards. By 1961, over 175 were in use in various settings.[55]

As we noted above, in 1952, Eckert proposed a range of machines to Remington Rand management. The range would include products at the low end, what became the 60 and 120, just described, up to large-scale, fast machines. Management agreed to parts of the proposal, but reneged on the high end. However, in 1954 when the University of California's Livermore Laboratory circulated a request for proposals for a "super" computer system, Eckert and his engineering group had the basis for a response in his earlier proposal. The high-end machine of the proposal turned into the Livermore Automatic Research Computer (LARC). IBM and Remington Rand competed head-to-head for this contract. Remington Rand received the contract because they agreed to the terms for payment and delivery date. IBM engineers thought the date too optimistic and asked for a later date, which Livermore rejected. IBM went on to develop the Stretch for the Los Alamos National Laboratory under an RFP with design help from a capable team at the Lab.

Much has been written about LARC, and the competitive IBM system Stretch, so we need only summarize its features here as a comparison to the other systems developed at EMCC during the same period. LARC development began in 1955, but delays prevented its delivery until spring of 1960, two years behind schedule. Livermore estimated that to handle its scientific problems it would need computer systems 100 times more powerful than any existing system. Since none in this power range existed, they decided to contract for one. For some reason, the proposal reached the ERA division but not Eckert-Mauchly, which would be consistent with the views of people inside Remington Rand who saw ERA as designing scientific computers and EMCC business computers. Of course, Eckert saw things differently. Eckert raised a fuss, a story we relate in the section on the sales division below, and eventually Philadelphia was designated as Remington Rand's respondent to the Livermore proposal. Because of the significance of the LARC for Remington Rand, it will be useful to summarize in some detail its properties and the problems the group encountered in the design and construction of the system.[56]

Eckert and his group designed LARC as a fast scientific computer to handle problems requiring large amounts of input–output and extremely fast computing, such as data retrieval, linear programming, language translation, atomic codes, and equipment design. While preparing their proposal, EMCC knew that the Ferractor magnetic amplifier they developed for an air force contract to develop the AFCRC computer, of which more below, was too slow for the speeds to be required for LARC. At the same time, transistors remained expensive and their speed was still slow. Eckert decided to use a combination of magnetic amplifiers, transistors, and magnetic cores. If the magnetic amplifier cores were made smaller, they operated at higher speeds. EMCC designed a new circuit with the smaller cores called "coil gating." "Many high-speed magnetic cores were arranged in a serial array. A pulse could pass through the array depending on the saturated or unsaturated state of each core. A saturated core exhibited low impedance to the pulse while an unsaturated condition looked like an open circuit. Another winding on the core controlled whether the core was saturated or not. This type of logic element used many magnetic amplifiers and few transistors." They designed faster logic for the arithmetic unit, an instruction overlap sequence, and wanted to use a separate processor to handle the input–output components, which at first they thought would be the AFCRC computer. The rest of the components were to be standard UNIVAC designs. Eckert presented the Remington Rand proposal at a meeting in Livermore in April

1955, after which Edward Teller, director of the laboratory, visited the Philadelphia facility. Between April and September, Eckert, Arthur Gehring, Lloyd Stowe, Josh Gray, Herman Lukoff, and several others, continued to work on the design of the arithmetic unit and the circuits. On September 9, 1955, the contract for LARC was awarded to Remington Rand. The contract price was $2.85 million, with a completion date of February 1958. Final specifications were to be developed by EMCC and Livermore over the following six months, and this was done.[57]

When Livermore awarded the contract, Weiner, EMCC chief engineer, appointed Lukoff project coordinator. (After the specifications were developed, he became engineering director of the LARC project.) He had the responsibility to obtain a mutually agreeable set of specifications over the next six months. The team of negotiators consisted of Weiner, Eckert, Gehring, Tonik, and Lukoff for EMCC, and Livermore assigned the task to Sidney Fernbach, Kent Elsworth, James Norton, Lou Nofrey,

Figure 5.2
Herbert Ernst (left), Francis Holberton, Elizabeth Parker, and David Templeton discuss the progress in the initial testing of the second LARC at the David Taylor Model Basin, Washington, D.C.

Courtesy of the Charles Babbage Institute.

and James Moore. A final set of specifications approved by all sides took until March 1956.[58]

At the Eastern Joint Computer Conference in December 1956, Eckert confidently described the architecture of LARC as if it were a finished product. "LARC is Remington Rand UNIVAC's newest all solid-state large-scale computer, over 100 times faster than today's scientific computers and internally 1,000 times faster than today's business data-processing system."[59] Indeed, the final design of LARC did follow Eckert's description. But the achievement was not as straightforward as he believed at the time, and some major changes had to be made, especially in the fundamental circuit designs. Eckert acknowledged the influence of programming activity at EMCC on LARC. "LARC's increased speed is due in part to a complex and highly organized order code the use of which is made possible by modern automatic-programming techniques."[60] He referred specifically to the compiler work of Grace Hopper and other applications techniques developed by Mauchly and his group.

The delivered system contained two computer units, an input–output processor (not the AFCRC computer originally contemplated) to provide flexible, parallel, and coordinated control of the input–output equipment and a processor to handle the arithmetic functions, which operated independently. This second processor was capable of doing both fixed point and floating point calculations. LARC was a binary-coded decimal system. The tightly wound cores in coil gating did not achieve the specifications demanded, so EMCC turned to a high-speed magnetic core memory, divided into units, each of which was capable of storing 2,500 words of eleven-decimal digits each plus a sign digit. The system could incorporate up to 39 of these units for a total of 97,500 words. Magnetic drums served as secondary memory; up to 24 drums could be attached to the system, capable of storing up to 250,000 words. In contrast to ERA drums, the EMCC system operated with one air-floated, read-write head assembly that achieved high reliability with high pulse densities.[61]

The logic designers estimated that the arithmetic unit would need nine levels of logic to achieve the speeds desired. The maximum propagation time under these conditions would be forty nanoseconds. They would have to stretch transistors of the day to the limit of their ability. Lukoff concluded research would be required to do this. Lukoff visited several East Coast advanced laboratories to learn of any work in high-speed logic. Philco was producing some fast, new surface barrier transistors (in the 30 MHz range). EMCC began working with Philco. Dropping the magnetic amplifiers and using only the transistors would increase the system's cost to double the contract price. Unthinkable! And the AFCRC as a processor would have to go, and a new processor designed. Even a second contract for a LARC with the David Taylor Model Basin would not help lower the development costs much.

With an unexpected logic design task facing them, EMCC had to find more logic designers. Few were available. So EMCC organized a training program. The effort consumed more months before the designers were ready and progress was possible. Several other phases had to be worked on in parallel. The phases were packaging and power supplies, ferrite core memory, drum mass storage, and various other input–output devices.

Lukoff designed a new basic logic circuit using the surface barrier transistor, which could meet the speeds desired, if they were careful about the packaging on printed-circuit boards. The transistors would have to be only of the highest quality, which meant working closely with Philco manufacturing. Transistors of the period had very low current gain, so could not normally drive the load required by this fast computer design. Other circuits were devised to compensate for this.

William Bartik, in charge of the group building a four-microsecond ferrite core memory, also ran into difficulty. State-of-the-art was twelve microseconds! Switching was too slow. Building smaller cores compensated some, but the transistor's slowness proved to be another problem. New pulsed power supplies were developed to drive the circuits. Again the cost went up as the design involved more components. And on it went. The new flying head for the magnetic drum storage posed its own problems. As Lukoff noted, "As we looked further into the designs, we found we were uncovering more problems than we were solving."[62] Printed circuit board connectors—almost a million of them—led to questions about reliability. Bell Labs consultants suggested using gold as the contact material. They did; more cost. Once they completed the circuits, all the other standard design areas had to be addressed and minimized or eliminated—crosstalk, stray capacitance, wire congestion reduction, and good, stable connections. To accomplish this, Lloyd Stowe designed the first automated backboard wiring system, whose reliability also had to be demonstrated.

The final design closely approximated the specifications, although the design group changed to a five-bit binary coded decimal number system, giving a sixty-bit word (the original would have been 11 bits). The LARC had twenty-six general-purpose registers that could function as either index or arithmetic registers. For greater speed, the system could overlap instructions, so that at a given instant, four instructions could be in various stages of execution. Addition time was four microseconds, as compared to 525 microseconds on UNIVAC I. Manufacturing began in the summer of 1958, and the Livermore machine was delivered in May 1960, over two years late. The second, and last, LARC went to the Model Basin nine months later in February 1961.[63] Later, Remington Rand advertised the machine as good for large-scale accounting and billing and other transactions of business to try to sell LARCs in the business market, but without success.

One last system of the period deserves notice: the UNIVAC Calculating Tabulator (UCT). Norwalk developed or proposed a series of externally programmed machines that used plugboards to set up a short routine of calculations. The UCT system owes its origins to the series of Norwalk Laboratory's-inspired machines the 409 and the 409-2 (not to be confused with the 490). In the 409, data entered the system by punched cards. On each card the sequence of calculations governed by the plugboard was performed and the results were punched back onto the cards.[64] The 409-2 possessed increased capability of calculation, faster performance, intermediate storage, and a self-checking feature. Norwalk and EMCC collaborated on the circuit design of the electronic calculating unit.[65] In its continuing efforts to cooperate with the Norwalk Laboratory, EMCC proposed the 409-3, which would have internal program capability and components similar to other EMCC systems. The proposed 409-3 was really an upgraded Model 60/120, retaining the plugboard and adding a drum memory. The project was shelved in 1952.

Contemplating the needs for successor systems, Eckert sought a replacement for vacuum tubes and delay lines. In the early 1950s, EMCC engaged in development of magnetic amplifiers. Such amplifiers had been used for some time, but at lower frequencies than those required by fast electronic computers. "Bob Torrey, Ted Bonn, and others found that winding miniature cores of thin permalloy metal provided the basis for amplifiers that would work at 1 MHz with up to seven loads."[66] EMCC obtained several patents for this device, which they named the Ferractor. While in the midst of this development project for the magnetic amplifier, the air force approached EMCC to develop a system for their Cambridge Research Center. Again the 409-3 was redesigned, this time to contain the magnetic amplifier for internal storage and a high-speed drum. This became the AFCRC computer delivered in March 1956. UCT was a commercial version of this AFCRC system, whose commercial version was the UNIVAC Solid State. According to Lukoff, Remington Rand management deliberately held back the UCT in the United States market to favor the File systems.[67]

Through all these development years, EMCC continued to hemorrhage money. Sales in the years 1953, 1954, and 1955 increased from $1.71 to $7.46 million. However, expenses always exceeded this income, so the division suffered losses of from $2.23 to $4.11 million over the same years.

In spite of all this development, EMCC did not have a successor to UNIVAC I. Neither the Solid State 80/90 nor LARC could serve this purpose. Remington Rand management wanted a follow-on system to compete with the range of IBM systems. When EMCC received the LARC contract, ERA was assigned a project to develop a UNIVAC II. There is some debate about how this happened. People from ERA believed it was pushed on them in spite of their resistance. EMCC people came to believe ERA outbid them for the project. The evidence is weak for either position. We will take up development of UNIVAC II in our discussion of ERA activity in the next section.

ERA

In some ways, ERA's activities are easier to discuss than EMCC's. Because of its military contracts, the group coupled design changes for the 1101 commercial system based on Atlas I with a new navy system Atlas II to plan the 1102, 1103, and 1103A. Completion of Atlas occurred at the end of 1950 with delivery in December to NSA, successor to CSAW. ERA announced the commercial version of Atlas I, the 1101, in December 1951. ERA expected to sell this machine to scientific users, and so it arrived with no operating manual.[68] A programming manual of sorts illustrated how the instructions operated and how problems were set up. Like so many other machines of the period, programs were organized in octal machine code and punched on paper tape. The input–output facilities were by typewriter and paper tape. Only three systems, two Atlases and one 1101, were built. The company installed the one 1101 in its Washington office to run a service bureau, but the laborious programming made this system impractical and the machine was donated to Georgia Tech in 1954.[69] An improved version, the 1102, was delivered to the Arnold Engineering Development Center in July 1954. In the fall of 1954, two more 1102s arrived at the center in Tullahoma, Tennessee.[70]

During 1950 to 1953, ERA worked on Atlas II for the navy. Its design differed from Atlas I in the following ways. It was a 36-bit parallel machine with two-address logic, and an enlarged instruction set. For storage, it contained a Williams tube and a larger drum memory, with facilities for magnetic tape, punched card, and paper tape input–output. Two versions were delivered to the navy in September 1953 and October 1954. The commercial version carried the designation 1103. By this time, ERA had become part of Remington Rand and there was money to finance inventory and sales.

In fall 1952, ERA requested and received permission from the navy to slightly alter the Atlas II design and offer the system as a commercial device. A presentation to Remington Rand management, previously unacquainted with the machine because it was classified, in November led to permission to construct two copies and buy parts for two more. The 1103 was a binary machine with two-address logic and 36 bits per word, and an instruction length of one word. It operated in both fixed- and floating-point arithmetic. Model 1103 had 41 instructions, and Model 1103A had 50. The arithmetic unit contained vacuum tubes, and operated in parallel mode with a basic pulse repetition rate of 500,000 cycles per second. The 1103 was ERA's first magnetic core memory system, with a capacity of 4,096 words. A magnetic drum of 16,384 words' capacity provided secondary storage. Some later units would use magnetic tape, employing Uniservos as the standard device. Equipment for input–output remained magnetic tape and punched card readers. Programming remained a glaring deficiency, and eventually limited the number of sales. Officially announced on February 5, 1953, in contrast to its ERA predecessors, the 1103 was an immediate success. Some twenty units were sold over the next few years.[71]

ERA also sought to address the small- and medium-scale markets with hybrid machines using some equipment from the Norwalk Laboratories, similar to the efforts of EMCC. In 1950, the John Plain Company, at the suggestion of consultants from Arthur D. Little, Inc., approached ERA for a data processing system to handle their large inventory problems. Harold Lackman, chairman of the board, and Walter H. Richter, president, of John Plain became very enthusiastic about having an up-to-date data processing system, and kept pressing ERA for designs that would serve their needs. John Hill reported that the company's objectives were to mechanize their entire operation, a mail order catalog business with many outlets across the nation accepting orders. John Plain rented space from country stores to display their catalogs and write orders. Not counting sizes and colors, the catalog contained 8,000 items. Over 80 percent of their business transpired in the last six weeks of the calendar year, during which they processed up to 15,000 orders per day. Each order contained an average of ten items. During the rest of the year, orders were fewer than 2,000 per day. Temporary staff of over 250 people joined the company in the busiest weeks. Each year there were new items added to the catalog. The John Plain CEO wanted to mechanize all of this and provide for the possibility to obtain projections from orders received each week to track demand over the remaining portion of the period so they could order more items from their suppliers if demand was high. In the late 1940s, all this tracking and ordering was done by a large staff of people. The company wanted to mechanize this for more effective use of the data. Hill thought the receipt of orders and tracking sales was the most effective thing ERA could do for John Plain. Hill thought ERA was not sophisticated enough to provide the automation of billing and inventory control. ERA assigned Hill responsibility for development and Gordon Welchman became the liaison with John Plain.[72]

In 1953, Remington Rand named an upgraded version of this system the Speed Tally System to market it to other firms, and the John Plain Company called the original system the 140 GP Distribution System (GP for Girl Power). The company claimed that the new system used 10 operators to do the work that previously required 150. "It eliminated an employment problem, permitted us to engage more highly skilled operators and saved much needed office space. It helped keep inventories balanced . . . giving top service to our customers."[73] Here we focus on the characteristics of the Speed Tally as marketed by Remington Rand.

Speed Tally employed the same magnetic drum as used in the ERA 1103. The 17-inch diameter drum supported 125 magnetic reading and recording heads, and rotated at 1,800 rpm. The system contained two drums, only one of which could be operated at a time. Keyboard indicators similar to adding machines served as input of numerical data on items and orders, and a printer responded to paper tape from a control unit in printing out a list of inventory or tally totals. Punched cards were used for the preparation of invoices on a separate system.

Since the early days of ERA, its engineers repeatedly returned to the dream of creating an airline reservation system. From the experience with Speed Tally, ERA believed they had a viable system and developed it into the File 0 computer. For part of the development, File was a joint project with Norwalk in that it combined many peripheral features of the tabulator world. File 0 incorporated a building-block versatility. Multiple input and output units could be attached to the system and used simultaneously (including typewriter, paper tape, punched cards,

Figure 5.3
The ERA Speed Tally Computer developed for the John Plain Company in the mid-1950s.

Courtesy of the Charles Babbage Institute.

perforated tape, and magnetic tape). Up to twenty-four high-capacity storage units could be attached as needed. The basic computer unit had an arithmetic processing section, program control section, intermediate storage section, and input–output storage section. Figure 5.4 is a functional diagram of the system, illustrating the interaction of the system's parts. File 0 could operate either on-line (direct key entry) or off-line (any of the tape systems), so it offered real-time service. It was a binary coded decimal system, with twelve digits per word, in a three-address format, and fixed point arithmetic. File 0 had no stored program capability; all the instructions were programmed through an external plugboard (comparable to IBM's Ramac of the same period). The system

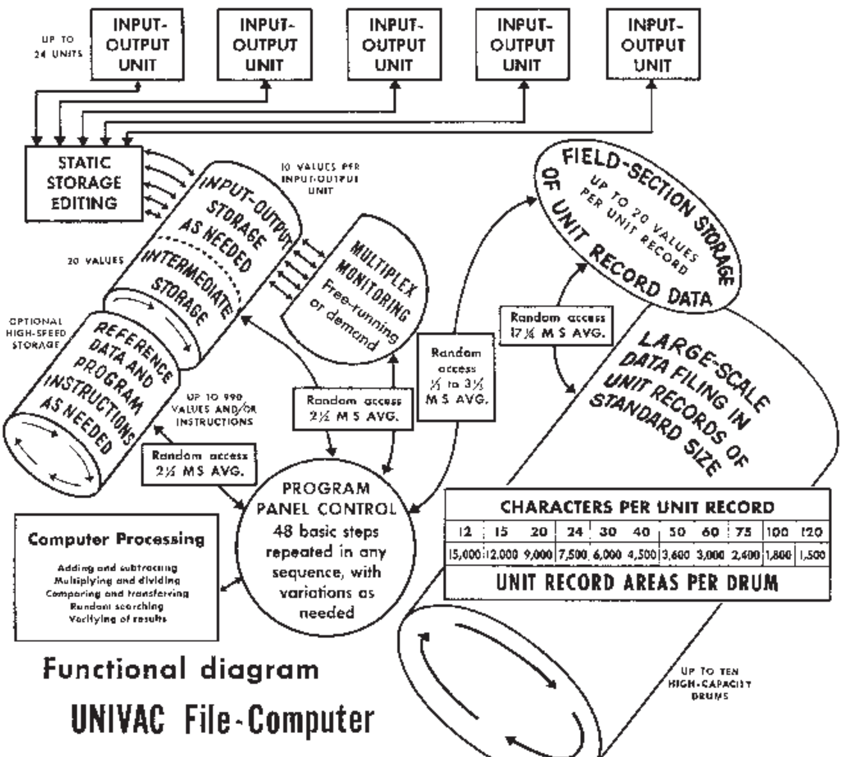


Figure 5.4
The Flow Diagram for the ERA Subsidiary File 0 computer system. From the sales brochure for the File 0 in the Product Literature Collection, Charles Babbage Institute.

provided random access to 180,000 alphanumeric characters on one drum (1,070-word drum) and to the magnetic core memory, allowing access to stored data files. In 1956, the first File 0 went to Douglas Aircraft, Remington Rand's biggest tabulator customer, to be used for general accounting, labor distribution, cost and expense ledgers, material, and payroll on the DC-8 aircraft project. Some thirty units were produced and shipped.[74]

The lack of stored programming capability limited the attractiveness of the File 0, so the engineers in the ERA division worked on providing a new version, which they labeled the File 1. The File 1 had twenty words of core storage, enough to provide some internal programming capability. This capability was further enhanced in a File 2 (with 1,740 words of core memory). There were twenty-seven instructions in the internal instruction set, and the memory instructions were 12-decimal digits in length.[75] Not much time was required to make the modification, and they built the first File 1 in 1957 and began quantity deliveries in 1958. Eastern Airlines and Northwest Orient Airlines both used File computers for their reservation systems. Douglas Aircraft acquired six File 1s in addition to their two File 0s. Eventually over 175 File 1 units were sold or rented.[76] Meanwhile, File 0s were upgraded in the field to File 1s. As transistorized systems came on the market, they replaced the File 1. Customers often moved to the UNIVAC 490.

While continuing to address the market with various scientific and business systems, the ERA division continued quietly to serve its military customers with specialized, classified computers. Among the many systems supplied, two stand out in the Remington Rand period: Athena and Bogart. Both systems had significant implications for future ERA designs. The air force contracted with ERA to develop and produce a ground guidance computer for the Titan missile system. ERA considered using the magnetic amplifier, but also investigated the possibility of transistors for storage. To contrast the capability of the two components, Seymour Cray organized two projects: MAGTEC (Magnetic Switch Test Computer) and TRANSTEC (Transistor Test Computer). The test satisfied him that the transistor was a superior component and the Athena system used them. Athena's processing capacity was 256 words of 24-bit core memory with an 8,192-word magnetic drum as secondary storage. ERA delivered Athena in 1957. As reported by Gray and Smith, Athena was the first in a line of missile guidance computers produced by ERA, including ADD 1000, the Target Intercept computer (1960) for Nike-Zeus, and a computer for the Nike-X antimissile project.[77]

The National Security Agency continued its interest in various types of computers for its secret intelligence work. In December 1953, ERA submitted a proposal for a new data editing system. They signed a contract in July 1954 to build two systems using diodes and magnetic cores for the logic in the arithmetic and control units. Since this was to be a preprocessing machine, secondary memory was inconsequential, so the system had no magnetic drums. The system was named BOGART, reportedly for John B. Bogart, a well-known city editor of the *New York Sun*. BOGART prepared data for input to other more powerful systems. The final logic provided for a word size of 24 bits, with the capability to select any of three eight-bit portions of a word. The system contained several registers. In July 1955, modification in the contract called for four machines and to allow for the use of IBM Type 727 magnetic tape drives. ERA delivered the four machines between July 1957 and January 1958. The prototype became the fifth BOGART when it was delivered in December 1959. Samuel Snyder, in an article on the history of computing in NSA, stated that BOGART was the first computer in the United States that used design automation techniques. He also noted that it influenced the design of several later computers, the family of machines for the Navy Tactical Data Systems (starting with AN/USQ-17), the UNIVAC 490 included the index registers and repetition feature, and later designs at CDC, the CDC 1604 and CDC 160 (also designed by Cray).[78]

Regardless of how ERA came to be assigned the UNIVAC II project, they assumed a very difficult task. The technical background behind previous ERA machines was of an entirely different philosophy than that behind EMCC systems. The philosophy did not travel well. In 1955, EMCC sent ERA a UNIVAC I for instructional purposes about the design scheme. ERA personnel had to learn how UNIVAC I operated and then design a 2,000-word memory, double the capacity of UNIVAC I. Many ERA engineers complained that the task was too difficult and time consuming for ERA considering all the catch-up they had to do to design a new system. At first sight it might seem a simple project. By that time (1954), delay lines had become obsolete and the ERA division possessed good capability in core technology as evident in the 1103 design, so the project would replace delay lines with magnetic cores for storage. However, this change required major modifications in the UNIVAC design. Core technology meant a redesign of the processor-memory interface, because in a core system data was sent and received in parallel mode, rather than serially as with delay lines. To keep ahead, the UNIVAC II would use new tape drives (Uniservos II), designed in Philadelphia, whose

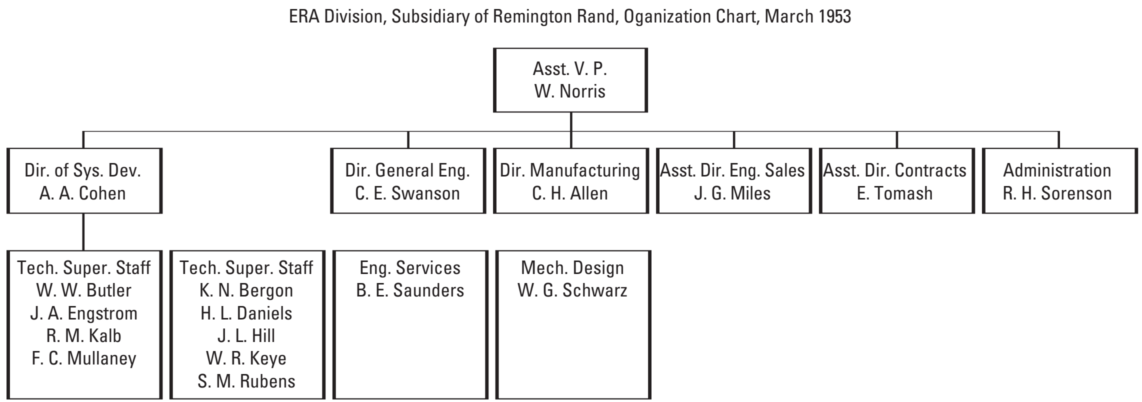


Figure 5.5
ERA division organization chart, March 1953.

recording density was double that of the earlier model. The new design called for some new instructions as well.[79]

William Keye, head of commercial engineering, appointed Ward Lund[80] to head the design team. The design team took more time than expected, so the development team under Art Engstrom[81] began building the first five machines before the design was fully tested. Since ERA had never built either a UNIVAC I or II, Engstrom's group would do performance and acceptance tests on these machines, and would train the manufacturing technicians in the procedures. As they uncovered problems in the design, they made the necessary changes in all five systems. This, too, was no simple matter as the two teams were in different buildings five miles apart. Reports, memos, and suggested changes went through company mail. As the problems mounted, the delay lengthened.

David Lundstrom joined ERA just as Engstrom formed his group, and Lundstrom was sent to a four-month maintenance-training course on UNIVAC I in Philadelphia. On his scheduled return to St. Paul, Lund's group would be offering a course discussing the differences between the two systems. After that course, it was expected that Lundstrom and others would be ready to help with the testing of the first five UNIVAC IIs, which would be finished by then. In fact, Engstrom called Lundstrom back to St. Paul before the Philadelphia course ended, as he was needed at the plant.[82] Lundstrom found Lund's group in a chaotic state. He understood the group's problem to be inherent in the attempt to transfer technology from one development site to another. Let him describe this problem, as he understood it.

> The problem in transferring technology . . . arises from the nature of engineers and engineering. Most engineers hate to write. When absolutely forced to, they will keep their descriptions as cryptic as possible and will plagiarize existing documents wherever they can. A complete engineering design consists of a great stack of engineering drawings, supplemented by a stack of specifications and test procedures. If the developing engineering group has strong discipline and if the engineers are conscientious, this great pile of paper will represent perhaps 90 to 95 percent of what the receiving group needs to know about the design. Missing will be the subtle tricks of timing, methods of compensating for known weaknesses in components, etc. These are not in writing because no one ever thought of a need to write them down.[83]

Lundstrom went on to say that if the sending group had little esteem for the receiving group, maybe only 70 percent to 75 percent of the needed information would be supplied. He implied that this was the case with UNIVAC I documentation, and it was difficult for the ERA engineers to ferret out the missing information.[84] By the summer of 1957, Remington Rand management was clearly nervous about the problems with the UNIVAC II project. Very early in the year, Weiner took some of the UNIVAC II design drawings to Lukoff and asked him to evaluate them and prepare a report for Norris. Lukoff isolated thirty design faults in a long memorandum to Norris in February.[85] By summer, there seemed no choice but to send a team of UNIVAC I engineers to ERA to take over the design effort. Lukoff led the team, which included Lou Wilson (control section), Art Gehring (logic design), Bernard Victor, Edward Loss, and Peter Simon. By the end of the first week in St. Paul, it was evident to Lukoff that several months of redesign would be necessary. The good news was that the arithmetic section and the core memory design were in good shape; the bad news was that the input/output and control areas were most in need of attention. By September, the redesign was ready for testing, and the first UNIVAC IIs came off the line in the spring of 1958. The design was late in reaching the market; consequently, only twenty-seven were produced.[86] Like its predecessors, UNIVAC II was a binary coded decimal machine, twelve decimal digits per word, two instructions per word, and 54 instructions. This system used fixed-point computation and one address for instructions. The capacity of the magnetic core memory was 10,000 words in 42 separate magnetic core planes of 50 by 80 cores. Various devices served the input and output needs: magnetic tape (run on the Uniservo II[87]), keyboard, card-to-tape converter, tape-to-card converter, and high-speed printer. If this system had reached the market earlier, the 1950s rankings of companies in the computer industry might have been quite different.

The ERA division did not have the same large losses shown by the EMCC division, mostly due to the range of government business that came ERA's way. Besides the computers for the navy and air force, they engaged in many other projects. For example, Wright-Patterson contracted for diaphragms for flight instruments (1951). The Signal Corps maintained an R&D services contract similar to that of the Office of Naval Research for such studies as a serial coincidence detector (1951) and a serial subtractor (1952). The navy continued to support research on magnetics. Task 41 in 1954 called for an investigation of nondestructive read out from memory arrays. In the same year, ERA looked into driving systems for a magnetic core matrix. And most lucrative of all, the division continued its work on the antenna coupler, trying to make them smaller and more effective (1954–56).

Figure 5.6
ERA assembly line for the antenna coupler unit in the mid-1950s, which was a major product sold to the aviation industry.
Courtesy of the Charles Babbage Institute.

During the three years 1952 to 1955 after Remington Rand purchased ERA, the company did a significant amount of scrambling to try to make the two new electronic computing divisions successful. While there is some doubt that Remington Rand understood the new market, they did apply some traditional practices to design and manufacture products. The computer market was still in embryonic form, so Remington Rand cannot be faulted for their missteps in these years. Other companies were bringing their first computer systems to market—IBM with the 701, NCR with the 301, Raytheon with the Raydac, and so forth. IBM was working valiantly to develop a range of systems for different uses—the 702, the 650, and later the 704 and 705. No other company could match this array of machines in the mid-1950s. Remington Rand embarked on the design of new systems, largely sparked by Eckert and Draper, but it provided insufficient resources and leadership to bring them to market with the aplomb of IBM. The other companies were in the same fix as Remington Rand. IBM, perhaps, was most successful in developing finance and account control programs for IBM systems, which helped them to gain significant market share at the expense of the other firms.

The merger of Remington Rand with Sperry Gyroscope to form Sperry Rand in 1955 promised a new era for the divisions. As noted above, the two companies did not manage in the same way, and Sperry, the dominant firm, reorganized the Remington Rand practices. Sperry's major revenue source came from military materials and projects, so it saw Remington Rand's military, indeed its government business, as small and adding little to the Sperry military programs, especially as to profits. Harry Vickers told Norris that he saw little need to enlarge the ERA business with government. Was any thought given to merging ERA with some of the Sperry Gyroscope government business? I found no evidence this was considered. Vickers and his management team continued their support for the R&D in the two divisions, but within a few months came to the conclusion that it was necessary to form a single division of the digital computer activities. But even they at first seem not to have designed a coherent plan for the computer market. What plan did Vickers have for the computer area? He adumbrated one to Norris during one of their conversations, but it was not enough to plot a clear path for even the short term.

The first year after the Sperry Rand merger, that is, 1956, was taken up with organization of the new UNIVAC Division according to the Sperry Gyroscope rubric of management, as we will see below. It seems that no attention was given to the different approaches of ERA and EMCC in this early reorganization. The disagreements between the two old firms as well as the differences in their styles of design and marketing acted as an anchor to the new division. Repeated attempts to solve this with reorganizations served only to drive away many of the better designers and managers of ERA. The mix of projects in Philadelphia and St. Paul did not seem to be rational, and this caused many delays in reaching the market with new products. By early 1957, a short time (about 18 months) in retrospect, a clear path was evident for the separation of niche markets between Philadelphia and St. Paul, but this path did not extend to management of the UNIVAC Division. Meanwhile, infighting among the more established divisions and ERA, or more rightly Norris, sapped the energies of UNIVAC Division management away from the real needs of the division. It almost seems that one aim of Marcel Rand, B. F. Anderson, and maybe even Vickers, was to drive out a few of the management people of ERA. One thing Norris did not comprehend was the necessity of being close to the management offices in New York City. The daily politics of the firm transpired in a context from which he was excluded. He applied a rational technique to managing a division, while other managers sought to aggrandize some of ERA's functions. Manufacturing, for example, had no trouble convincing Philadelphia to turn over most of its manufacturing to other localities, in spite of the effects on time and quality. Eckert was less interested in manufacturing anyway. Norris saw this as an integral part of delivering reliable systems to the market. Yet Norris seems to have paid little attention to manufacturing in Philadelphia. Was this because the number of systems in production there was too small to worry about? Norris's battles were always about St. Paul matters and his role in the firm. Was this too shortsighted a view, and if so, was Norris's view apparent to Sperry management? Brisker sales of computer systems and better coordination among managers of the whole firm might have overcome many of these difficulties. To understand this situation, let us examine the sales program for computers in the years 1953 to 1957 and separately, the management situation in Sperry Rand.

The UNIVAC Sales Program under Parker

The two divisions managed to sell a number of systems in the second half of the decade of the 1950s under Sperry Rand management and after the formation of the UNIVAC Division. What was the problem in the years 1953 to 1955, when there seemed to be a less effective sales program? On January 1, 1953, Parker assumed a new position as vice president and manager and was authorized to set up a new office in New York City called the Electronic Computer Department within the sales division. Apparently, Parker recommended to Remington Rand management that William Norris was best suited to lead the St. Paul group. Staffing the office in New York became a matter of controversy, and extensive discussions were held to consider how customers in business and government could best be served. Parker wanted to take some engineers from St. Paul, notably Erwin Tomash and James G. Miles for his sales staff. However, Miles argued that sales of 1101s should remain the province of St. Paul, because unless engineers stayed close to development they would very quickly become outdated, making it difficult to work with potential customers and prepare adequate proposals.[88] Tomash eventually moved to the New York office, but was immediately assigned to run a sales operation in Los Angeles.

Norris submitted to A. R. Rumbles, head of Remington Rand sales, a recommended plan for engineering sales in late January. In his memorandum, Norris reviewed the basic mission of ERA and the engineering sales operations of ERA. He noted that "all ERA sales efforts are of a highly technical nature and require extremely close co-ordination with engineering." ERA saw the main benefits to this closeness as an assurance that proposals for sales were "realistic, accurate, and competitive,"[89] and to assure that engineers understood customer requirements. Norris agreed that all future sales for 1103 computers should be passed on to Parker's operation in New York, with liaison provided by ERA engineers from St. Paul. In a peculiarly worded paragraph, Norris went on to say, "Where the development of computer systems is required, it is recommended that the sales responsibility remain in ERA with co-ordination to be supplied by the New York and Washington offices of Remington Rand. By this method ERA can develop the most realistically-engineered systems for eventual sale as computer products."[90] It was peculiar because in the previous paragraph, Norris stated that all "future ERA computer products will be automatically passed on for sale as soon as fully developed."[91] This peculiarity could have been the cause of future difficulties between ERA and the New York office.

Slightly later, Norris also took up the question of how to integrate the computer sales force with the tabulator sales force, believing that new ideas came mostly from the field engineering staff. At that moment, the field-engineering people most closely associated with the customer were the tabulator salespeople. He also expressed the concern that eventually, as computer sales increased and tabulator sales decreased, the morale of the tabulator personnel would decline. Close coordination of the two groups was essential. He suggested that other regions follow the example of St. Paul, which worked closely with the regional sales office in seeking contracts for ERA systems. Materials and educational meetings would be used to acquaint branches with the program.[92]

After a meeting in Parker's office with Art Rumbles, Al Seares, Herbert Goodman, William Norris, and Howard Engstrom in attendance, Rumbles, head of sales for Remington Rand, essentially agreed with Norris, and directed that ERA St. Paul would provide the quotations on engineering projects and special products, and these would be coordinated with H. H. Goodman of the Washington office who was in charge of government contracts for the ERA computer systems and with Parker in the New York office for domestic commercial sales.[93] Rumbles hoped this arrangement would eliminate a problem that had arisen. Requests for bids were getting lost as they arrived at the wrong office and were not forwarded. In addition, requests received in St. Paul sometimes were handled by suggesting that the customer send representatives to St. Paul.

Rumbles thought Remington Rand people should go to where the business was.[94]

At least in the beginning, this new sales department focused on the sale of UNIVACs and ERA 1101s to commercial concerns.[95] This decision removed digital computers from the normal sales offices of Remington Rand. Both right and wrong, this decision was to have long-term consequences. An inherent competition between the tabulator salespeople and the computer salespeople ensued. Parker arranged for two people to join him initially in this office: Luther Harr and Herbert F. Mitchell. Harr served as assistant sales manager, while Mitchell became director of applications. By 1955, just four years later, the office had over twenty-three people in New York and ten regional representatives, some with staffs of their own.[96]

Parker implemented a six-pronged strategy for sales, including many of the elements discussed among Remington Rand management in the early months of the office's existence as shown in the above paragraphs, with particular emphasis on the "UNIVAC system as a thoroughly proven and economical method of processing accounting data in the business firm."[97] The most important element in this strategy was a training program in the logic, programming, operation, and maintenance of computer systems. He invited tabulator salespeople to six-week courses, where they were to become knowledgeable about the UNIVAC, with the idea that they could represent the firm in sale of computers right along with sale and rental of tabulators. Employees of firms and government agencies who wanted to obtain a UNIVAC or 1101 attended these courses also, to be able to run and program the machine for the customer. In the first six months of operation of courses, eighty people from thirty companies attended, including Remington Rand personnel.[98] Second, the computer sales office used the service bureaus in New York City and Arlington, Virginia, as a place where prospective buyers could try out the machine to learn whether it would serve their needs. Third, he believed that sales could only be made if the customer sold himself. Thus, he instituted a round of "seminars" each year, sometimes in New York, at other times in major cities around the country. As regional representatives became established, they ran these meetings in their regions. We receive an impression of how dynamic this part of the strategy was by noting that in the first six months alone, eighteen one-day seminars were held around the country. During these meetings, speakers described the engineering facilities of Remington Rand, the applications knowledge possessed by Remington Rand technical people, and the array of systems available from Remington Rand for both general and special purpose computing. Fourth, Parker, Harr, and Mitchell sought cooperation with major consulting firms, such as Arthur Andersen, Peat, Marwick and Mitchell, and Ernst and Ernst, to obtain their assistance in helping companies to decide to obtain a computer system. Employees of these firms attended the training classes, received printed materials for use in presentations to companies, and involved them in evaluating applications.[99] The fifth leg of this strategy was advertising and promotion. Such advertising ranged from reports of Remington Rand,[100] to a booklet for distribution by the firm on advancements in computation, to use of UNIVAC for projections of returns in the 1952 election. The sixth element of this strategy was one John Mauchly had promoted for EMCC almost from the beginning: programming and programming research. As Parker wrote in his evaluation of the sales program in 1953, "The art of designing equipment has forged ahead of the art of using equipment."[101] To make up for this disparity, programming groups in Remington Rand, both in engineering departments and the sales office, worked on development of new applications and routines, accommodated customer programs to general use with UNIVACs, and examined possible automatic programming techniques to ease the programming burden.

At the time Parker prepared this report, there were three UNIVACs in operation and no 1103s. He believed that twenty-three prospects for UNIVACs over the following fifteen months were firm. Among them, he hoped to sell Commonwealth Edison in New York, where Remington Rand was head-to-head with IBM and their 702. This sale would be a prestige sale that might influence the entire electrical utility industry.[102] Sales records show that in that fifteen-month period eleven UNIVACs were sold, and in the next six months an additional eight UNIVACs were sold, bringing the total UNIVACs in operation in July 1955 to twenty-two systems. However, projections made in October 1955 for new installations (see fig. 5.7) were wildly off the mark. Three developments or events had important effects on the ability of Remington Rand to maintain a strong position in the market. First, there was the rising tide of IBM machines, and the IBM practices in sales and service. The tempo of activity at IBM continued to intensify in the years after 1946, as the company positioned itself to transform the tabulator market into the digital computer market, although this was not explicit until 1950. In contrast to Remington Rand, IBM proceeded with development by involving several groups at the same time. A future needs group worked with engineering and both sought evaluations from sales and service. Management set guidelines about

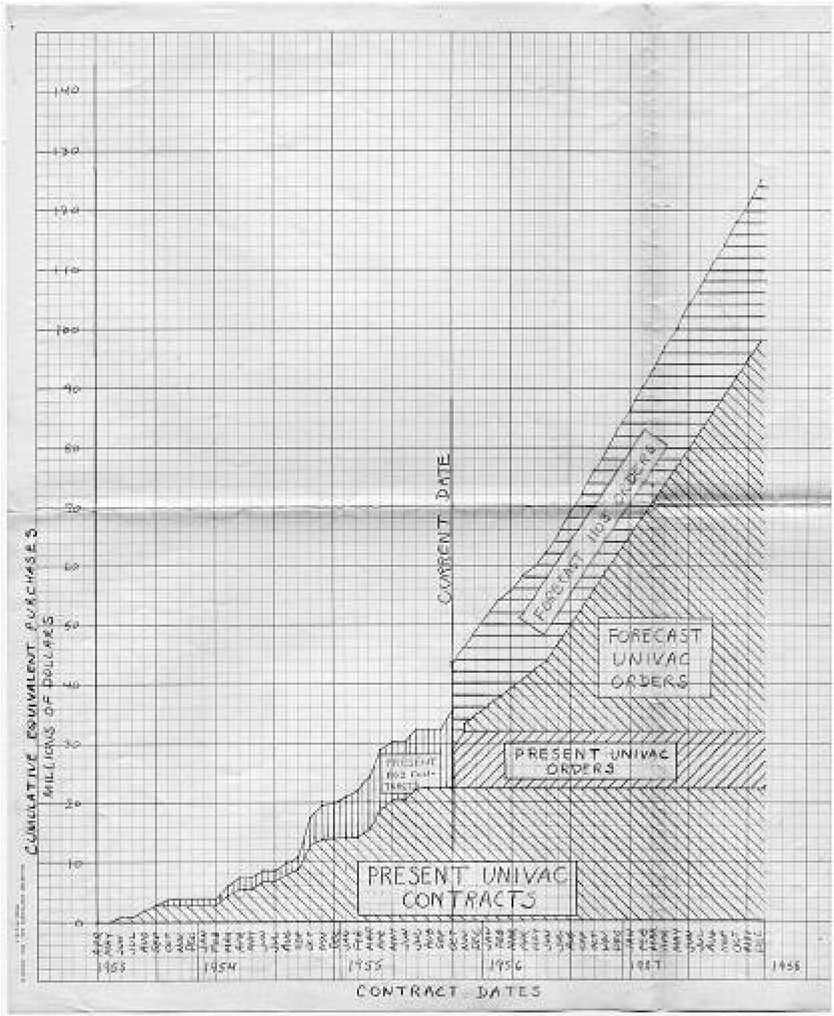


Figure 5.7

A 1956 sales forecast prepared by the office of John E. Parker, vice president of Remington Rand.

Courtesy John E. Parker Papers, Charles Babbage Institute.

functionality and price of a new design at the beginning, and monitored progress of the groups to see that these guidelines governed the characteristics of the final product. At the same time, IBM measured its activity against other companies in the same market, namely Remington Rand. Sales and service staff received training during the construction phase of systems, so that they were ready to sell the products before they were ready, and service the products from the day the product left the plant. It was this consistent attention inside to company capability and outside to market that brought IBM success, and allowed them to outstrip the competition, no matter how good the competition's designs.

Second, a substantial disconnect existed between the sales office and the production facilities of the Eckert-Mauchly division. One major example can illustrate this disconnect. Remington Rand sold the first commercial UNIVAC I (Serial Unit 9) for business applications to General Electric for its new Appliance Park in Louisville, Kentucky. Appliance Park was a new, state-of-the-art major appliance manufacturing facility, much of it automated, put into service in 1953. At the time of the order, four UNIVACs were in government service, and GE felt comfortable going ahead with the order. UNIVAC would serve four initial applications, which given the programs available from Remington Rand, should have been possible on startup in 1956. First, the payroll application computed incentive pay, gross pay, deductions, and net pay for approximately 12,000 employees, and prepared the distribution to the appropriate cost accounts. Second, a program maintained material scheduling and inventory control. This program also recorded and adjusted daily open vendor orders. Third, another application processed orders received from distributors and prepared shipping schedules, consolidated car shipments, and prepared invoices, sales, and cost of sales accounting records. Fourth, data from these three applications was used as input to a general and cost accounting program that produced the general and special ledgers, reports, balance sheets, and operating statements.[103] Remington Rand wished to promote this new use of UNIVAC, but ran into difficulty in the installation phase.

Apparently, when the system was twelve months late in delivery, GE complained, first to Remington Rand and then specifically to John Parker, head of UNIVAC sales. How much Parker knew of the situation is not clear; nor is it clear what he passed on to William Norris in St. Paul when he asked to borrow Willis Drake for a while to visit Louisville to help smooth things out for the installation. When Drake arrived, he found a disaster in the making. Only parts of the system had arrived. The

UNIVAC I mainframe and the tape units were there. At the time, major input and output for business applications were still by punched cards, though the UNIVAC I was also a tape-processing machine. Thus, the GE system unit employed tape-to-card/card-to-tape converters and a high-speed printer. Drake found none of these input–output devices available. Programmers tried to write a range of programs for payroll, inventory control, production scheduling, and so forth, but could only test small pieces of these programs due to the absence of peripherals.

Drake was dumbfounded, and realized this would not be a short-term job.[104] His family relocated to Louisville and settled in for a long stay. Naively, Drake approached Parker with a list of needs, at which Parker expressed surprise. The memos Parker had received indicated that machinery was on its way out the door, so the problems had all been solved. In fact, he told Drake during one telephone call that a shipment in that week for a card-to-tape machine had been held back to make a last-minute change. Conversation with Parker led to assurances from Philadelphia that the required parts were being shipped. For example, Drake later remembered Parker assuring him that "the card-to-tape [unit] was due to ship on Wednesday, but there was a last minute change they [the EMCC people] feel that would enhance your reliability if they put that in before they sent it and as long as its this late why we felt we ought to do that. Printer is slipped a little bit, too; it'll be another couple of weeks."[105] And so on through the list of other delayed items, all had been held up to make minor changes, but it would go out quickly. The less important tape-to-card reader would leave Philadelphia after that. Drake later reported that he felt good after this, because he could finally tell the GE personnel that all the problems had been solved.[106]

Time passed and nothing more arrived. Each time Drake approached Parker about more delays, Parker seemed to know nothing about them. Since the plant operated during this time with Remington Rand tabulator machines, management began to get nervous that the efficiencies of automation with digital computers could not be achieved. Drake came to believe that the Eckert-Mauchly group was "totally irresponsible in the sense of any feeling of commitment to the company's delivery program."[107] Now higher management learned of the difficulties and Marcel Rand and Art Rumbles came into direct communication with Drake, which did not endear him to the EM Division. Drake decided to visit Philadelphia to view the state of the peripherals and try to speed up delivery. When Drake arrived in Philadelphia, he found the machines dismantled and being worked on. The engineers in charge, according to Drake, reacted to the delivery date from Parker with alarm.[108] Input–output peripherals were literally disassembled for changes and strewn over a "ping pong table"; little was ready to be shipped, and the assessment he received was that it would not be ready for somewhere around a year! He immediately went to New York to consult with Parker.[109]

When he reported on his findings of the state of things in Philadelphia, Parker, according to Drake, did not believe him. He pulled letters from Philadelphia out of his desk that assured him that all was well with the system for Louisville. Parker promised to look into the matter and Drake returned to GE. While all this was going on Parker and Drake took the occasion to use Drake's time to visit companies in Pittsburgh, Pennsylvania, and Gary, Indiana. In time, all the parts arrived and Drake and the Remington Rand service engineers brought the computer system into operation. Drake was able to help install the GE system and ensure that it would perform to GE specifications. He then returned to St. Paul.

This example shows that the Eckert-Mauchly Division was still plagued with the same engineering vices that are evident in the years when the company was independent. Repeated redesigns prevented frozen specifications and led to few machines being identical. Sometimes these changes came from customer requests, and instead of trying to meet the requests with software, engineers redesigned hardware, lengthening the assembly phase. But the problem went more deeply into the company than just Eckert-Mauchly redesigning. Remington Rand management provided no leadership to the new digital computer activity. The only thing the Remington Rand executive committee seemed to do in response was to request that more machines be assembled. At a time when three machines were in assembly, they asked if it could be raised to four; this request happened several times. When fewer sales and rentals were made than expected or desired and money kept hemorrhaging from the EM division, Arthur Rumbles, vice president of sales, expressed his dismay.[110] Within a few days, Parker responded to Rumbles. Once again, Parker listed the number of contacts by his office's staff, and noted that if he had more staff, more contacts could be made.[111] One year later, Parker submitted a nine-month report on sales activity. Staff numbers had increased by a very significant 64 percent.[112] In that same period, installations included two UNIVACs in commercial sites and three UNIVAC Scientifics—two in government sites and one in a commercial site. Parker expected three more commercial installations to occur before the end of the year. The remainder of the report illustrates that the staff was very busy soliciting business from an array of companies, consistent with Parker's overall strategy.[113]

In the fall of 1955, at the time of the Sperry/Remington Rand merger, the sales division of the new firm Sperry Rand floated a plan to distribute the sales activities for UNIVACs across sales regions of the United States. Managers would be drawn from "existing or former tabulating supervisors of the old Remington Rand." "These managers, compensated under a straight management commission plan, would be given full responsibility for the sales and services of all standard products of the division: tabulating equipment, UNIVAC File Computer, UNIVAC Scientific, and the UNIVAC System. An assistant manager, especially trained in electronics, and a professional staff of instructors, sales engineers and programmers would be assigned to each region to assist the manager and his former tabulating salesmen in the conduct of these activities."[114] In spite of all the time spent with sales representatives of the tabulating group, Parker reported that in some four years the tabulator salespeople had succeeded in obtaining only one customer. In addition, the tabulator salespeople possessed little or no technical knowledge of the equipment and its use, had no entrée to top management, and would not be able to direct the professional personnel needed to run such a system. Parker suggested that a plan he had submitted a year-and-a-half before for the establishment of regional offices for UNIVAC sales be delayed until such time as a sufficient group of well-trained and knowledgeable people were available and then the two staffs could be merged. And so it remained until the organization of the UNIVAC Division in 1956.

Management Difficulties

The Remington Rand merger with Sperry-Gyroscope occurred in mid-1955. To its credit, the new firm, Sperry Rand, reorganized its computer activity, combining the three groups into one UNIVAC Division, with William Norris at its head. This rationalization did not stop the bickering between the various operations. Turmoil in computing activities continued over the next two years. Resources were still short of perceived need. The head of the new corporation, Harry Vickers, possessed little imagination for the computer business. At first, he told Norris that he wanted Sperry Rand to be first in the computer business, but as losses mounted he shied away from this view. He refused to increase R&D resources to the UNIVAC Division, and provided little guidance to the entire organization to maximize possibilities.[115]

Sperry Rand, like Remington Rand before it, exhibited much political infighting to gain territorial rights. Philadelphia and St. Paul encountered some of this infighting with manufacturing. The head of most Sperry Rand manufacturing, B. F. Anderson, repeatedly tried to gain control over computer manufacturing in the firm. In mid-1954, Anderson proposed to the operations policy committee that the company move all manufacturing activities at ERA to one of the company's other plants as quickly as possible.[116] This attempt was ultimately not successful, but he succeeded in removing computer memory manufacturing from Philadelphia and resettling it in Elmira, New York, where tabulator machines were made. Manufacturing personnel paid little attention to the need to transfer knowledgeability about the parts to be manufactured, and for some time faulty components were the result.[117]

Management problems existed in many directions. The sales organization for computers had little staff, no set policies of commissions for sales, few trained field engineers, and little authority to coerce any change within the company to solve these shortcomings. Sales seemed to have no focus, and little ability to deliver a product as contracted, since the engineering staff of the divisions repeatedly tinkered with designs rather than freezing designs for a period of manufacture and preparing for a subsequent model. Executive managers kept calling for larger numbers of computers without any understanding as to what was going on in the divisions with respect to manufacture. There were frequent changes in reporting lines for division leaders. Sometimes a person reported to several people on different matters.

Product planning, if it existed at all, resided within a division with little or no contact with other divisions trying to market similar products. Remington Rand management often used the ERA Division, for example, as a backup for the Eckert-Mauchly Division. EMCC often took on too much or it simply did not want to develop a certain product, as was the case with the UNIVAC II in which Eckert lost interest leaving the firm with no follow-on product to UNIVAC I.

Responsibility for manufacturing rested in each division, but occasionally reorganizations led to changes that left division engineers in the dark about developments or too far removed geographically to influence what transpired with change modifications. Requests for more space were met in the corporate offices with skepticism, and even when acted upon, it was a usually late and inadequate response.

Changes in one division sometimes left staff in another division uneasy about the future and people began to search for new positions. ERA Division frequently experienced this problem between 1952 and 1957.

When ERA became part of Remington Rand, 95 percent of its operations were in St. Paul, where William Norris served as general manager, and the Arlington, Virginia, facility constituted about 5 percent. Norris remained general manager, but reported to two new individuals in Remington Rand and not to Parker, who was transferred to New York City to head the computer sales office. Norris's reporting line changed about every six months. At first he reported to Beverly Bond and L. E. Jamison. Bond, who was assigned to other duties,[118] was replaced by B. F. Anderson (production operations), and not long after A. M. Ross (research and development) replaced Jamison. Ross was shunted aside and replaced by Arthur R. Rumbles—all of this in about eighteen months.[119]

Difficulties also resulted from the existence of separate divisions for computer design and construction. These difficulties were compounded by problems with personalities, especially J. Presper Eckert. One glaring example surrounded the RFP that was circulated in late 1954 by the Livermore Radiation Laboratory for a superior performing computer system, henceforth know as a super computer called the Livermore Automatic Research Computer (LARC). Edward Teller, laboratory director, and Sidney Fernbach, director of computing, solicited responses from IBM and Remington Rand.[120] IBM met with Livermore leaders in January 1955 and learned from Teller that he was in a hurry to have such a computer, and that it should contain solid-state components because of their inherent superiority to vacuum tubes. In the view of Ralph Palmer and Wallace McDowell, the time allotted precluded development of significantly improved solid-state components. IBM discussed the RFP, but there was disagreement inside IBM about the necessity to design new components to meet the requested performance and how long it would take. Eventually, the Palmer and McDowell view prevailed and IBM submitted a proposal to deliver a system at the desired price in forty-two months.[121]

ERA, through the New York City sales office, also responded to the Livermore RFP with a design prepared by ERA engineers. When Eckert heard of the RFP and proposal from ERA, he had the engineers in Philadelphia prepare their own proposal. According to Norris, Erwin Tomash of the New York sales office tried to stop Eckert from presenting the proposal to the Livermore Radiation Laboratory until a meeting was held inside the company to try to present a united front to the lab. But Eckert refused and presented a proposal for a computer system that was to have much superior performance at a lower cost and an earlier delivery date than the ERA proposal.

A meeting finally occurred within the company, where an acrimonious fight developed between St. Paul and Philadelphia. Norris's argument rested on priority: ERA developed a proposal and presented it with favorable response from Livermore. For Eckert to jump in after that could only harm the company. Eckert challenged on the basis of capability: the ERA division would lose the contract to IBM. On the other hand, his engineers in Philadelphia could build a much better computer for less money than ERA. There was no objective way to resolve this accusation. There is some disagreement about what decision was made and who made it. Norris later claimed that management made a weak decision to let both divisions submit proposals at the same price at the same time.[122] Lukoff, in his autobiography, wrote that management decided that Philadelphia should make the proposal.[123] Whichever version is the correct one, Philadelphia presented a proposal. Livermore accepted the Philadelphia bid and the two sides negotiated on detailed specifications.

Between the time Livermore made its decision and the contract was let, Sperry Rand made a number of organizational changes and Norris became head of a new UNIVAC Division. Shortly after, he advised Howard Engstrom to withdraw the LARC proposal because of the potential losses involved. Engstrom telephoned Rand, who reversed Norris's decision. Charles Green, a senior Sperry Rand executive, advised Norris to accept the fact because Rand wanted the contract. The LARC computer system ultimately met these specifications, but was two years late and over budget by at least $16 million.[124] Norris was long gone from Sperry Rand by delivery time. For Norris, this failure of management resulted from having three divisions inside the company competing with each other for the same computing business, all the divisions having different managers and different reporting lines. Eckert's maverick status inside the company further complicated this situation. One might argue that executive management's gaze was directed at the time toward the negotiations for a merger of Remington Rand and Sperry Gyroscope, and failed to see the implications of the St. Paul/Philadelphia argument about LARC. But this position is difficult to accept because of the many other shortcomings of management at this time.

As noted, in the fall of 1955 toward the end of the LARC negotiations, more management changes were made in Remington Rand, just after the merger with Sperry Gyroscope. Charles Green, head of the Sperry portion of the new firm, with agreement by Harry Vickers, offered Norris the job as head of a new computer division. Norris, who had not sought the position, agreed to take it only if the lines of authority were clear and not violated, and he had the complete support of Vickers. All agreed to Norris's terms. Green sold the plan to James Rand. Green specified the type of organization desired, which was similar to that of Sperry Gyroscope—a product divisional concept, as opposed to Remington's functional concept. Rand sent out a letter naming Norris as general manager in charge of the UNIVAC Division, in addition to his position as vice president of the Remington Rand Division under the new company. The UNIVAC Division contained the Eckert-Mauchly organization, Philadelphia; Engineering Research Associates, St. Paul; Advanced Research Laboratories, Norwalk; and the tabulating division of Remington Rand. Norris took charge of engineering, manufacturing, sales and services of all lines of company products included in the UNIVAC Division, reporting to the head of the Remington Division.[125] A. R. Rumbles and A. M. Ross, although remaining vice presidents, were shunted aside to staff consultant positions. Marcel Rand became head of the Remington Rand Division. Relations between Marcel Rand and Norris were never very good. Attempts to rationalize manufacturing by B. F. Anderson of Philadelphia caused other problems for Norris. Norris also had repeated problems with Arthur Draper and Presper Eckert; after October 1955 both men supposedly reported to Norris.

Green made a number of suggestions to Norris at the time. Green believed Norris should concentrate first on improving the sales organization, which was the point of greatest weakness in the division. He advised Norris to institute as quickly as possible comprehensive and written policy and procedure and organization manuals, with job descriptions for each employee that would be known to all. He suggested Norris not worry too much about losses in the Eckert-Mauchly Division, but avoid increasing them. In a series of meetings with Harry Vickers, Norris learned that Vickers purchased Remington Rand to increase the commercial business not the military side. Sperry's military business was very high and increases in military business on the Rand side would not add much to the totals. Vickers preferred not to increase the military business. He agreed to pay the necessary costs to increase the computer side of the business, because Sperry had the money to pay for a growth spurt.[126] In the event, none of this was accomplishable.

Norris believed that the change in reporting authority for Parker to Norris instead of to the president of Remington Rand would result in Parker's resignation. Norris prepared for a change by asking Erwin Tomash to attend the New York meeting to announce the formation of the UNIVAC Division. If Parker resigned, Tomash would be named to replace him as national sales manager for the new division. To his surprise, Parker expressed a willingness to work with Norris, leaving Tomash as a peculiar presence at the meeting since he worked for Parker and Parker had not invited him. Tomash felt out of place and a victim to the politics of the front office.[127] A few months later, he resigned and joined Telemeter Magnetics in California.

In February 1956, Norris finalized a management team. Previously, he had appointed operations managers for the various sites. Arthur Draper remained as operations manager of Philadelphia, which by this time, pursued research, development, engineering, and preproduction manufacturing. Manufacturing was completely under Anderson, vice president for manufacturing. Norwalk had no manufacturing; it was practically all engineering and development. Robert Sorensen headed Norwalk. Norris selected Robert McDonald as operations manager of St. Paul, where the activity was much broader. In St. Paul, ERA performed development engineering, marketing, manufacturing, servicing for defense systems and also did development, manufacturing, and servicing for some commercial activities, such as the File computer systems. The idea was to push responsibility lower in the organization so problems did not ascend too high for resolution.[128] As we will see, other management leaders in Remington Rand and Sperry Rand repeatedly attacked this organizational structure.

Norris wanted to make some changes in the sales office of the UNIVAC Division, and took his concern directly to James Rand, chairman of the board. Norris first met with Green, president of the Sperry part of the new firm. Following the meeting, Norris traveled to Florida to try to see Rand. Rand at the time was on his yacht, which was docked at Palm Beach. Green had even tried to smooth the way by telephoning Rand first.[129] Since he was unable to meet with Rand and had to cut his visit short, Norris wrote Rand a letter informing Rand about his changes in the division. The principal concern Norris wanted to lay before Rand had to do with Parker. He wrote in a letter the next day: "We have reached the point where it is necessary to get John out of the sales picture entirely in the very near future."[130] According to Norris, Parker was not developing new prospects for the UNIVAC II and was being a hindrance to others in the division, though Norris did not specify which persons. Norris wanted to name Parker's assistant, Charles E. McNamara, to replace him.[131] Also, Norris was close to hiring Carl Knorr of Ingersoll Rand as sales manager. (Knorr arrived at UNIVAC in spring 1956.) James Rand did not respond to Norris's letter.

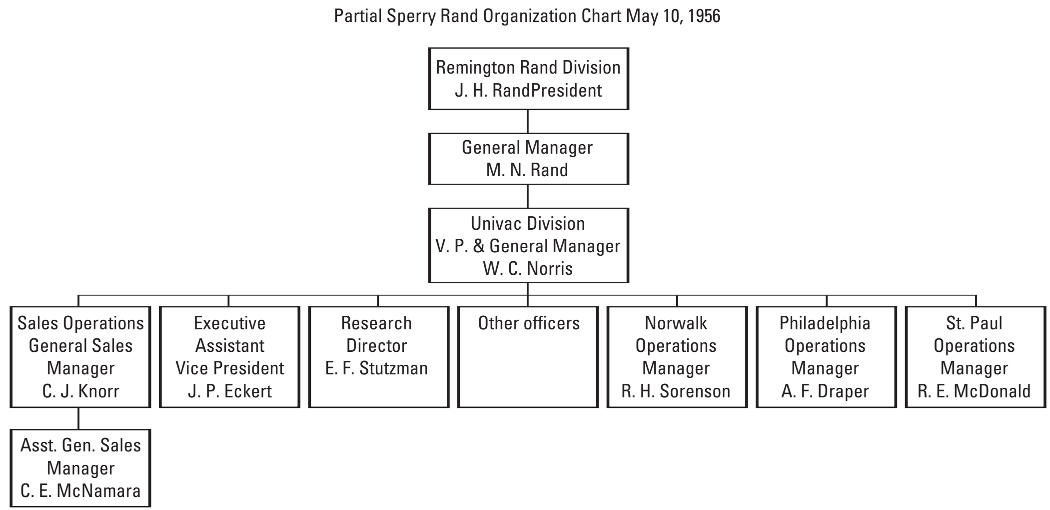


Figure 5.8
Sperry Rand organization chart, abbreviated to show only the organization of the UNIVAC Division and Norris's direct reporting line.

Norris had been assembling a management team for the division in St. Paul. Dr. Stutzman relocated to St. Paul to become director of research and head of product planning. Robert McDonald became manager of the St. Paul operations, responsible for manufacturing the File Computer, the UNIVAC II, the 1103, and other systems. Norris expected to move the general sales manager to St. Paul as well to complete the team and make St. Paul division headquarters. All of these changes caused some agitation in Philadelphia. Moving everyone in management of the division to St. Paul would not be easy.

Norris's trip to Florida points up an attitude among top management about how to run a major corporation. Rand did not advise Norris he was leaving for the winter, and did not give him a forwarding address, hence Norris's inability to reach him in February. Green also relocated to Florida, as did Rumbles and others. In fact, Norris wrote that only his peers were available throughout the firm at this time.[132]

Norris proceeded with the move of the sales office to St. Paul. In the meantime, Marcel Rand, son of James Rand, became head of the Remington Rand portion of Sperry Rand. However, Norris discussed the move as part of discussions in the executive policy committee, of which Marcel Rand was a member as head of foreign sales at the time, no one expressed dissent. However, shortly after M. Rand assumed his new role, he stopped the move cold. Many employees were caught unawares; Knorr had purchased a home in Minneapolis and George Campbell, his number two man in sales, had rented one. Knorr and Norris met with Rand to try to get the order modified, but Rand would not even discuss the matter. He said he would think about it, but Norris never heard anything. Norris wrote a memorandum suggesting a compromise that he did not find palatable, but thought it would be acceptable.[133] Marcel Rand never responded.[134]

Norris did not handle this situation well from the beginning, and he recognized this later. He mixed the two issues of a central office for the division in St. Paul and the sales office location. In his June 14 memorandum to M. Rand, he noted "I have always recognized the advantages of New York City from a sales point of view and initially had in mind that if John Parker would stay with us he would stay in New York as well as would C. E. McNamara. I was looking to Carl Knorr more from the point of view of over-all management than from the point of view of the real hard selling job."[135] Norris proposed that the status quo be maintained. The headquarters of sales would stay in New York; Campbell would be named general sales manager and Knorr as vice president in charge of

Figure 5.9
Remington Rand executive team in late 1956. From left, unidentified, J. E. Parker, H. V. Widdoes, H. H. Goodman, M. N. Rand, H. T. Engstrom, A. R. Rumbles, A. N. Sears, H. Hicks, unidentified, W. C. Norris, B. F. Anderson, S. H. Ensinger.
Courtesy of the Charles Babbage Institute.

sales. Knorr's main job would be planning and organization located in St. Paul. Four product line managers—tabulators, UNIVAC I and II, 1103, and special products—would be divided between the two locations. Ironically, Parker left Sperry Rand in 1956, but the fallout from the dispute continued to rain down on Norris.

Another type of response came from Rand three months later: Rand notified Norris that the sales function was removed from the UNIVAC Division. Knorr, Campbell, and Drake were demoted. When asked, Norris refused to go over Rand's head to Green or Vickers, because he felt it would forever alienate Rand to the detriment of the division. Norris later reported that he felt at the time that he had not been given a fair chance to perform on the job, and that Rand's action was a clear violation of his understanding "with Green and Vickers that I would be supported completely."[136] Moreover, Rand dealt directly with Draper and Eckert in Philadelphia in violation of Norris's job description. For example, in the winter of 1957, Rand asked Eckert to make a report to him about St. Paul progress on UNIVAC II without Norris's knowledge. Eckert was very critical and made an unfavorable report to Rand, which certainly did not help Norris's position with Rand.[137]

Also in the fall of 1956, B. F. Anderson, in a memorandum of August 23 that I have not been able to find, engaged in another political play that cost Norris part of the manufacturing responsibilities of the division. Anderson recommended in August that the major part of the File Computer production in St. Paul be transferred out to a location in the East under Anderson's jurisdiction. UNIVAC Division management disagreed with Anderson's position on a number of points. First, transfer of File Computer manufacturing from St. Paul would entail "a tremendous extra expense" to the company and introduce a serious delay. Production talent involved in printed circuitry, automatic assembly, production engineering, and so forth, were shared with other manufacturing operations and therefore not movable, and would need to be duplicated in Philadelphia with such a move. Second, St. Paul had made a substantial investment in computer manufacturing facilities. Third, a time delay would be encountered in initial startup at a new location. Anderson argued that economic manufacturing was not possible in St. Paul. At the time, manufacturing operated out of a number of hastily rented facilities to meet production schedules. Norris pointed out that at the moment this was correct, but they were waiting for the completion of a new facility. A comparison with the manufacture in St. Paul of other products would show that economy would be obtainable. Nothing was said about UNIVAC Division manufacturing in Philadelphia.[138]

Norris arranged a meeting at Rockledge for September 12 during which presentations were made by McDonald on the UNIVAC Division production program, Keye on manufacturing at St. Paul, Keye on the new equipment program, McDonald on "the peculiar requirements of computer manufacturing," Vye on printed circuit and mechanized assembly, and McDonald on manufacturing space requirements.[139] While the presentation did some good for Norris and St. Paul, it did not stave off another reorganization. Remington Rand established a new position of vice president for manufacturing, which was given to Anderson. Norris's position was modified and he now reported to Anderson for manufacturing and Rand for the UNIVAC division.[140] The result was an awkward reporting line, justified by Rand as due to his own lack of knowledge about manufacturing.

Slowly over these months, an erosion of responsibility occurred for Norris. In September, an advisory management committee recommended that electronic equipment maintenance be transferred from the division to sales. Norris objected on two grounds. First, supervision of this maintenance had been placed in New York after the establishment of the UNIVAC Division. Tabulator maintenance was satisfactory, but sales personnel had handled electronic maintenance unsatisfactorily. Without direct control by St. Paul costs of training and service would rise. Second, setting up a worldwide field organization for computers required recruitment of technical personnel, which could only be done satisfactorily by the division not the sales office.[141] This memorandum, too, was never answered and maintenance was moved from the division. A similar situation arose with electronic training of sales personnel, which was also removed from the division in spring 1957.[142] Again, Rand did not answer memoranda written by Norris on these matters.

Since Norris was at the center of all these changes, we must address the question: was it a certain ineptitude on his part that caused all these difficulties or was it lack of strong management at the top of Sperry Rand? Norris believed that he had been given authority to run the UNIVAC Division and yet in the eighteen months he held the post every time he turned around someone was trying to remove some section from the division. His memoranda to senior management were reasoned and clear, but seemed never to be accepted and dealt with as real issues. Instead, there seemed to be some personality issue between Rand and Norris. Norris came to suspect this, and asked Green about his suspicions during a meeting with Green on June 13, 1957, after Green retired. Green confirmed a number of things for Norris. First, he placed some blame with Vickers, who he claimed had not done his job. Because of the large amount of Rand-held stock in Sperry Rand, Vickers wanted Marcel Rand to run the Remington Rand side of the firm. Green wanted another Sperry person placed second in command, who would be allowed to run the operation. Vickers would not agree. This disagreement occasioned Green's decision to retire. Second, Green told Norris that Marcel Rand's animosity to Norris developed over the Parker sales matter even before Rand became head of the Remington Rand Division.[143] Rand's technique for dealing with Norris seems to have been passive aggressive, on the one hand, saying nothing in response to disagreements about and discontent with Norris plans and decisions, and on the other hand, reorganizing the division to obtain his will over Norris. When Norris finally resigned from the firm, Rand did not ask him to reconsider and stay with the firm.

Moreover, events suggest that Anderson, M. Rand, and maybe others, engaged in activities to set up a Norris resignation. Norris reported these as violations of his job description, and indeed they were. In winter 1957, Anderson took the position there was no longer a UNIVAC Division. Later in the spring, he released a number of St. Paul staff, perhaps as many as 100, without Norris's knowledge. Anderson's subordinates began to give orders to St. Paul personnel under Norris's authority. McDonald, general manager of St. Paul, had his reporting line changed in April 1957, and began reporting to four bosses including Norris and Eckert. In this same April reorganization, Norris was demoted to vice president and chief engineer in charge of military products, reporting to Thornton Fry, now head of the UNIVAC Division.[144] By July, Norris had decided to leave Sperry Rand.

Morale in the ERA Division slid downward as a result of all these changes and rumors, some benign and some vicious, that circulated about management of the computer activities and the capability of the ERA personnel. Norris must have felt constantly under siege. Robert McDonald found it all very disconcerting. In the winter of 1957, he responded to conflict between his two managers putting him in the middle by threatening to resign at least twice.[145] Anderson repeatedly second-guessed Norris on budget items, claiming that since there was no manufacturing in St. Paul, certain capital and special expenses were unnecessary, expenses submitted by McDonald and approved by Norris.[146] The items were to satisfy military contracts and not within Anderson's purview. Anderson and his people made repeated requests that St. Paul lay off people to reduce overhead regardless of contractual obligations. When Norris complained about what he saw as interference, Anderson responded that since McDonald was an engineer maybe he should be made head of engineering and manufacturing could be put under someone else, and by implication not of Norris's choosing. Norris rejected the idea. Anderson seemed to have no compunction about inserting himself into the management of the St. Paul operations, even to laying off personnel in St. Paul without notifying either McDonald or Norris. Norris and McDonald repeatedly compromised because they could not get the support of Marcel Rand.[147]

Problems compounded in the spring of 1957. Rand and Thornton Fry wanted to give Eckert responsibility for engineering, which Norris opposed. In a meeting, Norris reviewed for Rand the problems with Eckert and Draper and cited instances of Eckert's negative behavior that cast a bad light on the firm. At one meeting with a customer, Eckert entered into a controversy with a Sperry engineer. Others reported on Eckert's poor leadership qualities and that "he pushed his people into the background and took all the credit and did all the talking himself."[148] Biweekly meetings about UNIVAC II between St. Paul and Philadelphia and interference from Eckert caused other difficulties. At this same meeting, Norris also took up the problems with Anderson, requesting help to get people to adhere to their job descriptions. He indicated the repeated meddling in the File Computer and UNIVAC II operations in St. Paul, which had negative consequences for both programs because as a result "St. Paul manufacturing got disorganized and inefficient with several people giving orders directly to people down the line."[149] Norris suggested that Rand meet with all the divisions' heads and emphasize the need for compliance with job descriptions. Rand did not accept the suggestion, but he did agree to talk with Anderson.[150]

Meanwhile on April 13, Arnold Ryden and Byron Smith met with Norris for lunch. Ryden's purpose at the lunch was to describe the new company he and a few others were forming, which would become Control Data Corporation, and asked Norris to be president of the new firm. They stated that they knew that Norris was not being treated fairly in Sperry Rand and that Rand was not going to succeed in the computer business because of poor management. Norris stated he could not discuss participation in a new company "until I had done everything reasonable to make the present situation work." After a meeting to occur two days later at Rand headquarters, he would be in a better position to know what to do.[151]

Norris must have been disappointed with the headquarters meeting with Rand and Kenneth Herman, president of the Remington Rand Division. Rand began the meeting by citing that things had not gone well in the UNIVAC Division. Moreover, there had been no spirit of cooperation between St. Paul and Philadelphia. The division had been under almost constant investigation. Hence, they decided to bring in a "national figure" on engineering and after some searching had decided on Thornton Fry. Engineering in the new organizational scheme was split between government and commercial. Eckert would be vice president and chief engineer of commercial and Norris vice president and chief engineer of government. Essentially, manufacturing was removed from St. Paul.[152]

The news of the latest reorganization traveled like lightning through the St. Paul facility. Even before the change, resignations began to occur, mostly the result of Anderson's actions. In the previous two weeks, six important people in manufacturing resigned: Haugseth (File Computer prototype construction), Rankin (mechanical engineer on the File project), Ripka (quality control on File), Al Slindee (purchasing), and several others. Outside manufacturing Howard Shekels was interviewing with NCR and had sold his house. Proops (ICBM program) and Wilson (production engineering) both left. The reaction in St. Paul was against Eckert, according to Norris. When he told all this to Fry, Fry asked him to "point out [to critics] the very important qualities of technical leadership that Pres has and try to get these people to understand that everything that is being done is being done with the object of pulling the technical activities closer together and improving the cooperation between this area and not in any way pulling St. Paul down."[153] Fry seemed to side with the New York and Philadelphia people, which implied that St. Paul and Norris were at fault. Ironic, inasmuch as Fry came to Sperry Rand through the good graces of Norris, who hired him as a consultant to the UNIVAC Division, only to be replaced by Fry.

On April 16, Norris met with Byron Smith and L. Stutzman. The three talked about the reorganization, following which Smith asked Norris if he was now ready to become an active participant in the organization of the new company. Norris responded that while he did not like the reorganization, he did not wish to discuss the new company. He said he would carry out the Sperry Rand reorganization according to the company's wishes, and only then would he decide if he would stay with Sperry.[154]

By this time, the St. Paul section of Remington Rand Division once under the control of Norris in the space of six months had been divided into eight and a half pieces, of which seven and a half reported to people in the East. The pieces were:

Maintenance

Training

Commercial engineering (50 percent in St. Paul)

Research, product planning, and information science

Commercial and military sales

Policies and procedures

Military products

Manufacturing ($\frac{1}{2}$ piece)

Norris felt little responsibility for any of it. Moreover, the people he had placed in charge of these areas now reported to others, so he felt no more responsibility to them.[155] He now began to contemplate finding a new position in the Twin Cities. In July, he notified Fry that he no longer wished to work for Sperry Rand, and officially resigned on July 26, 1957. Rand and Fry visited St. Paul and asked Mullaney to assume Norris's old position. But Mullaney had already decided to depart with Norris for CDC. His no was emphatic. At first, they tried to change his mind, but when they became convinced he meant no, they asked his advice for a suitable replacement for Norris. Mullaney recommended McDonald, who assumed some of Norris's old duties in Sperry Rand.[156] Fry was somewhat hostile because of the formation of the new company, but suggested that Norris work out his termination with Marcel Rand. Rand agreed that the company would pay Norris until September 1, 1957. He was to be on call to the firm until that time, although he would have only requested duties to perform.[157] Norris became president of Control Data Corporation (CDC) in August 1957. He was part of an exodus from Sperry Rand of experienced engineering personnel, who became the core of the new computer company.

What was the reaction of Sperry Rand's management to the formation of CDC? The firm reacted in two important ways. First, management people visited St. Paul to meet with the Sperry Rand personnel, telling them that Sperry Rand intended to continue to support the activities in St. Paul and there would be opportunities for those who remained with the company.[158] Second, as time passed, Sperry Rand, especially Thornton Fry, head of the UNIVAC Division, became concerned that the former Sperry Rand personnel now with CDC were using computer system designs developed while they were still employees of Sperry Rand. Sperry Rand brought suit against CDC for theft of trade secrets, a suit eventually settled out of court.

McDonald became head of defense activities, much of which was in St. Paul, reporting to Fry. McDonald was a 1940 graduate of the University of Minnesota with a double major in electrical engineering and business. He then studied for two master's degrees, one at Iowa State University in liberal arts and a second at the University of Chicago business school in industrial relations. He worked for a while with Commonwealth Edison in Chicago before joining the navy in 1943. McDonald spent time at Harvard and MIT in the radar program. After the war, he became part of the engineering department of Northwest Airlines, participating in evaluating new plane purchases, planes which had more electronics than previously and the company needed to be aware of what they were buying.[159] He joined Remington Rand in St. Paul in 1953, and succeeded Norris in 1957.

As the UNIVAC Division gained stability and more computer products reached the market at the end of the 1950s, things began to settle down and the division functioned adequately. This situation was also helped as more management personnel came to Sperry Rand from the outside, as people left or retired, and who had no vested interest in the earlier disagreements. Bibby succeeded Fry; Lou Rader succeeded Bibby; Jay Forster succeeded Rader in the early 1960s. McDonald, himself, eventually became head of the UNIVAC Division. By 1980, the division had gross revenues at almost $1.5 billion. From a slow, bumpy start, the division became one of Sperry's major sources of revenue and a real competitor to other companies, IBM among them.

At the end of 1957, Sperry Rand was on the cusp of success in the new computer industry. The firm had surmounted its earlier hesitancy to become an aggressive actor in the industry. Over the five years since 1952, a range of new Sperry Rand computer products came into existence, a sales force had been organized, and sufficient applications programs made the products salable. These computer products, brought to market mostly after 1957, provided the possibility for different companies to acquire Sperry Rand systems. The new UNIVAC Division addressed the commercial and military markets separately, with little overlap between them. Beginning in 1956, new Sperry Rand computer products appeared almost yearly, and by the end of the decade of the 1950s profitability was within Sperry Rand's grasp. While it never regained the commanding lead it had in 1952, when both EMCC and ERA became part of Remington Rand, Sperry Rand became one of the most important firms in the industry worldwide, and still markets systems as the Unisys Corporation.

Conclusion: A New View of EMCC and ERA and Their Contributions

Some Trends in the 1950s

In his farewell address on January 17, 1961, President Eisenhower in his famous remarks about changes in the conduct of university research noted, "For every old blackboard there are now hundreds of new electronic computers."[1] Largely exaggerated, the remark does illustrate the fact that the new computing systems had entered the consciousness of leaders of the nation. Sales certainly were on the rise. Montgomery Phister's exhaustive data lists the number of computer systems in use in 1961 as approaching 10,000, almost a doubling from the previous year's number.[2] Companies shipped around 2,000 systems in 1961, and the curve of deliveries against time would have a steep rise thereafter. Several new computer companies began in the late 1950s, and among them were pioneering software firms. The industry rapidly matured. New transistorized machines, such as the IBM 1620 and IBM 1401, could be found in many universities, where students and staff used them for research, teaching, and administration. Computer science programs emerged,[3] and within a few years a cadre of programmers and computer engineers constituted a major professional group. All of this was accomplished in only fifteen years. Fifteen years from the founding of ERA and EMCC, the turn to electronic computation by business machine firms such as IBM, Remington Rand, Burroughs, and National Cash Register, and a host of R&D projects at major research universities, computing systems were becoming necessary to the nation. In many ways, this activity emerged when it did through a sustained and sustaining interest of the federal government. This pattern was becoming evident in Europe and the Far East as well.[4]

But it also emerged through the interest of entrepreneurs and companies to develop and market digital electronic computers for business. In the United States, IBM is the preeminent example. But Remington Rand, Burroughs, NCR, CDC, DEC, and so forth, played significant roles as well. A number of engineering startups delivered their ideas into the mix also. These companies—EMCC, ERA, California Research Corporation, for example—became part of the larger firms, because financial difficulties prevented their remaining independent. As a result, these engineering firms are often categorized as failures. This hides their great successes and their contributions to the field.

Frequently in business history, companies that encounter difficulties either of a financial or design nature are labeled as failures. Better-known and larger firms purchase them to obtain their assets and market base or they go under. The talent is usually distributed around the acquiring firm, and often these people leave the new firm within a few months or years. A number of such mergers in the computer business are examples of this phenomenon. ERA and EMCC are both positive and negative examples of this phenomenon. Both were acquired when they faced a market whose requirements they could not meet. ERA needed funds to finance inventory to assemble 1101s for sale. Its leaders thought their new parent Remington Rand would provide these funds. EMCC faced much the same problem and harbored the same hopes. Remington Rand executives possessed different hopes, hopes nurtured by years of success acquiring companies and melding them into a successful firm. Unfortunately for them, the world of business was changing faster than they could adjust to the new world. The most successful company at adapting and then leading the new wave was IBM. Remington Rand did achieve a modicum of success in computing over the decades after 1960, and that success flowed from their two acquisitions.

R&D funds did flow into the two new Remington Rand subsidiaries; the subsidiaries also obtained the funds for inventories, and brought more machines to market. The sales department changed to embrace the new computer systems, though at a slower pace then needed in the new business world. Remington Rand's concerns for new products promoted development in the two subsidiaries, and the federal government's seemingly insatiable demand for computer systems helped balance the books of EMCC, ERA, and Remington Rand. Both EMCC and ERA developed path-breaking technology. They helped initiate an industry that later thrived. For these accomplishments, the two entrepreneurial startups can be classified as successes.

ERA

Examined from the perspective of staff, however, ERA/Remington Rand lost a number of talented professionals, both engineers and businesspeople, through mismanagement, misjudgment, and misapprehension. Some of these people began or joined new enterprises, which also had a successful spell. I refer specifically to William Norris, Frank Mullaney, Seymour Cray, James Thornton, Willis Drake, Erwin Tomash and others, who in 1956 and 1957 left Remington Rand/Sperry Rand. The first four men played substantial roles in the success of CDC (formed in 1957), Mullaney and Cray also in Cray Research (formed in 1972), Drake in Data Card (formed in 1973), and Tomash in Dataproducts (formed in 1962).

The success of ERA emerged from its careful attention to design detail to meet a customer's specific need. As time passed, the company was able to enlarge these designs, eventually designing full computer systems with market potential. They focused on magnetic components, as this represented the strengths of the engineering staff. The magnetic drum also superbly met the needs of their navy customers and of the National Security Agency after its organization in 1947. At first, ERA tried to jury-rig well known and accepted input–output schemes such as the Vannevar Bush photoelectric reader. But this proved too slow and unreliable as an input device. The conservative solution was the use of cards off line to magnetic drums, which greatly increased the speed of input and output, at least in and out of the CPU. The radical solution of magnetic tape by EMCC revolutionized the field. ERA adopted EMCC tape units for later models after the two firms became part of Remington Rand. EMCC seems not to have adopted anything in return. Norwalk turned into a service unit for other segments of the company, and had little impact on development.

The nature of the computer design assignments to ERA focused it on efficient, reliable, high-density storage, with a minimal amount of attention to auxiliary equipment. From one perspective, the ERA designs can be viewed as early scientific machines, because of their attempt to process large amounts of data internally with very little output. The only requirements for input were efficiency and speed. Furthermore, intelligence activities for which the machinery was destined involved significant comparison of elements rather than computation on the data, which consisted largely of alphabetic characters. This focus began to change only with the design of Atlas, which itself is a scientific device for use in logistics, intelligence, and engineering design. Auxiliary equipment, or as we now say peripherals, were secondary elements at best. Hence, ERA divided its activity into R&D and development.

Over time, though, ERA garnered two reputations, which seem at odds with this reality. Primarily, the company came to be seen as a project-oriented data processing firm. The various designs for the navy and the National Security Agency—Goldberg, Hecate, Bogart, and so forth—highlight the evidence for this view. However, examination of the design function in the firm and the operating function of these devices indicates that a great deal of R and R&D were needed before the D stage could be engaged in. New recording–reading heads, new magnetic substance for drums, better understanding of magnetic recording, all needed research before efficient, reliable, high-density storage devices could be delivered. Some people inside Remington Rand focused on this aspect of the company and concluded that ERA was primarily a research organization and this reputation spread. For example, General Leslie Groves, head of research for Remington Rand, after hearing a presentation of the activity of the newly acquired ERA Division, commented that they were a project organization not a research company, as he had been led to believe. The tenor of the comment showed his disappointment.[5] Based on their view, the purchase by Remington Rand can be seen as an attempt to add a strong research arm to the development arm of EMCC and the applications arm in the Norwalk Laboratory. Perhaps this is too rationalized a view of Remington Rand interests, but it does bear consideration.

EMCC

No one can gainsay the remarkable collection of computer design talent inside EMCC in 1950. Starting with Presper Eckert, the electronics marvel, whose strengths and weaknesses both were a focus on design improvement, and moving on to John Mauchly, Frasier Welsh, James Wiener, Bradford Sheppard, and Herman Lukoff, the team was one of the most outstanding in the world. Led by Eckert and Mauchly's vision of electronic computation as the next great wave of business development, the team sold the EMCC designs on the basis of applications. Starting with a set of specifications to accomplish tasks at cost savings to a firm, EMCC customarily set the objective for a design to achieve a higher level of performance for even greater savings. Often, according to Mauchly, the firm could have done just as well by even halving the original concept specifications, but Eckert refused to do so. Consequently, since applications to different businesses called for new input–output auxiliary equipment, and other related peripherals, a repeated technological push–pull situation occurred when it was time to attempt to integrate the components into a system. Many delays in development resulted from these attempts at integration. Thus, EMCC seemed always to be in difficulty, but faith by outsiders in the ultimate result remained strong, if reserved.

Since the focus in EMCC was on applications, the task to design and build computer systems required more development than research, since the basic materials for construction were known. EMCC entered a research phase only after the sale to Remington Rand. For example, searching for greater speed and memory, they initiated a research project on magnetic amplifiers, which they ultimately rejected in favor of transistors. Repeatedly, EMCC tinkered with their design objectives to meet customer demand, but only up to a point. Some potential contracts were dropped; occasionally suitors concluded EMCC would not go far enough in bending the objectives, so went elsewhere, usually to IBM.

Remington Rand made no attempt to achieve strong central control over their new facilities through which they hoped to gain a major position in the computer market. This abdication of effort occurred decidedly in the face of attempts, mostly successful, to achieve such control in other areas of the business office markets. Instead, management let the subsidiaries march to their own drummers, sometimes at cross purposes. Remington Rand took few steps to rationalize product development. The occasional associations with the Norwalk Advanced Laboratory simply made the laboratory a service group to EMCC and ERA. The attempt to rationalize sales was more for ease in accounting and office space utilization than to meld the two sales objectives of traditional office equipment with new computing systems.

Remington Rand

The computer market of the 1950s possessed little rationality, and this is reflected in the companies in that market. NCR hewed closely to their cash register history and produced systems primarily for this market. The same can be said for Burroughs and their dominance in the banking industry. IBM and EMCC resembled each other in the markets they sought, although IBM was a more rigidly run company and defined projects to satisfy their main customers. This is not to say they did not branch out. General Electric helped design and build the ERMA system for the

Bank of America, and then went on to design similar systems for related businesses such as airlines. In a sense, except for IBM, there were one-product companies in the computer area. EMCC and ERA unconsciously tried to be like IBM and serve many customers. Without the deep capabilities of IBM it took ten years to accomplish this after they became part of Remington Rand. The subsidiaries lacked discipline and the parent company, at first, neglected to instill it in them. Business personnel inside the subsidiaries lacked sufficient knowledge (perhaps because too little effort was devoted to the task of acquiring the knowledge) to price, schedule production, and sell the new systems. Once again Remington Rand did not have any familiarity with the computer business and could offer no guidance. It seems they did not even recognize the correct questions to ask, so even consultants offered them little guidance. Most needs they uncovered through their interchanges with customers using UNIVAC systems. Gradually, this experience led them to policies, procedures, pricing, and promotions that made the computer portion of the company profitable, but this was only after the merger with Sperry.

In the case of EMCC, management placed a seasoned executive with experience of running two different kinds of companies in the position of general manager of the subsidiary. Some members of the firm came to believe that Arthur Draper became the captive of Eckert and essentially represented Eckert's ideas to management rather than directing the subsidiary. The contrast between EMCC and ERA in this regard could not be different. In management meetings, Eckert did most of the talking for EMCC, while Norris delegated to others responsibility to speak for segments of the ERA subsidiary, primarily the general manager of ERA Robert McDonald. Eckert most often criticized programs of other groups, which did not endear him to other members of the firm. Norris and his ERA contingent tried to be supportive of all Remington Rand programs.

Once Sperry merged with Remington Rand, their management saw the wisdom of integration and ultimately achieved it, but with some resistance from the Remington Rand side of the house. Harry Vickers suggested Norris seek the advice of one of Sperry's strong executives, Charles Green, in setting up the computing section that shortly thereafter became the UNIVAC Division of Sperry Rand, which Norris did. Among Green's suggestions was the need to achieve better control over personnel through carefully developed and approved job descriptions, careful organization of the computing activities to maximize results by

EMCC, ERA, and Norwalk, assembling a strong management team, and obtaining the services of a consultant from a recognized business school with good experience. Norris acquired the services of two consultants. Thornton Fry, recently retired from Bell Laboratories, and Arnold Ryden, a graduate of Harvard Business School with much experience in the Twin Cities area. Both men evaluated the computing activities in Sperry Rand and provided advice for change, some of which Norris took under advisement. However, as shown at the end of chapter 5, Norris continuously had to look over his shoulder as people with other management responsibilities in Sperry Rand attempted to siphon away Norris's building empire. Individually the subsidiaries could not achieve sufficient strength either to arrive at their own accommodation or fend off the powerful sharks from other functional areas of Remington Rand like manufacturing. Although EMCC gave over much of its manufacturing without complaint, the EMCC and ERA people cooperated very little, making matters worse.

It took several years and the departure of a significant number of staff members to make circumstances conducive to meld the two subsidiaries into a single working unit. The price paid for the effectiveness of this new unit was the transfer of many of the functions of EMCC and ERA to other functional areas of the company, such as manufacturing and sales. Most of the authority for the new UNIVAC Division resided in the Philadelphia area, that is, in the EMCC vicinity, and was closer to management offices in New York City and Norwalk, Connecticut. Thornton Frye headed the new UNIVAC Division in 1957, and as an outsider from a well-respected company involved with path-breaking R&D programs, he could evaluate the technical areas of the division and not be overwhelmed by Eckert as Draper had been. By this time, Norris was gone from Sperry Rand.

Remington Rand and Sperry Rand paid a high price for this delay. The emerging computer industry was not like earlier high-tech industries. Technology moved ahead faster in this new industry. IBM's increasing focus on technology and its determination to develop a competent sales and service staff for the new computer systems after 1946 meant they could leap ahead of any firm lagging in the competition. In the1950s, almost the entire future of the computer became established.

In their attempts to penetrate the market, Remington Rand established two computer service centers in 1952–53, one in New York City with a UNIVAC system in aid of the sales department under Parker, and one in Washington, D.C., with an 1101 soon replaced by a more powerful and versatile 1103. EMCC had already fortified the UNIVAC system with an array of programs and routines; the 1101 system was not similarly able, and the Washington office expended much effort in programming in order to solve the problems brought to them by an array of companies. But the D.C. office faced a hampering dilemma: to program effectively to address expected business it needed more staff, but management wanted to see a backlog of business before adding such staff making it difficult to meet customers' needs, which firms tended to want solutions more quickly than the small staff could deliver them. Management did not want to view these endeavors as loss leaders that eventually would stimulate sales and rental of systems to their customers, although they said this was their objective and provided courses to the company personnel of other firms. Impatience with losses led management to disband these offices before they could demonstrate their worth in sales and service.

We are dealing here with a uniquely creative group of people in these two firms. The concentration on research in magnetics, development of logical circuitry following the leads of von Neumann and his colleagues adumbrated in the famous papers of the period 1945 to 1947, and investigations into coding techniques and representative problems, and then sharing all this with the community helped every group to move ahead. To be sure, they borrowed from the other important groups in the field, especially MIT and IBM. Indeed, each group sometimes measured one or more of its designs against similar efforts in one of the other firms or university projects. IBM evaluated their magnetic drum design against that of ERA. As part of this effort done under contract, IBM acquired rights under ERA (later Remington Rand) patents filed on techniques of making drums and on read–write magnetic heads for use in storage systems. The groups frequently met at conferences called for the purpose of sharing information on computer system design and functioning. Computer designers acknowledged the ingeniousness of the EMCC magnetic tape memory system, and saw it as superior to the wire recording, paper tape, and punched card input–output systems.

ERA took a more conservative approach with work on drums. The construction, mechanical action, and read and write mechanisms of the drum were easier to integrate than the component parts of the tape systems, but ran at faster rates than drums. Both ERA and EMCC made contributions to the literature in aid of the field. Eckert, for example, published (1953) a survey paper on the different types and strengths and weaknesses of storage systems. ERA prepared (1950) the exhaustive handbook of techniques for use in design of high-speed computing devices, including reviews of some of the major systems available at the time of publication. While ERA and IBM moved by steps into designing and building digital electronic computers, EMCC raced headlong into the field from the start in a manner similar to the university projects. Government computer projects, particularly those organized by NBS, benefited greatly from the contributions of ERA, EMCC, MIT, IAS, and the University of Pennsylvania's Moore School.

Once Norris left Sperry Rand, there was little agitation by ERA for change and resources. This section of the division had been relegated to the military market. Not long after Norris's departure, many other people left Sperry Rand to join the new Control Data Corporation, including the foremost designers in the ERA bullpen, leaving Eckert as the company's most talented designer. But the market moved faster than Eckert, and much of the controversy between sections of the division evaporated as they cooperated more and more on a unified line of products (the 11xx series of systems). Moreover, Sperry Rand policies demanded frozen designs that could be manufactured in time to garner a place in the market against IBM and the several other companies that competed in computer sales. Even in the beginning of CDC, there was little competition between them and UNIVAC, except in the military area, which turned out to be large enough for both firms and for IBM.

A Final Summing Up

While the focus of this study has been the selected people and firms at the start of the so-called computer revolution, it is not difficult to imagine that people like Eckert, Mauchly, Lukoff, Mullaney, Cohen, Coombs, and others would find the present world of computing and communications compatible, if not identical, to the dreams they dwelled on in the 1940s and 1950s for use of the computer. As we examined the role of these visionaries, we paid attention to the demands of the users, demands for equipment and for applications, even in some cases, the users active role in developing specifications to be met (CSAW, the Prudential). The companies could not have achieved what they did without the eager participation and significant contributions of the new users of the computer systems. The visionaries of the National Security Agency, Prudential Insurance Company, air force strategic programs, and at least a dozen others, not to mention the university-based designers and users, participated in the determination of specifications, demanded compatibility with earlier computation systems to preserve historical data, and reorganized their pattern of activity to make more effective use of the new systems. This involvement led to more rapid integration of computer systems into business, organization, and government settings. Each new computing development seemed to point the way to more possibilities, which led to rapid growth of the industry and the spread of computers into everyday life. When the computer converged and combined with communications systems, the new world envisioned by some in the 1950s became a reality, and that reality continues to evolve today.[6] Many of the people in ERA and EMCC had glimmerings of this new world as they struggled to bring new computer systems to market. It was often a struggle to convince people mired in older technologies and techniques to enter the new world. This was certainly the case with the sales force of Remington Rand, who were wedded to the tabulator and the commissions they earned upon sale or rental. A computer system sales technique had to evolve before they saw any benefit to them. The sale of use time on computers did as much for defining commissions as discussions about selling computer systems directly.

IBM seemed to have a much better grasp of problems like this and developed more new products to handle the problems than any of the new firms entering the market. The principal difference here was that the highest level of management in IBM set the policies for a gradual shift from one technology to another, and from an early stage asked the field engineering and sales force to participate in bringing a new computer system to market.[7] Tabulators and other business machines were only part of the Remington Rand world, and a small part at that, so computer systems rarely received the attention needed to build a market. Management was too much concerned with R&D and production costs and too little concerned with convincing potential buyers of the value in such systems. The subsidiaries ERA and EMCC and the New York computer sales office under Parker had to carry this burden on their own. These departments tried similar programs to those of IBM—classes for salespeople, courses for customers, advertising, training of field engineers, and the like. But each division conducted its own version of each of these programs. Most of the time one division did not know what the other divisions were doing. Hence, they competed with each other, rather than present a common face to the market, although in fairness it should be noted that Parker tried to coordinate all the group's actions in the period 1952 to 1956. It took the merger with Sperry, the organization of a single division—the UNIVAC Division—and the exit of a number of employees in St. Paul to help Sperry Rand mold a successful division.

What made it even more difficult for Remington Rand (later Sperry Rand) was the typical IBM assault on technological development and the production of new systems rapidly brought to market. In some respects, these new systems—for example, the IBM 305 RAMAC (1956), which was a newly designed magnetic disk system, and the IBM 650—were only marginally better than Sperry Rand's answer to them—the File Computers, UNIVAC II, ERA1105. But the Sperry Rand systems reached the market too late to compete or were not cost effective.[8]

It is tempting to compare this situation in Philadelphia and St. Paul with British Tabulating Machine Company (BTM) in England. In BTM's case, a divisional structure did not exist either, but a similar competitive market—BTM vs. IBM—hampered the activities of BTM. Unlike Sperry Rand, BTM had little military business to provide some R&D funds and few sales to large government enterprises. BTM depended on the indigenous commercial market and exports to the European continent. Like ERA and EMCC they fumbled with new products to try to stay ahead of their competitors, without much success. Sperry Rand managed to stay close enough to the frontier to compete regularly with new advanced products, but slipped with every downturn in the market. The 1986 merger of Sperry Rand with Burroughs to create Unisys resembled the various mergers in England to try to make BTM (now ICL) more competitive.[9] Both companies—Unisys and ICL—still have solid positions in the market, but not without repeated trials.

Those who left the ERA Division founded a succession of companies around the country and as a result continue to participate in the definition of computing and the computer market. Norris, Mullaney, Ryden, Keye, Drake, Cray, and many others left Sperry Rand in the late 1950s to found Control Data Corporation, which began by marketing computer systems similar to those of Sperry Rand and to some of the same customers, beginning with the U.S. Navy. CDC followed a strategy similar to Sperry Rand by designing small and large machines to cover the market, eventually rising to the presentation of very large systems—supercomputers—as a type of follow-on to the LARC. CDC, too, found this strategy to be short-lived, and began to change their mode of business, especially after unbundling when they began to sell large numbers of peripherals for IBM systems. When the atmosphere that had driven these people out of Sperry Rand began to descend on CDC, a new exodus began.[10] For example, Cray, Mullaney, and others left in 1972 to found Cray Research, but this time with the blessing and some start-up funds of the parent firm—an excellent investment by CDC. Both companies eventually foundered on changing computer system designs, changing consumer expectations, and changing market strategies.[11] A similar story can be told for the software companies established in Minnesota, at least, by former employees of Sperry Rand and its spinoffs.

One peculiar problem remains: the influence of the von Neumann, Goldstein, Burks papers of 1946 and 1947, especially the essay on coding. I found little evidence that these works significantly influenced people in ERA and EMCC. I found nothing other than hearsay evidence that the 1947 paper on logical design influenced ERA designers. I did learn that the paper arrived at ERA too late to be influential in the design of Atlas.[12] The specifications developed by CSAW and ERA for Atlas did not reflect the von Neumann style of coding. Yet, several interviewees assert that these papers influenced them. Unless this influence came through MIT on circuits, a route I doubt, I cannot understand how the influence occurred on logical design. This came by and large from the Draft Report of 1945.

In coding, Mauchly and his group went their own way, closely following the hardware design concepts developed at EMCC. Without some more concrete evidence of the use, either for development or to react against, of the IAS series of papers, I must conclude the influence claimed is incorrect. This reinforces the theme in this book of the creativity of these organizations. Even though boundaries are permeable, any influence on EMCC was indirect at best. Eckert kept the team focused on the problems in front of them, not on seeking answers elsewhere. ERA did seek answers elsewhere, partly pushed by naval contracts, and partly due to the desire of some staff members to break out of the navy straightjacket they found themselves in at the beginning. It was only in their Remington Rand days that ERA successfully broke away from the navy.

Far more important is to situate EMCC and ERA, along with their latter-day parent Remington Rand, as prime movers in the design and development of computer systems, particularly EMCC. Both firms needed the discipline of a large organization to meet timely goals. Remington Rand was good at this for its product line, but did not seem to be able to make it work in EMCC. Norris, as a vice president in Remington Rand, certainly had ERA performing well, and was undeserving of the criticism of Eckert and others from Philadelphia. Sperry, with its larger knowledge of defense and government projects, brought the needed discipline to the computing activity of Remington Rand. But both Remington Rand and Sperry Rand lacked knowledge of pricing and financing for products to users other than the government and this showed in their attempts to market computer systems.[13] With experience, they learned. Within a few years, the new UNIVAC division produced a number of successful market systems, and went on to successful competition in the industry. Of course, it did not become equal to IBM, but then, no other company did either. At IBM, discipline worked exceptionally well to the advantage of the firm. But to compare Remington Rand to IBM will always redound to the disadvantage of Remington.

If anything, this book is designed to show that Remington Rand and its two subsidiaries grew up in the computer business together. Along the way, their efforts influenced other firms, including IBM, both by their successes in design and their shortcomings in marketing. EMCC also influenced Remington Rand management, much more so than ERA. According to the recollections of Robert McDonald, Remington Rand management wanted to participate in decisions of the subsidiaries. In the case of EMCC, this was possible through Draper and the proximity of EMCC to corporate headquarters. ERA, besides being in the middle of the country at a time when flying was just emerging as a travel strategy for companies, wanted autonomy for the computing activities and set up barriers for communication, especially with the military aspects of the ERA work. "ERA was very heavily into scientific computation and Remington Rand had virtually no experience in marketing to this community."[14] Remington Rand management made very little attempt, if any, to understand this subsidiary in order to communicate better with them, and so disagreements proliferated. The fact that few management people came west to St. Paul did not help this situation. In the end, because of the proximity of the Philadelphia operations to New York, Eckert, in his idiosyncratic way and without conscious intent, did more to help Remington Rand management to understand the computer business than Norris.

It was necessary for Sperry Rand to separate the two halves of the computing enterprise into commercial and military to depress or eliminate the animosity of the two facilities—St. Paul and Philadelphia—that made up the UNIVAC division. In a metaphorical sense, we might see the tug-of-war between Norris and Eckert as a struggle for the heart of the division. Both men, and their respective followers, wanted to emphasize something different. What the division needed was both emphases. Eckert wanted supremacy of his designs. Norris wanted a range of products developed by both groups and autonomy for the division. But even Norris allowed the separation between military, as in St. Paul, and commercial, the reality of Philadelphia and the hope of St. Paul, to develop in the 1950s by keeping all the classified work in St. Paul. So it should have come as no surprise to him when the company made the separation effective. The difficult part for Norris was his demotion in the process of creating the separate programs within the division.

Eckert, however, had reached the top of his game. Design teams increased in size, consequently Eckert's role decreased. He continued to be an important member of the company for another two decades. Norris exhibited his great strength, management, through leading CDC to early success with the help of some truly exceptional engineers and salespeople. During that same two decades after 1957, CDC rose to high status as a mainframe computer design company and a successful volume seller of peripherals. By the late 1970s, the markets had changed and both CDC and Sperry Rand found competing more difficult. These two men and their associates, though, had laid the basis for the business of these two companies. The origin of this basis was in EMCC and ERA, two important early firms in the computer industry.

Notes

Introduction

1. I. Bernard Cohen, *Howard Aiken: Portrait of a Computer Pioneer* (Cambridge, Mass.: MIT Press, 1999).

2. Kent C. Redmond and Thomas M. Smith, *Project Whirlwind: The History of a Pioneer Computer* (Bedford, Mass.: Digital Press, 1980).

3. Nancy Stern, *From ENIAC to UNIVAC: An Appraisal of the Eckert-Mauchly Computers* (Bedford, Mass.: Digital Press, 1981).

4. Colin Burke, *Information and Secrecy: Vannevar Bush and Memex* (Metuchen, N.J.: Scarecrow Press, 1994).

5. Emerson W. Pugh, *Memories That Shaped an Industry: Decisions Leading to IBM System/*360 (Cambridge, Mass.: MIT Press, 1984). Redmond and Smith, *Project Whirlwind.*

6. Contrast the study of this interaction by Kenneth Flamm, *Creating the Computer: Government, Industry, and High Technology* (Washington, D.C.: Brookings Institution, 1988), with that of the 1960s and 1970s portrayed in Arthur L. Norberg and Judy E. O'Neill, *Transforming Computer Technology: Information Processing for the Pentagon, 1962–1986* (Baltimore: Johns Hopkins University Press, 1996).

7. An increasing number of works on earlier technologies present histories of very dynamic and often fast-paced developments. Among the most revealing are electric system development by Thomas Parke Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore: Johns Hopkins University Press, 1983); radio by Hugh G. J. Aitken, *The Continuous Wave: Technology and American Radio, 1900–1932* (Princeton: Princeton University Press, 1985); and photography by Reese V. Jenkins, *Images & Enterprise: Technology and the American Photographic Industry 1839 to 1925* (Baltimore: Johns Hopkins University Press, 1975).

8. See, for example, Michael R. Williams, *A History of Computer Technology* (Englewood Cliffs, N.J.: Prentice-Hall, 1985); Martin Campbell-Kelly and

William Aspray, *Computer: A History of the Information Machine* (New York: Basic Books, 1996); and Mark Poster, *The Mode of Information: Poststructuralism and Social Context* (Chicago: University of Chicago Press, 1990).

9. Flamm has provided the best history of this interaction in *Creating the Computer.* Robert W. Seidel has studied the activities of Los Alamos in computer development, especially their intense interaction with IBM. See Robert W. Seidel, "'Crunching Numbers' Computers and Physical Research in the AEC Laboratories," *History and Technology 15* (1998): 31–68.

10. A view of early computing in the Los Angeles area can be found in Richard E. Sprague, "A Western View of Computer History, *Communications of the ACM 15* (no. 7, 1972): 686–692.

11. Coverage of these historical activities is spotty at best. On General Electric see, Homer R. Oldfield, *King of the Seven Dwarfs: General Electric's Ambiguous Challenge to the Computer Industry* (Los Alamitos, Calif.: IEEE Computer Society Press, 1996); George Snively, "General Electric Enters the Computer Business," *IEEE Annals of the History of Computing* 10, no. 1 (1988): 72–78.

12. Charles J. Bashe, Lyle R. Johnson, John H. Palmer, and Emerson W. Pugh, *IBM's Early Computers* (Cambridge, Mass.: MIT Press, 1986).

13. Maurice Wilkes, *Memoirs of a Computer Pioneer* (Cambridge, Mass.: MIT Press, 1985), p. 123.

14. Stern, *From ENIAC to UNIVAC.*

15. Redmond and Smith, *Project Whirlwind.*

16. "Special Issue on SAGE," *Annals of the History of Computing* 5 (October 1983). For an insightful analysis of the political and social context surrounding SAGE, see Paul N. Edwards, *The Closed World:Computers and the Politics of Discourse in Cold War America* (Cambridge, Mass.: MIT Press, 1996).

17. Redmond and Smith, *Project Whirlwind.* Also see their second volume, *From Whirlwind to MITRE: The R&D Story of the SAGE Air Defense Computer* (Cambridge, Mass.: MIT Press, 2000).

18. Pugh, *Memories That Shaped an Industry.*

19. Emerson W. Pugh, *Building IBM: Shaping an Industry and Its Technology* (Cambridge, Mass.: MIT Press, 1995).

20. David F. Noble, *Forces of Production: A Social History of Industrial Automation* (Oxford: Oxford University Press, 1984); Norberg and O'Neill, *Transforming Computer Technology;* and Douglas Ross, "APT Session," in Richard L. Wexelblat, *History of Programming Languages* (New York: Academic Press, 1981), pp. 279–368.

21. Samuel S. Snyder, "Computer Advances Pioneered by Cryptologic Organizations," *Annals of the History of Computing* 2 (January 1980): 60–70; Burke, *Information and Secrecy.*

22. Erwin Tomash and Arnold A. Cohen, "The Birth of an ERA: Engineering Research Associates, Inc. 1946–1955," *Annals of the History of Computing* 1 (October 1979): 83–97. See also Burke, *Information and Secrecy,* and Arthur L. Norberg, "New Engineering Companies and the Evolution of the United States Computer Industry," *Business and Economic History* 22 (fall 1993): 181–193.

23. Redmond and Smith, *Project Whirlwind.* William Aspray, *John von Neumann and the Origins of Modern Computing* (Cambridge, Mass.: MIT Press, 1990).

24. Nancy Stern, *From ENIAC to UNIVAC;* Tomash and Cohen, "The Birth of an ERA"; Colin Burke, *Information and Secrecy;* and Norberg, "New Engineering Companies."

25. Pugh, *Memories That Shaped an Industry;* Charles J. Bashe, Lyle R. Johnson, John H. Palmer, and Emerson W. Pugh, *IBM's Early Computers* (Cambridge, Mass.: MIT Press, 1986); Emerson W. Pugh, Lyle R. Johnson, and John H. Palmer, *IBM's 360 and Early 370 Systems* (Cambridge, Mass.: MIT Press, 1991); and Pugh, *Building IBM.*

26. See the forthcoming book by JoAnne Yates, *Structuring the Information Age: Life Insurance and Information Technology in the 20th Century* (Baltimore: Johns Hopkins University Press, 2005).

27. On NCR, see the excellent article by Richard S. Rosenbloom, "Leadership, Capabilities, and Technological Change: The Transformation of NCR in the Electronic Era," *Strategic Management Journal* 21 (2000): 1083–1103.

28. An exception to this statement is the recent history of semiconductor development, especially by Intel, by Ross Bassett, *To the Digital Age: Research Labs, Start-up Companies, and the Rise of MOS* (Baltimore: Johns Hopkins University Press, 2002).

29. Pugh, Johnson, and Palmer, *IBM's 360 and Early 370 System.*

30. For example, some history about ERA is embedded in Burke's *Information and Secrecy*—a study of navy intelligence activity from 1930 to 1960; in James Worthy's *William C. Norris: Portrait of a Maverick* (Cambridge, Mass.: Ballinger, 1987)—a discussion of the commercial background of Control Data; Tomash and Cohen's brief review of ERA history cited above ("Birth of an ERA"); and Norberg's contrast of ERA, IBM, and Eckert-Mauchly ("New Engineering Companies").

31. Flamm, *Creating the Computer;* Norberg and O'Neill, *Transforming Computer Technology;* Janet Abbate, *Inventing the Internet* (Cambridge, Mass.: MIT Press, 1999).

32. See as examples Alfred D. Chandler, Jr., "The Computer Industry: The First Half Century," in *Competing in the Age of Digital Convergence,* ed. David B. Yoffie (Boston: Harvard Business School Press, 1997), pp. 37–122; and F. M. Fisher, J. W. McKie, and R. B. Mancke, *IBM and the U.S. Data Processing Industry: An Economic History* (New York: Praeger, 1983).

33. Pugh in *Building IBM* states that EMCC provided very little software to customers, unlike IBM (p. 190). Campbell-Kelly in his new study of the U.S. software

industry accepts this assessment and discusses only IBM and not other groups. Yet EMCC organized a substantial applications program beginning in 1947 that developed many software programs for the BINAC and UNIVAC. Basing their evaluation of EMCC software on the one example of General Electric and UNIVAC is misleading.

34. Paul E. Ceruzzi, *Reckoners: The Prehistory of the Digital Computer, from Relays to the Stored Program Concept,* 1935–1945 (Westport, Conn.: Greenwood Press, 1983). Ceruzzi examines four projects, three of which originated in the 1930s: Konrad Zuse's work in Germany, the combined effort of Howard Aiken at Harvard and IBM, and George Stibitz's work at Bell Telephone Laboratories. The fourth project is ENIAC. William Aspray, ed., *Computing Before Computers* (Ames, Iowa: Iowa State University Press, 1990). Colin Burke, *Information and Secrecy.*

35. Flamm, *Creating the Computer.*

36. The contrasting IBM story is well told in Bashe, et al., *IBM's Early Computers;* and Pugh, *Building IBM.*

37. Norberg, "New Engineering Companies."

Chapter 1

1. Julius A. Furer, *Administration of the Navy Department in World War II* (Washington, D.C.: U.S. Government Printing Office, 1959), pp. 118–119. Colin Burke, *Information and Secrecy: Vannevar Bush, Ultra, and the Other Memex* (Metuchen, N.J.: Scarecrow Press, 1994), p. 54.

2. Edward Van der Rhoer, *Deadly Magic: A Personal Account of Communications in World War II in the Pacific* (New York: Scribner's, 1978), p. 49.

3. The description that follows on the differences between codes and ciphers is taken from David Kahn, *The Codebreakers: The Story of Secret Writing* (London: Weidenfeld and Nicolson, 1966), pp. xiii–xvi.

4. Burke, *Information and Secrecy,* pp. 57–71, passim.

5. Ibid.

6. Kahn, *Codebreakers,* p. 371; Burke, *Information and Secrecy,* p. 139.

7. Kahn, *Codebreakers,* p. 378.

8. For a full explanation of the Index technique, see Kahn, *Codebreakers,* pp. 377–384. For the navy's adoption of the technique, see Burke, *Information and Secrecy,* pp. 140–141.

9. Burke, *Information and Secrecy,* p. 153.

10. Details of designs and purposes for the Rapid Selector can be found in Burke, *Information and Secrecy,* chapter 8.

11. Brian Randell, "The COLOSSUS," in *A History of Computing in the Twentieth Century: A Collection of Essays,* ed. N. Metropolis, J. Howlett, and Gian-Carlo Rota (New York: Academic Press, 1980). Sponsorship and dates of this project appear to be taken from MIT project reports.

12. This review is based on the description provided in Vannevar Bush, *Pieces of the Action* (New York: Morrow, 1970), pp. 187–190.

13. David L. Boslaugh, *When Computers Went to Sea: The Digitization of the United States Navy* (Los Alamitos, Calif.: IEEE Computer Society Press, 1999), pp. 76–77. Burke, *Secrecy and Information,* relates some of the day-to-day concerns at NCML early in the war, pp. 292–297. See also J. A. N. Lee, Colin Burke, and Deborah Anderson, "The US Bombes, NCR, Joseph Desch, and 600 WAVES: The First Reunion of the US Naval Computing Machine Laboratory," *Annals of the History of Computing* 22, no. 3 (July–September 2000): 27–41.

14. William C. Norris interview conducted by Arthur L. Norberg for the Charles Babbage Institute, July 28, 1986, OH 118, p. 7.

15. Memorandum to the Files by Section 945, U.S. Navy, "History of Engineering Research Associates," August 16, 1946, SRH-267. The subject of this document is NObs-28476—"development contract with Northwestern Aeronautical Corporation, St. Paul, Minnesota"—"Summary of Background Information," National Security Agency Document in Record Group 457, National Archives and Records Agency.

16. Burke, *Information and Secrecy,* p. 224.

17. Engstrom's Ph.D. dissertation was entitled "On the Common Index Divisors of an Algebraic Field," Yale University, 1929. One of his important papers in the field of interest in cryptology was "Polynomial Substitutions," *American Journal of Mathematics,* 63 (1941): 249–255.

18. William C. Norris, "World War II Experiences," unpublished manuscript, n.d., CBI Biography File on W. C. Norris.

19. David Kahn, *Seizing the Enigma: The Race to Break the German U-Boat Codes, 1939–1943* (Boston: Houghton Mifflin Company, 1991), p. 239.

20. "History of Engineering Research Associates," SRH-267, note 15.

21. Burke, *Information and Secrecy,* p. 311.

22. Ibid.

23. Memorandum "Research and Development Plan," February 22, 1945, John E. Parker personal files (given to the author by Mr. Parker). The enclosure "National Electronic Laboratories, 12 February 1945" was not attached to Mr. Parker's copy of the memorandum. However, it is available in the Sperry Corporation Records, Acquisition 1825, Box 323, Folder "ERA Orrganization (1946–1948)," Hagley Museum and Library.

24. Norris interview, p. 10.

25. The list included: Ray Voyes, Western Union, Standard Oil Company of New York, Fairchild Instrument and Camera, Aeronautical Radio, Association of American Railroads, Hazeltine Corporation, Harold Vanderbilt, and P. R. Mallory & Company.

26. "History of Engineering Research Associates," SRH-267, note 5.

27. Ibid.

28. James H. Wakelin interview conducted by Arthur L. Norberg for the Charles Babbage Institute, February 27, 1986, p. 22.

29. We can infer who some of the other people were from a November 24, 1945, memorandum prepared on this subject for a special projects division of ERA. Besides Wakelin, a physicist, there were Samuel D. Cornell, physicist; John T. Burwell, Jr., physicist in MIT's mechanical engineering department; Ralph A. Krause, electronics engineer; John L. Magee, physical chemist; Bruce S. Old, chemical engineer; and Thomas C. Wilson, physical metallurgist.

30. "Potential Products and Services," n.d. "Prospectus for the Special Projects Division Engineering Research Associates," November 24, 1945, carries the letters for the names of James H. Wakelin, Bruce S. Olds, and John T. Burwell (all members of the staff of the coordinator of research and development in the Office of the Secretary of the Navy). Both documents are in the Sperry Corporation Records, Acquisition 1825, Box 323, Folder "ERA Organization (1946–1948)," Hagley Museum and Library.

31. "Articles of Incorporation," December 27, 1945, and amended articles January 8, 1946. Sperry Corporation Files, Defense Products Group (St. Paul, Minnesota), Box 5366, now at Hagley.

32. "Report of Meetings held on Wednesday, June 13th, and Thursday, June 14th, 1945, with a Group of Naval Personnel," June 19, 1945, IBM Archives. This document was generously brought to my attention by Mr. John H. Palmer of IBM.

33. "Memorandum for the File: Conference with Mr. Ralph Damon, President of American Airlines, 21 June 1945," June 22, 1945; apparently written by Engstrom. A paranthetical statement was added to the line about ticket and reservation sales with automatic registers: "the very thing we have talked about in connection with pullman [sic] ticket sales." Sperry Corporation Files, Acquisition 1825, Hagley Museum and Library.

34. "Potential Products and Services," note 16.

35. Norris interview, p. 19.

36. "History of Engineering Research Associates," SRH-267, note 15.

37. Ibid.; and Norris interview.

38. C. Russell MacGregor to Ralph Thompson, November 15, 1945. Sperry Corporation Records, Acquisition 1825, Box 323, Folder "ERA Organization (1946–1948)," Hagley Museum and Library. MacGregor had also been an officer at CSAW.

39. Norris, in his interview, commented that at the time they were trying to decide what to do he and Engstrom met with J. Presper Eckert to describe what the ERA group had in mind and suggested that the two groups pool their resources. Norris reported in the interview that Eckert preferred to go his own way and not join with ERA. Norris interview, p. 18. If this meeting took place, I believe it had to be later than this. Eckert was still hard at work on EDVAC in late 1945, and, although he might have been considering a company of his own, the ideas had not gelled yet.

40. "History of Engineering Research Associates," SRH-267, note 15.

41. For a discussion of Northwestern Aeronautical Corporation see William H. Nicholas, "Gliders—Silent Weapons of the Sky," *National Geographic Magazine* 86 (August 1944): 149–60; and Mary C. Barnes, "The History of the Glider Program at Northwestern Aeronautical Corporation," Army Air Force, Air Technical Service Command, Central District, September 1945, copy in CBI 27, Charles Babbage Institute. For a description of the founding of NAC see John E. Parker interview conducted by Arthur L. Norberg for the Charles Babbage Institute, December 13, 1985; and Erwin Tomash and Arnold A. Cohen, "The Birth of an ERA: Engineering Research Associates, Inc., 1946–1955," *Annals of the History of Computing* 1 (October 1979): 83–97.

42. Parker interview.

43. Ibid., p. 17.

44. Ibid., p. 18.

45. "Amended Articles of Incorporation" filed January 8, 1946, note 17.

46. Parker interview.

47. "History of Engineering Research Associates," SRH-267, note 15.

48. Ibid.

49. Parker interview.

50. We are fortunate to have a good amount of biographical material on Norris. See, for example, James C. Worthy, *William C. Norris: Portrait of a Maverick* (Cambridge, Mass.: Ballinger, 1987), and the Norris interview with A. L. Norberg, CBI.

51. Norris interview.

52. Worthy, *William C. Norris,* pp. 24–25.

53. Arnold A. Cohen, "Introduction" to the 1983 reprinted edition of *High-Speed Computing Devices,* Engineering Research Associates, Inc. (New York: McGraw-Hill, 1950); Charles Babbage Institute Reprint Series (Los Angeles: Tomash Publishers, 1983).

54. Indeed, Frank Mullaney excelled in his ability to design computer systems and to lead engineering and management groups. A graduate of the University of Minnesota, he received a bachelor of science in electrical engineering degree in 1943, and joined ERA in 1946 after two years of service in the navy.

55. Seymour Cray, James Thornton, and Erwin Tomash all received bachelor of science in electrical engineering degrees from the University of Minnesota in 1949, 1950, and 1943, respectively. Cray and Tomash were awarded master's degrees also in 1951 and 1950 respectively. Willis Drake graduated from Purdue University in 1947 with a bachelor's degree in aeronautical engineering.

56. Joseph M. Walsh interview conducted by Arthur L. Norberg for the Charles Babbage Institute, August 13, 1986, OH 117.

57. Sidney M. Rubens interview conducted by Arthur L. Norberg for the Charles Babbage Institute, January 6, 1986, OH 102, p. 47.

58. Ibid., pp. 51–52.

59. J. E. Parker to the secretary of the navy, February 26, 1946, draft (sent in slightly modified form on February 27). Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

60. "History of Engineering Research Associates," SRH-267, note 15.

61. "Research and Development Task Order Contract, ONR N6onr-240," September 1, 1946." Yutter Collection, Acquisition 1904, Hagley Museum and Library.

62. "Navy Department: Office of Naval Research. Task Order 1—Constituting a Part of Contract N6onr-240 with Engineering Research Associates, Inc.," September 1, 1946. Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

63. Mina Rees, "The Computing Program of the Office of Naval Research, 1946–1953," *Annals of the History of Computing* 4 (April 1982): 102–120.

64. Hakala Associates, ERA History (St. Paul: Sperry Corporation, 1986).

65. Arthur L. Norberg, "New Engineering Companies and the Evolution of the United States Computer Industry," *Business and Economic History* 22 (1993): 181–193.

66. "Proposal for a Computing Machine Investigation," n.d., Technitrol Suit Files, Acquisition 1901, Hagley Museum and Library. I have seen several copies of this document. A later letter from James S. Clifford, Jr., assistant secretary of ERA, to the chief of the Office of Research and Inventions (ORI) states that the

proposal was submitted on March 26, 1946 (June 19, 1946, Acquisition 1901, Box 7, Hagley). A chronology of interactions with ORI about this proposal developed by Clifford and dated July 19, 1946, confirms this date (Acquisition 1901, Box 7, Hagley). Although ERA formally withdrew the proposal after several consultations with ORI personnel, it contains many of the elements of the later ONR contract for computing work that ERA received.

67. Ibid., pp. 1–2.

68. Ibid.

69. Ibid., p. 3.

70. Ibid., p. 5.

71. Ibid., p. 6.

72. Ibid., pp. 6–7.

73. Congress created the Office of Naval Research (ONR) in 1946 and the new agency absorbed the earlier naval Office of Research and Invention (ORI).

74. "Computing Machine Investigation: Supplement to the Proposal Submitted by Engineering Research Associates." N.d. Technitrol Suit Files, Acquisition 1901, Box 7, Hagley Museum and Library. Noted in the Clifford chronology as discussed at a meeting of April 10, 1946, with representatives of ORI (see note 66).

75. "General Specifications for Breadboard Models of a Computer," August 31, 1947, Appendix II of "Progress Report No. 6, Contract N6onr-240 Task Order I, 1 July 1947–31 August 1947." Arnold A. Cohen Papers, Charles Babbage Institute.

76. Clifford to Parker, June 6, 1946, Technitrol Suit Files, Acquisition 1901, Box 7, Hagley Museum and Library.

77. Clifford to Parker, July 15, 1946.

78. Clifford to the files, August 15, 1946.

79. Robert Weller, "Review of the Naval Cryptologic Museum," *Cryptologia* 8 (July 1984): 228.

80. J. M. Walsh to ERA/NAC personnel, September 17, 1946, "Corrected list of project numbers, titles, engineers and supervisors," Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

81. Brian Randell, "The COLOSSUS," in *A History of Computing In the Twentieth Century: A Collection of Essays,* ed. N. Metropolis, J. Howlett, and Gian-Carlo Rota (New York: Academic Press, 1980), 47–92, see pp. 80–81. Bush, *Pieces of the Action* (New York: William Morrow, 1970), p. 188.

82. "Project No. 1011," June 6, 1946, Yutter Collection, Acquisition 1901, Hagley Museum and Library. This is the date on which the project was authorized.

83. Ensign M. B. Klein to NCML Dayton, June 27, 1946, requesting that the Palmer apparatus be sent. "This equipment will aid Mr. Howard in his work on Project N-1011." Cohen Papers, CBI. "Weekly Progress Report—Orion," June 28, 1946, Sperry Corporation Records, Acquisition 1825, Hagley.

84. "Monthly Progress Report, Project N-1011," June 1946, Sperry Corporation Records, Acquisition 1825, Hagley.

85. "Weekly Progress Report—Orion," July 14, 1946.

86. "Weekly Progress Report—Orion," July 28, 1946.

87. Coercivity is the magnetic intensity needed to reduce to zero the magnetic flux density of a fully magnetized magnetic specimen or to demagnetize a magnet. Interview with Sidney M. Rubens conducted by Arthur L. Norberg for the Charles Babbage Institute, January 6 and 15, 1986, OH100, p. 55.

88. Monthly Report—Project N-1011-A," July 1946, Technitrol Engineering Company, Acquisition 1901, Hagley Museum and Library.

89. Ibid.

90. "Weekly Progress Report—Orion," August 2, 1946.

91. "Weekly Progress Report—Orion," August 9, 1946.

92. "Weekly Progress Report—Orion," August 16, 1946.

93. von Heinz Lubeck, "Magnetische Schallaufzeichnung mit Filmen und Ringkopefen," *Akustische Zeitschrift* 2 (1937): 272–295. The English translation along with a photostat of the original German article are still in the Rubens files of the Sperry Corporation Records, Hagley.

94. Rubens interview, CBI, p. 54.

95. Ibid., p. 55.

96. "Weekly Progress Report—Orion," August 23, 1946, Technitrol Engineering Company, Acquisition 1901, Hagley Museum and Library.

97. "Monthly Report—Orion," August 1946.

98. "Program for Orion," n.d. but attached to the original memo from Tompkins dated September 9, 1946, File: "N-1011-A," Rubens files, Hagley. Rubens interview, CBI.

99. "Parallel Investigation of Components," Goldberg, September 1946, 6–13; "Program for Orion," pages 1 to 5 are on a study of a film splicing technique worked on by John L. Hill; pages 6 to 8 are on "Magnetic Storage"; pages 9 to 13 are on "Delay Line Storage."

100. Walsh, note 76. "Navy Projects—Venus," August 9, 1946, Project: Venus (N-1011-C), Technitrol Engineering Company, Acquisition 1901, Hagley Museum and Library.

101. J. M. Walsh to ERA Technical Group, September 30, 1946, changed the designations for Goldberg. Sperry Corporation Records, Acquisition 1825, Rubens files, Hagley Museum and Library.

102. "Weekly Progress Report—Orion," September 22, 1946, Technitrol Engineering Corporation, Acquisition 1901, Hagley.

103. "Weekly Progress Report—Goldberg," September 29, 1946. The Orion name was dropped toward the end of September.

104. "Weekly Progress Report—Goldberg," October 6, 1946.

105. Ibid.

106. "Weekly Progress Report—Goldberg," October 13, 1946.

107. "Weekly Progress Report—Goldberg, Part II," October 18, 1946.

108. "Weekly Progress Report—Goldberg, Part II," November 2, 1946.

109. "Weekly Progress Report—Goldberg, Part II," November 10, 1946. See also the Rubens interview, CBI, p. 55.

110. "Weekly Progress Report—Goldberg, Part II," November 17, 1946.

111. "Weekly Progress Report—Goldberg, Part II," November 23, 1946.

112. See, for example, William W. Wetzel, "Review of the Present Status of Magnetic Recording Theory," *Audio Engineering* 31 (November 1947): 14–17, 39; (December 1947): 12–16, 37; 32 (January 1948): 26–30, 46–47.

113. Interview with Robert Herr conducted by Arthur L. Norberg for the Charles Babbage Institute, May 19, 1986, OH 111, p. 50.

114. "Weekly Progress Report—Goldberg-II," December 15, 1946, and "Weekly Progress Report—Goldberg II," December 22, 1946, Technitrol Engineering Company, Acquisition 1901, Hagley Museum and Library.

115. "Weekly Progress Report—Goldberg II," December 29, 1946.

116. "Weekly Progress Report—Goldberg II," January 5, 1947.

117. William C. Norris, "Memorandum to the Files," January 31, 1947, Cohen Papers, CBI.

118. "Weekly Progress Report—Goldberg I," February 9, 1947, Cohen Papers, CBI. "Weekly Progress Report—Goldberg II," February 9, 1947; and "Weekly Progress Report—Goldberg III," February 2 and 9, 1947, Technitrol Engineering Company, Acquisition 1901, Hagley Museum and Library.

119. John Coombs, "Engineering Notebook, #85," from December 13, 1946.

120. "Part II Report—Report on Film Splice Technique," n.d., 1–4, see footnote 99.

121. Interview with John Lindsay Hill conducted by Arthur L. Norberg for the Charles Babbage Institute, January 15 and 22, 1986, OH 101, pp. 36–37.

122. Ibid., p. 37.

123. Ibid., p. 39.

124. "Weekly Progress Report—Goldberg N-1011-B," January 26, 1947, Cohen Papers, CBI.

125. "Monthly Progress Report—Goldberg, Part II," Report No. 6, January 1947.

126. Ibid., p. 3.

127. BuShips to Commanding Officer, NCML, St. Paul, "Memorandum," February 6, 1947, Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

128. Samuel S. Snyder, "Computer Advances Pioneered by Cryptologic Organizations," *Annals of the History of Computing* 2 (1980): 60–70.

129. "Monthly Progress Report—Goldberg, Part I," February 1947, Cohen Papers, CBI.

130. "Monthly Progress Report—Goldberg, Part I," April 1947.

131. Ibid., p. 4.

132. Gutterman to Coombs, "Status of Work on Magnetic Recording Heads on Problem 1-H," March 24, 1947, Cohen Papers, CBI.

133. Coombs to Olafson, April 1, 1947, Cohen Papers, CBI.

134. "Monthly Progress Report—Goldberg, Part I," April 1947, Cohen Papers, CBI.

135. Snyder, "Computer Advances," p. 61.

136. "Monthly Progress Report—Goldberg, Part II," April 1947, Cohen Papers, CBI.

137. "Proceedings of a Symposium on Large-Scale Digital Calculating Machinery," *Annals of the Computation Laboratory of Harvard University,* vol. 16 (Cambridge, Mass.: Harvard University Press, 1948). Also volume 7 in the Charles Babbage Institute Reprint Series for the History of Computing (Cambridge, Mass.: MIT Press; Los Angeles: Tomash Publishers, 1985).

138. Pages 130–132 and 223–237, respectively, of the CBI reprint edition.

139. Edmund C. Berkeley, "Memorandum for Mr. H. J. Volk, 2nd Vice President, Mr. C. B. Laing, Director of Organization and Methods, and Mr. E. F. Cooley, Assistant Director, Methods Research Division," January 13, 1947, 21, Sperry

Corporation Records, Acquisition 1825, Hagley Museum and Library. The memoranda are also available in the Edmund Berkeley Papers, CBI 50, Box 10. Attendees listed were: Dr. Chuan Chu, Moore School of Electrical Engineering; Dr. S. N. Alexander, National Bureau of Standards; Mr. Otto Kornei, Brush Development Company; Professor Howard H. Aiken, Harvard Computation Laboratory; Dr. Benjamin L. Moore, Harvard Computation Laboratory; Dr. Morris Rubinoff, Harvard Computation Laboratory. Charles Tompkins of ERA contributed to the discussion as the text makes clear. No others were listed, although over twenty people attended the rump session.

140. J. M. Coombs and J. L. Hill, "Disclosure of Invention," April 4, 1947, Cohen Papers, CBI.

141. B. H. T. Lindquist to H. T. Engstrom, April 18, 1947, Cohen Papers, CBI.

142. Ibid.

143. W. F. Winget to E. C. Olofson, April 21, 1947, Cohen Papers, CBI.

144. Coombs to Engstrom, May 7, 1947, Cohen Papers.

145. Coombs to Engstrom, May 8, 1947, "Subj: Technical details of magnetic recording system," Cohen Papers, CBI.

146. Coombs and Hill, "Summary Report: Storage of Numbers on Magnetic Tape," June 17, 1947, Cohen Papers, CBI.

147. "Progress Report—Goldberg, Part I," April 1947, Cohen Papers, CBI.

148. Ibid.

149. J. M. Coombs and J. L. Hill, "Storage of Nmbers on Magnetic Tape," June 17, 1947, Cohen Papers, CBI.

150. "Progress Report—Goldberg, Part I," May 1947, Cohen Papers, CBI.

151. Burke, *Information and Secrecy,* p. 319.

152. "The President's Annual Report," January 15, 1947, ERA Minute Book 1, Acquisition 1825, Hagley Museum and Library.

153. Ibid.

154. "Minutes of the Management Committee," March 25, 1947, March 31, 1947, April 2, 1948, July 28, 1948, April 21, 1949, and December 15, 1949, Acquisition 1825, Hagley Museum and Library.

Chapter 2

1. The report is reproduced as an Appendix in Nancy Stern, *From Eniac to Univac:* An Appraisal of the Eckert-Mauchly Computers (Bedford, Mass.: Digital Press, 1981). See also William Aspray, "The Stored Program Concept," *IEEE Spectrum* (September 1990), p. 51.

2. Stern, *From Eniac to Univac,* pp. 91–92.

3. For the list, see Martin Campbell-Kelly and Michael R. Williams, eds., *The Moore School Lectures: Theory and Techniques for Design of Electronic Digital Computers* (Cambridge, Mass. and Los Angeles, Cal.: MIT Press and Tomash Publishers, 1985), pp. xvi–xvii.

4. *Moore School Lectures,* p. 113.

5. J. W. Mauchly, "Preparation of Problems for EDVAC-Type Machines," *Proceedings of a Symposium on Large-Scale Digital Calculating Machinery, Annals of the Computation Laboratory of Harvard University* XVI (Cambridge: Harvard University Press, 1947).

6. See Stern, *From Eniac to Univac,* Appendix.

7. Eckert, *Moore School Lectures,* pp. 122–123.

8. See Stern, *From Eniac to Univac;* Herman H. Goldstine, *The Computer from Pascal to von Neumann* (Princeton: Princeton University Press, 1972). On the continuing commentary, see Aspray, "Stored Program Concept," 51; Paul E. Ceruzzi, *A History of Modern Computing* (Cambridge, Mass.: MIT Press, 1998), pp. 20–21.

9. Goldstine, *The Computer,* p. 188.

10. Ibid., p. 196.

11. Ibid., p. 191.

12. Ibid., report cited by Goldstine.

13. Ibid., p. 192.

14. For example, see Aspray, *John Von Neumann and the Origins of Modern Computing* (Cambridge, Mass.: MIT Press, 1990); Aspray, "The Institute for Advanced Study Computer: A Case Study in the Application of Concepts from the History of Technology," in Raul Rojas and Ulf Hashagen, *The First Computers—History and Architectures* (Cambridge, Mass.: MIT Press, 2000).

15. On this last point, see Arthur L. Norberg, "New Engineering Companies and the Evolution of the United States Computer Industry," *Business and Economic History* 22, second series (1993): 181–193.

16. "Summary of Present State of Development of Large High-Speed Digital Computing Machines as of June 11, 1946," an enclosure of J. H. Curtiss to J. C. Capt, June 12, 1946, Exhibit 4580, Honeywell Collection, CBI.

17. J. P. Eckert, "Disclosure of Magnetic Calculating Machine," January 29, 1944, Box 19, Folder: "Technitrol v. USA—J. Presper Eckert, Jr.," Acquisition 1901, Hagley Museum and Library.

18. Stern, *From Eniac to Univac,* chapters 1 and 2.

19. J. Mauchly, "Notes from a Conversation with Mr. Madow of the Census Bureau," October 9, 1944, ENIAC Trial Records, Exhibit 2488, Film 22, Microfilm Edition, CBI. Copies of the films are also available at the Hagley Museum and Library and the University of Pennsylvania Archives.

20. William B. Jordan (in company with Charles Concordia), "Memorandum on Computing Machines," October 24, 1944.

21. "Notes on a Conversation with Lieutenant-Colonel S. Kullback," October 11, 1944, Honeywell Collection, Exhibit 2491, CBI.

22. "Notes on Sorting Problems Occurring in Cryptanalysis," April 14, 1945, Sperry Corporation Records, Acquisition 1825, Box 73, Folder 4, Hagley.

23. J. Mauchly, "Notes on Some Problems Requiring High Speed Sorting and/or Computing," April 14, 1945, ENIAC Trial Records, Exhibit 3109, Film 24.

24. J. Mauchly, "Notes on Sorting Problems Occurring in Cryptanalysis," April 14, 1945.

25. "Minutes of the Committee on Tabulation Methods and Mechanical Equipment," Bureau of the Census, March 20, 1946, ENIAC Trial Records, Exhibit 4253, Honeywell Collection, CBI, and Minutes of a Meeting at the National Bureau of Standards, April 2, 1946, Exhibit 4291.

26. James L. McPherson to J. Mauchly, March 22, 1946 (labor); William H. Mautz to John Moore, March 27, 1946 (industry, for transmittal to EMCC); H. E. Robison to J. Moore, March 28, 1946 (agriculture, for transmittal to EMCC). All in the John W. Mauchly Papers, Box 3:C:10, Folder 219, University of Pennsylvania Archives.

27. J. Mauchly and J. P. Eckert, "Census Bureau Problem No. 1—MLF—Table 131," and "Treatment of Export Statistics," both in the George Stibitz Papers, ML27, Dartmouth College Library; "Some Tentative Specifications of Proposed Computer Machines," J. Mauchly Papers, Box 3:C:7, Folder 152, University of Pennsylvania Archives.

28. "Minutes of the Mathematical Computing Advisory Committee of the Navy Department," April 10, 1946, RG167-78-8, Box 2. Committee members represented the Office of Research and Development, the chief of naval operations, the Bureau of Aeronautics, the Bureau of Ordnance, the Bureau of Ships, the Naval Ordnance Laboratory, the David Taylor Model Basin, and the Naval Proving Ground, Dahlgren. Dr. Allan Waterman chaired the committee at this time.

29. Ibid., p. 3.

30. Ibid., p. 4.

31. J. H. Curtiss to J. W. Mauchly, May 20, 1946, Sperry Corporation Records, Acquisition 1825, Box 4a, EMCC Misc. Papers, Hagley.

32. “Agreement,” June 5, 1946, ENIAC Trial Records, Exhibit 4546, Honeywell Collection, Box 10, Folder 11, CBI.

33. “Proposed Electronic Calculator Company (Rough tentative statement of requirements . . .).” Stern dated this document as June 14, 1946, *From Eniac to Univac*, 267, note 69, Sperry Corporation Records, Acquisition 1825, Box 4a, EMCC Misc. Papers, Hagley.

34. Cited in Joel Shurkin, *Engines of the Mind: A History of the Computer* (New York: Norton, 1984), p. 220.

35. Ibid.

36. Ibid., p. 221.

37. In his deposition for the *United States v. IBM* case given in the 1960s, Eckert asserted under oath that the choice of name Electronic Control Company was an easy avenue into the commercial computer business. Eckert and Mauchly thought they would “build a very small machine that could be used in a chemical plant or power station . . . to control some simple problems they had there.” Cited in F. M. Fisher, J. W. McKie, and R. B. Mauchly, eds., *IBM and the U.S. Data Processing Industry: An Economic History* (New York: Praeger, 1983), p. 7.

38. For example, see Peter Eckstein, “J. Presper Eckert,” *Annals of the History of Computing* 18 (1996): 25–44; John Costello, “As the Twig Is Bent: The Early Life of John Mauchly,” *Annals of the History of Computing* 18 (1996): 45–50; Stern, *From ENIAC to UNIVAC;* and Shurkin, *Engines of the Mind.*

39. Ibid., p. 110.

40. Ibid., p. 111.

41. Ibid., p. 124.

42. Stern, *From Eniac to Univac,* p. 92.

43. Goldstine, *The Computer,* p. 202. On “programming” of the ENIAC, see Arthur W. Burks and Alice R. Burks, “The ENIAC: First General-Purpose Electronic Computer,” *Annals of the History of Computing,* 3 (1981): 310–388; David Alan Grier, “The ENIAC, the Verb ‘to program’ and the Emergence of Digital Computers,” *Annals of the History of Computing* 18 (1996): 51–55. Before the arrival of the digital electronic computer, the label “computer” referred to the problem-solving activity of humans, often female.

44. Goldstine, *The Computer,* p. 156.

45. Eckert-Mauchly Computer Corporation, “Biographical Summary” (attached to “General Historical Summary,” September 30, 1949), ENIAC Trial Records, Exhibit 7241, Honeywell Collection, CBI 1, CBI.

46. Isaac Auerbach, interview conducted by Nancy Stern, April 10, 1978, CBI, pp. 20–21.

47. “Memorandum of Agreement,” September 25, 1946, ENIAC Trial Records, Exhibit 5096, Honeywell Collection, CBI.

48. Originally, in October 1946, NBS agreed to a $50,000 contract. After six months, NBS increased the contract by $25,000 due to the added work agreed to after the initial negotiation. NBS contract Cst 7964. Nancy Stern conflated these two figures into the Initial contract amount, citing the contract DA-2, which seems to be an NBS division label. Copies of the contract in the ENIAC Trial Records, Records of the National Bureau of Standards, and the J. W. Mauchly Papers detail this sequence.

49. J. H. Curtiss to Electronic Control Company, March 28, 1947, RG167-76-67, Box 1, also Exhibit 5754, ENIAC Trial Records, CBI. John Curtiss and Edward Cannon, “NBS DA-2 Progress Report: ‘On the National Bureau of Standards Program for the Construction of Electronic Digital Computing Machines for the Office of Naval Research and the Bureau of Census,’ 21 November 1946,” as cited by Stern, *From Eniac to Univac,* p. 106.

50. “Basis for Estimates of Funds Required,” June 1946, Sperry Corporation Records, Acquisition 1825, Box 4a, EMCC Miscellaneous Papers, Hagley Museum and Library. Stern, *From Eniac to Univac,* dates this document as June 14, 1946, note 69, p. 267.

51. Stern, *From Eniac to Univac,* p. 106.

52. See the erratically maintained diaries of John Mauchly. Mauchly Papers, Van Pelt Library, University of Pennsylvania.

53. “Proposal for the Construction of a Group of Electronic Statistical Machines, January 4, 1947,” Sperry Corporation Collection, Acquisition 1825, Box 4a, EMCC Miscellaneous Papers, Hagley Museum and Library.

54. F. R. Dent, Jr., to EMCC, February 21, 1947, Mauchly Papers, Box 3:C:1, Folder 6, Van Pelt Library, University of Pennsylvania. (To avoid confusion, I will always refer to the Eckert and Mauchly company as EMCC, rather than ECC.)

55. Ibid.

56. “Requirement for an Electronic Computer for the Army Air Forces.” One copy in the Mauchly Papers bears his handwritten date of May 21, 1947. Box 3:C:1, Van Pelt Library, University of Pennsylvania.

57. J. W. Mauchly, “Notes on Visit to Northrop Aircraft and Other Companies,” May 24, 1947, Mauchly Papers, Box 3:C:17, Folder 330, Van Pelt Library, University of Pennsylvania.

58. Quoted by Stern, *From Eniac to Univac,* pp. 117, 119.

59. Mauchly to Berkeley, March 28, 1947, Exhibit 5755, Honeywell Collection, CBI.

60. Berkeley to Volk, "Calculators with Sequence Control," September 30, 1946. There are many copies of this and other Berkeley memoranda, which were mimeographed and circulated, in collections for computing history. My copies came from the Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library. For a fuller treatment of Berkeley's activities at the interface between the insurance industry and the computer developers, see JoAnne Yates, "Early Interactions Between the Life Insurance and Computer Industries: The Prudential's Edmund C. Berkeley," *Annals of the History of Computing* 19, no 3 (1997): 60–73.

61. Edmund C. Berkeley, "Sequence Controlled Calculators for the Prudential—Specifications—First Draft, November 1946," November 5, 1946, Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

62. Edmund C. Berkeley, "New Machinery to Handle Information—Path of Development," December 18, 1946, Sperry Corporation Collection, Acquisition 1825, Hagley Museum and Library.

63. Edmund C. Berkeley, "Symposium on Large Scale Digital Calculating Machinery at the Harvard Computation Laboratory, January 7 to 10, 1947—Report," January 13, 1947, Sperry Corporation Collection, Acquisition 1825, Hagley Museum and Library.

64. The report was divided into two parts. I found part one—"Application"—in the Mauchly Papers, Box 3:C:1, Folder 18, Van Pelt Library, University of Pennsylvania, and part two—"Plan for a Statistical EDVAC"—in the Honeywell Collection, Exhibit 5863.5, CBI.

65. Mauchly to Engineering Personnel, April 3, 1947, Sperry Corporation Records, Acquisition 1825, Box 4a, EMCC Miscellaneous Papers, Hagley Museum and Library.

66. This estimate is most explicitly stated in the letter from Mauchly to Berkeley of March 28, 1947, and frequently used thereafter by the two parties. Exhibit 5755.

67. "Analysis by J. H. Curtiss used at 4 June 1946 meeting [at NBS]," National Archives and Records Agency, Record Group 167-78-8, Box 3.

68. Stibitz to Curtiss, May 20, 1946, Stibitz Papers, Dartmouth College Library.

69. This conclusion is borne out in an earlier evaluation by Herman Goldstine in a letter to John von Neumann, May 15, 1945 (Exhibit 3188, Honeywell Collection, CBI). Commenting on a Stibitz report on relay computers, Goldstine wrote, "I don't think it is too good, especially I think his appendix on the relay interpolator is weird. He professes surprise at the variety of problems he can handle; I don't wonder that he does, considering his amazing method of considering a problem. Essentially he has a machine capable of forming linear combinations but he chooses to regard this as an analog of an electric circuit. Hence he apparently takes a given mathematical problem, mentally converts it into a circuit, tries to fit the circuit into the mechanism and solve."

70. Curtiss to Capt, June 12, 1946, Exhibit 4580, p. 3, Honeywell Collection, CBI.

71. Ibid.

72. "Progress Report on the Establishment of a Central Government Computation Facility under the Sponsorship of the National Bureau of Standards," Curtiss to the Mathematical Computing Advisory Committee of the Navy Department, October 23, 1946, p. 3, NARA, Record Group 167-78-8, Box 2.

73. Otto J. Scott, *The Creative Ordeal: The Story of Raytheon* (New York: Atheneum: 1974), p. 39.

74. Ibid., chapter 6.

75. Interview with Robert V. D. Campbell by William Aspray, February 22, 1984, OH67, CBI, p. 52.

76. Ibid., p. 53.

77. Mauchly diary, October 10, 1946, Honeywell Collection, CBI.

78. Curtiss to EMCC, November 12, 1946, Exhibit 5331, Honeywell Collection, CBI.

79. "Progress Report," November 21, 1946, NARA, Record Group 167-78-8, Box 2.

80. Curtiss to Harry Diamond, December 11, 1946, Exhibit 5469, Honeywell Collection, CBI.

81. Ibid.

82. Mauchly to G. F. Powell, December 2, 1946, NARA, Record Group 167-78-8, Box 3.

83. Curtiss to Diamond, December 11, 1946, Exhibit 5469, Honeywell Collection, CBI.

84. *Proceedings of a Symposium on Large-Scale Digital Calculating Machinery (1947), Annals of the Harvard Computation Laboratory,* 16, (Cambridge, Mass.: Harvard University Press, 1948); CBI Reprint Series (Cambridge, Mass. and Los Angeles: MIT Press and Tomash Publishers, 1985), pp. 248–253.

85. Diamond to Curtiss, January 6, 1947, Exhibit 5551, Honeywell Collection, CBI.

86. J. P. Eckert, Jr., "The ENIAC," in *A History of Computing in the Twentieth Century,* ed. N. Metropolis, J. Howlett, and Gian-Carlo Rota (New York: Academic Press, 1980), pp. 525–539.

87. J. P. Eckert, Jr., "A Survey of Digital Computer Memory Systems," *Proceedings of the IRE* 41 (October 1953): 1393–1406.

88. “Progress Report, Electronic Control Company, Contract CST-7964, January 28, 1947,” Exhibit 5626, Honeywell Collection, CBI.

89. “Proposal for the Construction of a Group of Electronic Statistical Machines, January 4, 1947,” Sperry Collection, Acquisition 1825, Box 4a, EMCC Miscellaneous Papers, Hagley Museum and Library.

90. Irven Travis to Harold Pender, February 25, 1947, Exhibit 5675, Honeywell Collection, CBI.

91. Davis to Cinaudagraph Division, Indiana Steel Products Co., February 22, 1947, NARA, Record Group 167-76-67, Box 1.

92. Davis to Huntoon, February 22, 1947, NARA, Record Group 167-76-67, Box 1.

93. Huntoon to Davis, March 4, 1947, NARA, Record Group 167-76-67, Box 1.

94. Slutz to Huntoon, March 20, 1947, NARA, Record Group 167-76-67, Box 1.

95. “Quarterly Progress Report, January–March 1947,” NBS Electronics Section, NARA, Record Group 167-78-9, Box 1.

96. “Army Soon to Get Super-Calculator,” *New York Times,* March 3, 1947.

97. Mauchly to Pender, March 3, 1947, Exhibit 5699, Honeywell Collection, CBI.

98. “Release for Morning Papers Friday March 7, 1947,” Exhibit 5719, Honeywell Collection, CBI.

99. This is mentioned in the EMCC press release.

100. “Conferences on EDVAC II Design, March 11, 12, 1947,” Exhibit 5724, Honeywell Collection, CBI.

101. “Progress Report, Electronic Control Company, Contract CST-7964, March 31, 1947,” Exhibit 5757, Honeywell Collection, CBI.

102. Curtiss to EMCC, April 10, 1947, NARA, Record Group 167-76-67, Box 1. In the Honeywell Collection, there is a copy of a letter dated March 28, 1947 (Exhibit 5754) that is much like this one, which appears to be a draft. The language is softer in one critical place: “The specific components the scientific officer had in mind were the mercury acoustic delay memory tube and associated electrical regeneration circuits and the tape transport mechanism.” “Scientific officer had in mind were” is crossed out and the words “Bureau considers most critical are” were printed over them. Who made the change is not indicated.

103. Curtiss to T. B. Morrow, Executive Officer, April 14, 1947, Exhibit 5795, Honeywell Collection, CBI.

104. “Memorandum of Supplemental Agreement, 14 April 1947,” Exhibit 5796, Honeywell Collection, CBI.

105. The contract text went through several drafts, beginning with a proposal from Prudential sent to EMCC in June after the company had had time to examine the EMCC documents on the plans for EDVAC II (see endnote 106). An almost complete draft is dated July 25, 1947, and the final text is dated August 4, 1947, followed by a visit to EMCC. These documents are contained in the Mauchly Papers, Box 3:C:1, Van Pelt Library, University of Pennsylvania.

106. "Plan for a Statistical EDVAC," Exhibit 5863.5, Honeywell Collection, CBI.

107. E. C. Berkeley, "Memorandum for Mr. F. B. Gerhard, . . . May 24, 1947," Mauchly Papers, Box 3:C:1, Folder 18, Van Pelt Library, University of Pennsylvania.

108. Ibid., p. 1.

109. All quotations are from Berkeley, "Memorandum for F. B. Gerhard."

110. Ibid. The numbers are somewhat confusing in this document. One-third return on R&D would be a minimum.

111. Mauchly to engineers and coding specialists, June 11, 1947, Mauchly Papers, Box 3:C:1, Folder 5, Van Pelt Library, University of Pennsylvania.

112. Mauchly to Berkeley, March 28, 1947, Exhibit 5755, Honeywell Collection, CBI.

113. Ibid.

114. Mauchly, "Memorandum Concerning Name for Electronic Machines Made by This Company," May 24, 1947, Exhibit 5885, Honeywell Collection, CBI.

115. Mauchly to engineers and coding Specialists, June 11, 1947, Exhibit 5918, Honeywell Collection, CBI 1, CBI.

116. Mauchly to Cannon, June 6, 1947, NARA, Record Group 167-76-67, Box 1.

117. Mauchly to Curtiss, June 16, 1947, NARA, Record Group 167-76-67, Box 1.

118. "Memorandum of Supplemental Agreement," June 12, 1947, Exhibit 5922, Honeywell Collection, CBI. On August 1 another form of this agreement was signed, which changed the nature of the supplement to extend the contract for "the sole purpose of allowing time for the preparation of final reports . . . ," Exhibit 6024.

119. "Progress Report," Division of Applied Mathematics, NBS, July 15, 1947, NARA, Record Group 167-78-8, Box 2.

120. Prudential Contract, "Schedule B—Technical Services," Exhibit 6023.5, Honeywell Collection, CBI. This is a draft of the final schedule included with the contract signed on August 5, 1947, Exhibit 6027, Honeywell Collection, CBI 1, CBI.

121. Ibid., p. 3.

122. NBS, Division of Applied Mathematics, “Progress Report, July 15, 1947,” NARA, Record Group 167-78-8, Box 2.

123. EMCC to the Prudential, August 4, 1947 (signed by Prudential on August 5), Exhibit 6027, Honeywell Collection, CBI.

124. George Gore to Mauchly, July 25, 1947, Exhibit 6012, Honeywell Collection, CBI. The official contract was dated October 9, 1947, but the delivery date and the conditions remained the same, Exhibit 6138.

125. Mauchly to Prudential, September 5, 1947, Exhibit 6067, Honeywell Collection, CBI.

126. Only IBM could rival the EMCC work on software development in this period.

127. W. Barkley Fritz, “The Women of ENIAC,” *Annals of the History of Computing* 18 (fall 1996): 13–28.

128. UNIVAC Conference Transcript, OH 200, CBI. Comment by Frances E. Holberton, p. 52.

129. Fritz, “The Women of ENIAC,” pp. 18–19. This article contains substantial information about Bartik, her training, and the programming of ENIAC.

130. Herman Lukoff, *From Dits to Bits: A Personal History of the Electronic Computer* (Portland, Oregon: Robotics Press, 1979), p. 74.

131. Interview with Frances E. Holberton, OH 50, passim, CBI.

132. Ibid.

133. UNIVAC Conference Transcript, p. 65.

134. Ibid., p. 68.

135. T. W. Brown to H. L. Strauss, “Report on Applications Dept.,” March 31, 1949, Sperry Corporation Records, Acquisition 1825, Box 83, Chronological File, Hagley.

136. Grace Hopper published or gave several versions of this talk, “The Education of a Computer,” but the justifications changed for each specialized audience. Indeed, there is a basic text, but she claimed they were separate talks. The example quoted is in “Proceedings, Symposium on Industrial Applications of Automatic Computing Equipment,” Midwest Research Institute, Kansas City, Missouri, January 8 and 9, 1953. Hopper Information File, CBI.

137. Ibid.

138. “Conferences on EDVAC II Design,” March 11, 12, 1947, Sperry Corporation Records, Acquisition 1825, Box 37, Hagley.

139. Ibid.

140. Ibid.

141. Ibid.

142. Data taken from a comparative chart in the Frances E. Holberton Papers, CBI 94, Box 13, File: UNIVAC Code Development.

143. Ibid.

144. Ibid.

145. Stern, *From ENIAC to UNIVAC,* p. 133.

146. "Training Course for EMCC's Engineers," spring 1950, Holberton Papers, Box 5.

147. Mauchly, "Chronology," October/November 1947, Mauchly Papers, University of Pennsylvania Archives, Box 3:C:1, Folder 5.

148. Lukoff, *From Dits to Bits,* passim on Eckert's presence at the office and how he interacted with personnel.

149. F. E. Snyder and H. M. Livingston, "Coding of a Laplace Boundary Value Program for the UNIVAC," *Mathematical Tables and other Aids to Computation (MTAC),* 3 (January 1949): 341–350.

150. H. Liebmann, "Die ausgenährte Ermittlung harmonischer Funktionen und konformer Abbildungen (nach Ideen von Boltzmann and Jacobi)," Akademic den Wissenschaft Zu Munich, *Berichte,* 1918, pp. 385–416.

151. "Coding of a Laplace Boundary Value Problem," EMCC 1948, Holberton Papers, Box 13.

152. Mauchly to Berkeley, March 28, 1947, Exhibit 5755, Honeywell Collection, CBI.

153. Emerson Pugh, *Building IBM: Shaping an Industry and Its Technology* (Cambridge, Mass.: MIT Press, 1995), p. 156.

Chapter 3

1. C. B. Tompkins, "Summary of Computing Conferences Held 9 October 1946," Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

2. Ibid.

3. Ibid.

4. Ibid.

5. Tompkins to Norris, October 8, 1946, Sperry Corporation Records, Acquisition 1825, Box 7, Hagley Museum and Library.

6. Tompkins to Engstrom, October 7, 1946.

7. Tompkins to Norris, October 8, 1946.

8. Clifford to Parker, December 6, 1946.

9. Clifford, "Memorandum to the File," December 16, 1946.

10. B-3001 originally was organized as a project for the ONR services contract as Task 1. As more ONR contracts for computer work came to ERA, they were incorporated into B-3001.

11. I am indebted to William Aspray for finding this item in the Goldstine Papers at Hampshire College.

12. Cohen to Chaloux, October 16, 1947, "File: Correspondence on Basic Design," Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

13. "Bimonthly Progress Report (Contract N6onr-240—Task Order I), Report No. 5, 1 May 1947–1 July 1947," Engineering Research Associates Records, Cohen Papers Series, Acquisition 2015, Hagley Museum and Library.

14. Cohen to Tompkins, March 24, 1947, "Project B-3001," Sperry Corporation Records, Acquisition 1825, File: B-3001: General File, Hagley Museum and Library.

15. Tompkins to Cohen, March 11, 1947, "Project B-3001—Conference of 10 March 1947."

16. The five organizations were Harvard, IAS, Moore School, NBS, and the Electronic Control Company. Tompkins noted that the work of the latter was unknown.

17. Cohen to Chaloux, October 16, 1947, Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

18. A good discussion of storage system parameters, for both cyclic systems (delay lines and drums) and noncyclic (relay and electrostatic), can be found in ERA, *High-Speed Computing Devices* (New York: McGraw-Hill, 1950), chapter 14.

19. Tompkins to Cohen, March 11, 1947, Sperry Corporation Records, Acquisition 1825, File: B-3001: General File, Hagley Museum and Library.

20. Cohen to Tompkins, March 24, 1947.

21. Coombs to Olafson, April 1, 1947.

22. Lindquist to Engstrom, April 18, 1947, Engineering Research Associates Records, Cohen Papers Series, Acquisition 2015, Hagley Museum and Library.

23. Cohen to Gutterman and Rubens, April 28, 1947.

24. Coombs to Engstrom, May 7, 1947.

25. Cohen to Lindquist, "Subj: Project B-3001: Research program on magnetic digital recording for rapid internal storage," with an enclosure "Outline of subject research program," May 9, 1947, Sperry Corporation Records, Acquisition 1825, File: B-3001: General File, Hagley Museum and Library.

26. Ibid.

27. Ibid.

28. Ibid.

29. Ibid.

30. Tompkins to Cohen, "Magnetic Recording Program," May 16, 1947.

31. Coombs and Hill, "Summary Report: Storage of Number on Magnetic Tape," June 17, 1947, Engineering Research Associates Records, Cohen Papers Series, Acquisition 2015, Hagley Museum and Library.

32. A. Cohen and W. Keye, "Selective Alteration of Digital Data in a Magnetic Drum Computer Memory," unpublished, Engineering Research Associates, Inc., 1948.

33. S. M. Rubens, "Summary Report: Magnetic Recording of Pulses for the Storage of Digital Information," June 19, 1947.

34. A. A. Cohen, "Internal Storage by Magnetic Recording," June 30, 1947.

35. ERA, *High-Speed Computing Devices,* reprint edition (Los Angeles: Tomash Publishers, 1983).

36. G. A. Hardenbergh, "Input and Output Media," June 30, 1947, Engineering Research Associates Records, Cohen Papers Series, Acquisition 2015, Hagley Museum and Library.

37. Progress Report 5, note 12. The appendix is "Magnetic Recording of Digital Information," see note 32.

38. Copies of these logbooks can be found in the Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

39. Keye logbook, p. 6.

40. Keye logbook, July 30, 1947, p. 17.

41. *Description of a Magnetic Drum Calculator, The Annals of the Computation Laboratory of Harvard University,* vol. 26 (Cambridge, Mass.: Harvard University Press, 1952), pp. 60–61.

42. See especially the Arnold A. Cohen interview conducted by Arthur L. Norberg for the Charles Babbage Institute, July 2, 1987, OH 138, CBI.

43. For example, see Hardenbergh, "Input and Output Media."

44. Kent C. Redmond and Thomas M. Smith, *Project Whirlwind: The History of a Pioneer Computer* (Bedford, Mass.: Digital Press, 1980), chapter 4. It is tempting to speculate how much of this was an elaboration on work done at MIT, under an NDRC contract in the early part of the war. NDCrc-146 MIT, "Studies and experimental investigations in connection with counter tubes and circuits, to develop high-speed counter tube circuits in decade rings, covering the use of thyratrons, pentodes and double triodes, and the development of a 'digitron' tube and counter circuit using this tube." Summary Reports, NDRC Records, National Archives.

45. David R. Brown, "High-Speed Digital-Computer Circuits," April 2, 1947, MIT Archives, MC140/B14/F9.

46. Ibid., p. 6.

47. "Notes taken during conversation with J. W. Forrester, MIT Servomechanisms Lab, 6 March 1947," ERA Records, Acquisition 2015, Box 9, Folder 22, Hagley Museum and Library.

48. Cohen also pointed out in his notes that the input–output was being done by Eastman Kodak.

49. Copy of the Cohen logbook #84, December 9, 1946–April 28, 1948, p. 41, Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

50. Ibid.

51. Ibid., p. 42, italics in the original.

52. Cohen logbook, p. 44; Keye logbook, p. 1.

53. Cohen logbook, p. 48; Keye logbook, p. 10.

54. Bruno Rossi, "Method of Registering Multiple Simultaneous Impulses of Several Geiger Counters," *Nature* 125 (1930): 636.

55. See the discussion of Rossi-type circuits in ERA, *High-Speed Computing Devices,* pp. 37–40.

56. Cohen logbook, pp. 51–52, Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

57. Cohen referred to an "NDRC Counter Report (1942)" and Whirlwind Report R-113 then (August 6, 1947) in preparation. See Cohen logbook, 52.

58. Cohen logbook, p. 54.

59. "Progress Report No. 6—1 July 1947–31 August 1947," Appendix 4.

60. Keye logbook, p. 26.

61. "Status Report: An Experimental Investigation of Selective Alteration of Digital Data in Magnetic Recording Storage Systems," September 1, 1947.

Appendix 3 of "Progress Report No. 6," Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

62. Appendix 3, p. 13.

63. "Progress Report No. 6," p. 2.

64. Tompkins to Coombs, September 22, 1947, Technitrol Engineering Corporation, Acquisition 1901, Hagley Museum and Library.

65. Cohen notes "B-3001 Programs," Engineering Research Associates Records, Cohen Papers Series, Acquisition 2015, Hagley Museum and Library.

66. Coombs to Tompkins, September 12, 1947, Technitrol Engineering Corporation, Acquisition 1901, Hagley Museum and Library.

67. "Bimonthly Progress Report, Contract N6onr-240-Task Order I, Report No. 7, 1 September 1947–31 October 1947," Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

68. Cohen to Norris, October 17, 1947, Engineering Research Associates Records, Cohen Papers Series, Acquisition 2015, Hagley Museum and Library.

69. The patent, no. 2,540,654, was granted to Cohen, Keye, and Tompkins on February 6, 1951.

70. J. H. Howard to R. I. Meader, March 12, 1948, Engineering Research Associates Records, Cohen Papers Series, Acquisition 2015, Hagley Museum and Library.

71. Howard to Meader, "Subj: Symposium on Magnetic Drum Applications," n.d., Technitrol Engineering Company, Acquisition 1901, Box 7, Hagley Museum and Library.

72. A file of these, "Magnetic Drum Suggested Applications," can be found in Box 20, Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

73. Howard to Meader, "Subj: Applications of High-Speed Storage Systems with Special Attention to Magnetic Drums," March 11, 1948.

74. Coombs to Meader, "Subj: Conference with Representatives of the Institute for Advanced Study," March 18, 1948.

75. Rees to Goldstine, June 30, 1947, Honeywell Collection, Box 12, CBI 1, CBI.

76. Goldstine to Rees, July 2, 1947.

77. Ibid.

78. David L. Boslaugh, *When Computers Went to Sea: The Digitization of the United States Navy* (Los Alamitos, Calif.: IEEE Computer Society, 1999), p. 95.

79. Norris to Meader, May 27, 1948, Technitrol Engineering Corporation, Acquisition 1901, Box 20, Hagley Musueum and Library.

80. Coombs to File, June 17, 1948.

81. See the list in Martin Campbell-Kelly and Michael R. Williams, eds., *The Moore School Lectures: Theory and Techniques for Design of Electronic Digital Computers,* vol. 9, CBI Reprint Series for the History of Computing (Cambridge, Mass.: MIT Press; Los Angeles: Tomash Publishers, 1985), p. xvi.

82. James Pendergrass interview conducted by William Aspray for the Charles Babbage Institute, March 28, 1985, OH 93, p. 14.

83. Cohen interview, CBI OH 138, p. 33.

84. Ibid., p. 26.

85. Ibid., p. 34.

86. Ibid.

87. "ERA Project Initiation: 13-100," August 4, 1947, Technitrol Engineering Corporation Records, Acquisition 1901, Hagley Museum and Library.

88. Tompkins to Engstrom, May 20, 1947.

89. "Progress Report (Contract NObsr-42001), Task No. 13," August 4, September 1, 1947, Engineering Research Associates Records, Acquisition 2015, Hagley Museum and Library.

90. Tompkins to Engstrom, May 20, 1947, Technitrol Engineering Corporation Records, Acquisition 1901, Hagley Museum and Library.

91. David R. Brown, "High-Speed Digital-Computer Circuits," April 2, 1947, MIT Archives, MC140/B14/F9.

92. "Atlas Characteristics," April 15, 1948, 2 vols., Technitrol Engineering Company, Acquisition 1901, Box 6, Hagley Museum and Library. Describing a multiplex capability given to the storage system, ERA noted that "until such time as high-speed storage can be added, it is desirable to incorporate any readily attainable features which might improve the effective speed of the machine," p. 5, vol. 1.

93. A. A. Cohen and J. M. Coombs notes, July 31, 1947, Engineering Research Associates Records, Acquisition 2015, Hagley Museum and Library.

94. Tompkins to the file, "Whirlwind Programming," August 8, 1947, Sperry-UNIVAC Company Records, Acquisition 1825, Box 176, Hagley Museum and Library. This memorandum described a presentation on Whirlwind to Forrester, Goheen of ONR, Perry Crawford of Special Devices Center, a Mr. Wood of Chance Vought, and Tompkins, which occurred on August 5, 1947.

95. A. A. Cohen notes, August 7, 1947.

96. Cohen to Chaloux, October 16, 1947, Engineering Research Associates Records, Acquisition 2015, Hagley Museum and Library.

97. "Progress Report," August 4–September 1, 1947.

98. "Progress Report (Contract NObsr-42001) Task 13," October 1–November 1, 1947, Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

99. Ibid.

100. "Progress Report (Contract NObsr-42001) Task 13," November 1–December 1, 1947, Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

101. "Notes by JTP—11/18/47," File: Notes: Gilhooley & Smorgasborg. Gilhooley & Smorgasborg were the pseudonyms for Pendergrass and Campaigne in the unclassified files kept by Cohen, Cohen private communication.

102. Compaigne to Coombs and Cohen, November 21, 1947.

103. "Progress Report (Contract NObsr-42001) Task 13," December 1, January 1, 1948.

104. Ibid.

105. "Progress Report (Contract NObsr-42001) Task 13," January 1, February 1, 1948.

106. Tompkins to Coombs, November 14, 1947.

107. "Progress Report," January 1–February 1, 1947, Appendix 1.

108. Ibid.

109. A succinct description of the Atlas I, its instruction set, and a sample program can be found in George Gray, "Engineering Research Associates and the Atlas Computer," *Unisys History Newsletter*, vol. 3, no. 3 (June 1999), an on-line publication.

110. "Progress Report (Contract NObsr-42001) Task 13," February 1–March 1, 1948.

111. "Progress Report (Contract NObsr-42001) Task 13," March 1, April 1, 1948.

112. "Atlas Characteristics," 2 vols., April 15, 1948, Technitrol Engineering Company Records, Acquisition 1901, Hagley Museum and Library.

113. "Progress Report (Contract NObsr-42001) Task 13," May 1, June 1, 1948, Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library. Letter from BuShips, April 14, 1948, NObsr-42001, Serial 948-394.

114. "Progress Report (Contract NObsr-42001) Task 13," May 1, June 1, 1948.

115. “Progress Report (Contract NObsr-42001) Task 13,” June 1–July 1, 1948.

116. Ibid., Appendix 1.

117. Ibid.

118. See the progress reports for the period June through November 1948 and folders in Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

119. Cohen to Tompkins, March 24, 1947.

120. Rubens to Engstrom, March 9, 1948, Folder: MMM.

121. Wakelin to Engstrom, March 26, 1948.

122. Steinhardt to Parker, June 30, 1948, “Patent Protection for ERA Magnetic Storage Techniques.” Report is dated June 21, 1948, revised June 29, 1948. Technitrol Engineering Company Records, Acquisition 1901, Box 20, Hagley Museum and Library.

123. J. M. Coombs and Charles B. Tompkins, “Data Storage Apparatus,” patent disclosure filed March 25, 1948, granted November 11, 1952, no. 2,617,705.

124. A. A. Cohen et al., “Data Storage System,” filed disclosure March 25, 1948, granted February 6, 1951, no. 2,540,654.

125. See the many ERA reports on airlines reservations systems in the Robert M. Kalb Papers, CBI 4.

126. J. H. BeVier to L. R. Steinhardt, August 20, 1948, “Register of Invention Disclosures under Contract NObsr-42001,” Engineering Research Associates Records, Acquisition 2015, Hagley Museum and Library.

127. “Progress Report (Contract NObsr-42001) Task 13,” September 1–October 1, 1948, and December 1, 1948–January 1, 1949, Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

128. Ibid.

129. “Progress Report (Contract NObsr-42001) Task 13,” December 1, 1948–January 1, 1949, Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

130. “Progress Report (Contract NObsr-42001) Task 13,” January 1–February 1, 1949.

131. “Progress Report (Contract NObsr-42001) Task 13,” March 1–April 1, 1949.

132. “Progress Report (Contract NObsr-42001) Task 13,” June 1–July 1, 1949.

133. “Progress Report (Contract NObsr-42001) Task 13,” July 1–August 1, 1949.

134. See the series of Progress Reports for this period listed in note 133.

135. "Progress Report (Contract NObsr-42001) Task 13," November 1–December 1, 1949.

136. This modification at NSA was called interlacing. Interlacing was a manually plugged arrangement permitting variation in address layout for each program, so as to allow longer or shorter intervals between successive effective addresses. Samuel S. Snyder, "Computer Advances Pioneered by Cryptologic Organizations," *Annals of the History of Computing* 2 (January 1980): 60–70, p. 62.

137. Ibid., pp. 63–67.

138. Summary based on Frank C. Mullaney, "Design Features of the ERA 1101 Computer," *Proceedings Joint AIEE-IRE Computer Conference*, Philadelphia, December 10–12, 1951 (New York: American Institute of Electrical Engineers, 1952).

139. "Sales Reports, May '54–Aug. '56," Engineering Research Associates Records, Cohen Papers Series, Acquisition 2015, Hagley Museum and Library.

140. Computer Consultants Limited, *A Record of Vintage Computers* (Middlesex, England: Computer Consultants Limited, 1965).

141. For more information on these machines, see George Gray, "The Univac 1102, 1103, and 1104," *Unisys History Newsletter*, vol. 6, no. 1 (January 2002), on-line.

142. ERA, "Supplementary Report on Examination of Accounts Year ended October 31, 1951," Peat, Marwick, Mitchell & Co., December 31, 1951, Sperry Corporation Records, Acquisition 1825, Box 323, Hagley Museum and Library.

143. J. E. Parker to Joseph E. Sheehy (Federal Trade Commission), January 25, 1952, Sperry Corporation Records, Acquisition 2015, Box 8a, Hagley Museum and Library. Judging from the construction and content of Parker's letter, we can conclude that the commission had approached ERA with a set of sixteen questions ranging from factual data about the company's name and officers to expenditures, patents, staff types, product lines, and competitive position. Parker's letter consisted of twelve pages, and there were two meetings to discuss its content.

144. Information from the IBM side of this contract, which included data about IBM's evaluation of ERA, was provided to me by John Palmer of the IBM Technical History Project. ERA documents for this contract are available in the Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library.

145. Interview with John E. Parker, OH99, CBI, p. 55.

146. All quotations from Eltgroth to F. J. McNamara, "Report on Trip to ERA", January 7, 1952, Sperry Corporation Records, Acquisition 1825, Box 88, Hagley Museum and Library.

147. Parker to Sheehy, January 25, 1952, Sperry Corporation Records, Acquisition 2015, Box 8a, Hagley Museum and Library.

148. Ibid., p. 6.

149. Engstrom to the files, February 4, 1952 (meeting at the Federal Trade Commission), Sperry Corporation Records, Acquisition 2015, Box 8a, Hagley Museum and Library.

150. Ibid.

151. Ibid.

152. Engstrom to Sheehy, February 6, 1952.

153. Engstrom to the files, April 8, 1952 (meeting report).

Chapter 4

1. Herman Lukoff, *From Dits to Bits: A Personal History of the Electronic Computer* (Portland, Oregon: Robotics Press, 1979), p. 67.

2. Ibid., p. 68.

3. Mauchly to the Nielsen Company, September 18, 1947, Exhibit 6106, Honeywell Collection, CBI.

4. E. W. Cannon to EMCC, October 20, 1947, Exhibit 6156, Honeywell Collection, CBI.

5. Eckert-Mauchly "Minute Books," President's Report, December 15, 1948, Sperry Corporation Records, Acquisition 1825, Hagley Museum and Library. Mauchly reported that the number of employees was 36 (December 22, 1947); 74 (May 17, 1948); 83 (August 19, 1948); and 94 (December 1, 1948).

6. Berkeley, "Electronic Control Contract—Progress to Date," October 27, 1947, Mauchly Papers, Van Pelt Library, University of Pennsylvania.

7. Ibid.

8. EMCC to Prudential, November 19, 1947, Exhibit 6197, Honeywell Collection, CBI.

9. These memoranda, dating from August 14 to November 14, 1947, can be found in the Mauchly Papers, Box 3:C:1, Folder 18, Van Pelt Library, University of Pennsylvania. On Berkeley's career and service with Prudential, see the elegant article by Joanne Yates, "Early Interactions Between the Life Insurance and Computer Industries: The Prudential's Edmund C. Berkeley," *Annals of the History of Computing* 19, no. 3 (1997): 60–73.

10. Mauchly to Cannon, December 23, 1947, Exhibit 6238, Honeywell Collection, CBI.

11. McPherson to Mauchly, January 7, 1948, Exhibit 6288, Honeywell Collection, CBI.

12. Auerbach to Mauchly and Eckert, January 16, 1948, Exhibit 6295, Honeywell Collection, CBI.

13. Davis to Alexander, January 29, 1948, Exhibit 6309, Honeywell Collection, CBI.

14. Alexander to the files, March 1, 1948, NARA, Record Group 167-76-67, Box 1.

15. "Agreement of Sale," December 22, 1947, Exhibit 6233, Honeywell Collection, CBI.

16. Cannon to EMCC, October 20, 1947, Exhibit 6156, Honeywell Collection, CBI.

17. See Nancy Stern's report on this event in *From ENIAC to UNIVAC,* An Appraisal of the Eckert-Mauchly Computers (Bedford, Mass.: Digital Press, 1981), pp. 107–112.

18. Quoted by Stern, *From ENIAC to UNIVAC,* p. 109.

19. Ibid.

20. Ibid., p. 110.

21. Curtiss to EMCC, January 20, 1948, Exhibit 6300, Honeywell Collection, CBI.

22. Mauchly to Curtiss, March 13, 1948, Exhibit 6340, Honeywell Collection, CBI.

23. "Minutes, Committee on Use of Mechanical Equipment, April 7, 1948," Exhibit 6372, Honeywell Collection, CBI.

24. "Purchase Order, January 15, 1948," Exhibit 6293, Honeywell Collection, CBI. The price of the basic UNIVAC machine was $96,000, with an additional $24,500 in auxiliary equipment. No delivery date was included, only a request for prompt delivery was made.

25. Stern, *From ENIAC to UNIVAC,* p. 114.

26. Ibid. Committee on the Use of Mechanical Equipment, "Minutes," April 8, 1948, Exhibit 6372, Honeywell Collection, CBI. The cancellation mentioned by Stern must have been the Fairchild contract. Their offices were at Oak Ridge and their purchase order was for the powered aircraft division.

27. H. D. Huskey to Mauchly, April 12, 1948, Exhibit 6388, Honeywell Collection, CBI.

28. Mauchly to Eckert, et al., "Prospective Contracts, 1/12/48," Mauchly Papers, Box 3:C:1, Folder 6, Van Pelt Library, University of Pennsylvania.

29. Lukoff, *From Dits to Bits*, p. 71.

30. "Disclosure of an Electro-Static Memory System, 1/16/48," Exhibit 6296, Honeywell Collection, CBI.

31. Mauchly to Eltgroth, February 5, 1948, Exhibit 6315, Honeywell Collection, CBI.

32. Ibid.

33. Andrew V. Haeff, "A New Memory Tube," *Electronics* 20 (September 1947): 80–83.

34. Arnold A. Cohen and William R. Keye, "Selective Alteration of Digital Data In a Magnetic Drum Computer Memory," report prepared for Office of Naval Research, under Contract N6onr-240, Task I with Engineering Research Associates, December 1, 1947. Also subject of a paper delivered to the 1948 National Convention of the Institute of Radio Engineers, New York, March 25, 1948. The IRE did not publish conference proceedings until 1953, but the paper presented is the text of this report printed by ERA.

35. Mauchly, "The UNIVAC," March 16, 1948, Exhibit 6347, Honeywell Collection, CBI.

36. Lukoff, *From Dits to Bits*, pp. 79–80.

37. Ibid., p. 88.

38. Ibid.

39. Chief, Division 11, to Section 11.4 Files, January 22, 1948, Exhibit 6304, Honeywell Collection, CBI.

40. Page to Curtiss, February 2, 1948, NARA, Record Group 167-76-67, Box 1.

41. Diamond to Curtiss, March 3, 1948, NARA, Record Group 167-76-67, Box 1.

42. See Stern, *From ENIAC to UNIVAC*, pp. 130–132.

43. "Minutes of the Meeting of the Applied . . . ," March 22, 1948, NARA, Record Group 167-76-67, Box 1.

44. Ibid.

45. See chapter 3 for a discussion of the interaction between NBS and ERA concerning this contract.

46. "Minutes of the Meeting of the Applied . . . ," March 22, 1948.

47. Ibid.

48. Mauchly to Eckert and others, "Memorandum of the May 7 Bureau of Standards Visit," dated May 10, 1948, Exhibit 6439, Honeywell Collection, CBI.

49. "Chronological Breakdown of Delivery Schedule," November 23, 1948, Exhibit 6686.

50. Stern, *From ENIAC to UNIVAC*, chapter 6.

51. Robert Rawlins to EMCC, June 25, 1947, Mauchly Papers; also quoted in Stern, *from ENIAC to UNIVAC*, p. 117.

52. Interview with J. Presper Eckert, Kathleen Mauchly, William Clever, and James McNulty conducted by Nancy Stern, January 23, 1980, CBI OH 11, p. 1.

53. Northrop to Electronic Control Company, October 9, 1947, Exhibit 6138, Honeywell Inc., CBI, 1.

54. Lukoff, *Dits to Bits*, p. 77.

55. Ibid., p. 78.

56. Ibid.

57. Auerbach to Mauchly et al, "Progress Report—Northrop," May 26, 1948, Exhibit 6470, Honeywell Collection, CBI.

58. Lukoff, *From Dits to Bits*, pp. 77–79.

59. Stern, *From ENIAC to UNIVAC*, p. 120.

60. Ibid., pp. 119–120.

61. A. Auerbach, J. P. Eckert, Jr., R. Shaw, J. R. Weiner, L. D. Wilson, "The BINAC," *Proceedings of the IRE* 40 (January 1952): 12–29.

62. Lukoff, *Dits to Bits*, p. 77.

63. Ibid., p. 80.

64. Ibid., p. 81.

65. Stern, *From ENIAC to UNIVAC*, p. 124. Stern cites a number of examples from correspondence of Baker to Northrop.

66. "BINAC Press Release," August 22, 1949, as cited in Stern, *From ENIAC to UNIVAC*, p. 122.

67. Stern, *From ENIAC to UNIVAC,* pp. 124–128.

68. Reid, "Memorandum for Mr. Thomas J. Watson, Jr.," August 25, 1949, Exhibit 7182, Honeywell Collection, CBI 1; see also Sperry Corporation Records, Acquisition 1825, Box 84, Hagley Museum and Library.

69. The organizations were the University of Illinois, the Institute of Numerical Analysis at Los Angeles, Los Alamos Laboratory, and Project Rand. Only Rand might end up buying one or the other.

70. The president to the executive committee, "What are we going to sell?" August 18, 1948, Sperry Corporation Records, Acquisition 1825, Box 3, Mauchly Correspondence, Hagley.

71. J. W. Mauchly to J. P. Eckert, etc., "Decision against BINAC Production," August 28, 1948, Honeywell Collection, Exhibit 6583, CBI 1.

72. G. V. Eltgroth to J. A. W. Simpson, "Contract Status," February 24, 1950, Acquisition 1825, Box 1, Brown Correspondence, Sperry Corporation Records, Hagley Museum and Library.

73. *The UNIVAC System*, copyright 1948 by EMCC. Emphases in the original.

74. Ibid., p. 2.

75. Ibid., p. 6.

76. Ibid., p. 8.

77. "An Analysis of the EMCC," September 30, 1949, sections by different authors; "Electronic Equipment Section," by James Weiner, Honeywell-Sperry Case Files, Exhibit 7241, CBI. The contents of the document suggest it was developed for use in fundraising, contracting, and possible sale of the company, a search that went on assiduously over the next three months.

78. "Electro-Mechanical Section," by H. Frazer Welsh, Honeywell-Sperry Case Files, Exhibit 7241, CBI.

79. Lukoff, *From Dits to Bits,* p. 112.

80. Ibid.

81. Ibid.

82. Ibid., p. 113.

83. Ibid., p. 142.

84. Ibid., p. 131.

85. W. H. Reid to T. H. Watson, Jr., "Memorandum," August 25, 1949.

86. Association for Computing Machinery, "A quarter-century view, ACM71" (New York, 1971), and "An Analysis of the Eckert-Mauchly Computer Corporation," biographical summary section.

87. "Course Schedule: Programming for BINAC," Exhibit 7081, Honeywell Collection, CBI 1.

88. D. Knuth and L. T. Prado, "The Early Development of Programming Languages," *Encyclopedia of Computer Science and Technology* 7 (1977): 419–493.

89. "Early American 'Compilers,'" *Encyclopedia of Computer Science and Technology* 7 (1977): 452–455.

90. M. V. Wilkes, D. J. Wheeler, and S. Gill, *The Preparation of Programs for an Electronic Digital Computer, with special reference to the EDSAC and the use of a library of subroutines* (Cambridge, Mass.: Addison-Wesley, 1951; reprint edition, Los Angeles: Tomash Publishers, 1982). See Martin Campbell-Kelly's introduction to the reprint edition for an assessment of the significance of this publication.

91. Knuth and Pardo, "Early Development," p. 434.

92. "UNIVAC Short Code [Instruction Manual]," "Preface," Computer Product Manuals Collection, CBI 60, Box 186.

93. "UNIVAC Short Code," passim; and Sammet, *Programming Languages*, pp. 129–130.

94. G. M. Hopper, "Keynote Address," in *History of Programming Languages*, ed. Richard L. Wexelblat (New York: Academic Press, 1981), pp. 7–20, p. 10.

95. G. M. Hopper, "The Education of a Computer," Proceedings, Symposium on Industrial Applications of Automatic Computing Equipment, Midwest Research Institute, Kansas City, Missouri, January 8 and 9, 1953 (copy at CBI in Hopper File). This is one version of the talk. See note 100 below for an earlier published version.

96. Jean E. Sammet, *Programming Languages: History and Fundamentals* (Englewood Cliffs, N.J.: Prentice-Hall, 1969), p. 12.

97. Ibid.

98. The following description is taken from the instruction manual "A-0 Compiler," Computer Products Manual Collection, CBI 60, Box 205.

99. Hopper, "Keynote," p. 11.

100. "A-0 Compiler" instruction manual, p. 3.

101. Hopper, "Keynote," p. 12. For the original publication, see *Proceedings of the Association for Computing Machinery,* Pittsburgh meeting, May 2–3, 1952 (New York: ACM, 1952), pp. 243–249.

102. Richard K. Ridgway, "Compiling Routines," presented at ACM meeting September 8–9, 1952, Holberton Papers, CBI 94, Box 5.

103. L. Stowe, "Programming," *Summary of Papers Presented at the Seminar on Data Handling and Automatic Computer*, February 26 to March 6, 1951, Office of Naval Research, U. S. Government Computing Collection, CBI 63, Box 2.

104. See, for example, the description of expert system development in E. A. Feigenbaum and P. McCorduck, *The Fifth Generation: Artificial Intelligence and Japan's Computer Challenge to the World* (Reading, Mass.: Addison-Wesley, 1983).

105. "Progress Report on Bureau of the Census Problem, 4 January 1951," Holberton Papers, CBI 94, Box 23.

106. Stowe, "Programming," p. 80.

107. Ibid., p. 81.

108. Ibid.

109. James McGarvey, Adele "Millie" Koss, F. M. Delaney, Margaret H. Harper, and Richard K. Ridgway.

110. Hopper, "Keynote," pp. 12–13.

111. The following description comes from a Remington Rand "Instruction Manual: The A-2 Compiler System" published in 1955, Holberton Papers, CBI 94, Box 18.

112. Hopper, "Keynote," p. 14.

113. *Proceedings,* Harvard, 1948; reprinted as vol. 7 in the CBI Reprint Series, MIT Press and Tomash Publishers, 1985.

114. Mauchly Papers, Box 3:C:12, Folder 258, University of Pennsylvania Archives.

115. Stern, *From ENIAC to UNIVAC,* p. 145.

116. G. V. Eltgroth, "Financial Reorganization," November 28, 1949, Sperry Corporations Records, Acquisition 1825, Box 85, Hagley.

117. Ibid.

118. "EMCC Minute Book," December 15, 1949.

119. "EMCC Minute Book 2, Board Meeting, January 12, 1950," Sperry Corporation Records, Acquisition 1825, Hagley.

120. "EMCC Minute Book 2, Board Meeting, November 9, 1949," Sperry Corporation Records, Acquisition 1825, Hagley.

121. G. V. Eltgroth, "Financial Reorganization—R.F.C. Loan," December 13, 1949, Sperry Corporation Records, Acquisition 1825, Box 85, Hagley.

122. G. V. Eltgroth, "Financial Reorganization," January 10, 1950, Sperry Corporation Records, Acquisition 1825, Box 85, Hagley.

123. E. U. Condon to director, Office of Domestic Commerce, December 12, 1949, Sperry Corporation Records, Acquisition 1825, Box 85, Hagley.

124. "EMCC Minute Book," December 29, 1949, Hagley Museum and Library.

125. This comment was written in November 1949 as part of a chronology of financial exploratory contacts prepared for the board of directors by Wistar Brown. Apparently, in retrospect, he saw this visit as other than to evaluate a technical problem. "Report on Financial Exploratory Contacts to 11/22/49," T. Wistar Brown, November 28, 1949, Sperry Corporation Records, Acquisition 1825, Box 85, Hagley.

126. T. Wistar Brown, "Report on Financial Exploratory Contacts to 11/22/49," November 28, 1949, Sperry Corporation Records, Acquisition 1825, Box 85, Hagley.

127. Ibid.

128. Ibid.

129. Ibid.

130. "Draft Press Release," March 1, 1950, Sperry Corporation Records, Acquisition 1825, Box 2, Folder: G. V. Eltgroth, January–June 1950, Hagley.

Chapter 5

1. Percentages calculated from table 16.2 (Sources of Revenue for Top Five Vendors, 1948) and 16.1 (Revenues of Ten Largest Office Equipment Firms, 1948) pp. 225–226 in James W. Cortada, *Before the Computer: IBM, NCR, Burroughs, and Remington Rand and the Industry they Created, 1865–1956* (Princeton, N.J.: Princeton University Press, 1993). These numbers are meant to be indicative only, and should not be seen as absolute values of market share.

2. Sperry Rand Corporation, *A History of Sperry Rand Corporation,* 1964. See also James W. Cortada, *Historical Dictionary of Data Processing: Organizations* (New York: Greenwood, 1987), p. 237.

3. Cortada, in *Before the Computer,* reported their revenue ranking in 1928 as Remington Rand (59.6), NCR (49.0), Burroughs (32.1), IBM (19.7). By 1939 this ranking had become Remington Rand (43.4), IBM (39.5), NCR (37.1), Burroughs (32.5), p. 153.

4. Ibid, p. 155.

5. Cortada, *Historical Dictionary,* p. 237.

6. Cortada, *Before the Computer,* p. 155.

7. *Business Week,* March 4, 1950, p. 20.

8. Edmund L. Van Deusen, *Fortune,* August 1955, pp. 88–91, 122, 124, 128; see esp. p. 91.

9. Cortada, *Historical Dictionary,* p. 240. See also Cortada's discussion of Remington Rand in *The Computer in the United States: From Laboratory to Market, 1930 to 1960* (Armonk, N.Y.: M. E. Sharpe, 1993), pp. 89–94.

10. Emerson W. Pugh and William Aspray make this point in "Creating the Computer Industry," *Annals of the History of Computing* 18, no. 2 (1996): 7–17, p. 12.

11. Ibid., p. 11.

12. Data taken from the Remington Rand and IBM annual reports.

13. Remington Rand Annual Report for the year ended March 31, 1952, CBI 1, Box 39.

14. Robert S. Norris, *Racing for the Bomb: General Leslie R. Groves, the Manhattan Project's Indispensable Man* (South Royalton, Vermont: Steerforth Press, 2002), pp. 504–508.

15. EMCC Minute Book, February 16, 1950, Sperry Rand Corporation Administrative Records, Acquisition 1910, Hagley Museum and Library.

16. Robert E. McDonald interview with James Ross, May 4, 1983, recorded for the Charles Babbage Institute, OH 57, p. 3.

17. Comment by Louis D. Wilson at the UNIVAC Conference, OH 200. Oral history on May 17–18, 1990, Washington, D.C., pp. 11–12.

18. T. W. Brown to "Persons Listed Below," February 20, 1950, Acquisition 1825, Box 1, T. Wistar Brown Correspondence File, Hagley.

19. For example, the first reference to EMCC in the Remington Rand board executive committee minutes occurs nine months after the acquisition of EMCC on September 13, 1950, Sperry Rand Corporation Administrative Records, Acquisition 1910, Hagley Museum and Library.

20. Eckert to Ross, September 16, 1952, Exhibit 8128, Eniac Trail Records, University of Pennsylvania Archives.

21. Eckert, "Proposed Computer System Development Program for Remington Rand, Inc.," November 23, 1954, Acquisition 1825, Box 265, Hagley.

22. Eltgroth to McNamara, August 23, 1951, Trial Exhibit 7912, Eniac Trial Records, CBI.

23. Census hearings extracts, Trial Exhibit 7762, Eniac Trial Records, CBI.

24. James R. Weiner, "Operating Experience with UNIVAC Systems," *IRE Transactions on Electronic Computers* 1 (December 1952): 33–46.

25. Sheehy to Francis J. McNamara, April 28, 1952, Acquisition 2015, Box 8a (also Exhibit 8088 in the combined *Honeywell vs. Sperry Rand* trial records, reel 53). "The detailed information and material furnished by you and other data available to us here have been carefully considered by our staff, however, and on the basis of the information now available it is my conclusion that the situation would not warrant field investigation at this time. You understand, of course, that this will not preclude the Commission from undertaking an investigation if subsequent facts come to its attention that would warrant such action."

26. E. Tomash and S. M. Rubens to files, "Visit to Remington Rand Research Laboratories—May 27 and 28, 1952," June 12, 1952, Engineering Research Associates Records, Acquisition 2015, Box 8, Hagley.

27. "Minutes of Meeting Between Norwalk Laboratory, Eckert-Mauchly and ERA at Norwalk—May 27 and 28," June 23, 1952, Engineering Research Associates Records, Acquisition 2015, Box 8a, Hagley.

28. Ibid.

29. Ibid.

30. Ibid.

31. Tomash and Rubens to files, June 12, 1952.

32. By contrast, the IBM 650 drum, already available at announcement time in July 1953, was to be four inches in diameter and rotate at the advanced speed of 12,500 rpm, effectively twice as fast as a similar-sized ERA drum. See C. J. Bashe, L. R. Johnson, J. H. Palmer, and E. W. Pugh, *IBM's Early Computers* (Cambridge, Mass.: MIT Press, 1986), p. 170.

33. "Minutes of the Meeting," June 23, 1952, note 27.

34. Tomash and Rubens to the files, June 12, 1952, note 26.

35. Ibid.

36. "Minutes of the Meeting," June 23, 1952, note 27.

37. Tomash and Rubens to the files, June 12, 1952, note 26.

38. Ibid., Appendix D.

39. Ibid., "General Conclusion."

40. J. G. Miles to the files, June 25, 1952, "Sales-activities meeting," Acquisition 2015, Box 8a, Hagley.

41. A. N. Seares to A. R. Rumbles, "RR-ERA Meeting, New York City, June 20, 1952," Mauchly Papers, Box 3:C:4, Folder 83, University of Pennsylvania Archives.

42. Ibid.

43. Ibid.

44. Ibid.

45. D. V. Savidge to A. N. Seares, "Meetings with ERA, 7/2 and 7/3," Mauchly Papers, Box 3:C:4, Folder 83, University of Pennsylvania Archives.

46. See A. N. Seares to J. Mauchly, "Comparison of UNIVAC with ERA-1101 Unit," September 16, 1952, Mauchly Papers; and "Discussion of the Characteristics of the UNIVAC System and the ERA 1101, and the utility of these computers for certain fields of application," Mauchly Papers, Box 3:C:4, Folder 82, University of Pennsylvania.

47. Seares to Mauchly, September 16, 1952.

48. "Discussion of the Characteristics of the UNIVAC System," note 44.

49. Ibid.

50. Ibid.

51. Administration Committee Minutes, Sperry Rand Corporation Administrative Records, Acquisition 1910, Hagley Museum and Library.

52. George Gray and Ron Smith, "Sperry Rand's Transistor Computers," *Annals of the History of Computing* 20 no. 3 (1998): 16–26.

53. Lukoff, *From Dits to* Bits, p. 139.

54. For additional information, see George Gray, "The UNIVAC Solid State Computer," *UNIVAC History Newsletter,* vol. 1, no. 2 (1992), on-line publication.

55. Martin H. Weik, *A Third Survey of Domestic Electronic Digital Computing Systems* (Aberdeen, Maryland: Aberdeen Proving Ground, March 1961).

56. Many discussions of the IBM Stretch have appeared. See, for example, C. J. Bashe et al., *IBM's Early Computers,* Chapter 11.

57. Herman Lukoff, *From Dits to Bits*: *A Personal History of the Electronic Computer* (Portland, Oregon: Robotics Press, 1979), pp. 146–147. Lukoff offers many details about the team members from both EMCC and Livermore and the results of their deliberations in chapter 11.

58. This description of the engineering R&D program is taken from Lukoff, *From Dits to Bits,* pp. 147–157.

59. J. P. Eckert, "UNIVAC-Larc, the Next Step In Computer Design," *Proceedings of the Eastern Joint Computer Conference,* (1956): 16–20. It is interesting to contrast Eckert's self-confident presentation with one immediately following about the IBM Stretch. IBM acknowledged that the design was still in the research phase and that a number of important design decisions were still to be made. Everything about the IBM project was understated, *Proceedings,* pp. 20–22.

60. Eckert, "UNIVAC-Larc," p. 17.

61. Michael M. Maynard, "LARC," *Encyclopedia of Computer Science,* 4th ed., eds. Anthony Ralston, Edwin D. Reilly, and David Hemmendinger (London: Nature, 2000), pp. 958–960. On the drum head, see H. F. Welsh and V. J. Porter, "A Large-Capacity Drum-File Memory System," *Proceedings of the Eastern Joint Computer Conference* (1956): 136–139. For the specific details of the computer system, see also the entry in Martin H. Weik, *A Third Survey of Domestic Electronic Digital Computing Systems* (Aberdeen, Maryland: Aberdeen Proving Ground, March 1961).

62. Lukoff, *From Dits to Bits,* p. 156.

63. George Gray and Ron Smith, "Sperry Rand's Transistor Computers." LARC remained in service until December 1968.

64. William D. Bell, *A Management Guide to Electronic Computers* (New York: McGraw-Hill, 1957), p. 149. Other similar systems were the IBM Card Programmed Calculator and the Burroughs E101.

65. Loring P. Crosman, "The Remington Rand Type 409-2 Electronic Computer," *Proceedings of the IRE* (October 1953): 1332–1340.

66. Lukoff, *From Dits to Bits*, p. 137.

67. Ibid.

68. Erwin Tomash and Arnold A. Cohen, "The Birth of an ERA," *Annals of the History of Computing* 1 (1979): 83–97.

69. Remington Rand Sales Reports, May 1954 to August 1956, Acquisition 1825, Sperry-UNIVAC Company Records, Hagley.

70. Ibid.

71. Sales Reports, May 1954 to August 1956; Tomash and Cohen, "The Birth," 94. The first five systems contained drums and electrostatic storage (NSA, Convair, Eglin Air Force Base, White Sands, and Westinghouse—Baltimore), after which ERA shifted to magnetic core memory.

72. John L. Hill interview with Arthur L. Norberg, January 1986, CBI 101, pp. 109–111. John Plain Company, "140 GP Distribution," n.d., ERA-RR-SR Collection, CBI.

73. "140 GP Distribution," p. 11.

74. Weik, *Third Survey,* note 56, 932–939. For a fuller description see the on-line description by George Gray, "The UNIVAC File Computer," *Unisys History Newsletter* 2, no. 2 (1993).

75. Gray, "The UNIVAC File Computer."

76. Ibid., pp. 940–957.

77. Gray and Smith, "Sperry Rand's Transistor Computers," pp. 18–19.

78. Samuel S. Snyder, "Computer Advances Pioneered by Cryptologic Organizations," *Annals of the History of Computing, 2* (1980): 60–70.

79. David E. Lundstrom, *A Few Good Men From UNIVAC* (Cambridge, Mass.: MIT Press, 1987), chapter 1.

80. Lund joined ERA in 1946. An electrical engineer, who received most of his training in the navy during the war and through extension courses afterwards at the University of Minnesota, he worked on several machine designs, especially the development of read–write heads for drums.

81. John Arthur Engstrom, Jr., received a bachelor of electrical engineering degree from the University of Minnesota in 1942. After military service at the Army Signal Corps laboratories and a brief stint at General Electric, he joined ERA in 1948, where he supervised several computer development projects.

82. Lundstrom, *A Few Good Men*, p. 18.

83. Ibid., 20–21.

84. Ibid., 21.

85. Lukoff, *From Dits to Bits,* p. 158.

86. Ibid., pp. 158–163.

87. The Uniservo II was a complete redesign of the Uniservo I to eliminate the shortcomings of the earlier unit and to increase the speed of transfer of data.

88. Miles to Norris, January 19, 1953, Acquisition 2015, Engineering Research Associates Records, "Engineering Sales Problem (Dead)," Hagley Museum and Library.

89. Norris to A. R. Rumbles, "Recommendations on Plan for Engineering Sales," January 26, 1953.

90. Ibid.

91. Ibid.

92. Norris to A. N. Seares, "Recommendations for Remington Rand Automatic Systems and Equipment Engineering Services," February 6, 1953.

93. A. R. Rumbles to W. C. Norris, February 26, 1953.

94. A. R. Rumbles to A. Seares, "Sales Coverage," February 16, 1953.

95. Records show that the New York office eventually worked with government agencies and educational institutions as well as companies.

96. "Present Organization—Electronic Computer Dept.—Remington Rand," July 28, 1955, Parker Papers, CBI.

97. "An Evaluation of the Electronic Computer Sales Program," John E. Parker, November 20, 1953, Parker Papers, CBI.

98. Ibid., p. 2.

99. Ibid., p. 3.

100. "A Report from the Laboratories of Remington Rand," appeared in *Time* and *Business Week* in fall 1953.

101. "An Evaluation of the Electronic Computer Sales Program," note 89, p. 4.

102. Ibid., pp. 5–6.

103. Roddy F. Osborn, "GE and UNIVAC: Harnessing the High-Speed Computer, *Harvard Business Review* (July–August 1954): 99–107, 102.

104. Interview with Willis K. Drake by James Baker Ross, February 3, 1983, OH 46, CBI.

105. Ibid., p. 36.

106. Ibid.

107. Ibid., p. 39.

108. Ibid., p. 40.

109. Ibid.

110. A. R. Rumbles to J. E. Parker, August 25, 1954, Parker Papers, CBI.

111. Parker to Rumbles, September 1, 1954, Parker Papers, CBI.

112. Parker to H. V. Widdoes, "Sales Managers' Monthly Report (for January 1, 1955 to September 26, 1955)," September 26, 1955, Parker Papers, CBI.

113. Ibid.

114. Parker to Norris, "Regional Plan for Sales Department UNIVAC Division," November 1, 1955, Parker Papers, CBI.

115. Interview with William C. Norris by Arthur L. Norberg, July 28, 1986, p. 63, OH 116, CBI.

116. Minutes, Operations Policy Committee, vol. 8, June 1, 1954, Acquisition 1825, Sperry-UNIVAC Company Records, Hagley Museum and Library.

117. Ibid., pp. 82ff.

118. L. E. Jamison, "Organization Change," June 24, 1953.

119. "Original Memos—For Richard Lareau. RR-CDC Case," William Norris Papers, CBI 164, Box 8, p. 4-A. Norris wrote these memos in the early 1960s for use in the suit brought against CDC by Sperry Rand for theft of trade secrets.

120. Donald Mackenzie, "The Influence of the Los Alamos and Livermore National Laboratories on the Development of Supercomputing, *Annals of the History of Computing* 13 (1991): 179–201, 190.

121. Emerson W. Pugh, *Building IBM: Shaping an Industry and Its Technology* (Cambridge, Mass.: MIT Press, 1995), pp. 231–232.

122. Norris, "Original Memos," p. 5.

123. Herman Lukoff, *From Dits to Bits*, p. 146.

124. Mackenzie, "Influence of the Los Alamos," p. 190.

125. James H. Rand to All Officers of Remington Rand Division of Sperry Rand Corporation, October 1, 1955, Norris Papers, CBI 164, old Box 8, Folder "Original Documents Pertaining to Lawsuit—from W. C. Norris, SR-RR-CDC." In this collection, "Original Memos" and "Original Documents" are two separate items. The "Original Documents," written while he was at Remington Rand/ Sperry Rand, support the review provided by Norris to CDC attorneys called "Original Memos" prepared in the early 1960s.

126. "Original Memos," pp. 7–8.

127. Tomash interview, pp. 38–40.

128. McDonald interview, p. 18.

129. Norris to Rand, February 25, 1956, "Original Documents."

130. Ibid.

131. Ibid.

132. Norris, "Original Memos," p. 9.

133. Norris to M. Rand, June 14, 1956, "Sales Plan," "Original Documents."

134. Norris, "Original Memos," pp. 10–11.

135. Norris, "Original Documents."

136. Ibid., p. 11.

137. Eckert to Rand, February 26, 1957, "UNIVAC II," Original Memos—For Richard Lareau. RR-CDC Case," William Norris Papers, CBI 164, Box 8, p. 14.

138. Norris to M. N. Rand, September 7, 1956, "Future Space Requirements," "Original Documents."

139. "Agenda, UNIVAC Division Production Programs," "Original Documents."

140. M. N. Rand to Norris, October 31, 1956, and Rand to Norris, December 19, 1956, "Original Documents."

141. Norris to M. Rand, September 20, 1956, "Original Documents."

142. Norris, "Original Memos," 12; H. V. Widdoes to Norris, September 24, 1956, "Transfer of Sales Activities"; Norris to Widdoes, September 27, 1956, "Transfer of Sales Activities"; and Norris to M. Rand, "Training," "Original Documents," note 66.

143. Norris, handwritten "Memo to File," June 13, 1957, "Original Documents," note 66.

144. Norris, "Original Memos," pp. 15–16.

145. Norris to the file, March 5, 1957, "Original Documents."

146. Memo with Norris handwritten note at the top, "R. E. McDonald wrote this in April or May of 1957. He was afraid to sign it." Norris Papers, Box 38, SR Lawsuit, File 1, CBI.

147. Norris to file (on meeting with M. Rand), April 5, 1957, "Original Documents," note 111.

148. Ibid.

149. Ibid.

150. Ibid.

151. Norris to the file (handwritten memorandum), April 13, 1957, "Original Documents."

152. Norris to file, April 15, 1957, "Original Documents."

153. Norris to file, April 18, 1957, "Original Documents."

154. Norris to file, April 16, 1957, "Original Documents."

155. "Original Memos," following p. 20.

156. Frank Mullaney notes, December 20, 1966, 1980 Executive History Project Records, 1965–1981, Box 3A2C, Frank C. Mullaney "History Narrative," CDC Collection, CBI 80.

157. Ibid.

158. McDonald interview, p. 13.

159. Robert E. McDonald interview with James Ross, December 16, 1982, CBI OH 47, pp. 8–10.

Conclusion

1. *Public Papers of the Presidents, Dwight David Eisenhower 1960–61* (Washington, D.C.: National Archives and Records Service), pp. 1038–1039.

2. M. Phister, Jr., *Data Processing Technology and Economics*, 2d. ed. (Bedford, Mass.: Digital Press, 1979), p. 11.

3. William Aspray, "Was Early Entry a Competitive Advantage? U.S. Universities That Entered Computing in the 1940s," *Annals of the History of Computing* 22, no. 3 (2000): 42–87; William Aspray and Bernard O. Williams, "Computing in Science and Engineering Education: The Programs of the National Science Foundation," *Electro/93*, vol. 2, *Communications Technology and General Interest* (Ventura, Calif: Western Periodicals, 1993), pp. 234–239.

4. William Aspray, "International Diffusion of Computer Technology, 1945–1955," *Annals of the History of Computing* 8, no. 4, 1986): 351–360 and Sigeru

Takahashi, "Early Transistor Computers in Japan," *Annals of the History of Computing* 8, no. 2(1986): 144–154.

5. E. Tomash and S. Rubens to files, "Visit to Remington Rand Research Laboratories—May 27 and 28," June 23, 1952, Engineering Research Associates Records, Acquisition 2015, Box 8a, Hagley.

6. Steven W. Usselman, "Computer and Communications Technology," in *Encyclopedia of the United States in the Twentieth Century*, vol. 2 (New York: Scribner's, 1996), pp. 799–829. Readers need to be aware that the computing history presented in this essay is very IBM-centric and makes little if any mention of other companies' contributions to the field.

7. Charles J. Bashe, Lyle J. Johnson, John H. Palmer, and Emerson W. Pugh, *IBM's Early Computers* (Cambridge, Mass.: MIT Press, 1986), passim.

8. Irving L. Wieselman and Erwin Tomash, "Marks on Paper: Part I. A Historical Survey of Computer Output Printing," *Annals of the History of Computing* 13 (1991): 63–79, 66.

9. It is important to note that the British government stimulated the ICL merger, while the merger of Burroughs and Sperry Rand took place outside any government involvement. Martin Campbell-Kelly, *ICL: A Business and Technical History* (Oxford: Oxford University Press, 1989).

10. I. Bolie Elzen and Donald Mackenzie, "The Social Limits of Speed: The Development and Use of Supercomputers," *Annals of the History of Computing* 16, no. 1 (1994): 46–61; and "From Megaflops to Total Solutions: The Changing Dynamics of Competitiveness in Supercomputing," in *Technology Competitiveness: Contemporary and Historical Perspectives on the Electrical, Electronics, and Computer Industries*, ed. William Aspray (New York: IEEE Press, 1993), pp. 119–151.

11. The Cray spinoff resulted from discontent with a shift in CDC strategy, when it decided to emphasize computer systems with less capability than supercomputers. Later, Cray management decided to appeal to a larger market by producing smaller supercomputers, leading to another spinoff, the Cray Computer Company.

12. The 1947 von Neumann et al. paper on logical design is referenced in ERA's book *High Speed Computing Devices*, but the ERA book was published only in 1950.

13. Robert E. McDonald interview with James Ross, December 16, 1982, CBI OH 45, CBI, p. 30.

14. McDonald interview, pp. 21ff.

Sources

Archival Collections

Charles Babbage Institute

Edmund Berkeley Papers, CBI 50.

Warren P. Burrell Collection of Engineering Research Associates and Remington Rand UNIVAC Records, 1947–71, CBI 124.

Computer Product Manuals Collection, CBI 60.

Control Data Corporation Collection, CBI 80.

Engineering Research Associates Collection, CBI 27.

ENIAC Trial Records, Microfilm Edition, CBI 145.

John L. Hill Papers, CBI 24.

Frances E. Holberton Papers, CBI 94.

Honeywell Collection, CBI 1.

Robert M. Kalb Papers, CBI 4.

William Norris Papers, CBI 164.

John E. Parker Papers, CBI 100.

U.S. Government Computing Collection, CBI 63.

U.S. National Bureau of Standards Collection of Computer Literature, 1956–78, CBI 32.

Dartmouth College Library

George Stibitz Papers.

Hagley Museum and Library

Engineering Research Associates Records, Acquisition 2015.

Sperry Corporation Records, Acquisition 1825.

Technitrol Suit Files, Acquisition 1901.

Yutter Collection, Acquisition 1904.

Hampshire College

Goldstine Papers.

IBM Archives

MIT Archives

Magnetic Core Memory, AC 337.

National Archives and Records Administration

National Bureau of Standards, Record Group 167.

National Defense Research Committee Records, Record Group 153.

National Security Agency, Record Group 457 (includes World War II naval intelligence histories).

University of Pennsylvania Archives

John W. Mauchly Papers.

Interviews

Charles Babbage Institute

Walter L. Anderson interview conducted by Arthur L. Norberg, September 11, 1986, OH 119.

Dean Babcock interview conducted by Arthur L. Norberg, September 12, 1986, OH 120.

William W. Butler interview conducted by Arthur L. Norberg, November 8, 1984, OH 92.

Robert V. D. Campbell interview conducted by William Aspray, February 22, 1984, OH 67.

H. Dick Clover interview conducted by Arthur L. Norberg, June 5, 1986, OH 113.

Arnold A. Cohen interview conducted by Arthur L. Norberg, July 2, 1987, OH 138.

Willis K. Drake interview conducted by James Baker Ross, February 3, 1983, OH 46.

Hugh Duncan interview conducted by Arthur L. Norberg, August 14, 1986, OH 118.

Robert Herr interview conducted by Arthur L. Norberg, January 17, 1987, OH 111.

John L. Hill interview conducted by Arthur L. Norberg, January 15, 1986, CBI 101.

Frances E. Holberton interview conducted by James Ross, April 14, 1983, OH 50.

Robert E. McDonald interview conducted by James Ross, May 4, 1983, OH 57.

Frank C. Mullaney interview conducted by Arthur L. Norberg, June 2, 1986, OH 114.

William C. Norris interview conducted by Arthur L. Norberg, July 28, 1986, OH 116.

John E. Parker interview conducted by Arthur L. Norberg, December 13, 1985, OH 99.

James Pendergrass interview conducted by William Aspray, March 28, 1985, OH 93.

Sidney M. Rubens interview conducted by Arthur L. Norberg, January 6, 1986, OH 100.

Edward C. Svendsen interview conducted by Arthur L. Norberg, September 16, 1986, OH 121.

Erwin Tomash interview conducted by Arthur L. Norberg, May 15, 1983, OH 60.

UNIVAC conference transcript, oral history on May 17–18, 1990, Washington, D. C., OH 200.

James H. Wakelin interview conducted by Arthur L. Norberg, February 27, 1986, OH 104.

Joseph M. Walsh interview conducted by Arthur L. Norberg, August 13, 1986, OH 117.

Robert L. Westbee interview conducted by Arthur L. Norberg, June 5, 1987, OH 112.

J. Presper Eckert, Kathleen Mauchly, William Clever, and James McNulty interviews conducted by Nancy Stern, January 23, 1980, CBI, OH 11.

Isaac Auerbach interview conducted by Nancy Stern, April 10, 1978, CBI, OH 2.

Publications

Abbate, Janet. *Inventing the Internet.* Cambridge, Mass.: The MIT Press, 1999.

Aitken, Hugh G. J. *The Continuous Wave: Technology and American Radio, 1900–1932.* Princeton: Princeton University Press, 1985.

Annals of the Computation Laboratory of Harvard University, vol. 16. Cambridge: Harvard University Press, 1948. Also, vol. 7 in the *Charles Babbage Institute Reprint Series for the History of Computing.* Cambridge, Mass.: The MIT Press; Los Angeles: Tomash Publishers, 1985.

Annals of the Computation Laboratory of Harvard University, vol. 26. Cambridge, Mass.: Harvard University Press, 1952.

"Army Soon to Get Super-Calculator." *New York Times,* March 3, 1947.

Aspray, William. "International Diffusion of Computer Technology, 1945–1955." *Annals of the History of Computing* 8, no. 4 (1986): 351–360.

———, ed. *Computing before Computers.* Ames: Iowa State University Press, 1990.

———. *John von Neumann and the Origins of Modern Computing*. Cambridge, Mass.: The MIT Press, 1990.

———. "The Stored Program Concept." *IEEE Spectrum* (September 1990), p. 51.

———. "The Institute for Advanced Study Computer: A Case Study in the Application of Concepts from the History of Technology." In *The First Computers—History and Architectures*, edited by Raul Rojas and Ulf Hashagen. Cambridge, Mass.: The MIT Press, 2000.

———. "Was Early Entry a Competitive Advantage? U.S. Universities That Entered Computing in the 1940s." *Annals of the History of Computing* 22, no. 3 (2000): 42–87.

Aspray, William, and Bernard O. Williams. "Computing in Science and Engineering Education: The Programs of the National Science Foundation." In *Electro/93*, vol. 2, *Communications Technology and General Interest*, pp. 234–239. Ventura, Calif.: Western Periodicals, 1993.

Association for Computing Machinery. *Proceedings,* Pittsburgh meeting, May 2 and 3, 1952. New York: ACM, 1952, pp. 243–249.

Association for Computing Machinery. "A quarter-century view, ACM71." New York, 1971.

Auerbach, Al, J. P. Eckert, Jr., R. Shaw, J. R. Weiner, and L. D. Wilson. "The BINAC." *Proceedings of the IRE*, 40, January 1952.

Austrian, Geoffrey D. *Herman Hollerith: Forgotten Giant of Information Processing*. New York: Columbia University Press, 1982.

Barnes, Mary C. "The History of the Glider Program at Northwestern Aeronautical Corporation." Army Air Force, Air Technical Service Command, Central District, September 1945, copy in CBI 27, Charles Babbage Institute.

Bashe, Charles J., Lyle R. Johnson, John H. Palmer, and Emerson W. Pugh. *IBM's Early Computers*. Cambridge, Mass.: The MIT Press, 1986.

Bassett, Ross. *To the Digital Age: Research Labs, Start-Up Companies, and the Rise of MOS*. Baltimore: Johns Hopkins University Press, 2002.

Bell, William D. *A Management Guide to Electronic Computers*. New York: McGraw-Hill, 1957.

Boslaugh, David L. *When Computers Went to Sea: The Digitization of the United States Navy*. Los Alamitos, Calif.: IEEE Computer Society Press, 1999.

Burke, Colin. *Information and Secrecy: Vannevar Bush, Ultra, and the Other Memex*. Metuchen: Scarecrow Press, 1994.

Burks, Arthur W., and Alice R. Burks. "The ENIAC: First General-Purpose Electronic Computer." *Annals of the History of Computing* 3 (October 1981): 310–89.

Bush, Vannevar. *Pieces of the Action*. New York: Morrow, 1970.

Business Week. March 4, 1950, p. 20.

Campbell-Kelly, Martin. *ICL: A Business and Technical History*. Oxford: Oxford University Press, 1989.

Campbell-Kelly, Martin, and Michael R. Williams, ed. *The Moore School Lectures: Theory and Techniques for Design of Electronic Digital Computers.* Cambridge, Mass. and Los Angeles: The MIT Press and Tomash Publishers, 1985.

Campbell-Kelly, Martin, and William Aspray. *Computer: A History of the Information Machine.* New York: Basic Books, 1996.

Ceruzzi, Paul E. *Reckoners: The Prehistory of the Digital Computer, from Relays to the Stored Program Concept, 1935–1945.* Westport, Conn.: Greenwood Press, 1983.

______. *A History of Modern Computing.* Cambridge, Mass.: The MIT Press, 1998.

Chandler, Jr. Alfred D. "The Computer Industry: The First Half Century." In *Competing in the Age of Digital Convergence*, edited by Darro B. Yoffie, pp. 37–122. Boston: Harvard Business School Press, 1997.

Cohen, Arnold A., and William Keye. "Selective Alteration of Digital Data in a Magnetic Drum Computer Memory." Engineering Research Associates, Inc., St. Paul, Minn., 1948.

______. Introduction to the 1983 reprint edition of *High-Speed Computing Devices.* Engineering Research Associates, Inc. New York: McGraw-Hill, 1950; Charles Babbage Institute Reprint Series, Los Angeles: Tomash Publishers, 1983.

Cohen, I. Bernard. *Howard Aiken: Portrait of a Computer Pioneer.* Cambridge, Mass.: The MIT Press, 1999.

Computer Consultants Limited. *A Record of Vintage Computers.* Middlesex, England: Computer Consultants Limited, 1965.

Cortada, James W. *Historical Dictionary of Data Processing: Organizations.* New York: Greenwood, 1987.

______. *Before the Computer: IBM, NCR, Burroughs, and Remington Rand and the Industry They Created, 1865–1956.* Princeton: Princeton University Press, 1993.

______. *The Computer in the United States: From Laboratory to Market, 1930 to 1960.* Armonk, N.Y.: M. E. Sharpe, 1993.

Costello, John. "As the Twig Is Bent: The Early Life of John Mauchly." *Annals of the History of Computing* 18 (1996): 45–50.

Crosman, Loring P. "The Remington Rand Type 409-2 Electronic Computer." *Proceedings of the IRE* (October 1953): 1332–1340.

Eckert, Jr., J. P. "A Survey of Digital Computer Memory Systems." *Proceedings of the IRE* 41 (October 1953): 1393–1406.

______. "Univac-Larc, the Next Step in Computer Design." In *Proceedings of the Eastern Joint Computer Conference.* 1956.

______. "The ENIAC." In *A History of Computing in the Twentieth Century,* edited by N. Metropolis, J. Howlett, and Gian-Carlo Rota. New York: Academic Press, 1980.

Eckert-Mauchly Computer Corporation. *The Univac System.* 1948.

Eckstein, Peter. "J. Presper Eckert." *Annals of the History of Computing* 18 (1996): 25–44.

Edwards, Paul N. *The Closed World: Computers and the Politics of Discourse in Cold War America.* Cambridge, Mass.: The MIT Press, 1996.

Elzen, I. Bolie, and Donald Mackenzie. "From Megaflops to Total Solutions: The Changing Dynamics of Competitiveness in Supercomputing." In *Technology Competitiveness: Contemporary and Historical Perspectives on the Electrical, Electronics, and Computer Industries,* edited by William Aspray. New York: IEEE Press, 1993.

———. "The Social Limits of Speed: The Development and Use of Supercomputers." *Annals of the History of Computing* 16, no. 1 (1994): 46–61.

Engineering Research Associates. *High-Speed Computing Devices.* New York: McGraw-Hill, 1950; reprint edition, Los Angeles: Tomash Publishers, 1983.

Engstrom, Howard T. "On the Common Index Divisors of an Algebraic Field." Ph.D. diss., Yale University, 1929.

———. "Polynomial Substitutions." *American Journal of Mathematics* 63 (1941): 249–255.

Feigenbaum, E. A., and P. McCorduck. *The Fifth Generation: Artificial Intelligence and Japan's Computer Challenge to the World.* Reading, Mass.: Addison-Wesley, 1983.

Fisher, F. M., J. W. McKie, and R. B. Mancke. *IBM and the U.S. Data Processing Industry: An Economic History.* New York: Praeger, 1983.

Flamm, Kenneth. *Creating the Computer: Government, Industry, and High Technology.* Washington, D.C.: Brookings Institution, 1988.

Fritz, Barkley. "The Women of ENIAC." *Annals of the History of Computing* 18 (1996): 13–28.

Furer, Julius A. *Administration of the Navy Department in World War II.* Washington: U.S. Government Printing Office, 1959.

Goldstine, Herman H. *The Computer from Pascal to von Neumann.* Princeton: Princeton University Press, 1972.

Gray, George. "The Univac Solid State Computer." *Univac History Newsletter,* vol. 1, no. 2 (1992, on-line publication).

———. "The Univac File Computer." *Unisys History Newsletter,* vol. 2, no. 2 (1993).

———, "Engineering Research Associates and the Atlas Computer." *Unisys History Newsletter,* vol. 3, no. 3 (June 1999).

———. "The Univac 1102, 1103, and 1104." *Unisys History Newsletter,* vol. 6, no. 1 (January 2002).

Gray, George, and Ron Smith. "Sperry Rand's Transistor Computers." *Annals of the History of Computing* 20, no. 3 (1998): 16–26.

Grier, David Alan. "The ENIAC, the Verb 'to program' and the Emergence of Digital Computers." *Annals of the History of Computing* 18 (1996): 51–55.

Haeff, Andrew V. "A New Memory Tube." *Electronics* 20 (September 1947): 80–83.

Hopper, G. M. "Keynote Address." In *History of Programming Languages,* edited by Richard L. Wexelblat, pp. 7–20. New York: Academic Press, 1981.

Hakala Associates. *ERA History.* St. Paul, Minn.: Sperry Corporation, 1986.

Hughes, Thomas Parke. *Networks of Power: Electrification in Western Society, 1880–1930.* Baltimore: Johns Hopkins University Press, 1983.

Jenkins, Reese V. *Images & Enterprise: Technology and the American Photographic Industry: 1839 to 1925.* Baltimore: Johns Hopkins University Press, 1975.

Kahn, David. *The Codebreakers: The Story of Secret Writing.* London: Weidenfeld and Nicolson, 1966.

———. *Seizing the Enigma: The Race to Break the German U-Boat Codes, 1939–1943.* Boston: Houghton Mifflin Company, 1991.

Knuth, D., and L. T. Prado. "The Early Development of Programming Languages." *Encyclopedia of Computer Science and Technology* 7 (1977): 419–493.

Lee, J. A. N., Colin Burke, and Deborah Anderson. "The US Bombes, NCR, Joseph Desch, and 600 WAVES: The First Reunion of the US Naval Computing Machine Laboratory." *Annals of the History of Computing* 22, no. 3 (July–September 2000): 27–41.

Liebmann, H. "Die ausgenährte Ermittlung harmonischer Funktionen und konformer Abbildungen (nach Ideen von Boltzmann and Jacobi)." Akademic der Wissenschaft zu Munich, *Berichte,* 1918, pp. 385–416.

Lubeck, von Heinz. "Magnetische Schallaufzeichnung mit Filmen und Ringkopefen." *Akustische Zeitschrift* 2 (1937): 272–295.

Lukoff, Herman. *From Dits to Bits: A Personal History of the Electronic Computer.* Portland, Ore.: Robotics Press, 1979.

Lundstrom, David E. *A Few Good Men From Univac.* Cambridge, Mass.: The MIT Press, 1987.

Mackenzie, Donald. "The Influence of the Los Alamos and Livermore National Laboratories on the Development of Supercomputing." *Annals of the History of Computing* 13 (1991): 179–201.

Maynard, Michael M. "LARC." In *Encyclopedia of Computer Science,* fourth edition, edited by Anthony Ralston, Edwin D. Reilly, and David Hemmendinger. London: Nature, 2000.

Mauchly, J. W. "Preparation of Problems for EDVAC-Type Machines." *Proceedings of a Symposium on Large-Scale Digital Calculating Machinery, Annals of the Computation Laboratory of Harvard University* 16. Cambridge, Mass.: Harvard University Press, 1947.

Mullaney, Frank C. "Design Features of the ERA 1101 Computer." *Proceedings Joint AIEE-IRE Computer Conference,* Philadelphia, December 10–12, 1951. New York: American Institute of Electrical Engineers, 1952.

Nicholas, William H. "Gliders—Silent Weapons of the Sky." *National Geographic Magazine* 86 (August 1944): 149–160.

Noble, David F. *Forces of Production: A Social History of Industrial Automation.* Oxford: Oxford University Press, 1984.

Norberg, Arthur L. "High-Technology Calculation in the Early 20th Century: Punched Card Machinery in Business and Government." *Technology and Culture* 31 (October 1990): 753–779.

———. "New Engineering Companies and the Evolution of the United States Computer Industry." *Business and Economic History* 22 (fall 1993): 181–193.

Norberg, Arthur L., and Judy E. O'Neill. *Transforming Computer Technology: Information Processing for the Pentagon, 1962–1986.* Baltimore: Johns Hopkins University Press, 1996.

Norris, Robert S. *Racing for the Bomb: General Leslie R. Groves, the Manhattan Project's Indispensable Man.* South Royalton, Vermont: Steerforth Press, 2002.

Norris, William C. "World War II Experiences." CBI Biography File on W. C. Norris, n.d.

Oldfield, Homer R. *King of the Seven Dwarfs: General Electric's Ambiguous Challenge to the Computer Industry.* Los Alamitos, Calif.: IEEE Computer Society Press, 1996.

Osborn, Roddy F. "GE and UNIVAC: Harnessing the High-Speed Computer." *Harvard Business Review,* July–August 1954, pp. 99–107.

Phister, Jr., M. *Data Processing Technology and Economics,* 2d. ed. Bedford, Mass.: Digital Press, 1979.

Poster, Mark. *The Mode of Information: Poststructuralism and Social Context.* Chicago: University of Chicago Press, 1990.

Public Papers of the Presidents, Dwight David Eisenhower 1960–61. Washington, D.C.: National Archives and Records Service.

Pugh, Emerson W. *Memories That Shaped an Industry: Decisions Leading to IBM System 360.* Cambridge, Mass.: The MIT Press, 1984.

———. *Building IBM: Shaping an Industry and Its Technology.* Cambridge, Mass.: The MIT Press, 1995.

Pugh, Emerson W., Lyle R. Johnson, and John H. Palmer. *IBM's 360 and Early 370 Systems.* Cambridge, Mass.: The MIT Press, 1991.

Pugh, Emerson W., and William Aspray, "Creating the Computer Industry." *Annals of the History of Computing* 18, no. 2 (1996): 7–17.

Randell, Brian. "The COLOSSUS." In *A History of Computing in the Twentieth Century: A Collection of Essays,* edited by N. Metropolis, J. Howlett, and Gian-Carlo Rota. New York: Academic Press, 1980.

Redmond, Kent C., and Thomas M. Smith. *Project Whirlwind: The History of a Pioneer Computer.* Bedford, Mass.: Digital Press, 1980.

———. *From Whirlwind to MITRE: The R&D Story of the SAGE Air Defense Computer.* Cambridge, Mass.: The MIT Press, 2000.

Rees, Mina. "The Computing Program of the Office of Naval Research, 1946–1953." *Annals of the History of Computing* 4 (April 1982): 102–120.

Van der Rhoer, Edward. *Deadly Magic: A Personal Account of Communications in World War II in the Pacific.* New York: Scribner's, 1978.

Rodgers, William. *THINK: A Biography of the Watsons and IBM.* New York: Stein and Day, 1969.

Rosenbloom, Richard S. "Leadership, Capabilities, and Technological Change: The Transformation of NCR in the Electronic Era." *Strategic Management Journal* 21 (2000): 1083–1103.

Ross, Douglas. "APT Session." In *History of Programming Languages,* edited by Richard L. Wexelblat, pp. 279–368. New York: Academic Press, 1981.

Rossi, Bruno. "Method of Registering Multiple Simultaneous Impulses of Several Geiger Counters." *Nature* 125 (1930): 636.

Sammet, Jean E. *Programming Languages: History and Fundamentals.* Englewood Cliffs, N.J.: Prentice-Hall, 1969.

Scott, Otto J. *The Creative Ordeal: The Story of Raytheon.* New York: Atheneum: 1974.

Seidel, Robert W. " 'Crunching Numbers' Computers and Physical Research in the AEC Laboratories." *History and Technology* 15 (1998): 31–68.

Shurkin, Joel. *Engines of the Mind: A History of the Computer.* New York: Norton, 1984.

Snively, George. "General Electric Enters the Computer Business." *IEEE Annals of the History of Computing* 10, no. 1 (1988): 72–78.

Snyder, E., and H. M. Livingston. "Coding of a Laplace Boundary Value Program for the UNIVAC." *MTAC* 3 (January 1949): 341–350.

Snyder, Samuel S. "Computer Advances Pioneered by Cryptologic Organizations." *Annals of the History of Computing* 2 (January 1980): 60–70.

"Special Issue on SAGE." *Annals of the History of Computing* 5 (October 1983).

Sperry Rand Corporation. *A History of Sperry Rand Corporation.* 1964.

Sprague, Richard E. "A Western View of Computer History." *Communications of the ACM* 15, no. 7 (1972): 686–692.

Stern, Nancy. *From ENIAC to UNIVAC: An Appraisal of the Eckert-Mauchly Computers.* Bedford, Mass.: Digital Press, 1981.

Takahashi, Sigeru. "Early Transistor Computers in Japan." *Annals of the History of Computing* 8, no. 2 (1986): 144–154.

Tomash, Erwin, and Arnold A. Cohen. "The Birth of an ERA: Engineering Research Associates, Inc., 1946–1955." *Annals of the History of Computing* 1 (October 1979): 83–97.

Usselman, Steven W. "Computer and Communications Technology." In vol. 2 of the *Encyclopedia of the United States in the Twentieth Century,* pp. 799–829. New York: Scribner's, 1996.

Van Deusen, Edmund L. *Fortune,* August 1955, pp. 88–91, 122, 124, 128.

Weik, Martin H. *A Third Survey of Domestic Electronic Digital Computing Systems.* Aberdeen, Maryland: Aberdeen Proving Ground, March 1961.

Weiner, James R. "Operating Experience with Univac Systems." *IRE Transactions on Electronic Computers* 1 (December 1952): 33–46.

Weller, Robert. "Review of the Naval Cryptologic Museum." *Cryptologia* 8 (July 1984): 228.

Welsh, H. F., and V. J. Porter. "A Large-Capacity Drum-File Memory System." *Proceedings Eastern Joint Computer Conference*, 1956.

Wetzel, William W. "Review of the Present Status of Magnetic Recording Theory." *Audio Engineering* 31 (November 1947): 14–17, 39; (December 1947): 12–16, 37, 32; (January 1948): 26–30, 46–47.

Wieselman, Irving L., and Erwin Tomash. "Marks on Paper: Part I. A Historical Survey of Computer Output Printing." *Annals of the History of Computing* 13 (1991): 63–79.

Wilkes, Maurice. *Memoirs of a Computer Pioneer*. Cambridge, Mass.: The MIT Press, 1985.

Wilkes, Maurice, D. J. Wheeler, and S. Gill. *The Preparation of Programs for an Electronic Digital Computer, with special reference to the EDSAC and the use of a library of subroutines*. Cambridge, Mass.: Addison-Wesley, 1951; reprint edition, Los Angeles: Tomash Publishers, 1982.

Williams, Michael R. *A History of Computer Technology*. Englewood Cliffs, N.J.: Prentice-Hall, 1985.

Worthy, James. *William C. Norris: Portrait of a Maverick*. Cambridge, Mass.: Ballinger, 1987.

Yates, JoAnne. "Early Interactions between the Life Insurance and Computer Industries: The Prudential's Edmund C. Berkeley." *Annals of the History of Computing* 19, no. 3 (1997): 60–73.

———. *Structuring the Information Age: Life Insurance and Information Technology in the 20th Century*. Forthcoming, Johns Hopkins University Press.

Index