West Coast Contributions to the Development of the General-Purpose Computer

Building Maddida and the Founding of Computer Research Corporation

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The story told here is of the members of a computer group—established by Northrop Aircraft in the mid-1940s to develop a guidance system for a US Air Force missile—who subsequently founded a company that designed and built a general-purpose, digital computer. Successful, but in need of funds, the company was eventually absorbed by a larger enterprise.

The genesis of this history of Northrop Aircraft's pioneering work in digital computers during the 1946 Snark missile program was a 13 May 1996 meeting of myself [Donald Eckdahl], Irving Reed, and Harold Sarkissian at Sarkissian's Newport Beach, California, home. I subsequently undertook research that included numerous visits to the National Cash Register (NCR) Corporation archives in Dayton, Ohio, and a review of the extensive oral histories of many key early participants in the computer industry collected in the 1970s as part of a Smithsonian Institute–sponsored program. I have drawn particularly on the histories of Floyd George Steele, Richard Sprague, Sarkissian, Reed, and myself.

Briefly, Northrop's "computer group" developed a digital differential analyzer (a machine capable of analyzing and solving a system of ordinary differential equations), which it called the Maddida (Magnetic Drum Digital Differential Analyzer), and later founded Computer Research Corporation (CRC). Purchased by NCR in 1953, CRC became the technical and organizational underpinning of that company's electronics and computer structure. CRC personnel played a major role in NCR's transformation, during the 1970s and into the 1980s, from a mechanical-based office equipment company into a highly profitable electronics and computer systems company.

Most histories place almost all of the pio-

Editor's Note

In addition to collaborating with his coauthors, Donald Eckdahl received, during 1996 and 1997, editorial assistance and guidance from Eric Weiss, then biography editor of the *IEEE Annals of the History of Computing*. In mid-2000, Eckdahl presented a more or less finished manuscript to another editor, John Simon, who suggested some further refinements and restructuring and subsequently edited the manuscript.

Coauthor Harold Sarkissian passed away in February 2001 while this work was in process. The work was essentially completed and the manuscript had been accepted by *Annals* when Eckdahl passed away in July 2001. Simon subsequently worked with surviving coauthor Irving Reed to incorporate the helpful suggestions and address the insightful observations of the *Annals* reviewers, for which both are grateful.

Given the circumstances under which the article was drafted and Simon's unfamiliarity with the subject matter, there is clearly room for errors of omission and misinterpretation. Readers' added recollections and corrections are welcome.

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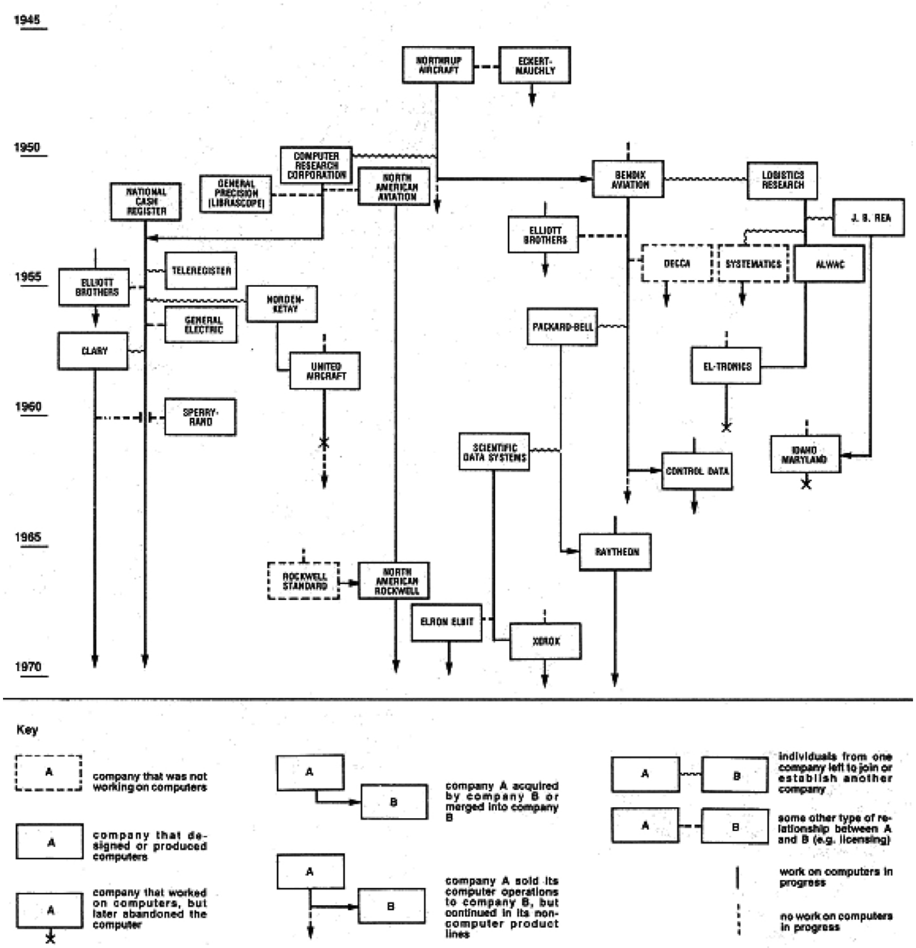


Figure 1. Genealogy of West Coast aircraft and computer industries. (Courtesy of the Charles Babbage Institute, University of Minnesota, Minneapolis.)

neering work in the development and manufacture of the digital electronic computers from which the current major computer industry evolved in the eastern half of the US.[1,2] This history documents how a group of people in the western US developed, between 1946 and 1953, a digital computer and digital computer design concepts that resulted in

- the invention and implementation of the digital differential analyzer;
- the development of logic and circuit design that used Boolean algebra comprehensively to implement germanium diode logic;
- the development of digital magnetic recording concepts and an airborne magnetic tape unit and early magnetic drum that was used as the main memory device of the digital differential analyzer;
- a series of digital computers that included digital differential analyzers and general-purpose computers the size of a small refrigerator, not the small room size that was still the norm in 1952;
- the first transcontinental shipment of a digital differential analyzer and its successful operation within 24 hours of arriving at its destination (to enable John von Neumann, then at the Institute for Advanced Study in Princeton, New Jersey, to operate the machine and evaluate its implications);
- the formation of a commercial computer company that would later be sold to NCR and become the basis of NCR's position in the computer industry in the 1960s and 1970s;
- the development of the piezo-electric quartz crystal oscillator clock;
- the definition of logic propositions as high or low voltage rather than the presence or absence of a pulse; and
- the spawning of about 14 other computer companies (see Figure 1).

Northrop and Project MX-775

Aeronautical engineer Jack Northrop founded Northrop Aircraft in 1939. Between entering the aircraft industry in 1918 and being named Lockheed Aircraft's chief engineer in 1972, he pioneered, among other novel design concepts, the monocoque or stressed-skin construction of the highly successful Lockheed Vega. During World War II, Northrop produced the P51 Black Widow, the first night interceptor aircraft, some of which were still test-flying prototypes of guidance equipment modules in 1946 when the company landed a US Air Force contract for a new missile that was to use a unique, automatic, extremely accurate guidance system for long-range missions.

The contract apparently did not specify a rocket drive, and the company chose the Black Widow, with a range and speed slightly greater than that of the latest WWII manned bombers, using navigation by the stars as was common before loran (long-range navigation, a technique that employed radio to plot the position of a ship at sea). The required range was greater than 5,000 miles with a required accuracy of one-tenth of a nautical mile. The original idea, to take star sights automatically every so often and then rapidly and accurately compute the true position, clearly required a digital computation system.

Further study led Northrop and the Air Force to call the system *inertial navigation* because using a gyroscope to maintain a stable platform in space was the same as locking a telescope onto different stars. Both concepts required continuous knowledge of the horizon or true vertical, and because the force of motion in a fast-moving aircraft or missile cannot be distinguished from the force of gravity, the computation continuously required the solution of a set of differential equations from the known initial conditions of the craft. Because navigating as done by ships at sea—by using the horizon to make star sights—was not possible in a rapidly moving aircraft, inertial guidance was the only way to go.

The development organization

In the spring of 1946 I had just been discharged from the US Navy, having served most recently as a naval officer on a supply ship in the Pacific. I had graduated from the University of Southern California (USC) in 1944 while still in the Navy, with a BS in electrical engineering. Now I wanted and needed a job, preferably as an engineer, as I'd had a long-term love affair with electronics and had held an amateur radio license since the age of 13. Having a child on the way helped me decide to take the job rather than a graduate fellowship at the California Institute of Technology (Caltech), although through evening studies at USC I was able to earn an MS in electrical engineering in 1949.

Engineering jobs were scarce in 1946. I found a few opportunities to work as an electronics technician, but none as a development engineer. After much searching, I obtained an interview with Eric Ackerlind at Northrop Aircraft in Hawthorne, California. Northrop management thought that a computer group was needed to help with the development of the guidance system. Ackerlind had been hired to create that group on the basis of his many years of experience in radio and communications development.

I was familiar with the mechanical and electronic analog computers used in the Navy, but not with the new digital computers. Evidently satisfied, however, by my excellent grades from the university and electronics experience (by way of my longtime ham radio hobby), Ackerlind hired me. Many times since August 1946 I have thought, How could a 22-year-old have been so lucky to find employment in such a difficult time and be dropped right into the beginning of the digital computer revolution?

Early on I learned that, although he visualized the use of digital computer techniques to help solve the guidance problem, Ackerlind did not presume an actual digital computer to be part of the in-flight equipment. He was aware that all of the digital computers built or proposed up to that time were "rooms full of equipment."

My new direct boss, Floyd George Steele, had been hired by Ackerlind in March 1946. Aged 28, with a BA in physics, a BS in mechanical engineering, and an MS in aeronautical engineering, he had worked at Douglas Aircraft in operations research from 1941 to 1944 and as a radar technician in the US Navy from late 1944 to early 1946. Ackerlind added Richard Sprague to the computer group in July 1946. Aged 24, Sprague held a degree in electrical engineering from Purdue University where he had done course work under a professor named Siskind in what was then the secret area of radar.

"He called it something else," Sprague recalled,

> but I took one of the first courses in radar at Purdue in 1941, as did many of us majoring in electronics. Upon graduation, I joined the General Electric Company in their test-engineering program at Schenectady [New York]. I stayed in that program for a year and a half and sort of

> managed to talk myself into radar projects all the time I was with them.[3]

In 1944 the Navy was looking for electrical engineering graduates to become radar officers; Sprague had enlisted and become a naval officer at Fort Schuyler, New York. Following a year of training, he was assigned to radar design work for the Naval Research Laboratory in Washington, D.C. "My view," he reflected, "is that the technologies that went into radar developments were just as important as almost anything else you could name in the beginnings of the electronic digital computer field."

The senior manager of Project MX-775, El Weaver, was an experienced Northrop project engineer from the airframe side of the business. He organized the MX-775 missile program with a comprehensive technical and administrative management team that represented the many disciplines needed to develop such a complex system, bringing in scientists, mathematicians, and designers in optics, celestial mathematics, gyros, communications, computers, and general airborne electronic equipment systems.

Knowing that the analog computers used as in-flight equipment in aircraft control systems could not deliver the required accuracy for a guided missile system, and that the size of proposed digital computers rendered them unsuitable for field use, never mind in-flight use, Weaver's team of technical and systems experts proposed to build or buy a "function generator" (or perhaps digital computer) for use on the ground. The generator was expected to develop a data string that would be recorded on tape by the new "magnetic" recording method demonstrated by the Germans during WWII.

In the months that followed my arrival, the computer group studied and learned. We read everything we could about digital computers, including the ENIAC design papers by J. Presper Eckert and John Mauchly at the University of Pennsylvania's Moore School of Electrical Engineering, reports from the Ballistic Research Laboratory at Aberdeen Proving Grounds, the ENIAC's purchaser and user, and the Electronic Discrete Variable Automatic Computer (EDVAC) proposal, written, I believe, by Eckert and Mauchly while still at the Moore School. The EDVAC proposal described an internally programmable machine that could store its own instructions and then modify its path through those instructions. It also proposed and conceptually elaborated the future "general-purpose" computer. We subsequently built and tested electronic circuits, taught ourselves how to build digital "gates" and "mixers" using vacuum tubes and germanium diodes, devised ways to build special-purpose computers and function generators, and considered storing digital numbers on magnetic wire and tape recorders.

Concurrently, the computer group began to expand. Will Dobbins joined in November 1946, Bernie Wilson in February 1947. In June 1947 two Caltech graduate students signed on as summer consultants. Herman Kahn stayed only for the summer, leaving for the Rand Corporation and later authoring the book *Thermonuclear War* (we encountered him again, for a short time, as an employee of CRC circa 1951). Irving Reed was later among the founders of CRC. "One of my jobs," he recalled, "was to try to find a guidance criterion using star trackers for guiding the missile."

Reed had earned a PhD in mathematics with a minor in physics from Caltech before joining Northrop as a full-time employee in June 1949. While a graduate student at Caltech, he had taken a course in symbolic logic from E.T. Bell. The former Navy electronics technician had asked Bell about the possible application of symbolic logic to the physics of relay switches. Bell had directed him to the seminal paper that Claude Shannon had authored in 1938 about the use of Boolean algebra in logic design for relay devices. Reed recognized this potential more clearly when he later became involved with digital computers at Northrop, where he introduced the concept and Shannon's paper to Floyd Steele. Steele later explained to others the mathematical concept of Boolean algebra and how it might be used in the design of electronics as well as relay logic.

In September 1947, Ackerlind and Steele hired Hrant (Harold) Sarkissian to be the computer group expert on magnetic recording. Upon graduating from the University of California at Berkeley with a degree in electrical engineering in 1944, Sarkissian had entered the Signal Corps. He spent two and a half years working with microwave equipment, eventually in Germany. "The reason I got the job [at Northrop]," Sarkissian recalled,

> at least I believe it is the correct reason, aside from the fact that they were beginning to hire electronic engineers again, was that I had seen one of the first tape recorders that the Germans had made called the Magneto-phone. That was as close to tape recording as anybody at Northrop had been, apparently, so that qualified me as a magnetics expert. In any case they put me into the computer group … under … Dr. Eric Ackerlind.

> … My immediate supervisor was Don Eckdahl. The group numbered 15 or so, but I do not remember exactly because they were hiring more rapidly at that time to get into the guidance and control of the Snark missile system.

From theories to devices

Steele, about five years older than the rest of us and the computer group's genius and spokesperson, was our conceptual leader. He lived with his family in Manhattan Beach, a small coastal town south of Los Angeles. I met Steele often for dinner and walks along the beach during which we discussed subjects both technical and intellectual, ranging from music to books by Dostoevsky and Oswald Spengler to the revolution that we believed was going to be precipitated by the effect of the new digital computers on business, entertainment, military systems, and so forth. He was our teacher; we, his disciples.

Dependent on the rest of us to develop and implement his concepts, theories, and ideas, Steele pushed us hard to apply the Boolean algebra concept to the implementation of logic in electronic digital circuits. He expected us to readily develop the methods for moving from Boolean equations to the design of a digital electronic logic system that represented those equations. He also promoted the notion that a computer was a set of stable states that could change in sequence in accordance with a logical system. He proposed that a logical proposition be defined as being equivalent not to the presence or absence of an electronic pulse, as was then common practice, but to a high voltage (true) or a low voltage (false).

DIDA

Steele, who had read Lord Kelvin's paper on the ball and disk integrator and about the operation and use of the large mechanical differential analyzers proposed and built by Vannevar Bush, had by late 1946 conceived the concept and general structure of a digital differential analyzer, later nicknamed DIDA. The device was to have two electronic registers for each integrator. Transferring a binary number from one register into the other as directed by a pulse stream, the input rate generated an output each time the second register overflowed; the sum of the output stream of pulses was the integral of the number in the first register times the input rate.

Asked by Steele to employ this concept to design and construct a digital differential analyzer, Sprague and Wilson designed the integrators and a pair of registers. Each stage comprised one flip-flop, which usually employed two vacuum tubes. A register that could hold an 18-bit binary number would thus require 36 vacuum tubes. A pair of registers became an integrator. The building of multiple copies of these flip-flop circuits and electronic registers was subcontracted to the then-fledging Hewlett-Packard Company, at the time a small but successful producer of quality test instruments for the electronic equipment industry (primarily radio receivers and audio amplifiers). Because each integrator existed as a pair of physical registers, a 10-integrator DIDA thus had 10 pairs of electronic registers. Integrators were interconnected according to the differential equation to be solved, the wires from the output of one integrator being connected to one of the two inputs of one or more of the other integrators. Sprague and Wilson built several integrators, eventually reaching the stage of waiting for parts needed from Hewlett-Packard to conduct a system test of a small DIDA.

Quartz clock

For a missile guidance system to continually solve differential equations required extremely accurate initial conditions at the outset of computation. Among these conditions were launch site and time. Whereas the launch site could be specified accurately using longitude and latitude, the state of the art in timekeeping technology was accuracy only to about one-tenth of a second. The government broadcasted from Washington, D.C., on a radio station with call letters WWV, a signal by which a clock could be set to an accuracy of about one ten-thousandth of a second, which was adequate for missile guidance if a clock could be built to keep time to the same or better accuracy. We concluded that a digital system could be devised to turn temperature-controlled quartz (piezo-electric) into a "clock." Steele assigned this development task to me.

Digital counters were designed and constructed that would start with the crystal oscillator's pulse rate, which turned out to be 100,000 cycles per second. We subcontracted the building of the constant-temperature oven needed to keep the crystal stable and prevent its frequency from drifting. We also developed the circuitry to convert the oscillator output from sine waves to pulses and a digital counter to reduce the rate to speeds that could be displayed as hours, minutes, seconds, and tenths and hundredths of seconds. The digital counters thus had to divide by (or count to) specific numbers such as 60. The detailed design for this project taught us a great deal about digital circuit design with vacuum tube flip-flops and germanium diodes.

The successful development of this clock device was the occasion for many evenings and late nights spent with other guidance system people flight-testing early modules. Our testbed was a P51 Black Widow aircraft. The quartz, piezo-electric, crystal oscillator clock was a precursor of today's quartz digital watch, which substitutes integrated transistor circuits for vacuum tubes to minimize size.

Magnetic digital recording and playback

Concurrently, Sarkissian was leading another small group engaged in the development of an airborne magnetic tape unit that was to record and play back digital signals unattended over an eight-hour period. Not only the circuitry, but the methods for recording and playing back digital numbers rather than audio voice or music, had to be developed. Recalled Sarkissian:

> There were wire recorders, so one of the first things I was supposed to do was pick out digital signals from a wire recorder. The specs were very difficult to meet for that time. The wire recorder was supposed to record digital information and then play it back in a precise manner. … Upon asking for background information I suddenly discovered that there was not any on tape recorders, either at Northrop or even in the literature, except some very basic things about the early history of wire recording or magnetic recording. This launched me, more or less, into research of what was then the state of the art and how we could make use of it.

Sarkissian's group exceeded the extremely tight reliability specifications established by the system designers for the digital magnetic recording endeavor. Sarkissian and I often drove together to Northrop Field in the evenings to help the team carry out the interesting, and educational, flight tests of the airborne magnetic tape unit.

Binac

In December 1947, an R. Rawlins, then assistant project engineer for guidance, let a contract to Philadelphia-based Eckert-Mauchly Computer Corporation to design an airborne digital computer to solve the in-flight guidance problem. This was a curious step, given that the rest of the technical and administrative management of Project MX-775 did not accept the practicability of an airborne computer solution. (Our computer group did not begin to accept the possibility of an airborne computer until the Maddida [pronounced "mad eyeda"] was close to a reality.) Eckert and Mauchly called the machine they delivered 18 months later the Binary Automatic Computer (Binac). The Binac, although small compared to other early computers, at 10 to 20 times the size of the Maddida was not even close to being a prototype for an airborne version of a computer (see Figure 2).

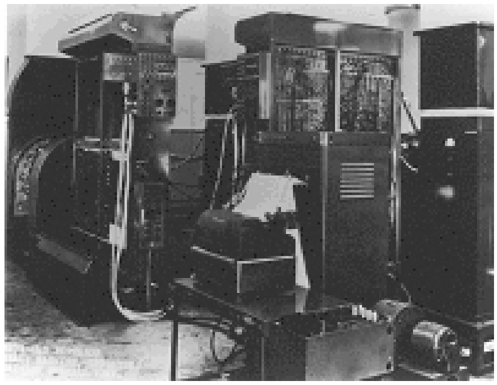


Figure 2. The Binac computer delivered in fulfillment of the contract to design an airborne digital computer. (Courtesy of the Computer History Museum, copyright 2003.)

"It was sort of a preposterous request to be an airborne computer," reflected Sarkissian.

> It was a best-effort thing. Perhaps they had other reasons for asking for this; it may have been a way for the government to sponsor development, which apparently was what was going on. Ike Auerbach, an engineer at Eckert-Mauchly, was on the other end of this at that time and he could probably see more of what was happening … than we could. I knew a little more about a year or so later when Northrop management was thinking about sending someone back to Eckert and Mauchly for training. Until that time, the Eckert-Mauchly program was hardly visible on our end. I think our computer group was essentially only advisory, with respect to the project head, on this particular program.

Genesis of the Maddida

In January 1948, after nearly completing work on the electronic digital clock, I was asked by Steele to develop a magnetic drum memory version of the digital differential analyzer (thus, Maddida). Steele believed Sarkissian to be far enough along in his study of magnetic recording to lead the development effort. I was to be project engineer and team leader. Jack Donan and Carl Isborn joined the computer group in the spring of 1948. Al Wolfe and Dobbins were among the other team members. Sprague continued to work on DIDA until January 1949, then, leaving its completion to Wilson, became an active participant in the Maddida development effort.

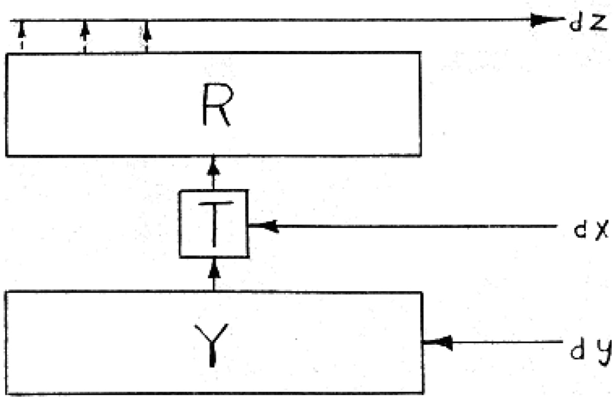


Figure 3. Diagram of the type of integrator used in the Maddida. (From *Maddida Preliminary Report, Project MX-775*, Report No. GM-545, Northrop Aircraft Inc., 26 May 1950; personal files of D. Eckdahl.)

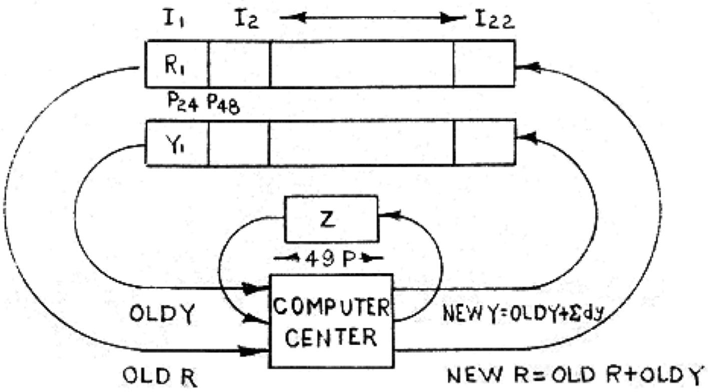


Figure 4. The flow of information through the Maddida. (From *Maddida Preliminary Report, Project MX-775*, Report No. GM-545, Northrop Aircraft Inc., 26 May 1950; personal files of D. Eckdahl.)

Concept

The integration concept for the Maddida involved adding and subtracting the contents of two registers, the number y in the Y register to or from the R register. This addition–subtraction update of the integrator was accomplished at the occurrence of an input differential dx (±1 divided by a scale factor, some power of 2). (The type of integrator used in Maddida is shown in Figure 3.) The R register had the same length as the Y register and would overflow or underflow depending on the size of the number y multiplied by the sign (±1) of the differential dx needed to form the output differential $dz = ydx$ of the integral $z = \int ydx$, where, again, the differential dz is ±1 divided by the appropriate power-of-2 scale factor. The method of integration in Maddida had the advantage over previous techniques of numerical integration of having minimal round-off-error growth. Reed successfully proved the validity of the Maddida technique of numerical or digital integration.[4]

In the overall Maddida system, a sequence of pairs of numbers, namely, the Y and R registers, were recorded along two tracks of a magnetic drum. These pairs, which represented a finite set of integrators (originally 22 integrators), were operated on sequentially every turn of the drum as they passed by the read and write heads. (The flow of information through the Maddida is shown in Figure 4.) These operations caused (or did not cause) two possible things to occur: increment the number y in the Y register by the differential dy, and add the number y, multiplied by dx, to the R register to form the output differential dz (±1 divided by the appropriate output scale factor of the integral).

Technical training

Early in 1948 we learned that Alvin Sugar was to offer at USC, during the winter semester, a graduate course in electrical engineering called "Programming a General Purpose Computer." Steele, Sprague, Sarkissian, and four or five others subsequently took advantage of this extraordinary opportunity. Sugar, who had recently been engaged as a consultant by Eckert and Mauchly, had been granted permission to use the planned instruction set for their Univac computer, which was then under development. This timely course, which ran a full semester, involved writing a program to perform matrix inversion. The Univac machine language's straightforward, one-address structure mirrored the computer's logical design. The concept of assembly and high-level programming languages had not yet been conceived, nor did the word software yet exist; all programming in that period was done in machine language.

Following development of the Binac in the summer of 1948, Mauchly began visiting Northrop every two to three months. In addition to whatever business he might have had with Northrop management, he routinely lectured members of the computer group about digital computer concepts and design, including logic, circuits, and memories. Being a professor of physics, Mauchly was an excellent teacher. He was also friendly and open. Over the course of more than a year, we benefited from about five half-day lectures.

Eckert's and Mauchly's design concepts involved the use of vacuum tubes (no germanium diodes) for both flip-flops and logic.

Moreover, they defined logical propositions as the presence or absence of a pulse. Finally, Eckert and Mauchly did not use Boolean algebra in logic or system design.

Logic and circuit design

Having been acquainted by Steele with the background and mathematical concepts of Boolean algebra and how germanium diode networks could be formed to represent any Boolean algebra expression, Sprague and I, while developing the Maddida's logical design, found a way to apply Boolean algebra to a total system of logic and circuits. Our method was to create and write the logic equations that defined the input to each input side of every flip-flop in the system. Each input equation was based on the states of all the other flip-flops. The result was the set of Boolean equations both necessary and sufficient to define the machine.

The mathematical logic (logical propositions) was represented electronically as a high voltage for true and low voltage for false. (In the ENIAC, Binac, and Univac, logical states or propositions were represented by the presence or absence of an electronic pulse.) The basic logic premises, electronic circuits, and total system design using Boolean algebra were thus all different and new in the Maddida and the machines descended from it.

Memory drum and NRZ magnetic recording

Sarkissian and Isborn developed the mechanical structure and system of adding the magnetic recording that was to become the Maddida's memory. The drum was about eight inches in diameter and an inch and a half thick. The magnetic surface was made by first dissolving the coating off magnetic tape and then spraying it on with a small airbrush-size paint sprayer (we did not yet know enough about magnetic coating to formulate our own).

Sarkissian related an instance of the give-and-take that culminated in the development of the digital magnetic recording system and circuits. "Don Eckdahl and I," he recalled,

> sat in a hotel room in New York City and solved this problem, and then … proved that it could be done. … [W]e devised a system that did not change the character of the logical signals, as was the case with the methods that other people used. … We felt people would be more satisfied with a solution that did not require a completely different technique to transform from one form and then retransform … back. Such things were occurring in mercury memories and in electrostatic memories and a variety of other schemes. …
>
> In lay … terms: … to record 0s and 1s you have to be able to detect … a zero or a one. The problem is how do you detect a zero. Many different schemes were tried to make a one and a zero look different on a drum. You can record it by saying if the magnetic field is north, that is a one; if it is south it is a zero; and so on. … The method we used, which is now old hat, is called the NRZ (non-return-to-zero) system. If the logical signal, say, is a one, we change it so that the recording is north. We stay there, we do not change anything, and the head continues to record north, north, north, north. … Then, when it goes from a one to a zero … we go from all north to all south. All we are worried about is that change. … [I]f that change occurs then we change the flip-flops. …

Misunderstanding and miscommunication

In April 1949, Ackerlind, apparently worried that he lacked authority to develop an airborne computer and that other jobs seemed to have much higher priority at Northrop, began to reassign members of the computer group to other activities. In May, in a memo to Ackerlind copied to Frank Bell, George Fenn, and a P.H. Taylor, Steele stated that the Maddida "already has" all of the timing and intelligent features to control star trackers and so forth and even estimated the total number of vacuum tubes required. If asked, as project engineer I would not have supported this highly optimistic suggestion that the Maddida might be adapted to the requirements of a full guidance system.

In July and August, some members of the somewhat free-running computer group were dispatched to Philadelphia to learn about the Binac. Donan, Dobbins, Isborn, and Bob Prathers visited Eckert-Mauchly Computer Corporation in July; Steele, Sprague, Reed, Jerry Mendelson, and I visited in August. Each group stayed for about a month. Probably arranged by management to keep us out of their hair, the visits also served to familiarize some engineers with the Binac before Northrop took delivery of it.

"The people we met with," recalled Sprague,

> included Ike Auerbach, Al Auerbach, Bob Shaw, and Grace Hopper. … Shaw was the logical designer of Binac and an incredible guy. He was responsible almost single-handedly for the logical design of all of the early Eckert and Mauchly machines. … He was almost blind. … He also had a spastic condition. … He had to walk on crutches. … In other words, he was pretty severely handicapped. But he was a brilliant guy and did a lot of the

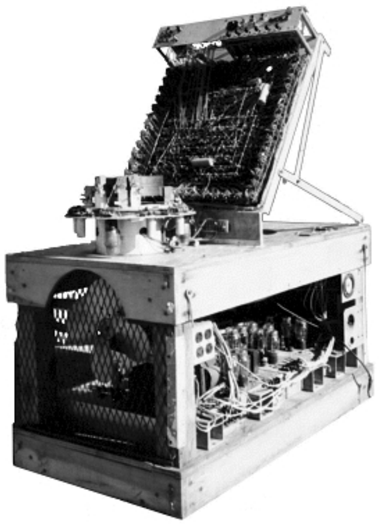


Figure 5. This is the Maddida designed, built, and tested at Northrop. It used a very different construction, even for that time. A large diode board, ringed with vacuum tube flip-flops, was hinge-mounted on the surface of a "teacart" provided with rollers for mobility. The drum memory was also mounted on the surface; situating the vacuum tube circuitry directly on the drum structure minimized the length of the leads between the magnetic heads and amplifiers. The power supply for the drum and logic unit was installed under the cart. The original Maddida is part of the permanent collection of the Computer History Museum. (Courtesy of the Computer History Museum, copyright 2003.)

design work in his head ....

When you are dealing with ... pulse circuits, gates, etc. you really had to draw these circuits on ... circuit diagrams. ... Shaw had help ... drawing ... circuit diagrams, but he had no help ... reading them. ... In order to read one of his own diagrams, he had to put it about three to four inches from his eyes and he could only see a little bit of it at any given point. ... The thing that was very impressive was he would have ... a piece of drawing paper four feet long and three feet high completely covered with Binac circuitry. And he would pick it up, look at one point on it, and immediately shift his way around on that diagram by moving it in front of his eyes to some other point. ... It was obvious he had the whole diagram stored in his head. He could not have done it otherwise. ... It was incredible. ... Al Auerbach was also a terrific circuit designer on the Binac.

Sprague recalled Ike Auerbach being astute in the marketing area and Hopper being a remarkable programmer. Of Eckert and Mauchly, he recalled how

> we would walk out into the laboratory and Eckert would be out there talking about the latest developments ... in very esoteric terms, using mathematical expressions while he was discussing whatever it happened to be. And all the time he would be talking with somebody, he'd be standing there twirling his key chain in a wide circle. ... Carefree, would you say? ... Mauchly [was] at the other extreme, very quiet.

Our group's political problems at Northrop worsened during the Maddida's initial debugging. Looking back, I see that we caused most of the problems ourselves. The project management must have had trouble keeping track of our group. Moreover, although accepted as the leader and spokesman of those in the computer group, Steele was never able to convince others, either technically or politically, of the promise or practicality of our work. The result was a sad and somewhat humorous succession of misunderstandings and conflicts between members of the computer group and the Northrop management structure. The Maddida was nearly a bootlegged or skunk works-type project; management tried many times to split it up, disband it, and reassign key personnel to other projects. Ultimately, management looked to other managers such as Lee (Leo) Ohlinger to try to control us.

We trusted Steele to represent our viewpoints to management; we believed that he really tried to demonstrate the importance of our developments in digital computers and the impact they might have on the problem of inertial guidance of the Snark missile. We also presumed that he had emphasized the probable business opportunities that a pioneering position in the then-new commercial computer sector might afford Northrop Aircraft. But we later found that Steele had, in fact, instead communicated to both the project management and to Jack Northrop the far more radical ideas that the new techniques associated with digital computers were so powerful that the company should scrap its entire guided missile program and begin anew with an all-digital system for all elements of the product, save the airframe. He almost surely did not propose a specific plan or offer to lead this total redesign. He must have believed that we had done and proven so much that it should be obvious to management that Northrop's full resources should be applied to this proposed change in direction.

The Maddida on tour

By the time I returned from my visit to Eckert and Mauchly, Sarkissian and Wolfe had made considerable progress. Although I had by then been directed to leave the project, I nevertheless returned to the project area in order to continue to debug the Maddida (management rescinded its stay-away order about a week later). Debugging progressed through many stages, including intercommunication between integrators. By November 1949 we had a working, 22-integrator digital differential analyzer, as Figure 5 shows.

Von Neumann's appraisal

The pressure on Northrop management to explain the apparent success and importance of this "bootlegged" machine was severe. In late February 1950, Steele and Reed convinced management to let us transport the Maddida to the Princeton Institute for Advanced Study for review and evaluation by John von Neumann. Steele, Reed, and I left for Princeton after packing and air shipping the Maddida. Also making the trip as a representative of Northrop management was Ohlinger, our new boss.

Our arrival at Princeton and subsequent interaction with von Neumann is chronicled by Reed:

> The first day we arrived in Princeton, the machine was put in a fourth-floor hotel room of the Princeton Inn. … We realized that we did not have any way to get the necessary power. We had a three-phase power supply. … I think it was Don [Eckdahl] who noticed that there was an electric company across the street, so before we went to bed we decided … to see if we could get a cable strung across the street. That … was done. A cable was run from the power company to the window on the fourth floor of the Princeton Inn. …
>
> Von Neumann told us that he had done some prior work investigating the machine and … had read what few reports there were. He told us that he had ideas similar to this before and that one of the reasons Whirlwind had come into existence was because he and some others had the idea that to build aircraft of the future they would need giant simulators. One of the purposes of the Whirlwind computer was aircraft simulation, initially the simulation of control systems. He said that he had another idea along these lines to build a differential analyzer machine. I think somebody at that time had built an extensive analog differential analyzer, but I do not remember whom.
>
> The big problems at that time were related to the fact that we were just getting into the jet age and people were worried about high-speed aircraft and the new control systems. … No longer could people steer airplanes directly with cables; they had to go through power units and servo systems and … we would have to build simulators to simulate the performance of such machines to make sure they worked. Von Neumann thought one possible application of a Maddida-type machine could be this simulator. I think he said as much in the document that he wrote to Jack Northrop. …
>
> [Von Neumann] asked to see a diagram of the machine. One of us, probably Don, pulled out a long list of equations and told him that this was our best description. He was very impressed and said that he always thought one could design a machine this way. I think he reminisced to some extent back to Turing and … EDVAC and ENIAC.
>
> [Von Neumann] asked about programming the machine and … I got up to the blackboard and showed him how we did it. All my student life and my professional life … I had known about von Neumann as a great mathematician and I thought he was almost omniscient in his capability. I said that we were going to program the Bessel equation and he asked me to write it down because he could not remember it. He was very nice in the sense that he played down the fact that he may have known the equation. So I wrote it on the board very quickly. … He raised my ego by having me do that. After this I showed him how we did the programming. I think that Don gave a short lecture on the logic and finally we came out with the logic diagrams. This all took place at his office before he ever saw the machine.
>
> I think Don explained a logic design formula to von Neumann and showed how we used it to go about the design of diode "and" and "or" logic circuits. Von Neumann was very impressed. I think to some extent the structure was also discussed. … There were only four channels on the drum. One was a clock track, which was only a read track. There was a circulating register track and … a pair of channels, which were both read and write, which served for the integrators and the code.
>
> I think Don … handled most of the explanation because Steele was not very good at explaining the details of how something worked. He was more of a philosophist, whereas Don was very exact, crisp, and to the point. …
>
> As Jerry Mendelson told it to [Robina] Mapstone [oral history interviewer for the Smithsonian's National Museum of American History], Steele would conceptualize on such and such and within a couple of days or [a] week … Eckdahl would have it manifested.
>
> Von Neumann was very impressed by the fact that we got this machine on an airplane and flew it to Princeton.
>
> It seems to me that during that afternoon we went to another location in Princeton and got a complete rundown on the [Institute for Advanced Study] IAS machine. It was under construction and quite complete, but not yet operational. We met both [Julian] Bigelow and [Herman] Goldstine. I do not think Bigelow particularly reacted, so I do not know if he was impressed or not. I have seen him since then, but I do not think he recalls that we were there. We did not make much of an impression on him.
>
> Before von Neumann came over to see the Maddida in our hotel room, we were invited over to his house where we had one of his … very dry martinis. He was famous for his martinis, which were probably pure gin. Bigelow was with him, and so was his wife. She was a scientist or a mathematician and I think she actually had

something to do with computing machines. She understood what we were doing more or less. Bigelow came over and I remember him sitting next to me on the couch. I still remember the fact that [von Neumann's] furniture was as worn as mine. He was not a very ostentatious man and he had what I would call rather plain furnishings, probably second-hand. This made me think he was really a scientist, although he looked more like a businessman. He seemingly enjoyed living and … was a humorist.

I was very impressed because he was everything I thought a mathematician and scientist should be. He was a hero to me, certainly, particularly since when in school I had studied game theory and had read part of his book, which is not easy to read.[5]

The next morning I programmed the machine with a particular case of the Bessel differential equation. It took quite a while … because the data had to be put in with push buttons. Don was the expert on loading it. He was really the only person who knew how to operate it. If it had not been for Don, I think it would have been a disaster. … Floyd and I were good at guessing where the trouble might be, whereas Don had everything under control and knew exactly what was going on within the machine.

To make a long story short, we had the machine programmed to do *J* of order one-half ($J_{1/2}(x)$), which is a simple program and easy to put into the machine, and Don was checking the program to make sure it went through the right value at a certain time, when von Neumann arrived unexpectedly. He … asked what we were computing and I told him we were computing the Bessel function. … He sat down and with a pencil and paper computed where the machine should be at the next checkpoint. The machine would calculate up to $T = 1$ and then it would stop so we could read … then … go on to $T = 2$, stop, and so on. There were three or four minutes between each of the values. We were working to a very high accuracy so it took many, many turns of the drum before reaching the value of $T = 1$. Von Neumann computed what it should be the next time it stopped and I remember being quite impressed by that because he did not have any tables. The value of *J* of order one-half is the cosine of *X* divided by the square root of *X*. I think I made the boundary conditions slightly different, so it wasn't exactly that; it … was a [linear] combination of *J* of order one-half and *J* of order minus one-half. He computed that. He did it the first time. He got better at it the second time. He was really good. I watched him as he did it, and as I recall, he had a very quick method of calculating the cosine of *X* and was very rapid at making estimates. … After the demonstration, he left extremely impressed. He was a humble man and he told us that it was a great privilege to meet us and he wished us all success. I think that was the last time I ever saw him.

Von Neumann subsequently communicated to Jack Northrop, in a letter reproduced in its entirety in the sidebar "Letter from von Neumann to Jack Northrop," his account of our visit and opinions of the Maddida.

Evaluation by the Air Force

On the way to Princeton, Steele had visited with a Colonel Bubb at Wright-Patterson Air Force Base and obtained approval for us to demonstrate the Maddida there on our return trip. We consequently shipped the Maddida by air to Dayton, Ohio, where we were joined by Sarkissian and Wolfe. Northrop's Dayton sales office made arrangements for transportation and hotels, and Bubb organized the meetings and demonstrations.

The Air Force wanted us to run a particular problem on the Maddida using documentation from a previous solution worked out on the mechanical Bush Differential Analyzer early in World War II. That solution had been worked in conjunction with a study of an electromagnetic cannon that the Germans were purportedly developing. As a double check, the problem had been rerun to four decimal places on Harvard University's Mark I. We were asked to demonstrate the Maddida in such a way as to make direct comparisons with the problem solutions from the tables computed by the Mark I and curves plotted by the Bush Differential Analyzer at the Massachusetts Institute of Technology (MIT).

Because the problem normally would have required more integrators than even the Maddida had, Steele and Reed spent most of one night reworking the problem so that the Maddida could be programmed to run it. The machine was demonstrated initially with some simpler problems. Many of the reviewers, among them Air Force computing experts and special consultants such as Harry Goode, professor of electrical engineering at the University of Michigan, were initially skeptical that the Maddida really was a differential analyzer. The purpose of the electromagnetic cannon problem was to put the Maddida and all of us from Northrop to a real test of credibility.

The next morning, after Steele and Reed programmed the problem, which involved solving a complicated scaling problem, the Maddida successfully duplicated the Mark I

Ed. note: The following letter was reproduced in its entirety in the Annals of the History of Computing*, vol. 9, no. 3/4, 1988, pp. 364-365.*

Letter from von Neumann to Jack Northrop

The Institute for Advanced Study
School of Mathematics
Princeton, New Jersey
March 14, 1950

Dear Mr. Northrop,

Mr. L.A. Ohlinger, as well as Messrs. F. Steele, I. Reed, and D. Eckdahl, have been in Princeton. We had several detailed discussions regarding the basic principles, the technical execution, the operational characteristics, and various possible and probable uses of the magnetic digital differential analyzer which this group has developed, as well as regarding other computing and control devices which could be designed on the basis of the same principles. They also demonstrated the differential analyzer very successfully. Our discussions took place on March 8th and parts of March 9th and March 10th. The demonstration was held in the evening of March 9th and the morning of March 10th.

I have given Mr. Ohlinger my conclusions from the discussions and the demonstration, and also discussed some other technical points with the other members of the group after Mr. Ohlinger's departure. The following are a summary of these conclusions.

I think that your magnetic digital differential analyzer is a most remarkable and promising instrument. The principles involved in its design and its engineering embodiment seem to me very sound. I would view the machine as it now stands as an example of what can be done, rather than as the actual solution for any particular purpose, but I consider that you have established the principles of a whole family of very new and most useful instruments. The present instrument has various limitations that your group will certainly be able to remove, as soon as they go into construction for specific applications. However, even as the instrument now stands, it is very remarkable and far ahead of other equipment for similar and similarly varied purposes. To be specific, I think that it is obsoleting the analogy type differential analyzer in its mechanical, as well as its electrical form. The proposition that instruments of your type can surpass analogy differential analyzers in precision, logical capacity, compactness, flexibility, and probably equal the best of them in speed, seems to me clearly established. It seems to me clear, too, that they are inherently cheaper in man-hours as well as in money.

Further developments on the basis of the principles that have been established by your digital differential analyzer are obviously called for. Your equipment can probably serve as a basis for worthwhile all-purpose computers of the intermediate type, but I would not consider this as the most important implication. It seems to me more interesting as a basis for a family of special purpose machines to deal with matrix problems. Among these I would mention the following: Performing linear transformations in n variables, solving n linear equations in n variables, determining the proper values and proper vectors of matrices of order n, solving the problems of game-strategy and of linear programming of order n, all of this for values of n of the order of 100 and even higher. The importance of the problems of the two first categories requires no comment. (To mention just a few obvious examples: The first category includes the Fourier-transformations that are needed in interpreting x-ray-crystallographic data. The second category occurs in the solution of flutter problems, also in the solution of various problems of chemical analysis of complicated mixtures of organic compounds.) The third class will have applications in connection with quantum-theoretical chemistry, in particular in determining molecular and atomic wave functions although here considerable further mathematical explorations will be required. Solution of problems of the last class will be of great importance, and may well be decisive, in certain phases, for enterprises like Project SCOOP, of the Air Materiel Command, and Project RAND, of the Army Air Forces. I shall be glad to give you further details on these subjects if you so desire.

I have started to discuss these questions with the members of your group, but I have thought about them more since they left, and I see now in more specific detail how certain variants of your equipment suit these purposes.

Please let me know whether you want at this time a specifically technical discussion of any phase of the present machine, and of possible variants, or whether it is preferable to reserve this for later, oral discussions.

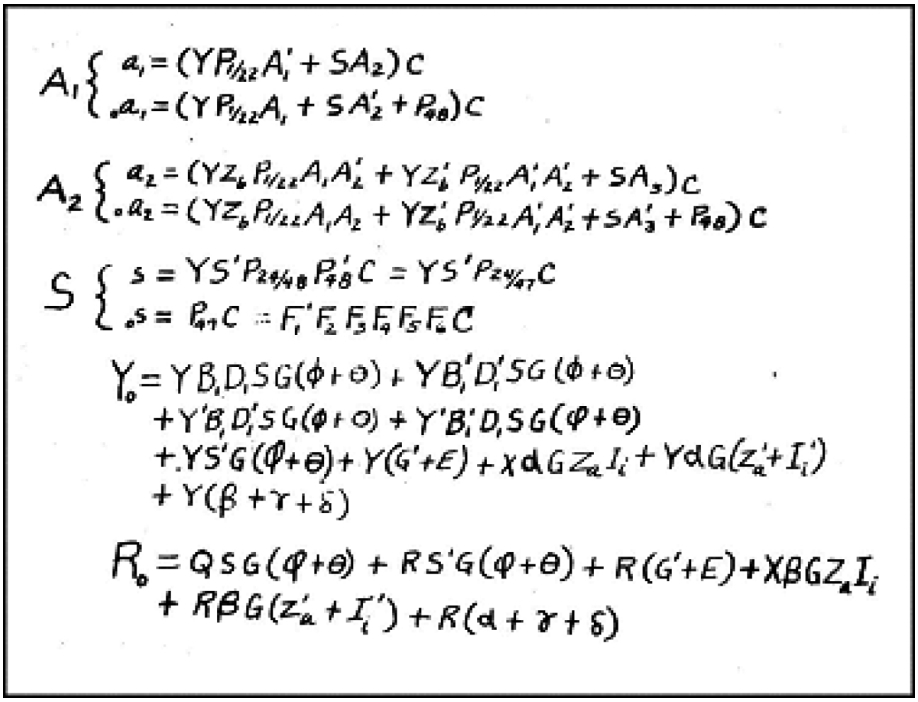
In conclusion, I would like to say that the fact that your machine could be transported by airplane and by truck from Los Angeles to Princeton and be satisfactorily running within 24 hours after its delivery is one of the most impressive engineering feats I have ever observed in this field. One has to be familiar with the great difficulties of running equipment of this type even under the most ideal laboratory conditions in order to appreciate the exceptional tour de force of your group, who were able to effect a brilliant and convincing demonstration under what amounted almost to "field conditions." They have certainly demonstrated the practicality of your equipment in a way which is outstanding for computing machines of this degree of complication.

It was a great pleasure to have had this occasion to discuss these problems with the members of your group and to see the demonstration.

I am,
Sincerely yours,

/s/ John von Neumann
John von Neumann
JVN:lo

Mr. John K. Northrop
Northrop Aircraft, Inc.
Northrop Field
Hawthorne, California



$$A_1 \begin{cases} a_1 = (Y P_{1/22} A_1' + S A_2) C \\ {}_0a_1 = (Y P_{1/22} A_1 + S A_2' + P_{48}) C \end{cases}$$

$$A_2 \begin{cases} a_2 = (Y Z_6 P_{1/22} A_1 A_2' + Y Z_6' P_{1/22} A_1' A_2' + S A_3) C \\ {}_0a_2 = (Y Z_6 P_{1/22} A_1 A_2 + Y Z_6' P_{1/22} A_1' A_2' + S A_3' + P_{48}) C \end{cases}$$

$$S \begin{cases} s = Y S' P_{24/48} P_{48}' C = Y S' P_{24/47} C \\ {}_0s = P_{47} C = F_1' F_2 F_3 F_4 F_5 F_6 C \end{cases}$$

$$Y_0 = Y B_1 D_1 S G(\phi+\theta) + Y B_1' D_1' S G(\phi+\theta) + Y' B_1 D_1' S G(\phi+\theta) + Y' B_1' D_1 S G(\phi+\theta) + Y S' G(\phi+\theta) + Y(G'+E) + X \alpha G Z_\alpha I_i + Y \alpha G(Z_\alpha' + I_i') + Y(\beta+\gamma+\delta)$$

$$R_0 = Q S G(\phi+\theta) + R S' G(\phi+\theta) + R(G'+E) + X \beta G Z_\alpha I_i + R \beta G(Z_\alpha' + I_i') + R(\alpha+\gamma+\delta)$$

Figure 6. A copy of the transparency prepared and presented by Donald Eckdahl at the Rutgers conference, showing examples of a portion of the Boolean algebra equations that defined the Maddida. (From the personal files of D. Eckdahl.)

results to better than three decimal places. The Air Force people, particularly Bubb, were quite impressed.

This is not to suggest that our achievement was not hard-won. "One of my (battle) scars," recalled Sarkissian, who had the assignment of reading and recording much of the data output during these demonstrations,

> came from a conversion I was asked to do. Our readout was on an oscilloscope; the pulses were laid out in a scattered way and I had to interpret them into a binary and then a decimal number. I made a mistake, a whole day's worth, and I almost got shot in the process.

Show-stealer at Rutgers University

While the Maddida was being introduced to von Neumann in Princeton, Sarkissian and Sprague were attempting to convince Walter Cerny, a key member of the Northrop management structure, to permit the machine to be presented at the first national meeting of the Association for Computing Machinery to be held at Rutgers University on 28–29 March 1950. Cerny's initial response, reflecting the lack of a market study and the fact that the Maddida was classified secret, was an emphatic "No." But in the face of the ensuing uproar among the computer group, Northrop acceded to further discussions and, ultimately, to the Rutgers visit. Ohlinger was once again to represent the company and initiate a market survey, and Steele and I were to be permitted to give papers. Sarkissian, Sprague, and Reed accompanied the Maddida, which Northrop decided could be declassified (it was later discovered that no secret classification had ever existed) to the ACM conference.

The Maddida was displayed in an expansive hall with equipment from other companies. The papers delivered by Steele and me were entitled "Maddida General Theory" and "Maddida—Design Features," respectively.[6] The abstracts submitted in fulfillment of ACM requirements are reproduced in the sidebar, "Abstracts of Papers Presented to the ACM Conference at Rutgers University." Figure 6 shows a copy of the transparency that I showed at that presentation.

"There was tremendous publicity," Sarkissian recalled of the Rutgers visit,

> because it was just what the [news]papers wanted to hear—automatic factories and all the usual futuristic science fiction stuff. That was quite an interesting thing. The dean of engineering of Rutgers was ecstatic over this. I was with the computer in the booth. Next to me was Jan Rajchman from RCA and he had this new Selectron tube. He was showing that and nobody was around him; they were all around the Maddida, about fourteen deep trying to see this thing. We literally stole the show.

Reed recalled

> that the Maddida was the only full-scale, working, electronic computing machine demonstrated at the meeting and one of the few transportable machines in existence at that time. The IBM punched card machines were portable, but basically were electromechanical machines with relays and so forth, although they may have used some vacuum tubes.

Abstracts of Papers Presented to the ACM Conference at Rutgers University

Ed. note: The following abstracts are reprinted as they were originally written.

Abstract by the Author of Paper Given Before
The Association for Computing Machinery
Conference at Rutgers University,
New Brunswick, New Jersey
March 28-29, 1950
"Maddida" — General Theory
By Floyd G. Steele

Two devices are normally used to simulate the mathematical process of integration—the analogy integrator and the numerical accumulator.

It is possible by employing a numerical technique to produce a device having the logical characteristics of an analogy integrator and the accuracy and repeatability characteristics of a numerical device.

A set of digital integrators may be inter-coupled in the manner natural to the ordinary Differential Analyzer to solve ordinary differential equations or sets thereof, either linear or non-linear.

Further, numerical integrators may be stored in a memory in a manner which yields simplicity of utilization and communication.

A magnetic drum digital differential analyzer called Maddida has been built and put into operation. It was designed to have 44 digital integrators, each having an accuracy of 1 part in a million. Fifty-six tubes were required, not including power supply and readout.

It is apparent that a machine having about 132 numerical integrators can be built with a total of about 100 tubes.

The digital differential analyzer appears to have the advantage of fewer tubes, economy, speed, accuracy, and possibly greater reliability over the normal analogue devices which solve ordinary differential equations.

In computation, it has the advantage of easy coding, accuracy, and considerable economy.

In control, it will be found to intervene between sensory devices and effectors more directly than the ordinary numerical machine and to require fewer components than standard analogy devices. It should prove of use in those control problems which require either extensive facility or high accuracy.

It is hoped that this type of machine can serve both to enlarge the scope of automatic control and to provide individual computation.

Acknowledgment is made to Donald Eckdahl and Dick Sprague for general logical contributions on the digital differential analyzer and to Donald Eckdahl, William Collison, Harold Sarkissian, and Dick Sprague for specific logical contributions on the machine Maddida. Valuable mathematic assistance has been rendered by Dr. Irving Reed.

Abstract by the Author of Paper Given Before
The Association for Computing Machinery
Conference at Rutgers University,
New Brunswick, New Jersey
March 28-29, 1950
"Maddida" — Design Features
By Donald E. Eckdahl

Maddida—Magnetic Drum Digital Differential Analyzer—is an electronic digital computer which integrates differential equations directly, as do the analogue Differential Analyzers. Integration is accomplished by operating on pairs of numbers by an additive transfer process. A register n digits in length containing a number "y" is added into a register "R" of equal length upon each occurrence of an input pulse "dx." All carries from register "R" are used as incremental outputs "dz." The number in "y" can be increased or decreased by an input "dy." The result is that dz = ydx/Bn where "B" is the base of the number system used. A paper by the originator of this type of machine, Floyd G. Steele, at this conference, covers fully the theory of such integrators and a number of different methods of possible realization. One machine, which will be discussed by Richard E. Sprague at some later date, utilizes complete flip-flop storage.[1]

Maddida stores the registers mentioned on a magnetic drum and operates on each pair of numbers serially. A pair of numbers is called an integrator. A total of 22 such integrators are stored on the drum. The control and arithmetic center sees only one digit of one integrator at a time. The number system is binary and the additive transfer process is accomplished by serial binary addition. A one-word register on the drum stores and routes the outputs of the integrators to inputs of other integrators. Each integrator contains a code section which defines the manner of connection with other integrators in the machine.

The memory stores 22 pairs of 48 digit words on two channels. A one-word register is provided on a third channel by closer spacing of the heads. A clock or timing source is permanently recorded on the drum for synchronization and constant delay adjustment of the memory. The drum is used as a delay memory in constant re-circulation. A non-return to zero system is used, the memory output controlling a flip-flop on two grids. At some later date, a paper by Harold H. Sarkissian will cover fully the details of this memory.[1]

The machine contains 60 vacuum tubes including those used in the memory. Additional tubes are present in the four regulated power supplies. One thousand germanium diodes are used for logical operations and for clamping and coupling on the flip-flops.

continued on p. 18

continued from p. 17

Design of the machine is based on the complete application of symbolic logic to parallel the model of a computer which is stated as a group of stable state devices that successively change themselves to a new configuration. A logical algebra using the "+" and "x" operators to define those operations directly accomplished by diodes, namely, the "inclusive or" and the "and," is utilized to write complete equations about each grid of every flip-flop in the machine. The memory record functions are also written in this algebra.

We have been using this algebra to design digital electronic circuitry for about two years, but this is our first machine in which it is applied in its complete form. The set of logical equations completely replaces the block diagram for the machine. All operations, including counting, are accomplished in this one general manner. The result is a machine which, in internal operation, is completely parallel, all flip-flops changing at the same time, i.e., at each clock interval.

The equations written define when a pulse should appear on the grid of a particular flip-flop in terms of the conditions of other flip-flops in the machine. The flip-flops controlled by the memory enter into these equations in the same way as all others. Each independent equation is simplified by the use of the theorems of the algebra. An attempt to find the most economical arrangement of diodes for groups of equations is then made by representing an arrangement in symbolic form and counting the diodes needed for each arrangement tried.

The resulting diode combinations are designed by a technique which results in applying two simple formulas repetitively starting at the highest level and working down to the basic flip-flop drivers. Often, some conditions in a net of diodes are impossible due to known relationships among the driving propositions, and these known relationships are taken into account during the design. The result is a selection of all resistors in the net and a tabulation of maximum load on each flip-flop plate. In only one case, in the present machine, was it necessary to parallel a flip-flop with another tube in order to handle the load. The maximum load allowed on a flip-flop is held well below maximum rating in order to allow for aging of the tubes.

After construction of the machine, about two months were required for initial check out. Very high reliability has been experienced. Fifty hours of operating time were recorded from the end of the initial check out to the first failure, which was found to be a critical overload caused by design error. Modifications to include a slightly more convenient readout were made at this time, and further reliability checks have not yet been undertaken.

Acknowledgment is made to Harold Sarkissian and Carl Isborn for their developmental work on the magnetic memory, and to Harold Sarkissian, Al Wolfe, and Dick Sprague for contributions to the logical and circuit design of the machine. Willis Dobbins and Jack Donan rendered valuable assistance during check out of the machine and in design of the read-out system.

Reference and note

1. Such a paper was, to our knowledge, never written.

Figure 7 shows the Maddida at the Rutgers University presentation.

After Rutgers, the Maddida was shipped to Washington, D.C., for another demonstration to the Air Force and others at the Pentagon. "What we were trying to do," explained Sprague,

> was to show the technology, both the digital differential analyzer technology and the computer design technologies that went into it, to a number of important people in the Air Force who sponsored and were the contracting agency for the MX-775, the Snark missile. … Some of the people who attended the meeting … were … involved with the Snark. Others were invited to attend a demonstration and … discussion of the machine by none other than Charles Lindbergh [who] was in a sort of evaluation status at that time as an Air Force general. Part of his responsibility was to visit aerospace firms around the country, evaluating things that were on the frontier from a technology sense. When he came to Northrop Aircraft in 1948, we demonstrated Maddida to him … and the assistant secretary of the Air Force. …
>
> [The meeting] was held in … a sort of auditorium with a slanting floor. I will never forget the Maddida on a podium, a raised stage, in a spotlight with red cloth draped over it, really done well, with all these Air Force generals and officers out there. … Floyd … gave the introductory presentation on the digital differential analyzer concept. …
>
> It was a classified presentation, by the way, so we talked about the missile and the guidance problems and what Maddida's original objective had been. … Then we demonstrated the machine solving some differential equations.
>
> The reaction first was skepticism. … Then … just tremendous enthusiasm. Not only for the machine but what its implications were. … [S]ure, it was not yet airborne, which was the ultimate objective, but it was not very far from it. The size was getting down to the point where it looked like it could be made to fly. Reliability and withstanding shock were something else again, but it was well received.

Figure 8 shows the control panel of the Maddida.

Disenchantment and disaffection

By the time we returned to Northrop, we were in a high state of enthusiasm and looking forward to an opportunity to tell the story of the various adventures of the Maddida to Project MX-775 management and personnel. Some of us carried “requests for bids” from various organizations that had seen and become excited about the Maddida. Our frame of mind was such that we definitely expected some form of commendation or praise for our work and results.

However, shortly after returning, we were summoned by Weaver to a meeting, held in Cerny’s office, that included Cerny, Ohlinger, Taylor, and another manager, named Silliman. Weaver produced a paper that he said was approved by Jack Northrop that contained strongly worded orders to all of us in the computer group to “return to your jobs on the Project” and “bring up anything you have in mind” with Taylor “by going through channels.” Neither Weaver nor Cerny nor any of the others asked to hear about what had gone on during the weeks we had spent back East. As Cerny left the meeting, I asked him if they were going to discuss anything further. He replied “No.” We were crushed. Not only had the commendation and praise we had anticipated not been lavished on us, but we had clearly been reprimanded. MX-775 project management, entirely frustrated with this “wild group and their bootlegged program,” was in no mood to hear glowing tales of outside interest generated by our trip.

With respect to whether Northrop management had rejected the Maddida “because they thought it couldn’t handle the problem at hand or … because they did not want to go commercial,” Reed was “convinced that it was a rejection of the people. We had become too hard to manage and control, and bright as we were, they must have decided that it was better to let us go.”

More than a year earlier, Herbert Metcalf, the resident patent counsel for Northrop, had assigned John Matlago, a young patent engineer who had been with the company for about two years, to work with, and follow the development and possible patent activities of, the computer group. Following our disastrous meeting with the project management, Matlago had pleaded with Metcalf to encourage Jack Northrop to set up a department or company to develop and manufacture computers. Metcalf agreed, but asked Matlago to find out, in the absence of any oral or written report on its activities, what had transpired during the com-

NEWARK EVENING NEWS, TUESDAY, MARCH 28, 1950

Brainy ‘Maddida’ Makes First Appearance

Machine Can Operate Whole Factories

BY GEORGE KENTERA
Staff Correspondent.

NEW BRUNSWICK--Will people become obsolete?

A mechanical brain was placed on public display here last night which makes possible production of goods without help from the human hand or human brain. Its inventor called it the forerunner of the automatic factory.

That machine is the magnetic drum digital differential analyzer (“Maddida” for short) built by Northrop Aircraft Inc., of Hawthorne, Cal. It was one of seven mechanical minds exhibited here last night as a three-day conference on automatic computing machinery opened at Rutgers University. The conference is being conducted by the College of Engineering in co-operation with the Association for Computing Machinery.

Until last week, the awesome “Maddida”was classified secret by the Air Force, for which it was built. Last night Its inventor, Floyd Steele, an earnest, 31-year-old physicist and aeronautical engineer of Manhattan Beach, Cal., said of his handiwork:

Big Impact on Economy

“It will make a big impact on the American economy—bigger than the industrial revolution”

Steele explained that “Maddida” was a calculator, all right, capable of an accuracy of one part in a million, able to handle 4,500 additions of eight-place decimal numbers per second.

“But it’s even a better control device,” he said. “It will take information from another machine, interpret that information and then run that machine.”

Flight Engineer Job

“Maddida” could, for example, take over the job of a flight engineer on a modern transport aircraft, and do that job better than a human. It can do the same with any piece of machinery.

“Its an automatic crew.” Steele said.

Despite these astounding claims, “Maddida” is not larger that a pinball machine and with its mass of wires, control buttons and flashing lights, strongly resembles such a device. Yet its small size is its greatest asset, for comparable electronic computers heretofore have been monstrous things as large as basketball courts

To Steele, that is the real significance of “Maddida” that it will, because f its small size and relatively low cost, be available in the future to any scientist who needs such a device. “Maddida 1,” on display here, cost about $25,000. Steele hopes that in five years, it will be no larger than a suitcase and priced at around $600.

Available to All Is Aim

Making such a computer available to every one is the fixed aim ofSteele,who thinks previous digital computers, with their$500.000 price tags, are essentially monopolistic because of their unavailability.

Because he thinks a “Maddida” can be mass produced at a low price, Steele believes his machine will initiate great strides in scientific endeavor. Equations can be solved, he says, which heretofore were immune to attack because of their complexity. Some equations, he said, have been gathering dust for 100 years or more, until they were forgotten,because no one had time to solve them manually.

Steele began working on his machine about 3 ½ years ago, and the actual construction and design, done by D. E. Eckdahl and Harold Sarkissian of Northrop, took eight months. “Maddida,” says Leo A. Ohlinger, chief of Northrop’s computing department, is only the first of a family ofsuch machines which will revolutionize computing machinery.

Exact Description

An exact description of the “Maddida’s” work: According to Ohlinger and Steele, it will solve ordinary differential equations or nonlinear. (Differential equations, it was explained, inherently describe motion and relate forces in physics.)

Dean Elmer C. Easton of the College of Engineering is quite taken with “Maddida” which he, like Steele is sure will open new avenues to scientists.Among other things, he says, “Maddida” could be used to measure the shock waves caused by travel over aroadbed and thus ascertain whether the highway is strong enough.

Among the other six exhibits last night was one which introduced a mechanical first aid note into the display. It was an oscillograph exhibited by the Allen B. Du Mont Co. of Clifton. Its computer function: Take care of other computers.

Other Exhibitors

Other exhibitors were the Reeves Instrument Corp. of New York, RCA Laboratories of Princeton, International Business Machines Corp. of NewYork, Raytheon Manufacturing Co. of Waltham, Mass., and the Zator Co. of Boston.

The conference will actually get under way today with eight sessions in two groups. Theme of the conference, according to Dean Easton, will be ways and means of reducing automatic computer costs.

Dean Elmer C. Easton of Rutgers School of Engineering, left, gets tips on electric brain from its inventor, Floyd Steele. That round thing in the foreground is Maddida’s memory gadget.

FLY MIAMI
CALIFORNIA $88
MI 2-4460
CONSOLIDATED
AIR SERVICE
ESSEX HOUSE
NEWARK, N. J.
$35

Figure 7. A copy of the picture and story from the 28 March 1950 edition of the *Newark Evening News* indicates that the other exhibitors at Rutgers were Alan B. Dumont Co. of Clifton, New Jersey; Reeves Instrument Corp. of New York; IBM Corp. of New York; RCA Laboratories of Princeton; Raytheon Manufacturing Co. of Waltham, Massachusetts; and the Zator Co. of Boston. This picture was made from a partial photograph of the Steele-only part of the picture from the *Newark Evening News* archives combined with the microfilm copy of the original news article and picture.

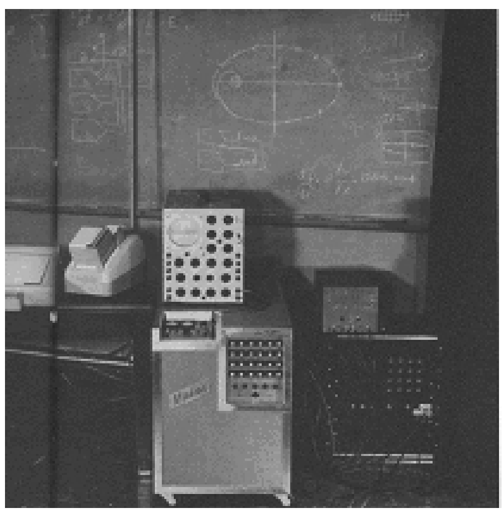


Figure 8. Photo of the front control panel of a commercial Maddida. Northrop brochure advertised the Maddida as a “deskside” computer. (Photo courtesy of the National Air and Space Museum, Smithsonian Institution.)

puter group's travels with the Maddida.

Initially we were defensive, submitting to Matlago only outlines of our work and the requests for bid that we had received. But after making clear that we had fully expected to give a verbal report of, and be questioned about, our trip, and that any lack of disclosure was not due to our lack of interest or readiness to disclose our activities, we agreed, somewhat reluctantly, to prepare a report, which was delivered to Metcalf within a few days. Metcalf, after reviewing the report, told Matlago to return one copy to the computer group and stated that it should be submitted to the group's immediate supervisor. Still, Northrop management would not inaugurate any exchange or discussion that might lead to resolution of the divisive schism that had developed between the computer group and Project MX-775 management.

A meeting held by some of the group with Taylor served only to reveal that Taylor possessed neither an understanding of the digital differential analyzer concept nor any interest in helping us find a use for the Maddida. In another meeting with Taylor, we (Reed, Sarkissian, and I) were advised by a Dr. Barthay, an Air Force advisor to Project MX-775 who had been evaluating the missile's guidance system, that the Northrop company and missile project were committed to a definitive prototype production schedule using the present system and that the existing contract would not allow the development of an all-digital system of the type being proposed in conjunction with the Maddida. Barthay added that, in his opinion, an all-digital system would definitely have been superior, but would have had to have been proposed and developed while the contract was in the research and development phase.

Sarkissian and I concluded that because the military system using the Maddida had been "blocked in the project," it was too late to secure a new development contract to pursue an alternate approach. In retrospect, it is also now clear that misunderstanding and lack of communication extended beyond Project MX-775 management to the entire Project MX-775 team and the rest of the scientific development organization.

Founding of Computer Research Corporation

"We had been talking about forming a company for months," Sarkissian recalled.

> Floyd would vacillate: one day yes and one day no. The situation kept getting worse. … After the management meeting, I remember Don and I talking about the lack of any good future at Northrop. I suggested we get a temporary job somewhere until Floyd and the others decided they had had enough, and then we could get together and do something. I actually arranged for a temporary job for both of us [at Electronic Engineering Company of California]. …
>
> There were five of us involved: Don Eckdahl, Dick Sprague, Floyd Steele, Irving Reed, and myself, Harold Sarkissian. … The five of us formed the company. We sat down in Manhattan Beach and formulated the company more or less on broad principles. Don and I started the process by quitting our jobs and leaving Northrop. … The rest of them quit over the next three weeks. In the meantime, Don and I were running around getting things set up. We rented … space on the second floor of a knit shop in Manhattan Beach; we could walk to work. On May 8 [1950] the five of us formed a formal partnership.
>
> Then we started looking for contracts. We needed money. We did not take any salary for as long as we could afford not to. We simply built up a backlog of debts. As I remember it, this company was really supported by widows and orphans; it was really a family affair. … There were no large sums; there were many little ones. I do not think our financing was any great shakes. As I remember, it was something like $30,000.

Reed and I recall the total being about $70,000, including a large contribution from a Reed cousin. During this period we struggled to find customers that might contract for the development of some type of computer. Steele every so often would make a plea to "pull out all the telephones and go back to design." But the rest of us, intent on securing contracts, were preoccupied with sales-related activities.

On 16 July 1950, in the Longmont, Colorado, office of attorney Lyman P. Weld, we formed Computer Research Corporation. Six days later the then-new CRC board voted to offer to buy (with shares of CRC stock) the original partnership. The five partners accepted the offer. Figure 9 shows a press release that announced the founding of CRC.

Dobbins, Isborn, Matlago, and Donan subsequently joined the firm, together with Albert Wolfe and Bernie Wilson. Senior electronics technicians employed as development engineers, Wolfe and Wilson were heavily involved in the construction and testing of the digital differential analyzer CRC later built for North American Aviation. Dobbins and Donan, both electrical engineers, worked on circuit and logic design for many CRC products. Isborn, an electrical engineer and physicist, worked with

Sarkissian on magnetic drum and tape memories. Matlago, with degrees in both engineering and law, wrote all of CRC's patents.

First development product contract

On 22 September 1950, North American Aviation signed a $45,750 contract with CRC for the development and manufacture of a digital differential analyzer with the following specifications:

- 50 integrators,
- 150 pounds and 7 cubic feet maximum,
- powered by 400 cycle ac (airborne) conventional aircraft (propeller or jet), and
- operational up to 25,000 feet pressure altitudes and ambient temperatures ranging from 0 to 35 degrees Centigrade.

Steele and Reed probably were instrumental in cultivating the interest of the corresponding group at North American Aviation before leaving Northrop. They had met with that group, which was developing a similar missile system called the Navaho, to discuss common problems associated with guidance systems. When North American engineers Jerry Weiderman and Lester Kilpatrick subsequently visited CRC to discuss how the Maddida might be used in the missile guidance problem, Reed and I seized the opportunity to negotiate and close the contract with them.

Just prior to formally landing the North American contract (see Table 1, next page), we had moved CRC to somewhat larger quarters in Torrance, California. We converted the second floor over a bakery, which housed six apartments—each containing a kitchen, bath, and living area—into development labs, parts storage, and a prototype construction area. It was in this building the following spring that we completed construction of the digital differential analyzer for North American Aviation. Outside facilities were used to run the environmental tests stipulated by the contract. The machine passed all tests with minimum trouble and required no significant modifications. The product was delivered and accepted by the customer on 15 May 1951.

The sustaining AFCRL contract

In late summer 1950, we were visited by John Marquette, head of the US Air Force's Cambridge Research Lab (AFCRL), George Valley, and two or three Air Force officers who inquired if we were the people who had developed the Maddida and written proposals about the detection and observation of aircraft using a network

DAILY BREEZE, Redondo Beach, California June 8, 1950

Five-Man Manhattan Firm Designs New Electronic 'Thinking Machines'

Designing thinking machines is the occupation of five young men who recently opened business at 1148 Highland Ave., Manhattan Beach.

Called the Computer Research Co., the business is run by five partners who formerly worked for Northrop Aircraft Co. They are Floyd G. Steele, president; Donald E. Eckdahl, Richard E. Sprague, H. H. Sarkissian and Irving S. Reed. At present there are four employes of the firm and more will be added.

The "thinking machine" is the non-technical way of saying "electronic digital computers." (To explain exact operations of the machines would necessitate attaching one of the gadgets to your reporter.)

The men built one machine for Northrop Aircraft Co. which was called Maddida, short for magnetic drum digital differential analyzer.

Maddida was demonstrated last March at the Association for Computing Machinery, meeting at Rutgers University. It was the "hit of the conference," said Sprague, one of the partners. Maddida was described by eastern newspapers as resembling "a pinball machine on a jackpot rampage."

"Pretty good competition" faced Northrop's machine Maddida, said Sprague. C. C. A., I. B. M., Reeves Instrument Co. and other top notch firms also demonstrated machines at the conference.

Maddida was a "specific purpose thinking machine," said Sprague. "Its job was only to solve differential equations."

The Computer Research Co. plans to design and build general purpose thinking machines. Several others are being designed throughout the country at present by U. C. L. A., University of California, M. I. T., and other leading universities.

"Our machines are to solve any kind of problem," said Sprague, "by performing arithmetical operations on numbers in specified sequences and changing their own sequences.

"They will have the ability to make up their own "minds" on what they will do and will make their own choices," he added.

The machines will be operated electronically with few moving parts. Sometimes they are called "electronic brains." Sprague says the machine will solve problems in an hour or two which formerly would take several days.

Figure 9. This press release in the Redondo Beach, California, *Daily Breeze* tells the story of the founding of CRC.

of radars. The answer, of course, was yes.

"Since we had so many ideas along these lines," Reed recalled,

> they decided to see how well we could do and they paid our way … to Cambridge … Research Labs. We talked to the people there about what they had in mind for detecting and observing aircraft, what their thinking was concerning the SAGE [semi-automatic ground environment] type thing of the future, and the types of radar they would probably use. We were then taken to visit the Instrumentation Laboratory and met Jay Forrester and all the people on [the] Whirlwind I

Table 1. Excerpt from table reproduced in J.E. Sammet, "Answers to Self-Study Questions."[7]

Year	Month	Name	Place
1951	Jan.–Feb.	Harvard Mark III	Cambridge, Mass.
	February	Ferranti Mark I	Manchester University
		Burroughs Lab. Comp.	Detroit, Mich.
	April	LEO	Lyons & Co., London
		Whirlwind	Cambridge, Mass.
	June	Univac, #1	Philadelphia, Pa.
		Maddida, #1	Northrop, Los Angeles
		Maddida, #2	North American Aviation, Los Angeles
	Summer	IAS	Princeton, N.J.
	Late	Pilot ACE	NPL, Teddington, England
1952	January	Cadac	USAF Cambridge Research Center
	February	Hughes Airborne	Wright-Patterson AFB, Dayton
	March	Maniac	Los Alamos
		Ordvac	Aberdeen, Md.
	April	EDVAC	Philadelphia, then Aberdeen, Md.
		Harvard Mark IV	Cambridge, Mass., then Dahlgren, Va.
	August	Illiac	Urbana, Ill.
	Summer	Teleregister SpeedH, #1	Griffis AFB, Rome, N.Y.
		Univac, #2	The Pentagon, USAF
		Teleregister SpeedH, #2	Griffis AFB, Rome, N.Y.
	August	Magnetronic Reservisor	New York (LaGuardia Airport?)
	November	Elecom 100, #1	Aberdeen, Md.
		Univac, #3	US Army Map Service
		Maddida, #3	Univ. of Utah, App. Phys. Lab
		Maddida, #4	Univ. of Utah, App. Phys. Lab
		Maddida, #5	Univ. of Utah, App. Phys. Lab
		Maddida, #6	Arnold Engineering
	December	Narec	Naval Research Lab, Washington, D.C.
		IBM 701, #1	IBM WHQ, New York City

> computer. When we saw this gigantic machine, we were convinced even more that we were really on the right track by building reasonably small processors rather than these gigantic machines, which, we thought, would bankrupt the country.
>
> We outlined what we might do under contract and … Marquette was very impressed with us. He was very interested in CW [continuous wave] radar, and we saw a demonstration of the continuous wave radar that had been built. Part of our contract was to study how to detect and track aircraft with a set of CW radars. We were awarded, probably about December 1950, a two-part contract: one was to study the problem of detecting and tracking aircraft with CW radar and the other … was to design and build a general-purpose computer that could be put at CW radar sites. As I recall, the contract was exactly $150,000, split $75,000 for the study and $75,000 to build a full-scale, general-purpose computer. We performed on both halves reasonably well. … We managed to do the whole job on less than $150,000; we built a full-scale general-purpose computer called Cadac [Cambridge Air Force Digital Automatic Computer], which was the prototype of what was later called the CRC102A.[8]
>
> My primary job was director of theoretical research; I think that was the title. Basically, I had … responsibility for the study part of that contract. I hired several mathematicians: Chester Stone, Leonard S. Abrahams, … Hal W. Banbrook. …

Sprague described the Whirlwind as

> a great, big thing stretching in one direction as far as the eye can see—an aisle going down the middle and then racks running off to two sides going out maybe 25 to 30 feet in either direction on both sides. … [Y]ou had to have a road map because you go down five aisle spaces and then over to the right six racks, let's say, to get to a part of the machine. I always had this great ambition of taking the CRC102, which had a 1,000 word memory—the Whirlwind had 500 words in the main memory, or the core …—and wheeling the CRC102 through the doors, down one of the aisles, and over to one of the corners.

Marquette also arranged for us to visit an existing, manually structured aircraft scheduling and control section at La Guardia Airport in the New York area. There we learned a great deal about current systems and the significant scope of the problem of tracking aircraft and missiles on an automatic system.

The AFCRL contract was defining for CRC, generating both sufficient funds and pressure to drive the design and manufacture of a general-purpose computer. As Reed and his group embarked on a study phase, Steele, Sprague, Sarkissian, and I concentrated on design and development.

A decision was made to go forward with the following set of preliminary design specifications. Drum memory was to be about 1,000 words, each word a 33-bit binary number recorded in binary serial on the drum. The drum was to contain a clock channel that, at normal speed, would generate a square wave of pulses 10 microseconds wide and 10 microseconds apart, yielding a clock frequency of 50,000 cycles (that is, Hertz) per second. We planned to use a three-address command structure, the first two octal digits being the command and the next three the address of the first operand; the second three being the address of the second operand; and the third three being either the address at which the answer was to be stored or the address designated by a compare or jump command. I recall Steele being a party to these parameters and frequencies, which were similar to those employed for the Maddida, and having conceived the concept of a three-address command structure. Sprague and I subsequently commenced work on the computer's logic and circuit design, Sarkissian and Isborn on the development of a drum memory.

The Maddida patent application issue

In late 1950, CRC resolved to try to secure a license from Northrop to avoid later arguments over patent rights to our various planned products. We had all signed Northrop patent agreements that clearly stated that all inventors would assign their rights to Northrop Aircraft. We tried to promote the rather weak argument that the Maddida had been developed "in spite of Northrop Aircraft" and, therefore, was really partly owned by the inventors. But in a key meeting, Steele, Matlago, and Richard Dabney were unable to convince Jack Northrop of the validity of this position. We then developed another questionable strategy of withholding the signatures of the inventors as a way to force Northrop to permit the patent to slip into the public domain as a result of late filing. On 20 March 1950, the five investors still at CRC (Steele and William Collison had left) offered to sign the patent application provided that certain "conditions" were met. Northrop at that point decided to locate and file, with Steele and Collison only, a potentially illegal or, at best, weak patent rather than put up with further antics on the part of the CRC people. Consequently, the filed patent application by Northrop Aircraft omitted Sarkissian, Sprague, Isborn, Wolfe, and me.

In later years, there was an "interference" fight at the patent office level between CRC/NCR and Northrop Aircraft, but there was never any move by Northrop to legally interact with CRC or NCR on the patent rights to the Maddida.

Inventing the flow diagram system of logic design

Applying the logic equation concepts of the Maddida to the general-purpose structure involved a series of command sequences that every so often interrelated the logic with memory operations. Progress was slow until one all-night session in Washington, D.C., during which the flow diagram and program counter concepts, and a major part of the design, were conceived.

Sprague described that episode in detail in "A Western View of Computer History" published in the *Communications of the ACM*.[9]

> In the winter of 1950 … we had reached a point in the logical design of the CRC102 that called for some clear thinking uninterrupted by the rest of the problems of a small, growing company. We were to go to Washington, D.C.; we decided to take all of the 102 logic diagrams and Boolean equations with us and hole up in our hotel until we solved the problem.
>
> We had reservations at the Statler Hilton, but on arrival discovered they had overbooked and we were spilled over to the Lee House about three blocks away. The Lee House Hotel was very old and cold and appeared to have been constructed at the time of General Lee's surrender. Between 6:00 p.m. and 10 p.m. we spread diagrams and equations all over the beds, the floor, the walls, and two card tables we were able to borrow. Each bellhop who arrived bringing more coffee looked around the room incredulously.
>
> Around midnight we were in our pajamas and just beginning to see a glimmer of light on our problem when the hotel fire alarm sounded. We ran out of the room and looked for the fire exit, calculating that the elevators might be filled with smoke. The fire door led down an inside circular stairwell and as we entered it we wondered why no one else appeared in the hallway with us.
>
> We ran as fast as we could down eight flights of stairs, burst into the lobby, and found complete serenity and no smoke. We dashed up to the desk in our pajamas and bare feet and asked where the fire was. The night manager looked up over the top of his glasses and said: "Oh, that alarm is on the fritz. It goes off by itself every so often."
>
> Laughing, we took the elevator and went back to our design task without thinking that a real fire would have destroyed the CRC102.
>
> By 4 a.m. we had evolved the flow diagram method, although we had not realized it yet. We were on our fourth pot of coffee when we heard a loud crashing sound outside our door. We found an elderly, gray-haired man lying in the hallway. … His head was bleeding.

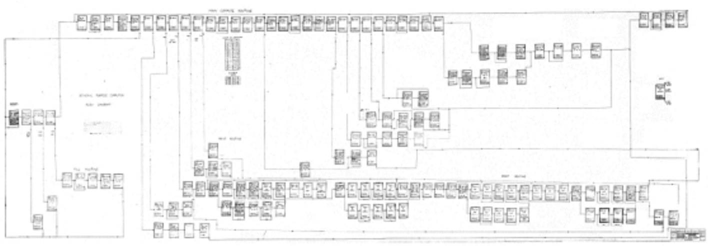


Figure 10. This is a much-reduced copy of the Cadac/CRC102 flow diagram dated 8 December 1950 and signed by Donald Eckdahl, Richard Sprague, and Will Dobbins (the original is 9 feet long by 3 feet high). Each small block on the diagram is a step in the flow and originally was one of the large sheets of accounting paper mentioned by Sprague in the main text.

> While Don helped him I rushed back to the phone and called the front desk. When I told the clerk what had happened, he asked me what the man looked like. I described him and he said: "Oh yes, that's the Colonel. He's always doing something like that." Fortunately for the Colonel, he was not as hurt as the blood led us to believe. The hotel doctor didn't arrive for about half an hour and only then were we able to return to the design of the 102.
>
> By morning we were finished. The flow diagram technique was perfect and the CRC102 logical design entered its final phase. I suppose the Lee House should be given some sort of credit for keeping us awake to complete our invention.

One important objective in our first general-purpose computer design was to significantly reduce the number of flip-flops. At that time, each flip-flop required two vacuum tubes, which were costly, generated heat, and tended to be somewhat unreliable. We thought we could share flip-flops between various functions, the same flip-flops used during command setup, for example, being used also for temporary storage for carry operations associated with arithmetic commands. Other flip-flops that did not have to be dedicated, such as those needed to time functions of mechanical devices such as printers, could also be used for computation functions.

At the time Sprague and I went to the Lee House, we had begun to use individual sheets of large accounting paper to describe what went on at a particular time or in a particular step (for example, which side of which flip-flop was being used for a particular equation). With each large accounting sheet representing the logic and connections for a particular time or sequence slot, it followed naturally that multiple operations could be described by stacking these sheets. It occurred to us that, each of these sheets being like a block in a flow diagram, a program counter could be made to control the sheets of sequences.

The result was a method of defining the machine in the time domain by associating the program counter with the flow diagram steps. Previously, machines had been defined in a spatial sense, that is, by identifying in drawings the accumulator register, adder, command decoder, and so forth. In the case of spatial descriptions, the time sequence was implied or existed only in the designer's mind or memory. For example, complete sets of spatial drawings existed for the Binac and Univac, but the respective time domains and sequences existed only in Bob Shaw's head. The physical drawing of the CRC102 was just a list of flip-flops by name. A flow diagram described the machine's time sequence and a set of Boolean equations described the logic between the program counter, flow diagram, and all the flip-flops and stable state devices in the machine. Figure 10 shows a reduced copy of the CRC102/Cadac flow diagram.

Progress on the CRC102, which we renamed Cadac (for Cambridge Air Force Digital Automatic Computer), was significant through the rest of November 1950, with Sprague and I making strides in the logic, Sarkissian and Isborn on the drum memory, and Dobbins, Wolfe, Donan, and Wilson on the circuit and mechanical designs. By May, the logic was complete.

Cash and management woes

Richard Dabney was recruited, at Steele's instigation, in October 1950 as CRC's business manager. He brought many key skills from planning and manufacturing management at Northrop Aircraft. Hired in mid-November that same year as finance manager, Jack Warshauer (a friend of Dabney's) was previously a professor of finance and accounting at the University of Alaska in Fairbanks. He arrived just as we were trying to secure our first progress payments from the Air Force. We were paid in early December following a progress payment audit on 30 November 1950.

Under the business and financial leadership of Dabney and Warshauer, we completed the computer hardware design and prepared reports on the system and technical memory research. These actions were required to continue to receive progress payments from the Air Force and thereby stay alive financially. We also completed the debugging and testing of the airborne digital differential analyzer for North American Aviation.

Angels from Los Angeles

Although the progress payment system associated with the Air Force contract contributed a great deal, CRC nevertheless found itself cash strapped as 1951 wore on. About March, Dabney, through some previous contacts, managed to enlist the help of two "angels." George Fuller and Gordon Turnbull, two wealthy Los Angeles businessmen, agreed to loan us money against future contracts and progress payments, solving CRC's financial problems for the rest of 1951 and into early 1952.

It also helped that on 15 May 1951, CRC delivered the digital differential analyzer (DDA) pictured in Figure 11 to North American Aviation for payment, after it had passed pressure, shock, and vibration tests for airborne use.

Diverging philosophies

Steele was often gone from the operation during this period, pondering and inventing new ways to think about digital systems and computers. He was interested in the logic design concepts we had developed, but never got close enough to see, for example, how a complete set of Boolean equations could be written and tied together by a flow diagram. Believing, nevertheless, that he totally grasped the flow diagram concept, he moved directly to try to conceive the next step in what he called the "tabula rasa" (that is, blank tablet) machine. I believe he actually began to envision how future machines might be built using the technique that has come to be known as microprogramming. Steele would literally disappear from the office for weeks. The rest of us would muse that "he had been out in the desert, sitting on a sharp rock and thinking." We recognized him to be a genius and believed that eventually he would land on something vital, but his attitude and actions were threatening the nature and continued existence of our new company. Even before we left Manhattan Beach, Steele had wanted us to stop work on Cadac and start over by finding a way to design his novel concept of the tabula rasa-like machine.

In March 1951, about the same time CRC's angels came through, the schism between Steele and those of us who had been his disciples came to a head. Our commitment to move forward as a businesslike organization to meet our schedules and contract terms with AFCRL was not shared by Steele. He was seldom present and not prepared to add his thinking to the problems of money, contract terms, and other business matters. Our design activities also suffered as Steele withheld his creativity. The teacher–disciple relationship frayed and ultimately snapped. Only Reed (whom I believe never fell as far as the rest of us into blind-faith mode) seemed able to maintain communication with Steele.

We finally decided to hold a board meeting to make the formal motions and secure the votes to remove Steele and install Dabney as president. Steele's brother, Arnold, the attorney who had helped us create CRC and subsequently advised us, both provided guidance in how to conduct the meeting and represented and protected his brother. The meeting was difficult and strained. A few weeks later, Steele resigned from CRC. It was a difficult and emotional time for all of us.

(a) (b) (c)

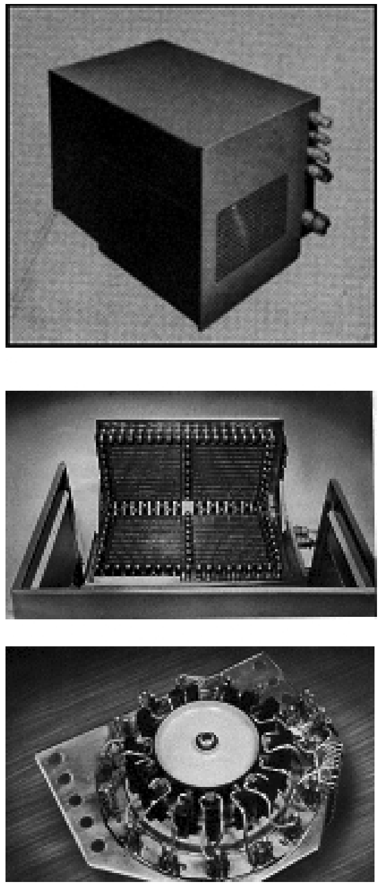


Figure 11. (a) Airborne Digital Differential Analyzer delivered to North American Aviation. (b) Logic section. (c) Drum memory.

Cadac meets the press

Debugging of the Cadac, which continued throughout the summer and fall of 1951, was a

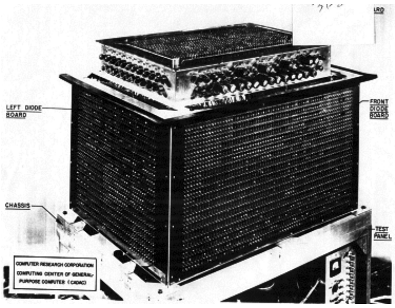


Figure 12. Like the Maddida, the Cadac used large boards to mount the many germanium diodes used for logic operations. The vacuum tubes, primarily flip-flops, were mounted on top. The power supply was underneath the diode board structure.

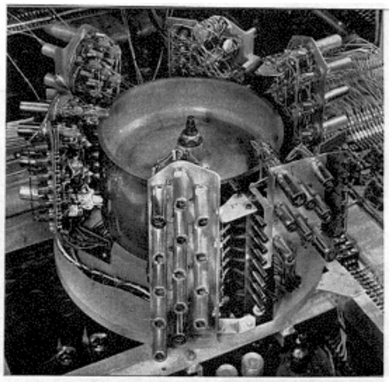


Figure 13. The Cadac drum memory included the clock channel and data channels that could store 1,024 32-bit words, or about 4,000 bytes.

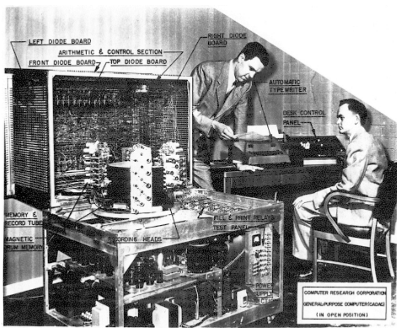


Figure 14. The Cadac and peripherals. Richard Sprague, left; Donald Eckdahl, right.

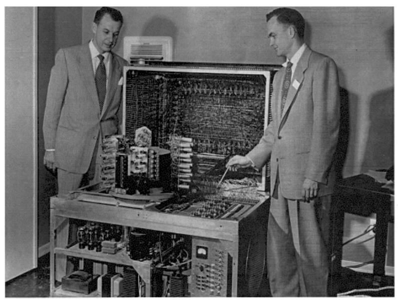


Figure 15. Cadac just before delivery to Cambridge Air Force Research Laboratory. Richard Dabney, left; Donald Eckdahl, right.

24-hour process. Sprague and I took some shifts; Dobbins and Wolfe, others. Present during most shifts to provide drum memory support was either Sarkissian or Isborn. We recorded on magnetic tape events, problems, and solutions as they occurred so that sometimes brief verbal summaries by tired people could be supplemented with detailed recorded recountings. Because the germanium diodes were mounted in clips on large diode boards, we could execute untested commands one at a time in an orderly process through step-by-step insertion of the diodes that would activate them. In the early years of digital computer development the debugging process was sometimes referred to as "commissioning," a probably more descriptive term that we believe originated with UK engineers.

By mid-November, the Cadac system was fully operational, and we showed and demonstrated it to everyone, including our original investor family and Turnbull and Fuller, as well as people from the Air Force. A press conference and demonstration held at CRC, which drew several members of the local press, generated some unexpected excitement as Sprague later recounted in the ACM article "A Western View of Computer History."[10]

Sprague, as vice president of marketing, held a press conference at which a reporter asked whether the machine being demonstrated could "think." Sprague explained, using the analogy of chess playing, that computers of the type being demonstrated, appropriately programmed by experts and much faster, might play and win often against human chess masters. The reporter's paper subsequently ran a story about an "electronic brain" that could play chess against a human being and win every time. Even as Sprague tried to calm the other, rather upset, CRC officers, the UP wire service picked up the story and it spread nationally. Things got worse as a rival general-purpose computer maker challenged the Cadac to a chess match, radio programs solicited interviews, and their producers requested that the machine appear on Edward R. Murrow's "See It Now" program and on the "Dean Martin–Jerry Lewis Show" to play chess with (and lose to) the latter. The Air Force, to Sprague's considerable surprise, was pleased with the publicity and the matter was laid to rest by explaining that the computer had to be shipped directly to the Cambridge Research Lab to perform important defense-related work.

The Cadac was shipped to AFCRL on 13 December 1951. In January 1952 it was moved to and made operational at MIT's Lincoln Laboratory in Massachusetts. Figures 12 through 15 show photos of the Cadac, its memory, and some of its peripherals.

CRC matures

CRC's success in acquiring contracts to build larger computers was accompanied by changes in facilities and personnel.

Contracts for larger computers

During the late spring and early summer of 1953, we courted a possible contract to develop a much larger general-purpose computer that would satisfy all of the US Navy Bureau of Aeronautics' business applications—to include payroll computation, spare parts management, and many other nontechnical applications. We proposed an ambitious system involving a 10,000-word (versus Cadac's 1,000-word) drum memory, one track of which was to contain approximately 1,000 words with 10 heads per track to speed memory access.

The system also involved contracting for the development of a high-speed mechanical printer and developing a magnetic tape storage unit to supplement drum storage. Although IBM punched card input-output units were to be a key part of the system, we also committed to develop a special input preparation device (called TEPU, for tape editing and printing unit) that would accommodate keyboarding to magnetic tape. The machine would store and calculate with decimal numbers (coded in binary) instead of direct binary storage of arithmetic operations as was the case with Cadac.

On 10 November 1953 we signed, with the Navy Bureau of Aeronautics, a contract to build what we called the CRC107. Shortly thereafter, we secured from the White Sands Proving Ground a contract to build a similar machine to perform missile data reduction and other scientific activities for the White Sands Missile Range, New Mexico (see Figure 16).

Figure 16. Data reduction at McDonnell Douglas, as at "every other aircraft company, typically used what can only be described as 'stockyards' of human 'computers' who sat at desks and used mechanical calculators like the popular Friden or Marchant models of the day. The scene was right out of Dickens: Rows of crewcut young men as far as the eye could see in shirtsleeves and skinny ties filling in calculation sheets month after month, year after year."[11] (Photo courtesy of P. Ceruzzi, *Beyond the Limits: Flight Enters the Computer Age*, MIT Press, 1989.)

Changes in plant and people

Before the Cadac was shipped in early 1952, CRC, needing more space for both engineering and manufacturing, moved from over the bakery in Torrance to a 21,600-square-foot industrial building in Hawthorne, California, close to Northrop Aircraft. About the same time, Reed, anguished over the falling-out among the founders that had preceded Steele's departure, left CRC. A good friend of Steele, he nevertheless appreciated the viewpoints of the other CRC founders. Reed subsequently joined George Valley at the prestigious Lincoln Laboratory. He later became a professor of electrical engineering and computer science at USC and, ultimately, an eminent mathematician.

When businessman/angel Turnbull died in early 1952, Fuller became concerned about going forward without his partner. He had also become concerned about our current method of financing. The cash advances on anticipated progress payments were still somewhat satisfactory, but we had begun to design a commercial model of the Cadac that we called the CRC102A, and he doubted that he could provide the capital to finance inventories, production facilities, and sales activities. Dabney, who had been our principal contact with the partners, advised us that Fuller's position was that we had plenty of time, but should begin to look for other methods and sources of financing.

We still were unsuccessful in interesting the traditional investment community, and the venture capital industry was at the time almost nonexistent. One Boston-area new-venture investor, American Research and Development, declined a solicitation by Dabney and Warshauer.[12] Our other option was to sell CRC to a company already in the electronics or office equipment field.

In search of a buyer

The first prospective buyer we approached was Pasadena, California-based Consolidated Electrodynamics, a smallish but well-established company that was one of the producers of the mass spectrometer, a large scientific instrument that identified samples of unknown materials through spectral analysis. Philip Fogg was the company's president; Jim Bradburn, its

Figure 17. At lunch on 29 July 1952 in NCR's Horseshoe Room were (left to right): Engineering vice president Williams, Donald Eckdahl, Charles Keenoy, Jack Warshauer, and Joseph Desch. (Courtesy of the NCR Archive at the Montgomery County Historical Society.)

vice president of engineering. My recollection is that Fuller made the contact and was instrumental in establishing a framework for the negotiations. Fuller was looking to the company to make loans against CRC contracts as he and Turnbull had done and buy him out for a negotiated price. This apparently was the only arrangement, no price or value being established for the rest of CRC or its other shareholders. When a New York banker representing Consolidated Electrodynamics made a definitive offer of price and conditions, Fuller was so disappointed and angry that he broke off negotiations immediately and left the meeting.[13]

Sprague, largely on his own, made overtures to a brother of Walt Disney named Larry, who represented himself to be in charge of "Disney Enterprises," only to discover that the latter had neither funds nor any authority or responsibility for his brother's money.

In July 1952, Warshauer and I traveled to the Midwest in search of a buyer. Warshauer had arranged a meeting with some of the top management of Admiral Radio in Chicago, but two hours of courteous, exploratory discussion failed to develop into any serious interest.

An adding machine salesman from NCR, with whom Sarkissian, at the behest of his brother-in-law, had agreed to meet, had asked if it would be all right to tell his regional manager about CRC. He subsequently did, and we soon received a visit from Jim Boyle, the accounting machine sales manager out of the company's Los Angeles office. Boyle, extremely enthusiastic about CRC, arranged for us to visit NCR headquarters in Dayton on 29 July.

NCR gave us a red-carpet welcome. We had lunch in the Horseshoe Room, which at the time seated about 200. Afterward, like all special guests of the company, we were presented with a picture that had been taken during lunch (see Figure 17). In attendance were all of the top management and supervisory management at the headquarters facilities, which included the large Dayton factory.

After lunch, we toured the headquarters and factory complex and a nearby residential area and visited the last home of Orville and Wilbur Wright, which was now owned by NCR and variously used as a guest house and for entertainment and meetings. We sat on the open front porch and were joined by our lunch hosts, Charles Keenoy, director of product planning, and Joseph Desch, senior director of special engineering. Williams, the engineering vice president [first name not known], did not join us. We were served cocktails in this afternoon setting and a little later were joined by executive vice president Robert Oleman. Warshauer and I told the CRC story, and the NCR team listened intently. Desch later made a definitive recommendation that his management proceed aggressively to forge a relationship with CRC.

The CRC/NCR relationship

CRC was subsequently visited by Desch and some of his subordinates: Keenoy and others from the product planning organization, executive vice president Oleman, and, toward the end, by NCR president Stanley C. Allyn. By September 1952 we had signed an agreement letter outlining general terms. CRC was to remain a separate corporation, under its own name. NCR was to buy 80 percent of CRC's stock, including that of the original investors, and pay off the long-term loan owed to Fuller. The founders and other employees were to retain 20 percent ownership of the company. The total value of this transaction was approximately $1 million. Following the negotiations, Oleman hosted a fancy dinner party for the founders and their spouses at Chasen's restaurant in Hollywood. All of us were familiar with this prestigious, upscale Hollywood restaurant, but had never imagined dining there. Positive attitudes prevailed on the part of both CRC and NCR, which made for a fine evening.

Owing to a Justice Department consent decree dating to its early years, NCR was required to testify in federal court on its plans to acquire a controlling interest in CRC. Sarkissian and I participated in the two to three months of preparation for what turned out to be a two-day hearing in federal court in

Cincinnati, Ohio. Court approval for the transaction was received in December 1952. By February 1953 the NCR transaction was complete. Figure 18 shows the announcement.

Culture clash

After an initial honeymoon period, problems began to develop in CRC's relationship with NCR. Although it had bought CRC because of its general-purpose computer product, NCR was not a systems company; few of the sales, product planning, and engineering personnel at Dayton had even a remote understanding of how or why IBM, which was a systems company, had been developing and selling applications for its punched card system products. NCR had difficulty seeing beyond fixed applications that extended its freestanding machines. Nor did it understand the systems concept of programming the capability to execute radically new business applications and systems into a general-purpose computer.

The idea that customers might conceive and develop the applications of the future (as customers of punched card systems had been doing for years) fit neither NCR's view nor the office equipment business philosophy. CRC was subsequently beset by questions from NCR: How can this "binary" computer ever be an important tool in business? Is it only a "scientific" computer? Why do you use punched cards and punch card readers and punches, products that aid and abet IBM, for input and output? (CRC had been using a punched card system to meet labor and other cost distribution reporting requirements for its many government contracts.)

NCR directed us to replace punched cards with paper tape as the input/output medium for CRC computers. NCR neither used IBM equipment directly nor contracted with processing companies that employed it, and because NCR equipment could not perform cost distribution and similar functions, the company's manufacturing and accounting simply did without. Because NCR machines tended to work on the fringes of the operations of typical industrial corporations, even such an obvious application of a general-purpose computer as payroll distribution was not really understood in its philosophical context.

That Sprague and his small sales organization had by spring of 1953 accumulated an impressive list of customers for the CRC102A (a fully production-engineered version of the Cadac), some of which planned to use the new machine for commercial (nonscientific) applications, did not alter the view of NCR senior management, which increasingly verbalized and wrote about CRC's "scientific computer." In June, CRC delivered its first real production computer, a CRC105 (a digital differential analyzer closely resembling the CRC102A in Figure 19) to Lockheed Aircraft in Burbank, California.

Meanwhile, the relationship between Dabney and Allyn had become strained. Dabney viewed Allyn as an equal, a perception Allyn did not share. Around midsummer, when he tried to reach him by telephone, Allyn found Dabney in the middle of a business trip relaxing for a few days at a first-class resort in the Caribbean. That Dabney's attitude had evident-

SEPTEMBER 30, 1952

Computer Firm Purchase Set For $1 Million

NCR Enters Accord To Enlarge Scope In Electronics

The National Cash Register company yesterday revealed it is making a $1,000,000 investment in the rapidly expanding field of electronic computation.

Stanley C. Allyn, president, said his company has entered into a stock purchase agreement with Computer Research corporation of Hawthorne, Calif.

The purchase price involves about $1,000,000, which covers payments for stock purchases, advance to principle stockholders and advances of working capital.

The transaction is subject to approval of the Federal district court in Cincinnati, since NCR operates under a consent degree issued in 1916 after a federal suit was filed in 1911.

The west coast company is both a research and manufacturing organization, producing a varied line of equipment designed to solve practically any kind of problem.

Up to $245,000

Most of the computers now installed are used by producers of ordnance material for the armed services, and have current prices ranking from $35,000 to $245,000.

Richard E. Sprague, vice president and a director of Computer Research, said his company is about 2½ years old, has 150 employes and is incorporated with 2,000 shares of common stock.

Sprague said his company now has a backing of contracts, both governmental and private, amounting to about $1,500,000, with prospects of about $3,000,000 more in the next six months.

Allyn said the purchase will give NCR a prominent position in the rapidly expanding field of electronic computation in scientific and technical applications.

And he emphasized it will enable the company to expand the scope of its research in the field of electronic computation in business and accounting applications.

Important Possibilities

"Computer Research has been proceeding along lines quite different from our own and has made no application of its computers to commercial accounting. We believe, however, that the principle they have followed may well hold important possibilities for use in developing accounting equipment," Allyn pointed out.

Items called Diodes, a tenth the size of tubes, are used in the company's products, making computer the size of a desk that can do work that would require a unit the size of a small room if tubes were used.

Figure 18. The NCR press release describing the CRC deal. (Courtesy of the NCR Archive at the Montgomery County Historical Society.)

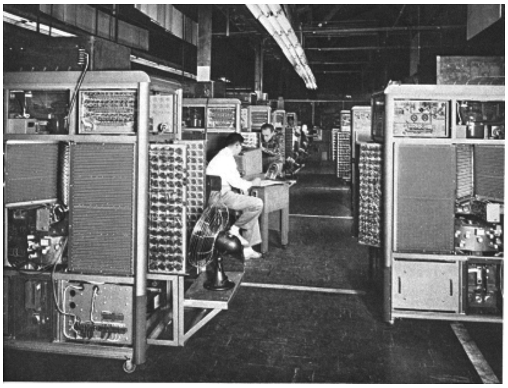


Figure 19. The CRC102A and CRC105 production floor in Hawthorne, California, about 1953.[14] (Courtesy of the NCR Archive at the Montgomery County Historical Society.)

Figure 20. CRC102A computer and output printer. (Courtesy of the NCR Archive at the Montgomery County Historical Society.)

ly been anything but humble when the NCR president finally reached him incensed Allyn, who ordered that Dabney be fired. The formal firing fell to Oleman and neither CRC nor other NCR management had the power to undo it.

Reorientation

In July, NCR dispatched Robert Pierson from Dayton to be president of CRC. Pierson was a member of the product planning organization and, like Keenoy, had previously been highly successful in sales and sales management. Pierson decided to run marketing directly, with Sprague as his vice president of sales. He asked Warshauer to be vice president of finance and me to be vice president of operations, which included engineering and manufacturing. Sarkissian continued as vice president of engineering. Our vice president of manufacturing, Harry Swanson, had considerable manufacturing systems experience and had been involved in a number of technology manufacturing plans at Northrop.

Swanson and the people he hired and brought with him had a significant impact on CRC's manufacturing philosophies and concepts. He was particularly knowledgeable about the learning curve theory developed by Northrop and other modern airframe companies of that period. He also introduced the notion that manufacturing assembly workers could and did contribute more by helping to identify superior manufacturing methods than by working harder or faster. These concepts not only permeated CRC, but also became the foundation of NCR's manufacturing philosophy in the electronics and computer era.

In October, in his "keeping up with the business" column in NCR's Dayton house organ, Allyn represented CRC as the development, manufacturing, and sales arm of NCR's computer business. By the end of 1953, CRC had made considerable progress thanks to a new president with a strong sales background and intimate knowledge of NCR politics and people.

The end of CRC

NCR's announcement in late January 1954 that CRC was no longer to be a freestanding corporation, but instead a division of NCR, required that all remaining founders' stock be sold back to NCR, a severe disappointment to the CRC founders. This was accomplished on 5 February 1954. We were again not offered stock options, so had ended up with no financial interest in either CRC or NCR. (During the initial NCR negotiations we had not even asked for stock options, in fact, did not know to ask, none of our senior advisors or attorneys having explained the concept to us.)

Pierson was subsequently named general manager of NCR's Electronics Division, and he named me assistant division manager.

First CRC102A delivered

Delivery of the first CRC102A to Holloman Air Force Base (New Mexico) was an important milestone for the new division. With the 102A in full production on our manufacturing floor, subsequent deliveries went smoothly; by October, 16 of these computers had been successfully delivered. Figure 20 shows the CRC102A.

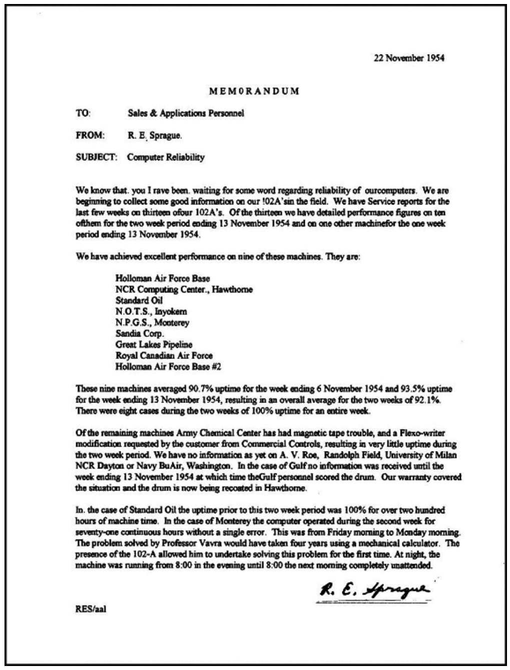
Many more CRC102As and CRC105s were delivered during the remainder of 1954. NCR management paid the division many visits during this period to review the progress of both new product deliveries and research and development activities. Figure 21 shows the NCR and CRC management group in 1954.

In mid-1954, the division initiated production of the CRC102D, a version of the CRC102 designed to allay NCR's concern about the use of binary numbers for internal computation (arithmetic operations were done in binary-coded decimal numbers and output was in decimal notation). But continued dissatisfaction on the part of NCR management, particularly Allyn, with the division's inability to be a profit producer rather than an expense, together with other signals of NCR's displeasure, led Sprague to carefully document customer satisfaction with the CRC102 computer. Figure 22 shows a memo that summarizes the level of computer reliability in the CRC102.

CRC107 delivered

On 18 August 1953, the division delivered to the Navy Bureau of Aeronautics in Washington, D.C., the CRC126 magnetic tape

Figure 21. NCR and CRC management group at CRC facilities in early 1954. From left to right: Robert Chollar, NCR vice president of research; Bob Pierson, CRC president (from NCR); Jack Warshauer, CRC treasurer; Stanley C. Allyn, NCR president; Dick Sprague, CRC vice president of sales; Bob Oleman, NCR executive vice president; Donald Eckdahl, CRC vice president of operations; and Harold Sarkissian, CRC vice president of engineering. (Courtesy of the NCR Archive at the Montgomery County Historical Society.)



22 November 1954

MEM0RANDUM

TO: Sales & Applications Personnel

FROM: R. E. Sprague.

SUBJECT: Computer Reliability

We know that. you I rave been. waiting for some word regarding reliability of ourcomputers. We are beginning to collect some good information on our !02A'sin the field. We have Service reports for the last few weeks on thirteen ofour 102A's. Of the thirteen we have detailed performance figures on ten ofthem for the two week period ending 13 November 1954 and on one other machinefor the one week period ending 13 November 1954.

We have achieved excellent performance on nine of these machines. They are:

Holloman Air Force Base
NCR Computing Center., Hawthorne
Standard Oil
N.O.T.S., Inyokern
N.P.G.S., Monterey
Sandia Corp.
Great Lakes Pipeline
Royal Canadian Air Force
Holloman Air Force Base #2

These nine machines averaged 90.7% uptime for the week ending 6 November 1954 and 93.5% uptime for the week ending 13 November 1954, resulting in an overall average for the two weeks of 92.1%. There were eight cases during the two weeks of 100% uptime for an entire week.

Of the remaining machines Army Chemical Center has had magnetic tape trouble, and a Flexo-writer modification requested by the customer from Commercial Controls, resulting in very little uptime during the two week period. We have no information as yet on A. V. Roe, Randolph Field, University of Milan NCR Dayton or Navy BuAir, Washington. In the case of Gulf no information was received until the week ending 13 November 1954 at which time theGulf personnel scored the drum. Our warranty covered the situation and the drum is now being recoated in Hawthorne.

In. the case of Standard Oil the uptime prior to this two week period was 100% for over two hundred hours of machine time. In the case of Monterey the computer operated during the second week for seventy-one continuous hours without a single error. This was from Friday morning to Monday morning. The problem solved by Professor Vavra would have taken four years using a mechanical calculator. The presence of the 102-A allowed him to undertake solving this problem for the first time. At night, the machine was running from 8:00 in the evening until 8:00 the next morning completely unattended.

R. E. Sprague

RES/aal

Figure 22. A summary memorandum of reliability and general customer satisfaction relative to the CRC102A computers installed in November 1954.

unit, the first piece of the large CRC107 computer system that we were contracted to deliver. In January 1954, the CRC127 TEPU and CRC128 high-speed printer were delivered. By fall, the two large units that comprised the central processor and 10,000-word memory drum had been installed. Subsequent problems with the bearings in the memory drum were resolved through extensive rework and testing. Rendered operational in late 1955, the Navy used the computer for many years thereafter for payroll, accounting, and parts system processing. Figure 23 is an artist's rendition of the system delivered to the Navy Bureau of Aeronautics.

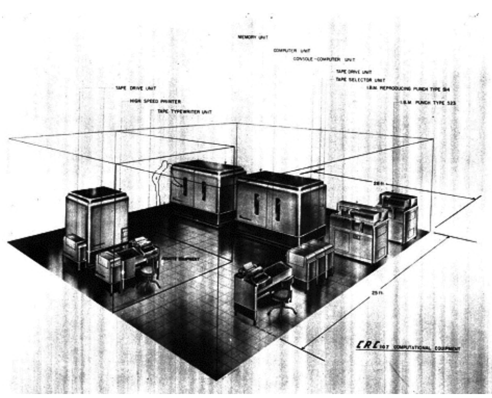


Figure 23. Artist's rendition based on design data for the CRC107 installed at the Navy Bureau of Aeronautics facility in Washington, D.C. Photographs could not be found of the CRC106 or CRC107. (Courtesy of the NCR Archive at the Montgomery County Historical Society.)

Changing of the mission and the guard

In late November 1954, Owen Gardner, head of accounting machine sales for NCR, assumed sales responsibility for the Electronics Division. In February 1955, Sprague left NCR to pursue an alternate career. In March, NCR returned Pierson to his previous position in Dayton and named me manager of the Electronics Division, charged with terminating all manufacturing activities and converting the division charter exclusively to research and development. Significant budget cuts were made throughout the organization. Sarkissian left in September 1955. A decade later, he founded Major Data Corporation and, frequently ahead of his time, developed electronic voting equipment for which the US is only now ready.

I remained with the Electronics Division, which, five years later, was renamed the Data Processing Division, with responsibility for all NCR computer systems' research, development, and manufacturing. I subsequently was named vice president in charge of that division and later transferred to NCR headquarters in Dayton to head, as senior vice president of the engineering group, all NCR engineering and manufacturing worldwide.

The legacy of the Maddida

"Maddida," the Project MX-775 report author summarized,

> is unique among large scale computers because of its compactness, simplicity of construction, and accuracy. A prototype model of Maddida required less than 600 man hours for its construction. It occupies only 7 1/2 square feet of floor space, yet it contains 22 integrators capable of six decimal place accuracy. To date, this model has operated for a total of more than 270 hours and for as much as 60 hours without a failure. Transported extensively by air, rail, and truck, it has been consistently placed in operation within 24 hours after delivery. The performance of this simple model has been remarkable; the potentialities of future models appear unlimited.[15]

Other chroniclers expounded on those potentialities. "Maddida represents," wrote Dag Spicer,

> a transitional period between two key technologies. While remaining faithful to its roots in the analog analyzers with which its inventors were comfortable, Maddida took a bold, bright step forward into the then-new and computationally-driven world of jet aircraft, missiles, and rockets. It was such advanced computation, provided economically and reliably by machines like Maddida, that enabled both the computing and aerospace industries to move forward.[11]

Spicer further observed that "the technological advances of so many computing projects are often equaled or surpassed by the formation of computer experts trained by the projects themselves, who then go on to propagate into and define the industry."[11]

"When Maddida appeared to be successful," recalled Fred Gruenberger,

> a group of men at Northrop … impatient at the efforts to promote such equipment … spun off into a new company, Computer Research Corporation. CRC was ultimately absorbed by National Cash Register. Northrop meanwhile went ahead with Maddida and later sold the rights to Bendix. Glenn Hagen, who was in charge of the Maddida project, left Northrop to help form Logistics Research, Inc., which later produced the ALWAC. And Floyd Steele, also of the Maddida group, formed Digital Controls, a company later absorbed by Litton Industries. Thus, the digital computer group at Northrop … had a finger in many computing pies, one way or another.[16]

Acknowledgments

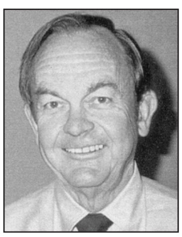
All figures for which no other source is given are courtesy of the Montgomery County Historical Society, Dayton, Ohio, which generously provided the authors access to its extensive NCR archives.

References and notes

1. T.C. Bartee, I.L. Lebow, and I.S. Reed, *Theory and Design of Digital Machines*, McGraw-Hill, 1962.
2. T.J. Bergin, ed., *50 Years of Army Computing: From Eniac to MSRC*, Army Research Laboratories and U.S. Army Ordnance Center and School, 2000.
3. Unless noted otherwise, all quoted material is from the Computer Oral History Collection of the National Museum of American History.
4. T.C. Bartee, I.L. Lebow, and I.S. Reed, *Theory and Design of Digital Machines*, McGraw-Hill, 1962, sections 10-8, 10-9, and 10-10.
5. O. Morgenstern and J. von Neumann, *Theory of Games and Economic Behavior*, Princeton Univ. Press, 1944.
6. Copies of the papers apparently do not exist; I believe they never existed as I remember giving my paper from notes, save for a projected transparency that contained examples of a portion of the Boolean algebra equations that defined the Maddida.—D. Eckdahl.
7. J.E. Sammet, "Answers to Self-Study Questions," *Annals of the History of Computing,* vol. 11, no. 1, 1989, p. 43. Sammet writes: "As can be clearly seen in the list … the most common computer in 1951–1952 was the Maddida, not the Univac."
8. Cadac was the name given to the CRC102 computer developed under contract for the Air Force and the CRC102/Cadac was the prototype for a subsequent commercial version of the computer called the CRC102A.
9. R. Sprague, "A Western View of Computer History," *Comm. ACM*, vol. 15, no. 7, July 1972, pp. 691-692.
10. R. Sprague, "A Western View of Computer History," *Comm. ACM*, vol. 15, no. 7, July 1972, pp. 690-691.
11. D. Spicer, "Maddida: Bridge Between Worlds," *CORE: A Publication of the Computer Museum History Center*, vol. 1.3, Sept. 2000, pp. 2-5.
12. But several years later, when the investment community began to understand that there might be some demand for these "giant brains" or "digital computers," American Research and

Development financed the start-up computer company Digital Equipment Corporation.

13. Consolidated Electrodynamics subsequently created its own computer company, Electro-Data, which later became the basis of Burroughs Corporation's entry into digital computers.
14. Tibor Fabian recalled a visit to the CRC facility made with UCLA Management Sciences Research Project "cubby-mate" Dick Canning in late 1952 or early 1953. "After security arrangements, we were led into a large industrial area, a relatively empty structure. On one side stood metal frames, similar to industrial metal shelves, in a long row, one behind the other. Those in the front were fairly well filled with electronic equipment and a great deal of wiring; those toward the middle were gradually emptier, while those toward the end were almost empty. It was clear that this was an assembly process, in which the assemblers moved gradually from the first to the last of the metal frames and added the electronics and wiring in the step-wise fashion of an assembly line. As Dick explained, the racks were computers-to-be." From E. Weiss, "Roger Sisson Biography," *IEEE Annals of the History of Computing,* vol. 18, no. 2, Summer 1996, pp. 67-76.
15. Northrop Aircraft, *Maddida (Preliminary Report),* Project MX-775, report no. GM-545, 26 May 1950.
16. F.J. Gruenberger, "A Short History of Digital Computing in Southern California," *Annals of the History of Computing,* vol. 2, no. 3, July 1980, p. 248.



Donald E. Eckdahl was born 29 April 1924 in Los Angeles and died 23 July 2001 in Tucson, Arizona. Eckdahl joined Northrop Aircraft in 1946, where he worked as a project engineer in helping to develop computer and guided-missile systems, including the Maddida. In 1950, he was a cofounder of Computer Research Corporation, which effectively launched a 30-year career with NCR, where he served as vice president and general manager of operations of the Electronics Division and, ultimately, as senior vice president of NCR's engineering and manufacturing group. In later years, Eckdahl was a partner in an executive search firm (1980–1985), joined Branford, Connecticut-based Multiflow Computer as president and CEO (1985–1990), and retired from ESA, a Connecticut consulting and executive search firm, in 1995. Eckdahl earned a BS and an MS in electrical engineering at the University of Southern California. He was a member of both the IEEE and the ACM.

Irving S. Reed is the Charles Lee Powell Professor of Electrical Engineering and Computer Science at the University of Southern California in Los Angeles, which he joined in 1963. Reed's career began at Northrop Corporation in 1949, where he helped develop the Maddida computer. In 1951, he joined MIT's Lincoln Laboratory and, in 1960, Rand Corporation. Reed, the principal originator of the Reed-Muller and Reed-Solomon error-correcting codes, has made many research contributions, most recently in adaptive arrays, digital signal processing, detection theory, and VLSI design of coders and decoders. Reed received a BS and a PhD from the California Institute of Technology. He served in the US Navy and is an IEEE fellow and a member of the National Academy of Engineering. Reed's many awards include the IEEE's Richard W. Hamming Medal in 1989.

Hrant H. (Harold) Sarkissian was born in 1922 in Fresno, California, and died 15 February 2001 in Newport Beach, California, as this article was being submitted to the *Annals*. Following his years at Northrop Aircraft and CRC with his coauthors, Sarkissian maintained a consulting practice and founded, in the mid-1960s, Major Data Corporation. His passion, according to wife Martha Sarkissian, was being an electronics engineer, whether on his knees earning a handsome consulting fee for removing a piece of chewing gum that had stopped a room-size dinosaur of a computer in its tracks or, so often ahead of his time, developing decades ago electronic voting equipment for which the US is only now ready. A 1944 graduate of the University of California at Berkeley, he held a BS in electronic engineering. Sarkissian was a member of the Signal Corps in WWII and was a Life Member of the IEEE.

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