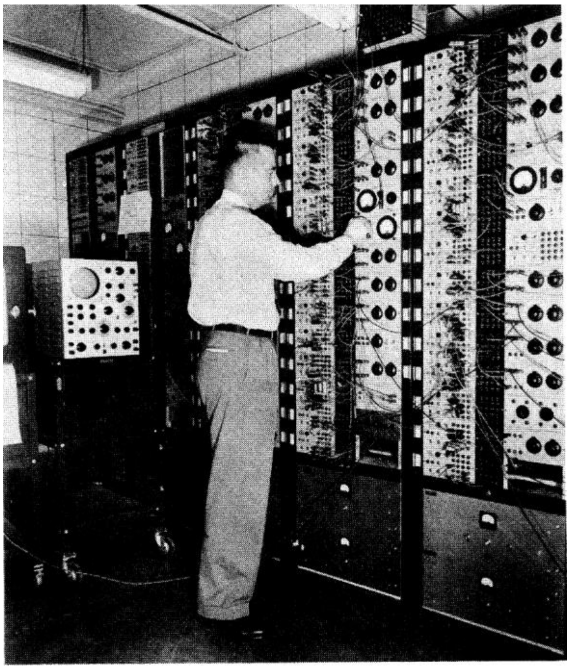
Monster Computers vs. Engineering Computing.
The early Computer Culture in the US, 1944-1953.



The Boeing Analog Computer 1950
(Source: Henry Paynter: Palimpsest on the Electronic Art, Boston 1955, p. 44)

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Content

Abstract

The paper explains the leading role of mathematicians in developing the high speed digital computer at the East Coast. The digital computer as cutting edge technology was a view of mathematicians and served the academic field in universities but not the Cold War R&D scenery where mainly analog computing was used. The military strength of the US armed forces relied on a strong air force and on the atomic bomb. But there was no need of high speed digital computers in the US weapon factories. Neither the cluster of aeronautical industry at the West Coast producing bombers and fighter planes (Lockheed, Boeing, Douglas, Northrop) nor the atomic bomb production facility in Los Alamos issued a request of an urgent need for a high speed digital computer. The mathematicians did not take the slow magnetic drum memory into account. Surveys showed that the overwhelming number of digital computers that were employed in the US did not contain high speed memories but drum memories.

1 Introduction

In the historiography of early digital computers in the US the focus is on the ENIAC, ready for operation in 1945, and the von Neumann computer at the Institute for Advanced Study (IAS) in Princeton, ready for operation in 1951. These computers combined a high speed electronic arithmetic unit with a high speed memory, were able to perform a long series of calculations with high speed and could be programmed for arbitrary calculation tasks. They used thousands of electronic vacuum tubes and filled a single room. Many books were published on these computers. But these studies did not take into account the rich landscape of machine computing that developed during the years 1944 to 1955 in the US. I claim that in the ecology of knowledge the high speed digital computer played only a minor role. The current success stories of the high speed digital computer overstated a need of high speed computing that was employed in the war (WW2) and Cold War science and technology laboratories in industry only to a small extent.

In my paper I explore the actors of machine computing and reveal the goals of computing. I scan the landscape of machine computing according to the following categories: digital computer vs. analog computer, high speed memory vs. low speed memory (drum), mathematicians as actors vs. engineers, inventions of mathematicians vs. experience with material in laboratories, academic needs in universities vs. design support in aeronautical industry.

The military strength of the US armed forces relied on a strong air force, a strong navy with a large fleet of aircraft carriers and on the atomic bomb. But neither the cluster of aeronautical industry at the West Coast producing bombers and fighter planes (Lockheed, Boeing, Douglas, Northrop) nor the atomic bomb production facility in Los Alamos addressed a request to the National Defense Research Committee for an urgent need of a high speed digital computer. Instead, the proponents of the high speed digital computer were mathematicians working in lowly ranked mathematical groups of the branches of military service, as a group in the RAND Corporation (Air Force), in the National Bureau of Standards in Washington D.C. or as a group in the Office of Naval Research in Washington D.C. and the Army's Ballistic Research Laboratory in Aberdeen. The expert movement of mathematicians was not extraordinary in the twentieth century. It witnessed various expert movements: the efficiency movement in the US around 1910, the rationalization movement in European industry around 1925 and the automation movement in the US and Europe around 1960. All these movements were already subject of critical studies exploring the goals of the movements and the limited extent to which they achieved their goals.[1] Further the studies explored the actors, the influence of government policy and the views in the public debate of the public, the scientists, the employers and the trade unions. This paper portrays the development of high speed digital computers in the US 1944 – 1955 as an expert movement of mathematicians and delivers a critical account of this movement.

The history of the digital computer was mainly written by mathematicians as its proponents and later by historians as success stories and heroic tales.[2] This paper will deconstruct this

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[1] Samuel Haber: *Efficiency and Uplift*, Chicago 1964. Charles Maier: *Between Taylorism and Technocracy: European ideologies and the vision of industrial productivity in the 1920s*, in: Journal of Contemporary History, vol. 5, no. 2 (1970), pp. 27-61. Ronald R. Kline: *Cybernetics, Management Science, and Technology Policy: The Emergence of "Information Technology" as a Keyword, 1948-1985*, in: Technology and Culture, vol. 47, no. 3, Technology (Jul., 2006), pp. 513-535.

[2] Herman Goldstine, *The Computer from Pascal to von Neumann*, (Princeton, 1972). Dantzig (cf. endnote 1). Roy Weintraub (ed.), *Toward a History of Game Theory*, (London, 1992). Thomas Haigh, Mark Priestley and Crispin Rope, *ENIAC in Action*, (Cambridge, Mass., 2016). George Dyson, *Turing's Cathedral. The Origin of the Digital Computer*, (New York, 2012). Dyson did much research in the archive of Princeton University. Dyson's book is written as heroic tale. A close fellowship of heroes work under difficult conditions in the IAS. They

history. I argue that the success stories of the digital computer as a story of high speed digital computers followed a view mathematicians perceive of the world and focussed only on leading edge digital technology. They did not regard the engineers‘ movement in computing machines that served the needs in the industrial laboratories better than the high speed digital computers. So I give some evidence to distinguish between industrial and academic needs of computation.

As primary sources this paper relies on contemporary journals on machine computing, as Mathematical Tables and other Aids of Computation, on the Newsletter on Digital Computers of the Office Naval Research, on the Proceedings of the Radio Institute Engineers (IRE) and the Transactions of the American Institute of Electrical Engineers (AIEE). In addition, the paper draws on the surveys on the development of computers around the year 1950 which the Ballistic Research Laboratory in Aberdeen and the ERA corporation provided.[3] Further I refer to the Computer History Museum in Mountain View.

2 Digital and Analog Computers

The years during 1940 and 1955 experienced a lively debate on digital and analog computers and the advantages of each kind. It is beyond the scope of this paper to give a full account of this debate. So for the following only the distinction between analog and digital computers is required as these kinds of computers developed to a field of competition. An analog computer is a physical analog to the problem it is solving. Its spread grows with the complexity of the problem. When the problem is simple also the analog computer remains simple. An analog computer gets its input from electrical and mechanical sensors that measures the variables of interest as physical quantities, as shaft rotation, electrical resistance, frequency, etc.. According to Bernd Ulmann an analog computer is a piece of equipment whose components can be arranged to satisfy a given set of equations, usually simultaneous ordinary differential equations.[4] As an electronic analog computer one regards an analog computer that was driven by DC–amplifiers based on circuits with electronic tubes.The debate at the beginning of the 1950s distinguished between small electronic analog computers and large systems in the flight simulation of missiles and aircrafts.

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worked in the basement boiler room due to the lack of office space. Michael Williams, *A History of Computing Technology*, Englewood Cliffs 1985, second edition 1997. William Aspray*, John von Neumann and the Origins of Modern Computing*, Cambridge, Mass., 1990. Martin Campbell-Kelly, William Aspray, Nathan Ensmenger and Jeffrey Yost, *Computer – A History of the Information Machine*, (New York, 1996, 2014). I refer here to the third edition in 2014.

[3] Martin Weik, *A Survey of Domestic Electronic Computer Systems*, report no. 971, Aberdeen 1955. ERA (ed.), *High Speed Computing Devices*, McGraw-Hill,New York 1950.

[4] Bernd Ulman, *Analog Computing*, Oldenbourg Publisher, Munich 2013, p. 2.

Image 1: Development team with three MADDIDA machines of Northrop Aircraft 1949. „The advances in MADDIDA in terms of simplicity and miniaturization are of great significance to the scientific and business world. A desk-side mechanical brain." Press release. (Computer Museum Mountain View, document no. 10885, 102710219)

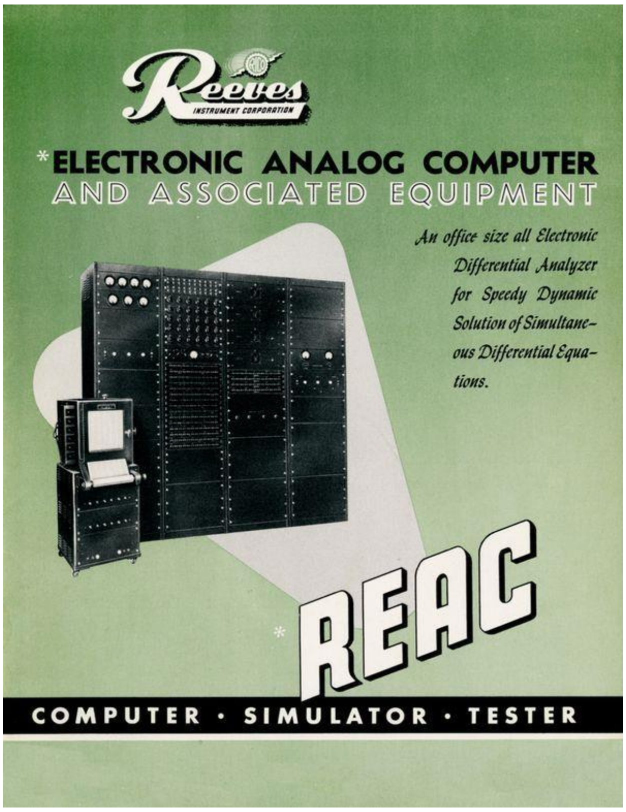

Image 2: Advertisement of Reeves Instruments with the solution of differential equations 1950. Reeves underlines speedy solutions. (Source: http://www.computerhistory.org/revolution/analog-computers/3/150)

For small applications electronic analog computers were rapidly developed into very useful commercially available devices by the firms Reeves Instruments, Goodyear Aircraft, Boeing

Aircraft, Electronic Associates, Northrop Aircraft and Philbrick.[5] It is striking that with Boeing, Northrop and Goodyear Aircraft three aeronautical firms entered the market of analog computers, because in this industry the design process in aircraft and missile projects relied heavily on the solution of differential equations. Analog computers served very well this need. In its advertisment Reeves Instruments underlines the speedy solution of differential equations with its computer REAC (cf. image 2). As the Lockheed engineers Mazelsky and O'Connel pointed out, aircraft design „usually involves numerous calculations involving a large number of variations of structural parameters."[6]

With their projects for guided missiles, military agencies induced a boom of electronic analogue computing machines. The Office of Naval Research (ONR) started the project Cyclone in 1946 with the firm Reeves Instruments, in New York City. The aim of Cyclone was to build a machine to simulate the flight of guided missiles.[7] This simulation was an important issue insofar as test flights ended in the destruction of the missile, because it had no device for landing. Northrop built a landing zone in Cape Canaveral for its Snake missile project to recover the airframes. The difficulty of controlling the missiles during test flights was shown when one Snake missile escaped erroneously to Brazil. Simulations would save money and time, and no replacement for a destroyed missile would be necessary. Sheldon and Tatum described the difficulties of obtaining test data during the test flight of a guided missile. Tracking it on a test range was the only way to make sure of its performance. At one test facility, this was done by planting camera batteries or photo-theodolites along a 100-mile course. During its flight, the missile position was recorded by each camera at 100 frames per second, together with the camera training angles. Before the digital IBM calculator, 604 would be employed, and the thousands of pictures from each camera were turned over to a crew of female computers, to determine just what had happened. It took two weeks to make the calculations for a single flight.[8]

In the Cyclone project, the firm Reeves embarked on the Bell Lab's special purpose electronic analogue computer and became the first supplier for commercial electronic analogue computing devices in 1948. It was marketed very successfully under the name

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[5] Arthur Vance, „The Role of Analog and Digital Computers in Simulation", *Proceedings of the Western Computer Conference*, held by the Joint IRE-AIEE-ACM Computer Conference Committee, Los Angeles, February 4-6, 1953, pp. 24-27, here p. 26. For large scale flight simulation in the project Whirlwind see Campbell-Kelly et al. (2014), cf. endnote 3, chapter 7. See also Henry Paynter: Palimpsest on the Electronic Art, Boston 1955.

[6] B. Mazelsky and R. O'Connel, „The Integrated Use of Analog and Digital Computing Machines for Aircraft Dynamic Load Problems", *Joint AIEE-IRE Western Computer Conference 1955, Los Angeles*, 68.

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James Small, Analogue Alternative. The Electronic Analogue Computer in Britain and the USA, 1930–1975, London 2001. James Small, 'General Purpose Electronic Analog Computing: 1945–1965', IEEE Annales of the History of Computing, Vol. 15 (1993), No.2, 8–18. Chris Bissell, A great disappearing act: the electronic analogue computer, IEEE Conference on the History of Electronics, 28-30 June, 2004, Bletchley, UK.

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John Sheldon and Liston Tatum, 'The IBM Card-Programmed Electron Calculator', *AIEE-IRE '51 Papers and discussions presented at the Dec. 10-12, 1951, joint AIEE-IRE computer conference: Review of electronic digital computers*, 30. Reprinted in Brian Randell's collection, *The origins of digital Computers*, Berlin 1973.

REAC. Three years after its market entrance, in 1950, there were already 60 REAC systems throughout the US, showing the high demand for computing solutions, presumably in the aeronautical industry. In New York City, the ONR organized a symposium for REAC–Techniques in 1951.[9]

In 1947, following up on Cyclone, the ONR contracted the Typhoon project with the Radio Corporation of America (RCA) lab in Princeton, New Jersey, which was also for simulating guided missiles and developing anti aircraft missiles.[10] Besides the policy to directly fund the development of electronic analogue computers, the military agencies gave contracts for airframes to aeronautical firms with sufficient financial volume to develop electronic analogue computers themselves, to conduct their designing tasks for airframes.

Digital computers did not dominate the entire field of applications in the 1950s. The aircraft and missile industry used analog computers in the design process and wind tunnel experiments until the end of the 1970s. The National Aeronautics and Space Administration installed in 1961 a large, general purpose analog computer at NASA's Langley Field for the Saturn V project.[11]

Other than analog computers that focus on analogs of physical systems, digital computers focus on numerical problems that could be solved by a sequence of elementary arithmetic operations. Digital computers get the input data as a stream of numbers that were supplied by punched cards or by tapes and stored in memories as numbers of base 10, base 5 or base 2. The memory technology developed from relay-based memories to electronic ones based on flipflop tubes, William tubes, mercury delay lines and later to magnetic drums or magnetic cores. Besides the memory unit, digital computers possessed a control unit which executes the commands of a program and an arithmetic unit which performs elementary arithmetic operations on numbers. The technology of the arithmetic unit changed from relay technology to electronic circuits with electronic tubes which could perform arithmetic operations very quickly in the range of microseconds. Examples of early digital computers with an electronic arithmetic unit are the ENIAC (Electronic Numerical Integrator and Computer) of 1945, IBM's SSEC (Selective Sequence Electronic Calculator) of 1948 and and the SEAC (Standards Eastern Automatic Computer) of 1950.[12] These computers were of

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Bauer, F. Bauer, L. Brock, P. Manfredi, B. Meissinger, H. Sherman, (eds.), *Symposium 1 on Reac techniques, March 15-16*, New York 1951.

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For the projects Cyclone and Typhoon see James Small, General Purpose (cf. footnote 7).

[11] Datamation, 1961 May, p. 8. For the social history of computing at Langley see Margot Shetterly, *Hidden figures: The untold story of the African American women who helped win the space race*, London 2017. Paul Ceruzzi, *Beyond the Limits. Flight enters the Computer Age*, MIT Press 1989, 172.

[12] For the SSEC see Charles J. Bashe, "The SSEC in Historical Perspective", *IEEE Annals of the History of Computing* (in the following: Annals), vol. 4, 1982, issue 4, pp. 296-312. For the ENIAC see Haigh et al. (cf. endnote 2).

considerable size and filled an entire room. In the contemporary debate they were also called monster computers, as an article in Time Magazine indicates on the delivery to the Navy of the Mark III computer built by Harvard Professor Aiken.[13] Digital computers were very useful in arithmetic calculations, for example the determination of large prime numbers, multiplying matrices and in accounting, for example in computing for thousands of customers consumption x unit price and billing in public utilities. Analog computers could not solve these problems. Also digital computers were used to solve sets of linear equations and of differential equations. The latter opened a field of competition to analog computers.

Standards Eastern Automatic Computer, 1950. Source: NIST.

3 The Digital Computer as an Invention of Mathematians

The mathematicians in the branches of armed services strongly supported the development of digital computers and related research. The Army's Ballistic Research Laboratory at

[13] Time Magazine, 27 January 1950.

Aberdeen, Md., were led by mathematicians and funded the development of the ENIAC computer at the Moore School of the University of Pennsylvania in Philadelphia. The Navy maintained an Office of Naval Research in Washington D.C. with a mathematical department and supported several R&D projects.[14] It edited also the journal “Naval Research Logistics Quarterly” since 1953 which published on models of battlefields and Operations Research and which became one of the leading journals in Operations Research in the 1950s. The Air Force employed the National Bureau of Standards (located in Washington D.C.) as R&D laboratories and agencies to finance research and development of digital computers. The latter bought in 1951 the first commercial digital computer – an UNIVAC I to support the manufacturing firm Remington Rand.

In the Cold War, during the 1950s, the SAGE program was based on the clear motivation to develop digital computers to detect on the radar screens an air strike of the enemy.[15] But in the 1940s the armed services lacked a clear goal to develop the digital computer. Anyhow the branches of services employed their own agencies and did not cooperate. This behavior strongly suggests the assumption that they saw the development of the digital computer not as an urgent matter but as a nice field of competition. Otherwise they would have centralized the development. Remarkable is that the the aeronautical industry at the West Coast producing bombers, missiles and fighter planes did not call for a high speed digital computer.

For an observer the funding policy of military agencies to enable the digital computer appears rather chaotic. Not even a survey under the research laboratories of their needs of machines to assist computing was undertaken. Already before the construction of the ENIAC machine at the Moore School was finished in 1945, the developing group of John Mauchly, Presper Eckert, Herman Goldstine and John von Neumann perceived a successor model (Electronic Discrete Variable Arithmetic Computer – EDVAC) in 1944 and got funds. The mathematician John von Neumann left the group to build his own computer as a private project. He received in 1945 the financial funds from the Army and from the Atomic Energy Commission to build a development laboratory for a digital computer on a site of the Institute for Advanced Study (IAS) in Princeton, N.J., where he was a permanent member. The aim was to design and construct a electronic digital computer, with 5K main memory and stored program ability, later known as IAS machine. It could be used not before summer 1951.[16] In Aspray's presentation on the development of the IAS computer, the memory question is somewhat unclear.[17] Based on a speed of 10 to 50 microseconds for a memory access, the Mercury Delay Line should be ruled out because it is too slow. On the other hand, there is talk about the requirement that the memory should have an access of a few milliseconds. In spring 1948, development work was also started at the IAS on a drum memory with a 5 inch

[14] Mina Rees, „The Computing Program of the Office of Naval Research, 1946-1953“, *Annals*, issue No. 2 - April-June (1982 vol. 4), pp. 102-120.
[15] For the SAGE program see Edwards (cf. endnote 4), chapter 3 and Campbell-Kelly et al. (cf. endnote 2), pp. 150-152.
[16] Aspray 1990, cf. endnote 2.
[17] Aspray, (cf. footnote 2), Von Neumann, pp.80–85.

diameter. The decision to buy a finished drum from ERA in St. Paul was turned down. But a drum would be slower in access than the required few milliseconds.

Also Air Force‘s RAND Corporation gave an order to the Bureau of Standards to build a machine (Standard Eastern Automatic Computer - SEAC). Also the project Whirlwind appeared rather chaotic.

The developing group at the Moore School perceived a digital computer (the EDVAC) that became later known as the “von Neumann architecture”.[18] It describes how the three units memory, control and arithmetic interact. As a mathematician von Neumann shaped this architecture from the logical point of view and not as an engineering implementation. The so called von Neumann architecture combined a high speed memory based either on the Williams tube or on mercury delay lines, with a high speed arithmetic unit, based on electronic tubes which enabled an adding operation of two numbers in 5 to 20 microseconds (exclusive access to memory). Brent Jesiek and Atsushi Akera identified the leading role mathematicians played in the development of the digital computer. They pointed out that this architecture would be a view for mathematicians to perceive the world as a space of numbers.[19] Engineers and scientists in laboratories gained personal experience with the material they studied, as Nathan Ensmenger showed at the example of an laboratory in biological research.[20] But mathematicians lacked these experience. Besides von Neumann also his colleague Herman Goldstine was a mathematician. In the Bureau of Standards the computer development was overseen by the National Applied Mathematics Laboratory.[21] The funding procedure of the military agencies reveal a top down approach. They funded developments that mathematicians perceived without doing any marketing study of the needs in the Cold War R&D laboratories, for example at the West Coast. The leading role of mathematicians one can recognize at the publication policy of the leading journal “Mathematical Tables and other Aids of Computation”. Between 1945 und 1950 only one paper appeared on analog computers that used engineers to develop aircrafts and missiles at the West Coast.[22]

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[18] For the von Neumann architecture and stored program concept see Haigh et al. (cf. endnote 2), chapter 6 and 11. Aspray (cf. endnote 2), p. 64.

[19] Brent Jesiek, „The Origins and early History of Computer Engineering in the United States“, *Annals*, vol. 35, 2013, October, pp. 6-18. Atsushi Akera, *Calculating a Natural World - Scientists, Engineers, and Computing during the Rise of U.S. Cold War Research*, MIT Press 2007, p. 242. The leading role of mathematicians in regard to the professional group of engineers in the development of digital computers also emphasized Lofto Zadeh, „Thinking Machines – A new Field for Electrical Engineering“, *Columbia Engineering Quarterly*, vol. 3, 1950, no. 1, pp. 12-13, 30-31.

[20] Nathan Ensmenger, „The Digital Construction of Technology: Rethinking the History of Computers in Society“, *Technology and Culture*, Volume 53, Number 4, October 2012, pp. 753-776.

[21] Akera, (cf. Endnote 15), p. 152. John H. Curtis, „The National Applied Mathematics Laboratories - A Prospectus“, *Annals*, vol. 11, 1989, issue 1, pp. 13-30.

[22] McCann, G. D. “The California Institute of Technology Electric Analog Computer.” Mathematical Tables and Other Aids to Computation, vol. 3, no. 28, 1949, pp. 501–513. For the aircraft industry at the West Coast see Richard Vahrenkamp: The Computing Boom in the US Aeronautical Industry, 1945–1965, in: ICON – The Journal of the International Committee for the History of Technology, volume 24, 2019, pp. 127–149.

As published in the books of Goldstine (1972), Williams (1985), Aspray (1990), Campbell-Kelly et al. (1996, 2014) and Haigh, Priestley and Rope (2016) the history of digital computing in the United States was written as a success story rising from step to step.[23] From the relay-based computers at Harvard University and in the Bell Laboratories over the electronic ENIAC at the Moore School to its followers EDVAC and the IAS machine. To justify the high speed digital computer these success stories focused always on the problem which the Ballistic Research Laboratory (BLR) ground in Aberdeen experienced to calculate the trajectories of the shells fired by guns and to compile firing tables. It employed a staff of 200 trained female computers. To employ large groups of female computers was not unusual but widespread in design departments of industry.[24] As Goldstine reported, in the Ballistic Research Laboratory was under pressure to accelerate the calculation of ballistic trajectories of shells. As early as 1996 Marcus and Akera pointed out that the justification for building the ENIAC computer, there would be a bottleneck in the creation of firing tables, stood on weak feet.[25] In fact, the fire tables produced by Aberdeen were of little help in practical use on the battlefield because they did not take into account specific conditions. The creation of firing tables could be seen as much more than a justification for the large mathematical department of Aberdeen. From the practical side of artillery companies there was no report of a need for firing tables. At the public inauguration of the ENIAC on February 15, 1946, a team of woman programmers had to program to compute an artillery trajectory as show case for the press.[26] This demonstration shows that computing trajectories was not urgent at the Aberdeen Proving Ground and only a show case for the press establishing the myth of urgent firing tables Goldstine conveyed.

For one trajectory a human computer operating with an office calculator needed about 12 hours, the Harvard-IBM machine (Mark I) with relay-calculator two hours und the relay-machine Mark II, which used high speed relays and was available at the Navy proving ground in Dahlgren at 1947 – the year ENIAC arrived at Aberdeen – needed 15 minutes.[27] IBM delivered at the end of 1944 two high speed calculators – based on electrical-mechanical relays – to the the Ballistic Research Laboratory in Aberdeen for the accelerated calculation of the trajectories of the shells, but they did not operate proper.[28] If one takes the 15 minutes for one trajectory computed with the aid of Mark II, then there seems no convincing need to build a high speed digital computer ENIAC for calculating a trajectory.

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[23] Cf. endnote 2.

[24] Beverly Columba, *Human Computers: The Women in Aeronautical Research*, dissertation 1994, in the web under https://crgis.ndc.nasa.gov/crgis/images/c/c7/Golemba.pdf. Shetterly, *Hidden figures* (cf. endnote 8), chapter 1.

[25] Mitchell Marcus and Atsushi Akera: Exploring the Architecture of an Early Machine: The Historical Relevance of the ENIAC Machine Architecture, IEEE Annals of the History of Computing, 18 (1996), no.1, 17–24. For the social history of the mathematical department BLR see Dyson,(cf. note 2) chapter 3.

[26] Walter Isaacson, The Innnovators, London 2015, paperback edition, p. 113.

[27] Goldstine, (cf. endnote 3), 138. Michael R. Williams, p. 249 (cf. endnote 2).

[28] Charles Bashe, Lyle Johnson, John Palmer, Emerson Pugh, *IBM's Early Computers*, MIT Press 1986, p. 302. Haigh et al. (cf. endnote 2), p. 119.

4 Digital Computer with Drum Memory

In contrast to what the success stories of high speed digital computing suggest, the propagation of magnetic drum digital computers was rapid and wide in the Cold War R&D scenery proving that the high speed machines were not really needed. The survey of Martin Weik at the Aberdeen Laboratory of Computing on computing machines in 1955 reported on 70 types of digital computers with drums out of 80.[29] IBM recognized by the "field men" of its applied science department the need for a medium priced drum machine in contrast to their expensive 701 model and announced in 1953 the IBM 650. This machine IBM leased very successfully since 1954 and offered it to universities at a discount rate of 60 percent for science and education of students.[30] So the students became acquainted with computer technology and paved the way to further marketing success of IBM. The 650 machine became the first digital computer that was produced in a great number and induced users to assemble in "user groups" in order to exchange programs and experiences with this machine. The historian Paul Ceruzzi compared the 650 machine with Henry Ford's model T.[31]

The computer developments in Göttingen should also be mentioned, where since 1948 the computers G1, G2 and G3 were built, which all had a drum memory and were used to solve differential equations at the Aerodynamic Experimental unit, i.e. exactly for the tasks that von Neumann had in mind.[32]

5 Analog Computing in the Aircraft Cluster

The focus on high speed digital computing in the historiography overshadows the rich landscape of machine computing that developed during the years 1944 to 1955, primarily at

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[29] Martin Weik, cf. endnote 6.

[30] Bernard Galler, „The IBM 650 and the Universities", *Annals*, Vol. 8, 1986, no. 1, pp. 36-38.

[31] Emerson Pugh, *Building IBM. Shaping an Industry and its Technology*, MIT Press 1995. He remarks that till 1959 the number of 1500 machines were installed, p. 365. Caroll Pursell, *Technology in Postwar America*, New York 2012, p. 176.

[32] Wilhelm Hopmann, The G1 and the Göttingen family of Digital Computers, in: Raul Rojas and Ulf Hashagen (eds.), The First Computers. History and Architectures, MIT Press, 2000, pp. 295–314. Heinz Billing; Die Göttinger Rechenmaschinen G1, G2, G3, in: D. Wall (ed.), Entwicklungstendenzen wissenschaftlicher Rechenzentren, Berlin 1980 ,pp.1–13.

the West Coast. In the ecology of knowledge the high speed digital computer played only a minor role. The success stories overstated a need of high speed computing that was employed in the Cold War science and technology laboratories in industry only to a small extent. When one regards the journals on machine computing and physics of this time they reveal a rich variety of computing machines for science and engineering. One finds a great number of analog computers and many digital computers with a high speed arithmetic unit (based on electronic tubes) but with a low speed access to the memory. Here I display some examples.[33] The California Institute of Technology in Pasadena, CA, built in 1947 together with Westinghouse Electric Corporation an all purpose electrical analog machine that could solve partial differential equations up to three variables. The machine worked within the error margin of 1% to 5% which was understood as sufficient for most of the engineering tasks. This computer the Douglas Aircraft Corporation used in the flutter analysis of aircraft wings.[34] The flutter of wings at a critical speed is known since 1920 and was always a problem in the design process that could not easily be solved without a computer. The Consolidated Engineering Corporation in Pasadena, CA, built in 1945 an analog computer to solve a system linear equations up to 12 variables. It built later the „Datatron" digital computer in 16 copies.[35] The Bell Lab's relay interpolator could perform tasks as integration, differentiation, solve linear differential equations of first order, harmonic analysis and determination of roots of polynoms.[36] The electrical-mechanical difference engine Vannevar Bush had built at MIT got an electronic counterpart to solve non-linear differential equations.[37] The Westinghouse Corpoartion employed analog computers to calculate electrical networks during the 1930s.[38]

To meet their computational needs the researchers in the Cold War industrial R&D scenery developed also themselves analog or digital computers in their laboratories or bought medium priced (50.000 to 100.000 Dollar) computers that were tailor-made for their needs. The Lockheed Aircraft Corporation conducted an analysis of the shock absorption on the landing gear by a Boeing analog computer.[39]

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[33] I draw on the journal Mathematical Tables and other Aids of Computation, sections News and Bibliography.

[34] Mathematical Tables and other Aids of Computation, Vol. 4, 1949, no. 28, pp. 501-513. E.L. Harder and G.D. McCann, „A Large Scale General Purpose Electric Analog Computer", *AIEE Transactions*, vol. 67, 1948, pp. 664-73. Charles Strang, „Computing Machines in Aircraft Engineering", *Joint AIEE-IRE Computer Conference. Review of Electronic Digital Computers*, Philadelphia 1951, pp. 94-101.

[35] Clifford Berry, Doyle Wilcox, Sibyl Rock & H. Washburn, "A computer for solving linear simultaneous equations", *Journal of Applied Physics*, vol. 17, Apr. 1946, p. 262-272. Weik, cf. endnote 6, p. 21.

[36] George Stibitz, Relay Computers, proposal for the National Defense Research Committee, February 1945, appendix.

[37] James Koehler, „An Electronic Differential Analyser", *Journal of Applied Physics*, vol. 19, 1948, pp. 148-155.

[38] William Aspray: Edwin L. Harder and the Anacom: Analog Computing at Westinghouse, in: IEEE Annals of the History of Computing, Vol. 15, No. 2,1993, 35–52.

[39] D. Drake and H. Foster, „Airplane Landing Gear – Performance Solutions with an Electronic Analog Computer", Proceedings of the Western Computer Conference 1953 (cf. endnote 35), pp. 86-97.

Image 3: Landing Gear of Lockheed P38 (Image Press Release)

The Northrop Aircraft Corporation built in 1949 in the context of the SNARK missile project a differential analyser called MADDIDA based on electronic means that recorded the data on a magnetic drum (cf. image 1 above). Although not a general-purpose machine, MADDIDA was ideally suited to a broad range engineering work at Northrop. Its magnetic drum recorded the million of data bits that were generated in aircraft development and reduced them to the main parameters. In contrast to the large computers ENIAC and BINAC its spread was comparable to a refrigerator. Northrop‘s press release said in 1949:„The advances in MADDIDA in terms of simplicity and miniaturization are of great significance to the scientific and business world. A desk-side mechanical brain“ (cf. image 4).[40] Northrop sold some copies to the West Coast laboratories but quitted the commercial market after two years due to a lack of capital.

[40] Computer Museum Mountain View, document no. 10885, 102710219.

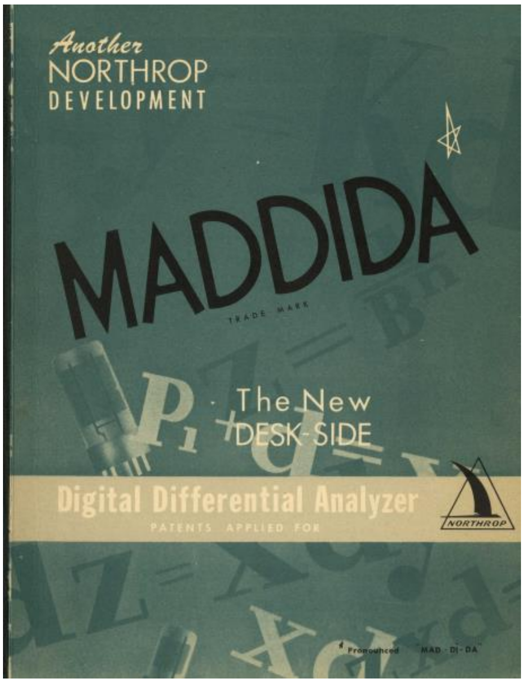

Image 4: Northrop's Booklet of MADDIDA 1950
Source: www.bitsavers.org

For a demonstration Northrop sent the MADDIDA from Los Angeles to the IAS in Princeton by air freight in 1950. John von Neumann – whose IAS computer was not in action before 1951 – was impressed by the plug and play ability of this computer. Under his supervision MADDIDA computed some values of the Bessel function.[41] It is not quite clear why von Neumann saw – after this demonstration of MADDIDA – his IAS–machine as superior to the currently available analog computers. For the broad field of differential equations – a field that was important for von Neumann's work – analog computers could deliver solutions very quickly (cf. image 2 above). Whether there was a serious contest between digital and analog computers to solve differential equations is an open question. The digital computers had in the 1950s so tiny memories that a solution of a system of differential equations could be difficult.

Other than mathematicians, who lacked expeces in laboratories, engineers and scientists in the Cold War industrial R&D scenery linked their experiments to the need to record the data they produced in experiments, e.g. in wind tunnels. In a second step, after recording and reducing the data, arose the need to perform calculations with the data for which simple computing machines were sufficient. The Computer Research Corporation offered their

[41] „Maddida", *Annals*, vol. 9, 1988, no. 3, pp. 357 - 368. Ceruzzi (cf. endnote 34), pp. 25-30. Dag Spicer, „Maddia – A bridge between worlds", *Core*, September 2000, pp. 6-9 (www.Computerhistory.org). The MADDIDA booklet of Northrop, Hawthorn 1950: The new desk–side Differential Analyser (PDF at www.bitsavers.org). I. S. Reed, H. H. Sarkissian and D. E. Eckdahl, "West Coast Contributions to the Development of the General-Purpose Computer: Building Maddida and the Founding of Computer Research Corporation," Annals, vol. 25, 2003, no.1, 4-33.

model CRC102 for data reduction and simple calculations.[42] From this kind of work flow the engineers and scientists did not derive a special need for high speed digital computers. In respect to computational support of engineering at Douglas Aircraft Corporation a leading manager, Charles Strang, regarded „a marked difference between our work and the academic applications“ for which high speed digital computers were built.[43] My paper follows this distinction between industrial and academic computational needs Charles Strang made. The academic proponents of high speed digital computers formulated a goal that did not meet the needs in the Cold War industrial R&D scenery. Insisting on a high speed memory, the proponents followed since 1944 a path of nearly unsuccessful search for a reliable memory unit until in 1953 the memory of magnetic cores was found.[44] The academic orientation of the proponents can also be shown by the list of problems which the Bureau of Standards published of its early use of the SEAC where industrial applications were absent. There were no flutter analysis of aircraft wings and no shock absorption of aircraft gears. During October 1950 to December 1950 the SEAC ran 525 hours alone on the academic problem of Linear Programming.[45] The academic orientation of funding the digital computer can also be shown by the order of the Office of Naval Research gave to the engineering Research Associates (ERA), Inc., of St. Paul, Minnesota, to build a digital computer for a logistic research project at George Washington University.[46]

In the engineers‘ professional organisations Brent Jesiek observed a growing attention for computing machinery during 1945 and 1953 to replace the leading role of mathematicians by engineers. The Institute of Radio Engineers (IRE) and the American Institute of Electrical Engineers (IAEE) had, during their national meetings, many panels on computing devices between 1947 and 1953.[47] In 1947, the lively computing scenery led to the foundation of the Association of Computing Machinery (ACM) in New York as the Eastern Association for Computing Machinery that joined engineers, scientists, manufacturers, dealers and users of computing machinery. Its creation reflects the increasing interest in computing devices as evidenced by several events, including a January 1947 symposium at Harvard University on large-scale digital calculating machinery, the six-meeting series in 1946-47 on digital and analog computing machinery conducted by the New York Chapter of the AIEE, and the six-meeting series in March and April 1947 on electronic computing machinery conducted by the Department of Electrical Engineering at MIT. Together the three associations, ACM, IRE and

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[42] Akera, (cf. endnote 15), p. 242s. For the predecessor machine CRC 101 see Digital Computer Newsletter, vol. 3, 1951, no. 2, p. 4.

[43] Charles Strang, „Computing Machines in Aircraft Engineering“, *Joint AIEE-IRE Computer Conference. Review of Electronic Digital Computers*, Philadelphia 1951, p. 94.

[44] Emerson Pugh, *Memories that shaped an Industry*, MIT Press 1984, Chapter 2 and 3. For the search of memory technologies see session four of *Symposium on Large-scale Digital Calculating Machines*, Harvard University 1947, jointly sponsored by the Navy Department Bureau of Ordnance and Harvard University at the Computation Laboratory, MIT Press 1947, reprinted 1985, MIT Press, with a new introduction by William Aspray.

[45] S. Alexander, „The National Bureau of Standards Eastern Automatic Computer“, *Joint AIEE-IRE Computer Conference. Review of Electronic Digital Computers, Philadelphia 1951*, p. 87s. Digital Computer Newsletter, 1951, vo. 3, no. 1, p. 3. The SEAC ran also the academic problem to find great prime numbers.

[46] Digital Computer Newsletter, 1952, vo. 3, no. 4, p. 3. Rees, (cf. endnote 10), p. 110, 117.

[47] Jesiek , cf. endnote 33, p. 8-10.

AIEE, conducted several conferences on computing machines serving as forum for industrial applications.[48]

6 The Digital Computer as Technology Push

In the following I distinguish between demand–pull technologies and push technologies that were known in technology policy.[49] In the aeronautical cluster at the West Coast there was no special need for a high speed digital computer. So, these computers were not a demand–pull technology but a technology push development. This paper explains in the following the high speed digital computer as technology push that was developed without a marketing study in the Cold War R&D scenery and formulated needs that mathematicians in military agencies presumed. The needs had to be invented as a marketing action for the digital computer since the first high speed digital computers had no convincing utility. Their main memory was very small und unreliable (mercury delay line)[50] and could hardly be used for programming because programming aids (operating systems, higher languages as FORTRAN, relative addresses) did not exist. The great influence John von Neumann had contributed to successful marketing actions for the high speed digital computer.

The proponents of digital computers, as John von Neumann and Robert Oppenheimer (the director of the Institute for Advanced Study in Princeton and former director in Los Alamos Manhatten Project), invented as marketing actions new fields of desire, as weather prediction, mathematics, engineering and forecast of elections, to justify the digital computer. These fields of desire were unknown before. In his speech at the marketing ceremony to introduce the IBM digital computer 701 on April 7, 1953, Oppenheimer described weather prediction as one important field of application.[51] From the topic weather one can derive an unlimited need of computational power and memory requirement if one refines the grid of data observation and the underlying models. Already in the phase of fund rising for his IAS computer in 1945, von Neumann offered military agencies the possibility of weather

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[48] Web site ACM, http://www.acm.org/about-acm/acm-history. New York Times December 14, 1947. Joint AIEE-IRE Computer Conference. Review of Electronic Digital Computers, Philadelphia 1951 (with support of ACM). Proceedings of the Western Computer Conference, held by the Joint IRE-AIEE-ACM Computer Conference Committee, Los Angeles, February 4-6, 1953. Introduction of William Aspray, 1985,(cf. endnote 30), p. x.

[49] Gregory Nemet, „Demand-pull, technology-push, and government-led incentives for non-incremental technical change“, Research Policy, vol. 38, 2009, 700-709.

[50] Nancy Stern reports on unreliable performance of the digital computer BINAC at Northrop Aircraft, Nancy Stern, „The BINAC: A Case Study in the History of Technology“, *Annals*, vol. 1, no. 1, 9-20, July 1979, here p. 14. The first Univac I Computer, delivered in 1951 to the Bureau of Census, required maintenance to a large extent, see Hermann Kukoff, *From Dits to Bits*, Robotic Press, 1979, chapter 10. On the reliability of the ENIAC see Haigh et al. (cf. endnote 2), p. 207. For the difficulties to program a IBM 701 at Douglas Aircraft see C. Baker, „The 701 at Douglas, Santa Monica“, Annals, vol. 5, 1983, no. 2, pp. 187-193. W. McClelland and D. Pendery, „701 Installation in the West“, *Annals*, vol. 5, 1983, no. 2, 167–170.

[51] *Annals*, vol. 5, no. 2, 157, April-June 1983.

prediction as one major field of digital computation. Von Neumann underlined the high importance of weather prediction for operations on the battlefield. The Office of Naval Research supported the „Numerical Meteorology Project“ with five researchers at the Institute for Advanced Study since 1946. But only as recently as 1952 could the numerical results for weather forecasting be derived on the IAS computer.[52] Already on the ENIAC von Neumann integrated the Barotop Vorticity Equation for weather forecasting. Whether this equation also could be integrated by an analog computer is unknown, but Vladimir Zworykin made 1945 a proposal for an analog computer for meteorological computations.[53] Von Neumann saw the analog computer as competitor to his ideas. In several speeches he issued warnings that the analog machine would make computing errors outside limits that could be tolerated.[54]

In the press release for the inauguration of the ENIAC in the public on February 15, 1946, the authors invented engineering as a new justification for digital computing that was unknown before and that industry did not demand. The release said, that with the ENIAC industry could perform more advanced designs based on complex mathematical calculations.[55] In December 1947 the Aberdeen lab conducted a great marketing show for the ENIAC where 300 persons participated.[56]

To introduce the new digital computer Univac I the producing firm Remington Rand took a marketing action to focus public attention. During the presidential election in 1952 it made a prediction of the outcome based on a statistical program that was evaluated on the Univac I.[57] In the academic field of mathematics the digital computer let the desire emerge to compute large prime numbers that analog computers could not compute. The mathematician Derrick Lehmer, the editor of the journal Mathematical Tables and other Aids of Computation, published already in 1947 on large prime numbers he found with the aid of the ENIAC. Also on the SEAC prime numbers were computed.[58] Also von Neumann used the topic of prime

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[52] Haigh et al. (cf. endnote 2), 214-220. Dyson, (cf. endnote 2), chapter 9. Aspray, 1990, (cf. endnote 2), 129-154. See also the announcement of the new IAS Computer in Mathematical Tables and Other Aids to Computation, Vol. 6, No. 40 (Oct., 1952), p. 245.

[53] J. Charney, R. Fjörtoft and John von Neumann, „Numerical Integration of the Barotop Vorticity Equation“, *Tellus*, vol. 2, 1950, 237-254. Aspray, (cf. endnote 2), 130.

[54] Winter Meeting of the American Institute of Electrical Engineers in New York, January 1947, *Mathematical Tables and other Aids of Computation*, vol. 2, 1947, p. 368. Summer Meeting of the Mathematical Association of America, September 1947 in Yale, *Mathematical Tables and other Aids of Computation*, vol. 3, 1948, p. 58.

[55] New York Times, Februar 15, 1946. For the press coverage of ENIAC see Dianne Martin: ENIAC Press conference that Shook the World, in: IEEE Technology and Society Magazine, Winter 1995/1996, 3–10.

[56] New York Times, December 14, 1947.

[57] For the forecast of the election of President Eisenhower in 1952 with the aid of Univac I see Campbell-Kelly et al. (cf. endnote 2), 110-112. Also IBM wrote software on the 701 for the forecast of the presidential election in 1956, see Cuthbert C. Hurd, "Early Computers at IBM", *Annals*, vol.3, no. 2, pp. 163-182, April-June 1981.

[58] Derrick Lehmer, „On the factors of 2^n +/-1“, *Bulletin of the American Mathematical Society*, vol. 53, 1947, 164-167. Goldstine gives an overview on the research problems that were calculated on the ENIAC in 1946, Goldstine (cf. endnote 2), 232s. Also Haigh et al. (cf. endnote 2), 96. Digital Computer Newsletter, vol. 3, 1951, no. 1, p. 4. For the computing of primes see Bullynck, Maarten: Computing Primes (1929-1949):

number computation to advertise the IAS computer to the public, as is shown by a note in the journal Mathematical Tables where it is stated that by computing prime numbers a theorem of algebraic number theory was tested.[59] On the EDSAC at Cambridge, England, B. Worsley computed in 1949 the prime numbers up to 1023 to demonstrate the utility of the machine for the academic public.[60] These examples support the conjecture that digital computers were an invention of mathematicians. Engineers were not interested in the topic of prime numbers.

It remains an open question, for which of the problems referred in this section a high speed digital computer is really needed or whether a slower digital computer as the IBM 650 would have been sufficient. This question one can also put on the list Cuthbert Hurd published as list of software programs IBM wrote for its high speed machine 701. Only in 1953, Mike Haynes and Jay Forrester invented with the core memory a reliable main memory for the digital computer. The path for the expansion of the digital computer was open. The extent of the main memory could be scaled up now.[61]

7 The Lack of Digital Computers at Los Alamos

As already observed by Peter Gallison, even the demand of high speed computing in Los Alamos was low. The scientists calculated with slide rules. There was no demand for high speed digital computers. This supports my thesis of technology push. One gets an impression of the surprisingly low importance of digital computing in Los Alamos if one considers that only at April 1953 the first digital computer (an IBM 701) arrived there – even though since 1951 an UNIVAC I or since 1950 an ERA 1101 or the SEAC the could have been delivered. There was no use of analog computers that were available since 1948.[62]

Transformations in the Early Days of Digital Computing, in: IEEE Annals of the History of Computing, July 2015, Vol.37(3), pp.44-54 and Bullynck, Maarten and Mol, Liesbeth: Setting-up early computer programs: D. H. Lehmer’s ENIAC computation, in: Archive for Mathematical Logic, 2010, Vol.49(2), pp.123-146.

[59] Mathematical Tables and Other Aids to Computation, Vol. 6, No. 40 (Oct., 1952), p. 245. For the computation of the 611 prime numbers see the note of von Neumann and Goldstine in Mathematical Tables and Other Aids to Computation, Vol. 7, No. 42 (Apr., 1953), p. 134. The programming of this problem was carried out by the programmer Atle Selberg.

[60] Brian Randell: The Origins of Digital Computers, Berlin 1973, p. 429.

[61] Hurd, cf. endnote 50, p. 170s. Pugh, (cf. endnote 320), pp. 34-80.

[62] Bashe et al. (cf. endnote 20), 177. On the role of IBM consultants at Los Alamos see Akera, (cf. endnote 15), p. 232. Peter Galison: Computer Simulation and the Trading Zone, in: Gabriele Gramelsberger (ed.), From Science to Computational Science, Zurich 2011, p. 111. Anne Fitzpatrick, Igniting the Light Elements: The Los Alamos Thermonuclear Weapon Project, 1942–1952, Los Alamos National Laboratory 1999, p. 268, quotated according to Haighs et al., ENIAC in Action, p. 322.

Until then the researchers could only use the punched card oriented IBM CPC machines. The punched cards as carrier of information and the IBM tabulator machines linked Los Alamos to IBM‘s digital computer in New York (SSEC) and to the one in Aberdeen (ENIAC). The computing results Klari von Neumann and Nicholas Metropolis derived on these machines for the improvement of the atomic bomb were punched on cards and sent by postal parcels to Los Alamos so that the research depended on the quality of the postal service.[63] In Los Alamos, the incoming cards were statistically analysed by IBM tabulator machines to get a heuristic insight into the chain reaction. That even the CPC machine was capable to derive solutions for the design problems in Los Alamos could also be demonstrated by the blast wave problem von Neumann raised. Goldstine estimated the execution time on punched card calculators to four hours compared to 10 seconds on the ENIAC. The blast wave problem was also computed in September 1946 on the ENIAC. The difference in computing time between four hours and 10 seconds is impressing, but does not induce a strong need for the ENIAC.[64]

8 Conclusion

The paper explores the influence that mathematicians took on the development of digital computers and shows that high speed digital computers did not meet the needs of the cold War R&D scenery in the cluster of the aeronautical industry at the West Coast. Instead the industry developed its own solutions for computing machines. Noteworthy is the leading role of the aeronautical industry in developing computing machines. It consisted of strong design departments and a well educated workforce of engineers that applied computational methods in aircraft design. Its a stroke of luck in historical research to find two clear cut patterns: The East coast with mathematicians and academic orientation building high speed digital computers. On the other side the West Coast, the engineers in the aeronautical cluster building small scale analog computers that served the needs of the aeronautical industry.

[63] Dyson (cf. endnote 2), chapter 10. A detailed description of the ENIAC programming is provided by Haigh / Priestley / Rope, ENIAC, 2016, Chapters 8 and 9. It is not known whether Neumann achieved his goal of "optimizing" the atomic bomb with the Monte Carlo simulation.

[64] Haigh et al. (cf. endnote 2), 96, 133. For the integration of the blast wave differential equation on IBM punch card machines in Los Alamos in April 1944 see *Critical assembly : a technical history of Los Alamos during the Opppenheimer years, 1943 – 1945*, by Hoddeson, Lillian, und Paul Henriksen, Roger Mead, Catharine Westfall, Cambridge UP 1993, pp. 158–161.

The following table summarizes this nice segmentation.

	Computer	Need	Proponents
East Coast	digital	Academic Technology push	Mathematicains
West Coast	Analog	Industrial Demand pull	Engineers

If we transfer this pattern into other countries, we find in the 1940s similar patterns of a strong aeronautical industry with a well educated workforce of engineers also in Great Britain and the Soviet Union. So we can expect similar developments of computing machines in these countries during the period 1940-1955. This question is left to further research.

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