Mathematical Instruments for Times of Crisis – Paper

Introduction

First, I thank the organizers, both for allowing me to speak here today and for patiently assisting me in unfamiliar means of presentation. I also thank all of you for attending – whatever that may mean.

The objects shown in the exhibits or stored in the cabinets of museums and mathematics departments – or used in mathematical research and teaching – rarely convey a sense of crisis. However crises create new roles, mix cultures, bring about new needs, make unexpected use of time (and sometimes free time from usual duties), and generate fear. All of these changes have shaped these now-placid objects. Examination of a few instruments, considering them as part of the lives of the mathematicians and others associated with them, suggests such connections. Here I will discuss a star map drawn at the time of the American Revolution, an instrument for mathematics teaching known as the numeral frame or teaching abacus, a tabulating machine from around 1890, a device to improve the aiming of guns from World War I, an electromechanical computer from the time of World War II, and a circular slide rule from the Cold War era. All of these represent mathematical instruments from times of crisis. Examples of most of them survive in the collections of the Smithsonian Institution.

The Star Map of Simeon de Witt

twenty-four year old graduate of Queen's College (now Rutgers University) in New Jersey, had, through the good efforts of an uncle, received an appointment as a geographer, drawing maps for George Washington and the Continental Army. He had moved to the New Jersey home of Robert Erskine, the Surveyor General, and spent time drawing maps of military importance. However, as sometimes occurs in times of crisis, de Witt was cut off from usual supply channels (that is to say, Great Britain). Like some others in times of crisis, he apparently had time on his hands. He used free moments to draw (image 2) a small but detailed celestial planisphere. It showed the stars visible from a latitude of 41 degrees (that is to say New Jersey), from first down to sixth magnitude. In addition to a rotating star map, the instrument included a perpetual calendar for the years1781 to1827. Tables on the back tracked the motion of the moon. As best I know, it is the first Anglo-American planisphere.

The instrument could be used for such tasks as finding the time of sunrise and sunset, the time of the rising and setting of stars, and the phases of the moon. In normal times, it would have been possible to purchase a similar instrument on the design of John and Mary Senex (1746) or James Ferguson (1757) (image 3). However, in time of crisis, de Witt relied on his own talents. So far as I know, he made no attempts to publicize his hand-drawn instrument. Americans would print celestial planispheres, but only from the 1810s and with no influence from de Witt. To summarize, amidst the crisis of the American Revolution, Simeon de Witt turned his drawing skills not only to making maps for the military but, cut off from usual sources, to drawing a chart of the stars.[1]

Jean Victor Poncelet and the Teaching Abacus

Crises can also take mathematicians to unfamiliar places and expose them to new instruments. Raised in Metz in Allsace-Lorraine, the Frenchman Jean Victor Poncelet (image 4) won a place at the École polytechnique in Paris, where he studied geometry with Gaspard Monge, graduating in 1809. Students from the École polytechnique went into the French army. Poncelet joined the corps of military engineers and continued his studies. During the Napoleonic wars, he took part in Napoleon's ill-fated attack on Russia. Captured and imprisoned by the Russians in 1812, he survived a long march to a prison camp [at Saratov]. There he not only continued his research on projective geometry, but became familiar with the Russian abacus. On this instrument (image 5), which was used at least from the early seventeenth century, beads move crosswise.[2] There are usually ten to a rod, with the highest rod representing the largest place value. Sometimes there are smaller numbers of beads in a row, representing fractions.

Intrigued by the possible pedagogical uses of the instrument, Poncelet brought one back to France when he was released from the Russian prison in 1814, and argued for its schoolroom use. Precisely how effective his argument was is unclear – there were other advocates of the teaching abacus in France and in Great Britain. Their main incentive seems not to have been the crisis of war but the patterns of industrialization that created a need for child care for children too young to work in factories. The growth of more general common school education also promoted the widespread sale of teaching abaci. Thus a crisis made available an instrument that proved suitable for normal times as well. Precisely what the abacus Poncelet brought back looked we do not know – accounts of his learning of the instrument and bringing it back to France are based on an 1843 narrative by the French mathematician Michel Chasles. We do know that two French émigrés to the United States [William S. Phiquepal and Marie Duclos Fretageot] initially founded schools in Philadelphia and then [under the sponsorship of Robert Owen] introduced new educational methods at the colony of New Harmony, Indiana, in 1825. The surviving example at New Harmony is held on the side (image 6). However, the instrument soon was made commercially available in devices held from below or supported on a stand (images 7). The colony of New Harmony soon faded, but numeral frames would become a standard of the American classroom in the second half of the nineteenth century. They survive today primarily as a toy for young children (image 8). Needless to say, the association with the Russian abacus – let alone the crisis of the Napoleonic wars – was and is rarely mentioned.[3]

The Tabulating Machines of Herman Hollerith

The present pandemic, with its accompanying mass of statistical data, has brought renewed general attention to statistical modeling and data science. Vast quantities of human effort and computer time have been devoted to accumulating data and making predictions. However, the crisis that is most generally associated with the introduction of machinery into large-scale statistical analysis in the United States is associated with a different sort of question – how does one count a growing population? The U.S. Constitution mandates that a Census be held every ten years to determine the number of representatives assigned to each state in the U.S. House of Representatives. Both the quantity of information collected and the population grew substantially over the years. Data from the 1880 Census was not completely processed until 1888. The population had grown, creating considerable concern about what would happen in 1890

One person who took an interest in such matters was Hermann Hollerith (image 9), an engineer trained at Columbia University who worked briefly for the Census after his graduation in 1879. There he became aware of the demand for new methods of tabulating data. By 1884, Hollerith had designed a set of tabulating machines, and soon began to file patents. In 1887, he was able to provide machines to compile mortality statistics for the city of Baltimore (image 10). A card was punched for each death. Its arrangement was inspired by contemporary railroad tickets. It had fields to record not only the cause of death but the rough age, sex, and occupation of the person who died. The system worked well, and Hollerith obtained a contract for the 1890 census of population. That too proceeded successfully (image11). Thus a crises anticipated long in advance was avoided. Unwilling to depend only on occasional censuses in the U.S. and abroad, Hollerith also found customers in business such as railroads and insurance. His firm would merge with other data processing concerns and, in the 1920s, be renamed IBM.[4]

The Census of 1890 did not come at a time of unexpected crisis. However, once tabulating machines were available, they could be applied to other situations. For example, in 1930, when an economic crisis racked the nation and the world, the Bureau of the Census carried out an unemployment, the data was tallied by machine (image 12). In response to that economic downturn, the U.S. federal government introduced Social Security payments for millions of senior citizens and disabled individuals. When the Social Security Administration began making payouts in 1940, checks issued by it were generated by tabulating machines (image 13). Perhaps more relevant to today's news, punch cards also found their place in medical studies. This IBM punch card from 1954 is one of many that were used in the evaluation of the polio vaccine introduced by Jonas E. Salk and Randall V. Kerr (image 14).

James W. Alexander in World War I

As historians of mathematics and computing well know, the development of both new weapons and new ways of delivering them prompted new theories of ballistics in World War I. David Grier, looking at the work of Oswald Veblen, Alan Gluchoff, considering contributions of Forest Ray Moulton,[5] and the contributors to a volume edited by David Aubin and Catherine Goldstein examine other research.[6] Here I would like to mention contributions of James W. Alexander (image 15), a topologist and former doctoral student of Veblen who actually designed a mathematical instrument.

Alexander (1888-1971) received his undergraduate degree, M.S., and PhD. from Princeton University – the last came in 1915. He stayed on at Princeton as a junior faculty member, but in October of 1917 began working as a junior officer at Aberdeen Proving

Ground. He spent the war working on improving the interior ballistics of high explosive shells.

Aberdeen would be known in later years for its purchase and use of such large scale computing devices as a room-sized differential analyzer on the design of MIT engineer Vannevar Bush (image 16). During World War II, it paid for the ENIAC computer built at the University of Pennsylvania (image 17). Alexander also designed a mathematical instrument while on the Aberdeen payroll, but on a much smaller scale. As yet I have not found an example of Alexander's pocket-sized "range and deflection corrector." According to Moulton's description, it consisted of three overlapping (but not necessarily concentric) plastic discs.

At war's end, Alexander returned to Princeton and mathematical research. One should mention that in his sixties he, like others who had done military work in World War I, was called to work in World War II. This time, he went as a civilian. In 1942, he was sent to England as part of the Operational Research section of the Eighth Bomber Command. However, he quickly concluded that higher mathematics was not involved in the operations analysis work he was supposed to be doing and returned to the United States.[7] Precisely what he did otherwise during the war is unclear. Reports of the Institute of Advanced Study, where he was a member, say only that he worked on (and I quote) "Operational research ; defense against enemy mining operations ; spent some time in England in I942 at Headquarters of Bomber Command of Eighth Air Force working on the problem of improving the bombing accuracy of our planes over Germany. Published several confidential reports."[8]

A Career Transformed: Grace Murray Hopper and the ASSC Mark I Computer

The American mathematician Grace Murray Hopper (1906-1992 – image 18) was considerably younger than Alexander. She received her doctorate from Yale University in 1934, well before the United States entered World War II. As a woman, she was not required to enlist in the armed forces. However, she came from a family tradition of military service and left her position teaching mathematics at Vassar College in 1943 to enter the WAVES (Women Accepted for Voluntary Emergency Service), a newly created branch of the U.S. Navy. After completing Midshipmen School in 1944, she was assigned to the Bureau of Ships Computation Project at Harvard University. There she programmed the ASSC Mark I, one of the world's first programmable computers (image 19). This room-sized electromechanical machine had been built by IBM on the design of Harvard professor Hugh Aitken, who also led the Navy project. As these drawings by Hopper from the time suggest (image 20), a variety of problems plagued the machine. IBM and then Harvard engineers called them "bugs" and Hopper adopted the term with enthusiasm. [9]

Unlike Poncelet and Alexander, Hopper was willing to leave theoretical mathematics behind. At Harvard she met a host of people who would be active in the nascent discipline of computer science – at universities, in government agencies, and in private corporations. They came not only from the United States but from abroad. She also became deeply familiar with the technical workings of the Mark I, compiling the detailed *Description of a Relay Calculator* that Harvard published in 1949.[10] When women were dismissed from active duty in the Navy at the end of the war, she joined the Navy Reserves. She also stayed on at Harvard (no going back to Vassar) and then went to work as a senior mathematician (and programmer) at one of the first American manufacturers of electronic computers, the Eckert-Mauchly Corporation (later UNIVAC). There she pioneered in such areas as the development of compilers and English-based programming languages. Once women were again allowed in active duty in the Navy at the time of the Vietnam War, she went on active duty once more – and eventually would reach the rank of rear admiral.[11]

Of course, Hopper was by no means the only mathematician diverted into what would come to be called computer science by the events of World War II. Historians have written learnedly on such figures as Alan Turing, John von Neumann, and the insurance actuary Edmund Berkeley.

Mathematical Instruments and Continuing Crises

The events I have described thus far –de Witt's making of a planisphere, Hollerith's design of a tabulating machine, Alexander's design of a gunnery instrument, and Hopper's work on the Mark I can be linked to specific crises. When the crisis passed, the makers moved on to other tasks – although not always the same sort of tasks they had done before. The effects of crises can linger – and mathematical instruments result. This is the case with the final and grimmest objects I wish to describe, a circular slide rules associated with the effects of nuclear weapons. By 1960, scientists had been ho had been studying the effect of atomic and then nuclear weapons for over a decade. Examination at Hiroshima and at Nagasaki led to the report *The Effects of Atomic Weapons* published by the Los Alamos Laboratory in New Mexico in 1950.[12] With the development of the hydrogen bomb by the United States and by the Soviet Union in the mid-1950s, there was occasion for further publication. Observers in Nevada and Bikini compiled data that would be summarized in a publication *The Effects of Nuclear Weapons* that first appeared in 1957 and was specifically designed for those engaged in Civil Defense efforts such as building bomb shelters.[13](image 21 - bomb shelter)

Using data from this report, staff at the Lovelace Foundation for Medical Education and Research in Albuquerque, New Mexico, and at the RAND Corporation in California designed circular slides rule describing the effects of radiation and blast from a nuclear weapon. This Rand Corporation Bomb Damage Effect Computer (image 22) was made by the Chicago slide rule manufacturer Perry-Graf. NASM has this example.

Amid the heightened Cold War concerns of the early 1960s, a new edition of *The Effects of Nuclear Weapons* was planned, as well as a new slide rule. The Lovelace Foundation again won a contract to design the instrument. This time they also prepared a technical report with the ponderous title *Nuclear Bomb Effects Computer: (Including Slide-Rule Design and Curve Fits for Weapons Effect)*. It describes how tables of data were reduced to continuous curves that were drawn on plans for the rule. These plans were produced using a plotter, attached to a Bendix G15 computer. The report also includes drawings from the plotter – I am not aware of other slide rules that were designed using electronic computers.[14] The instrument was generally distributed in a pocket at the back of *The Effects of Nuclear Weapons* although it could be purchased separately. Revised versions of the instrument appeared with later editions of that volume in 1964, 1970, and 1980.

Plotting the functions on the Nuclear Bomb Effects Computer required mathematical analysis but the design – like that of many other mathematical instruments – did not heavily involve mathematicians. The publication that described the instrument boasted six coauthors – Clayton S. White, I. Gerald Bowen, E. Royce Fletcher, Ray W. Albright, Robert F.D. Perret, and Mary E. Franklin. One, Clayton S. White ,was a Colorado-born physician expert on the effects of nuclear blast, the other authors had studied mathematics and physics at New Mexico University or, in the case the one woman involved, been drafted into computation from her work as a secretary at the Lovelace.

Combining their efforts, these authors designed a compact instrument designed to solve twenty-eight problems relating to the effects of nuclear weapons. Setting the indices on the front of the instrument for the yield of a nuclear bomb in megatons and the distance of its explosion in miles, scales describe changes in atmospheric pressure and winds associated with the blast, as well as cratering and the velocity of window glass. Charts on the back indicate the initial nuclear radiation and the thermal radiation. Tables indicate the probable medical effects of various doses of radiation, from no illness to severe burns to death. This makes for a very grim object indeed.

This Nuclear Bomb Effects Computer, like its predecessors, was available to the general public. As best I can tell, the market was not brisk. In the 1964 movie “Dr. Strangelove” a character is shown holding an example. Indeed, publicists for the film distributed copies of the instrument to potential reviewers of the movie.[15] Versions of the instrument continued to be available at least as late as 1980.

Conclusion

Here I have tried to suggest how mathematical instruments may remain as mute evidence of these past challenges and attempts to meet them. In conclusion, I would like to make three general observations. First, identifying objects with times of crisis is not automatic. Sometimes the objects have well-known military connections – as with the ASSC Mark I computer. Sometimes their very name describes the concerns that shaped them – as with the Nuclear Bomb Effects Computer. However, flushing out the stories of the people who made them, the place of the objects in their lives, and the specific connection of this work to national crises is not automatic. Sometimes – as with de Witt’s planisphere or the teaching abacus – the connection to times of crisis requires more digging.

Second, at least with these mathematical instruments, all of those who worked with them were paid for by their national governments. De Witt was a civilian working as a government surveyor; Poncelet, Alexander, and Hopper military officers; and Hollerith and the staff of the Lovelace Foundation government contractors. The planisphere of de Witt and the teaching abacus advocated by Poncelet were at best tangential to then-accepted government goals. The other instruments fit more closely to concerns about national defense and security.

Finally, one should note that crises abate – albeit sometimes slowly – and many mathematical people quickly moved on to other matters. However, the threats summarized on mathematical instruments may endure. In a 1981 article in the *New York Times* entitled "Ground Zero," writer David C. Morrison used a Nuclear Bomb Effects Computer to describe the devastation that would be wrought by nuclear bombs striking New York City.[16] Similarly, in the past five years there has been online discussion – citing the Nuclear Bomb Effects Computer - of the possible effects of nuclear weapons detonated by North Korea. Morrison concluded his 1981 article by writing that in the wake of a nuclear attack, and I quote, "New York would stand uninhabitable, a monument to a technologically brilliant, politically retarded civilization that wasted its intelligence contriving clever gadgets like the Lovelace Nuclear Bomb Effects Computer." A sobering thought indeed.

Thank you.

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[1] Kidwell, P.A., "The Astrolabe for Latitude 41°N of Simeon de Witt: An Early American Celestial Planisphere," *Imago Mundi*, 61 #1, pp. 91-96. For a related online exhibition, see https://americanhistory.si.edu/documentsgallery/exhibitions/dewitt_1.html.

[2] Burnett, Charles and W. F. Ryan, "Abacus," *Instruments of Science: An Historical Encyclopedia,* eds. Robert Bud, Deborah Jean Warner, Simon Chaplin, Stephen Johnston, Betsy Bahr Peterson, London(?): Taylor & Francis, 1998, pp. 5-7. A Russian abacus collected by John Tradescant in the early seventeenth century survives in the collections of the Ashmolean Museum. This appears to be listed (as Indian) in Tradescant, J., Hollar, W., Ashmole, E., Wharton, T., *Musaeum Tradescantianum, or, A collection of rarities preserved at South-Lambeth neer London.* London: Printed by John Grismond, and are to be sold by Nathanael Brooke ...., 1656, p. 54. - https://catalog.hathitrust.org/Record/101829812/Home for catalog record - for copy see https://babel.hathitrust.org/cgi/pt?id=gri.ark:/13960/t2993d14q&view=1up&seq=5.

[3] Kidwell, P.A., A. Ackerberg-Hastings, and D. L. Roberts, *Tools of American Mathematics Teaching*. Baltimore: Johns Hopkins University Press, 2008, pp. 88-104. Curiously, the numeral frame took quite a different form in France under the influence of Marie Pape-Carpentier. See https://musee-ecole-montceau-71.blogspot.com/2017/10/le-boulier-numerateur.html. For a printed source, see: Betham-Edwards, Matilda, 1836-1919. Six Life Studies of Famous Women. London: Griffith and Farran, 1880, pp. 131-170 (no mention of abacus).

[4] Kidwell, P.A. and Paul E. Ceruzzi, *Landmarks in Digital Computing,* Washington, D.C.: Smithsonian Institution Press, 1994, pp. 45-50

[5] Moulton, F.R., 1919a. History of the Ballistics Branch of the Artillery Ammunition Section. Engineering Division of the Ordnance Department for the Period April 6, 1918 to April 2, 1919. War Department, Office of the Chief of Ordnance, Washington, DC. – mentioned in Gluchoff, Alan, "Artillerymen and mathematicians: Forest Ray Moulton and changes in

American exterior ballistics, 1885–1934," *Historia Mathematica*, 2011, 38 #4, pp. 506-547. "He also wanted to make these results usable on the field: the Princeton topologist J. W. Alexander II was commissioned to design a pocket-sized range and deflection corrector for abnormalities in muzzle velocity, wind, air density, or weight of projectile [Moulton, 1919a, 69–70]. It is not an exaggeration to say that Moulton had a vision of the entire subject of exterior ballistics, its deficiencies, its possibilities, and its methods; these took place at all three levels we have described. On various WWI shells, see: https://books.google.com/books?id=3gtGAQAAMAAJ&pg=PA361&lpg=PA361&dq=6%22.+shell+Aberdeen+%22Mark+IV%22&source=bl&ots=ZG5QPEgxqf&sig=ACfU3U2Xwmn5p3uJlwz0ruCKkB4spBhjnw&hl=en&sa=X&ved=2ahUKEwiSybrHqfXpAhUjWN8KHaUNBQoQ6AEwAXoECAwQAQ#v=onepage&q=6%22.%20shell%20Aberdeen%20%22Mark%20IV%22&f=false.

[6] Aubin, David and Catherine Goldstein, *The War of Guns and Mathematics: Mathematical Practices and Communities in France and Its Western Allies around World War I*,____: American Mathematical Society,2014. See especially the article by Thomas Archibald, Della Dumbaugh, and Deborah Kent that begins on page 229.

[7]MacCarthur, Charles W., *Operations Analysis in the United States Army Eighth Air Force in World War II*, ____: American Mathematical Society, 1990, p. 29.

[8] Institute of Advanced Study, *Report of the* Director, Princeton: Institute for Advanced Study, 1946, pp. 7-8

[9] For image of bugs see https://americanhistory.si.edu/collections/search/object/NMAH.AC.0324_ref448.

[10] Harvard University Computation Laboratory, *Description of a Relay Calculator*, Cambridge: Harvard University Press, 1949.

[11] For an oral history of Grace Murray Hopper carried out by Uta C. Merzbach in 1968, see Computer Oral History Collection, Archives Center, National Museum of American History, Smithsonian Institution.For a brief account of her life see David L. Roberts, *Republic of Numbers: Unexpected Stories of Mathematical Americans through History*, Baltimore: Johns Hopkins University Press, 2019. For a biography, see Kurt Beyer, *Grace Murray Hopper and the Invention of the Information Age*, Boston: MIT Press, 2009.
1965 revision of The Effects of Nuclear Weapons at https://babel.hathitrust.org/cgi/pt?id=uc1.b3436169&view=1up&seq=761.
1962 edition at https://babel.hathitrust.org/cgi/pt?id=uc1.b3436169&view=1up&seq=761.

[12] Los Alamos Scientific Laboratory, U.S. Atomic Energy Commission, United States Department of Defense, *The Effects of Atomic Weapons.* Washington, D.C.: U.S. Govt. Print. Office, 1950.

[13] United States. Defense Atomic Support Agency, and Samuel Glasstone, *The Effects of Nuclear Weapons*. [Washington]: U. S. Atomic Energy Commission, 1957.

[14] Fletcher, E. Royce, Ray W. Albright, Robert F.D. Perret, Mary E. Franklin, I. Gerald Bowen, and Clayton S. White, (U.S. Atomic Energy Commission), *Nuclear Bomb Effects Computer: (Including Slide-Rule Design and Curve Fits for Weapons Effects).* Albuquerque, NM: Lovelace Foundation for Medical Education and Research, 1962.

[15] Tinee, M. (1964, Jan 12)." New comedy deals with atomic weapons," *Chicago Tribune,* p. G9. According to the ProQuest database, the same review ran January 5, 1964 in the same newspaper.

[16] David C. Morison, "Ground Zero," *The New York Times*, December 27, 1981, p. E15.