Mathematics and War

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Improbable Warriors: Mathematicians Grace Hopper and Mina Rees in World War II

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The vast expansion of the US Navy in World War II and its increasing reliance on quickly emerging new technologies owed its success, in part, to the previously overlooked work of women. Much of this work was at the level of technician and mechanic, but there were also numbers of women with advanced educational and professional qualifications who held responsible positions during the war and who made high-level contributions in technical fields.

This paper focuses on the war work of two of these women: mathematicians Grace Murray Hopper (1906–1992) and Mina Spiegel Rees (1902–1997). Both were college professors until war service intervened. One joined the navy and the other remained a civilian, but between 1943 and 1945 each held positions from which they influenced the US Navy's ability to wage a modern, math-dependent war.

The vast expansion of the US Navy in World War II and its increasing reliance on rapidly emerging new technologies owed its success, in part, to the work of women. Much of this work was at the level of technician and mechanic, but there were also women with advanced professional qualifications who held responsible positions during the war and who made high-level contributions in technical fields.[1]

My talk focuses on the war work of two of these women: mathematicians Grace Murray Hopper (1906–1992) and Mina Spiegel Rees (1902–1997). Both women grew up in New York City and both had fathers in insurance, perhaps predisposing their daughters to mathematics. Rees's father, however, was a salesman while Hopper's father worked in the family brokerage firm. Both Hopper and Rees taught mathematics in women's colleges – one of the few occupations open to women with advanced degrees in mathematics in the 1920s and 30s. When war service interrupted their careers Hopper joined the navy while Rees remained a civilian, but between 1943 and 1945 each held positions from which they influenced the US Navy's ability to wage a modern, math-dependent war. Both women had been trained in pure mathematics but like many other mathematicians during the national emergency they adapted to the wartime demand for applied math-

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ematics. Hopper and Rees knew of each other during the war, and afterwards their lives intersected frequently as they continued to move in the same professional circles.[2]

The war-service of these two women was different from that of most male scientists and mathematicians because they were both volunteers; neither of them was liable for the draft. Indeed, as teachers of mathematics they were in an occupation essential to the war effort and were strongly discouraged from leaving it. Their case was also different from that of women in Britain and the Soviet Union – among others – as there was no requirement for American women to participate in the war effort in any way, either in the military or as civilians. Indeed, Hopper and Rees chose to serve even though their homeland was neither invaded nor in danger of being overrun.[3] Why, then, did they decide to use their mathematical skills directly in the service of war? What did each contribute to the war effort, and how did they, as mathematicians, perceive the part they played in the conflict?

Grace Hopper

In 1983 Grace Hopper, then seventy-six years old, was made an admiral by special appointment of the President of the United States. In 1987, the US Navy named its new computer center in San Diego for Hopper, and in 1996, four years after her death, it launched the newest Arleigh Burke-class guided missile destroyer *Hopper*. The recipient of numerous medals, awards, and honorary degrees, Grace Hopper was esteemed as a pioneer in the field of computing. As befits a leader instru-

[1] For a comprehensive study of women scientists see Margaret W. Rossiter, *Women Scientists in America: Before Affirmative Action, 1940–1972* (Baltimore, MD: The Johns Hopkins University Press, 1978). For changing women's roles in wartime see among others: Karen Anderson, *Wartime Women: Sex Roles, Family Relations, and the Status of Women During World War II* (Westport, CT: Greenwood Press, 1981); Martin Binkin and Shirley J. Bach, *Women and the Military* (Washington, D.C.: Brookings Institute, 1977); D'Ann Campbell, *Women at War with America: Private Lives in a Public Era* (Cambridge, MA: Harvard University Press, 1984); William Henry Chafe, *The Paradox of Change*, rev. ed. of *The American Woman* (1972), (New York: Oxford University Press, 1991); Sherna Berger Gluck, *Rosie the Riveter Revisited: Women, War, and Social Change* (New York: Meridian, 1987); Maj. Gen. Jeanne Holm, USAF (ret.), *Women in the Military: An Unfinished Revolution* (Novato, CA: Presidio Press, rev. ed., 1992); Doris Weatherfield, *American Women and World War II* (New York: Facts on File, 1990); Nancy Baker Wise and Christy Wise, *A Mouthful of Rivets: Women at Work in World War II* (San Francisco: Jossey-Bass Publishers, 1994).

[2] Much of the following on Hopper and Rees appeared previously in Kathleen Broome Williams, *Improbable Warriors: Women Scientists and the U.S. Navy in World War II* (Annapolis, MD: Naval Institute Press, 2001). Hopper's doctoral thesis was on "The Irreducibility of Algebraic Equations." Yale University, 1934. Rees's doctoral thesis was on "Division Algebras Associated with an Equation Whose Group Has Four Generators," University of Chicago, 1932.

[3] Capt. Grace Hopper interview by Linda Calvert, 3 Sept. 1982–28 Feb. 1983 (hereafter Hopper interview, 1982–83), Women in Federal Government Oral History Project, OH46 (hereafter WFGOH46), Schlesinger Library, Radcliffe Institute, Cambridge, MA (hereafter SL), 10. For Britain see Gail Braybon and Penny Summerfield, *Out of the Cage: Women's Experiences in Two World Wars* (London: Pandora Press, 1987), pp. 157–160. I am indebted to Dr. Reina Pennington for information about Soviet women.

Figure 1. Destroyer USS *Hopper*, 1998. [Courtesy: DoD, Defense Visual Information Center, March ARB, CA]

mental in creating a whole new discipline, her message to everyone was above all to innovate and never to be tied to the old or customary way of doing things.[4] Admiral Hopper never went to sea, but her computer expertise and managerial skills made her a pivotal figure in the navy's path to the computer age. "She's challenged at every turn the dictates of mindless bureaucracy," noted Navy Secretary John Lehman, under whom she served her final years.[5] Even when she reluctantly retired in 1986 – the oldest serving officer in the navy – Grace Hopper continued working as a consultant for Digital Equipment Corporation. She died in 1992, and was buried with full military honors in Arlington National Cemetery.

At the heart of all these accomplishments was Hopper's brilliance in mathematics. Had it not been for World War II, however, she might never have left the idyllic and genteel campus in New York where she was teaching. It really all began that day in December 1943 when Grace Murray Hopper was sworn in to the US Navy.

Hopper had been born in New York City in 1906, and had gone on to major in mathematics at Vassar, one of a group of private women's colleges – the Seven Sisters – catering to the bright daughters of the affluent. In 1930 she earned a masters

[4] Carmen Lois Mitchell, *The Contribution of Grace Murray Hopper to Computer Science and Computer Education* (University of North Texas: University Microfilms, 1994), pp. 1–11, pp. 24–37, pp. 50–51, pp. 63–64; Charlene W. Billings, *Grace Hopper: Navy Admiral and Computer Pioneer* (Hillside, NJ: Enslow Publishers, Inc., 1989), p. 30, pp. 36–38, pp. 47–53, p. 111, p. 115.

[5] Quoted in Billings, *Hopper*, p. 10.

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Figure 2.
Lt. Grace M. Hopper, USNR (W), during World War II. [Courtesy: Mary Murram Westcote]

degree and in 1934 a Ph.D. in mathematics at Yale – a rare accomplishment for women in those days – and then she returned to Vassar to teach. By the time of Pearl Harbor, Hopper had worked her way up to associate professor of mathematics at Vassar, but a year later she joined the WAVES – navy women – explaining that she wanted to serve the war effort more directly than by teaching. After graduating from midshipmen's school, Lt. (j.g.) Hopper was sent to the navy's Bureau of Ships Computation Project at Harvard University.[6]

The rapidly expanding data management needs of World War II accelerated the development of modern digital computers, especially in Britain and the United States, although a true American electronic computer – ENIAC – was not completed until after the conflict ended. One electro-mechanical device that was ready

[6] Hopper's sister Mary graduated from Vassar in 1930 and her brother Roger from Yale in 1932. Mary Murray Westcote interview by author, 11 Dec. 1999. Hopper's brother later also earned a doctorate. For accounts of navy women see: *BuPers: The Story of Navy Manpower, U.S. Bureau of Naval Personnel* (Washington, DC: U.S. Government Printing Office, 1949); Winifred Quick Collins, *More Than a Uniform: A Navy Woman in a Navy Man's World* (Denton, TX: University of North Texas Press, 1997); Susan H. Godson, *Serving Proudly: A History of Women in the Navy* (Annapolis, MD: Naval Institute Press, 2001); Virginia C. Gildersleeve, *The "Waves" of the Navy: How They Began* (New York: The Macmillan Company, 1956); Joy Bright Hancock, *Lady in the Navy* (Annapolis, MD: Naval Institute Press, 1972).

in time to be used in the war was the brainchild of Howard Aiken, professor of physics and applied mathematics at Harvard. Frustrated by the tedious and time-consuming mathematical calculations required for his doctoral dissertation, Aiken had designed a mechanism to perform such calculations automatically. Engineers at IBM built Aiken's machine under his guidance. What emerged from this collaboration, the Automatic Sequence Controlled Calculator (ASCC) or Harvard Mark I, was the first functional, large-scale, automatically sequenced, general-purpose, digital computer to be produced in America.[7]

When the Mark I was completed in 1944, IBM gave it to Harvard as a gift. That spring it was installed at the university but was immediately leased for the duration of the war by the US Navy, desperate for gunnery and ballistics calculations. Aiken, a naval reserve officer, was put in charge of the Mark I for the Bureau of Ships.[8]

Aiken's computing machine was in many ways unique. It was fifty feet long, eight feet tall, and eight deep, filling an entire room. It had more than 750,000 parts, used 530 miles of wire, and weighed about five tons.[9] Aiken described the Mark I as a "general arithmetic machine capable of addition, subtraction, multiplication, division, and the transfer of numbers."[10] Most impressive were its speed of computation and its automatic functioning enabling it to proceed through a series of arithmetic operations without human intervention. Automatic sequence control was accomplished according to programmed instructions fed into the machine on punched paper tape while the output was handled either by punched cards or by two electric typewriters.[11]

The multiple-purpose capabilities of the Mark I – the fact that it could be set to accomplish a wide range of different types of numerical calculations – was one of its great strengths and set it apart from other contemporary computing devices. Aiken also estimated that the Mark I was nearly a hundred times more productive

[7] H. H. Aiken, "Proposed Automatic Calculating Machine," edited and prefaced by A. C. Oettinger and T. C. Bartee, *IEEE Spectrum*, (Aug. 1964): pp. 62–69; I. Bernard Cohen, "Babbage and Aiken: With Notes on Henry Babbage's Gift to Harvard, and to Other Institutions, of a Portion of His Father's Difference Engine," *Annals of the History of Computing* **10**, no.3, (1988): pp. 175–177.

[8] Howard H. Aiken and Grace M. Hopper, "The Automatic Sequence Controlled Calculator – I," reprint from *Electrical Engineering* (Aug. – Sept. 1946): 1, box 1, folder 2, Grace Murray Hopper Collection 1944–1965, (hereafter Hopper Papers), Smithsonian Institution, Washington, DC (hereafter Smithsonian).

[9] Emerson W. Pugh, *Memories that Shaped an Industry: Decisions Leading to IBM System 1360* (Cambridge, MA: The MIT Press, 1984), 6; Gregory W. Welch, "Howard Hathaway Aiken: The Life of a Computer Pioneer," *The Computer Museum Report 12* (Boston: Spring 1985):7; "General Purpose Digital Computers,"(n.d.), folder "Bell Telephone Labs," box A-C, UAV 289.2005, Records of the Computation Laboratory, 1944– (hereafter Aiken Correspondence), Harvard University Archives (hereafter HUA).

[10] H. H. Aiken to Dr. Arnold Lowan, 1 Nov. 1944, folder "(dead) BuOrd," box A–C, UAV 289.2005, Aiken Correspondence, HUA.

[11] For the most comprehensive account of Aiken and the Computation Lab see: I. Bernard Cohen, *Howard Aiken: Portrait of a Computer Pioneer* (Cambridge, MA: The MIT Press, 1999), and I. Bernard Cohen and Gregory W. Welch, eds., *Makin' Numbers: Howard Aiken and the Computer* (Cambridge, MA: The MIT Press, 1999).

than a manually operated calculator. Throughout the conflict trained specialists – usually women called "computers" – working on desk calculators were still a major source of the mathematical calculations required for the prosecution of a modern war.[12]

On 2 July 1944 Grace Hopper arrived at the Computation Lab. "That's a computing engine," Aiken snapped at her, pointing to the Mark I. "I would be delighted to have the coefficients for the interpolation of the arc tangent by next Thursday."[13] Aiken knew, of course, that Hopper was there because of her mathematics background and not because she knew anything about computers. Thirty years later, when she was asked how she became interested in computing, Hopper replied that she had had no choice in the matter. "I was ordered to the first computer in the United States by the United States Navy," she said, "and I reported to the Mark I."[14] Twenty-one-year-old Ens. Ruth A. Brendel arrived at the laboratory soon after. She had been an instructor in mathematics at the University of Buffalo and had joined the navy because she thought her technical skills could make a contribution to the war effort. The navy sent both women to Harvard in answer to a direct request from Aiken for WAVES for scientific billets.[15]

The original staff of the Computation Lab was small – fewer than a dozen. All were in the navy, although officers and enlisted alike were all reservists, serving only for the duration. Most of the enlisted men were IBM technicians in peacetime, and the officers were mathematicians; one of them a recent Harvard graduate and another a graduate student of Aiken's. Initially, Hopper was one of only three officers writing programs for the Mark I, and thus was one of the first-ever computer programmers – at that time called coders. Throughout the war this team, which had grown to almost forty by January 1946, ran the Mark I around the clock, churning out essential data for all sorts of military projects.[16]

The Computation Lab completed twenty-three reports for the Bureau of Ships in less than two years. The projects were so secret that even the coders usually identified them only by letters of the alphabet. The machine was much more pow-

[12] "IBM Automatic Sequence Controlled Calculator," (IBM Corporation, 1945), 5, IBM Archives; Douglas R. Hartree, *Calculating Instruments and Machines*, (Urbana, IL: University of Illinois Press, 1949), pp. 74–79; Charles J. Bashe, Lyle R. Johnson, John H. Palmer, and Emerson W. Pugh, *IBM's Early Computers* (Cambridge, MA: The MIT Press, 1986), 29; James W. Cortada, *Before the Computer: IBM, NCR, Burroughs, and Remington Rand and the Industry They Created, 1865–1956* (Princeton, NJ: Princeton University Press, 1993), pp. 190–191; Grace Hopper interview by Christopher Evans, 1976 (hereafter Hopper interview 1976), 12, OH 81, Charles Babbage Institute, University of Minnesota, Minneapolis (hereafter CBI).

[13] Rosario Rausa, "In Profile, Grace Murray Hopper," *Naval History* (Fall 1992):58.

[14] Hopper interview 1976, 1, OH81, CBI.

[15] Ruth Brendel Noller interview by author, 23 Dec.1996; "An Administrative History of the Bureau of Ships during World War II," (hereafter BuShips History), 4 vols., II, pp. 140–142, *U. S. Naval Administrative Histories of World War II No. 89*, 1952, Navy Department Library, Naval Historical Center, Washington, DC, (hereafter NDL/NHC).

[16] Gregory W. Welch, "Computer Scientist Howard Hathaway Aiken: Reactionary or Visionary?" (A.B. thesis, Harvard University, 1986), p. 47; Contract NObs-14966, folder "BuShips Computing Project," box 6, UAV.885.95.2, WW II Government Contract Records, HUA; Noller interview by author, 23 Dec. 1996; Aiken and Hopper, "The Automatic Sequence Controlled Calculator – I," 1, box 1, folder 2, Hopper Papers, Smithsonian.

erful than almost everything else then available to the navy and it ran calculations regarded as essential to the war effort.[17]

The first problem Hopper remembered working on at the lab was the one Aiken thrust at her on the very first day: finding the interpolation coefficients for applications of the arc tangent series. The purpose of the task was for computing rocket trajectories. Instead of shooting only inert objects (projectiles) the navy was now firing self-propelled missiles (rockets) for which there were no firing tables. Another similar early problem, typical of the work the lab did for the navy, was to figure fire-control calculations for 5"/38 caliber anti-aircraft guns. The completed solution accommodated input variables including target bearing, elevation and range, the ship's angle of pitch and roll, drift angle, time of flight, and residual projectile velocity. High capacity projectiles had been developed so much faster than their corresponding range tables that in 1942 the navy was already some five hundred tables behind. The advent of proximity fuses also meant extensive recomputation of existing tables. Until the Mark I became operational, Hopper recalled that the navy had had to rely on "acres of girls down at Aberdeen [Proving Ground] using hand-driven calculators" to create range tables.[18] Another problem Hopper worked on concerned the location of magnetic mines by conducting sweeps with a dipole dragged behind a minesweeper. The sweeper had to know the range of the dipole for an effective sweep, and Hopper made those calculations, in three dimensions, on the Mark I.[19]

Years later, when she was asked about her first days at work at Harvard and how she learned to program the Mark I, Hopper's reply was as straightforward as her approach to the problem must have been. "Well they gave me a code book and told me to do it," she said. "We were all in the navy," she would often say later, and "we didn't have time to react or think or anything. We just had to go ahead and do things."[20] Throughout the course of the war everyone at the lab was involved in an on-going experimental process requiring continual adaptation and development. "Mark I was new, a pioneer;" Hopper wrote some years later, "programs were improved or invalidated as changes were made in the computer's internal circuits to increase its efficiency."[21] After figuring out how to write the machine instructions, Hopper then punched them on tape, put the tape in the computer and hoped it would run. "But it was wartime, and there was never enough time to organize and systematize the information," she remembered.[22]

[17] Aiken, Preface to the *Manual of Operations* (n. p.), BuShip History IV 185, NDL/NHC.

[18] Report No. 7, July 1944, BuShips Computation Project Reports 1944–1945, Naval Research Laboratory, Washington, DC (hereafter NRL); *Annals of the Computation Laboratory of Harvard University*, vol. 26, (Cambridge, MA: Harvard University Press, 1951), p. 5; Hopper interview 1976, 2, OH81, CBI, for quote.

[19] Hopper interview 1982–83, p. 29, WFGOH46, SL.

[20] Hopper interview 1976, p. 11, OH81, CBI.

[21] Grace Murray Hopper, "The Education of Computer," p. 139, in: *Proceedings, Symposium on Industrial Applications of Automatic Computing Equipment*, pp. 139–144, Midwest Research Institute, Kansas City, MO, 8–9 Jan. 1953, from reprint in Hopper, Grace Murray Biographical Files, CBI.

[22] Hopper interview 1976, p. 6, p. 11, OH81, CBI.

Hopper was not particularly interested in hardware and had relatively little concern with it. Instead, she quickly focused on methods to speed the process of writing coding instructions to run individual problems. Hopper claimed to be "…lazy as all get out.[23] I never want to do anything over again." She was always looking for shortcuts, which in the early days meant assembling collections of subroutines. Hopper and her colleagues thus created what were essentially the earliest digital computer programs – the first software. These were stored programs, only independent of the machine itself, stored on punched paper tapes and in programmers' notebooks. Similar work putting together a library of mathematical subroutines was also being undertaken in England at the same time – as Hopper learned later. During the war, however, she was not at all aware of it. There was relatively little information around about different systems (even within the United States) because of security restrictions. Indeed, compartmentalization was the norm at the Harvard lab, each programmer working individually. "You didn't go after anything else unless you had an actual need to know," Hopper pointed out. Besides which, "…you were too busy trying to get the problem you had at the moment on and get the results out to think of anything else or go after anything else."[24]

Aiken, moreover, kept tight control of the work at the lab and it was he who handed out job assignments. Hopper was busy computing the extent of influence of the anti-mine dipole when Aiken put her to work (against her wishes) writing a manual. On Aiken's order she put together a 561-page *Manual* that gave a full and detailed description of the Mark I: all its parts with which she had become intimately familiar, and all its circuits, as well as how to program it.[25]

The Mark I not only ran numbers for a great variety of navy labs, but for the army as well, and for other academic labs.[26] By October, 1944, for example, Aiken's lab was undertaking computations for the Bureau of Ordnance in conjunction with the computing section at Columbia University for spherically and cylindrically symmetric underwater blast problems. At first it had been thought possible to carry out all the blast computations on Columbia's IBM punched-card equipment, but the volume of material involved was too extensive, so the Mark I was used as well.[27]

[23] Grace M. Hopper interview by Philip F. Holmer, 20 Jul. 1979, typed transcript, Oral History Interviews, (hereafter Hopper interview 1979), 8, series II, Sperry Univac Records Accession 1825 (hereafter sperry Acc. 1825), The Hagley Museum and Library, Greenville, DE (hereafter Hagley).

[24] Hopper, "Automatic Programming," 10, Marvin L. Stein Papers, (CBI 10), CBI; Hopper interview 1976, p. 10, OH81, CBI, for quote.

[25] Robert V. D. Campbell and Richard Bloch, interview by author, 12 Sept. 1997. Harvard students Campbell and Bloch, were Mark I's first programmers, soon joined by Hopper. Hopper interview 1982-83, 29, WFGOH46, SL.

[26] Reports No.10, Oct.1944, No.8, Aug. 1944, No.5, Jun.1944, BuShips Computation Project, NRL; Cohen and Welch, Makin‘ Numbers, 3, 57; Interim Progress Reports to AMP, 21 Aug. 1944, 23 Oct. 1944, 24 Jan. 1945, box 13, Applied Mathematics Panel General Records (hereafter AMP Gen. Recs.), Record Group 227 (hereafter RG227), National Archives 2, College Park, MD (hereafter NA2).

[27] Interim Report to AMP, 24 Jun. 1944, box 13, AMP Gen. Recs., RG227, NA2.

The largest problem run on the Mark I – problem J – was the compilation of tables of Bessel functions requested by the Naval Research Laboratory (NRL). Bessel functions were important in applications as diverse as radio wave propagation, heat flow, and frequency modulation.[28] The Computation Lab also computed tables of Hankel functions. These had been requested by NRL but were also used by other naval research activities, such as the Naval Ordnance Lab, the navy's Radio and Sound Laboratory, and the David Taylor Model Basin, for solution of problems of radio wave propagation and radiation, underwater sound propagation, and the like.[29] The Computation Lab also ran numbers for the celebrated mathematician, John von Neumann, for work regarding the plutonium bomb dropped on Nagasaki on 9 August 1945.[30]

The Computation Lab was far from alone in providing mathematical services to the navy during World War II. Howard Engstrom, for example, who had taught Hopper at Yale (and who was a longtime member of the Naval Reserve), was made a commander and headed a special research group of top mathematicians, engineers, and physicists from all over the country charged with applying mathematics to cryptanalysis. This effort, using versions of the Turing bombe, was part of the innocuously named Communications Supplementary Activities, Washington (CSAW). When she joined the navy, Hopper had initially expected to join Engstrom in whatever exciting and secret work it was that he was engaged in.[31]

In addition to working on the Mark I and writing its first manual of operations, Hopper was instrumental in the development of its successors, the Mark II – also electromechanical – and the Mark III – electronic – which were used by the navy after the war. Reflecting on the significance of military sponsorship of science, Hopper often maintained that there would not have been a computer industry without that early navy support.[32] Surely there would have been, but it would have been slower to develop.

[28] Robert V. D. Campbell interview by William Aspray, 22 Feb. 1984 (hereafter Campbell interview 1984), 23, OH67, CBI; I Bernard Cohen, "Howard Aiken and the Beginnings of Computer Science," CWI Quarterly 3 No. 4 (1990):318.

[29] Chief BuShips from NRL, 3 Jan 1945, folder "(Dead) BuOrd," box A–C, UAV 289.2005, Aiken Correspondence, HUA.

[30] Report No.11, Dec. 1944, BuShips Computation Project, NRL; Letter to Dr. Arnold Lowan from H. H. Aiken, 1 Nov. 1944, folder "(dead) BuOrd," box A–C, UAV 289.2005, Aiken Correspondence, HUA; Letter from Bob Campbell to author, 16 Aug. 1998. Von Neumann also worked on calculations for the hydrogen bomb, Andrew Hodges, *Alan Turing: The Enigma*, (New York: Simon and Schuster, 1983), p. 302.

[31] Colin Burke, *Information and Secrecy: Vannevar Bush, Ultra, and the Other Memex* (Metuchen, NJ: The Scarecrow Press Inc., 1994), pp. 224, 276, 291, 297; David L. Boslaugh, When Computers Went to Sea: The Digitization of the United States Navy (The Institute of Electrical and Electronic Engineers, Inc., 1999), pp. 72, 81–83; Grace Hopper interview by Uta C. Merzbach, Jul. 1968 – Feb. 1969 (hereafter Hopper interview 1968–69), pp. 5–6, folder 7, box 11, Series I, Computer Oral History Collection, National Museum of American History Archives Center, accession #196 (hereafter NMAHAC #196), Smithsonian Institution, Washington, DC.

[32] Grace Hopper interview by H. S. Tropp, 5 July 1972 (hereafter Hopper interview 1972), 68–69, folder 9, box 11, Series I, NMAHAC #196.

After the war, Hopper had wanted to transfer to the regular navy but was over the cut-off age and had to satisfy herself with staying in the Naval Reserve. Instead of returning to teach mathematics at Vassar, where she was offered a full professorship, she remained at the Computation Lab as a Research Fellow. After three years, when she failed to be promoted or to gain tenure – which was the usual case for women – she was forced to leave.[33]

In 1949, after careful consideration of the many job offers she received – including from Engstrom now at Engineering Research Associates – Hopper joined the Eckert-Mauchly Computer Corporation in Philadelphia, because she figured they were the closest to having a commercial computer – the UNIVAC – up and running. She had had an interview at IBM, "but that was back in the days when they still had an IBM flag and sang songs about it, and that was too much for me" she recalled.[34] Hopper remained with the UNIVAC division through Eckert-Mauchly's acquisition by Remington Rand in 1950, and then through the merger which created Sperry Rand (later to become UNISYS) in 1955. She finally retired from the company in 1971.[35]

At UNIVAC in 1952, Hopper developed the first compiler, the A-0, a library of subroutines that the computer itself could assemble into a program. In 1957 she completed FLOWMATIC, the first English language compiler. By 1960, FLOWMATIC became one of the main ingredients in the collaborative creation of COBOL, soon to be widely adopted as a universal computer language.[37]

During all this time Hopper enthusiastically maintained her navy reserve status, serving weekend and annual active duty stints. Finally, however, the years caught up with her and in 1966 she was forced to retire.[38] "It was the saddest day of my life," recalled Hopper.[39]

Only seven months later, however, the navy repented its bureaucratic efficiency and reversed the decision to let Hopper go. With the naval expansion in response

[33] Richard Bloch interview by William Aspray, 22 Feb. 1984 (hereafter Bloch interview 1984), pp. 19, 58, OH66, CBI; Hopper interview 1979, 1, Sperry Acc. 1825, Hagley.

[34] Hopper interview 1968, p. 5, folder 7, box 11, Series I, NMAHAC #196.

[35] Hopper interview 1982–83, pp. 30–31, 47, WFGOH46, SL; Anthony Ralston, ed., *Encyclopedia of Computer Science and Engineering,* 2nd ed. (New York: Van Nostrand Reinhold Co., 1983), pp. 685–686.

[36] "Hopper and Mauchly on Computer Programming," in: *Proceedings of the IEEE*, **72**, no.9 (September, 1984): p. 1216, Reprinted from Grace M. Hopper and John W. Mauchly, "Influence of Programming Techniques on the Design of Computers," *Proceedings of the I. R. E.*, **41**, no.10, (October 1953): pp. 1250–1254.

[37] Hopper interview 1982–83, pp. 32, 34–35, 47–49, WFGOH46, SL; Ralston, *Encyclopedia of Computer Science and Engineering*, pp. 685–686. Hopper credited A.E. (Gene) Smith with being "the first to move to use COBOL all out." Smith had been BuShips liaison to the Computation Lab during the war, and afterwards went to the Bureau of Standards, Hopper interview 1968–69, p. 15, folder 7, box 11, Series I, NMAHAC #196.

[38] Hopper interview 1976, p. 19, CBI.

[39] Quoted in Billings, *Hopper,* p. 87.

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to the Vietnam War, and the consequent increasing demand for computerized systems, Hopper's skills were once again invaluable.[40]

On 1 August 1967, Grace Hopper was recalled to active duty with a temporary appointment for six months. She stayed nineteen years. Her most important work was in the standardization of navy computer languages. She implemented a comprehensive program of standardization of COBOL in the navy, replacing the numerous and incompatible versions of the language then in use.[41]

From 1977 until her final, still reluctant, retirement in 1986, Hopper was at the Naval Data Automation Command Headquarters (NAVDAC, now NAVCOMTEL) in Washington, DC. In those final years "Amazing Grace," as her colleagues called her, became the navy's foremost propagandist for its computer program as NAVDAC's representative to learned societies, industry associations, and technical symposia.[42] She had surely repaid the navy in full measure for the opportunity it gave her to pioneer a new discipline. She was eternally grateful, always maintaining that of all the honors she received, the chance to serve in the US Navy was the most precious.[43]

Mina Rees

As Grace Hopper's career illustrates, the technological demands of World War II had an immense impact on the American scientific community, often channeling scientists in new directions. After the war many continued to work in their new fields, profiting from their wartime experiences.[44] Like Grace Hopper, Mina Rees's wartime service greatly affected her postwar career, in her case moving her out of teaching and into administration. In 1923 Mina Rees had earned a bachelor's degree, summa cum laude, from Hunter College in New York, a tuition-free public college for exceptional young women. In 1925 she received a Masters Degree from Columbia University, and in 1931, she was awarded a doctorate in mathematics from the University of Chicago.[45]

[40] Hopper was an exception to the trend among navy women whose numbers actually decreased during the war. They were restricted, as before, to less than a third of the enlisted ratings. Moreover, most WAVES continued to fill clerical, health service, and administrative positions; Godson, *Serving Proudly*, p. 207.

[41] "Captain Grace Murray Hopper, US Naval Reserve," July 1981, Grace Hopper Officer Biography, Box 313, Operational Archives, Naval Historical Center, Washington Navy Yard (hereafter OA/NHC).

[42] Williams, *Improbable Warriors*, p. 212.

[43] Godson, *Serving Proudly*, p. iv.

[44] Among other works see, for example: Harvey Brooks, *The Government of Science* (Cambridge: M.I.T. Press, 1968), Daniel S. Greenberg, *The Politics of Pure Science* (The University of Chicago Press, 1999), Daniel M. Hart, Forged Consensus: Science, Technology and the Economic Policy of the United States, 1921–1953 (Princeton University Press, 1998), Penick, Pursell, Sherwood, and Swain, eds., *The Politics of American Science, 1939 to the Present* (Cambridge: M.I.T Press, 1972), Michael D. Reagan, *Science and the Federal Patron* (New York: Oxford University Press, 1969), Daniel J. Kevles, *The Physicists: The History of a Scientific Community in Modern America* (New York: Knopf, 1978).

Figure 3.
Dr. Mina Rees at the office of naval research, march 1946. [Courtesy: US Navy]

Like Hopper, with doctorate in hand Rees returned to teach mathematics at her alma mater, Hunter College. For the next twelve years she worked her way from assistant to associate professor while assiduously keeping up with new developments in her field. She became active in the American Mathematical Society, sitting on its major committees, and getting to know mathematicians from all over the country. This gave her an overview of what was going on in the discipline, and meant that in a community of mathematicians which probably numbered only 3,000 or so, she was one of the best known of the women.[46]

Before World War II, beyond encouraging states to establish institutions of higher education, the federal government had done little to develop science. With the fall of France in 1940, however, it seemed to some key American scientists that U.S. participation in the war was inevitable. Recognizing the need to organize the scientific war effort, a group of them began to mobilize. They were led by

[45] Martha J. Bailey, *American Women in Science: A Biographical Dictionary* (Denver, CO: ABC-CLIO, 1994), 322; Louise S. Grinstein and Paul J. Campbell, *Women of Mathematics: A Bibliographic Sourcebook* (New York: Greenwood Press, 1987), 175; Mina Rees interview by Nina Cobb, 16 Nov. 1983 - 20 Jan. 1984 (hereafter Rees interview 1983-84), 1-15, 19-24, Women in Federal Government Oral History Project, OH40 (hereafter WFGOH40), Schlesinger Library, Radcliffe Institute, Cambridge, MA (hereafter SL).

[46] Rees interview 1983–84, pp. 52–59, 78–81, WFGOH40, SL.

Vannevar Bush, an electrical engineer and president of the Carnegie Institution. At the urging of Bush and a number of prominent colleagues, President Roosevelt established the National Defense Research Committee (NDRC) in June 1940. Bush believed that science had advanced so far since the last conflict that military leaders did not have a good grasp of what might be scientifically possible. Therefore, instead of reverting to the former pattern of having the military request from science the weapons it wanted, science should acquaint itself with the needs of the military so that it could advise on what was possible. Much of the initiative for scientific military research thus swung towards civilian scientists.[47]

Soon, academic and research institutions all over the country were drawn into war work, the NDRC engineering a massive exchange of personnel. Much was accomplished in one year to create a civilian-led mechanism for harnessing the nation's scientists to the war effort and to consult with the military without falling under their control. By June 1941, Bush had recruited 6,000 physicists, chemists, mathematicians, and engineers, a number that grew to 30,000 by the end of the war.[48]

By mid-1941, the NDRC had already grown to such an extent that its direction was given to a new, supervisory and administrative body, the Office of Scientific Research and Development (OSRD).[49] In December 1942, the work of the NDRC was divided among eighteen new divisions and two panels which continued to operate until June 1946. The divisions were concerned with such subjects as ballistics research, ordnance accessories, missiles, subsurface warfare, fire control, explosives, absorbents and aerosols, chemical engineering, radar, radio, optics, and metallurgy. The two panels were the Applied Psychology Panel and the Applied Mathematics Panel.[50]

With NDRC's reorganization, Warren Weaver (1894–1978), mathematician and director for the natural sciences at the Rockefeller Foundation, was appointed chief of the Applied Mathematics Panel (AMP). It was already clear by then that the demand for sophisticated mathematical studies had increased rapidly as had the need for mathematical assistance throughout the NDRC. Divisions requiring extensive mathematical investigations, computing, or statistical work had to designate at least one member to sit on the AMP. The AMP, for its part, was to provide expert consulting services to the divisions, and to conduct authorized studies. Projects could also come to the AMP from the army, the navy, allied governments, or from the OSRD itself.

[47] Irvin Stewart, *Organizing Scientific Research for War: The Administrative History of the Office of Scientific Research and Development* (Boston: Brown, Little and Company, 1948), p. 6; James Phinney Baxter, *Scientists Against Time* (Boston: Brown, Little and Company, 1946), p. 14.

[48] Stewart, *Organizing Scientific Research*, p. 34; Baxter, *Scientists Against Time*, p. 24. For a less sanguine view of the cooperation see Harvey M. Sapolsky, *Science and the Navy: The History of the Office of Naval Research* (Princeton University Press, 1990), pp. 18–19, 29–30.

[49] Stewart, *Organizing Scientific Research*, pp. 35–37.

[50] Stewart, *Organizing Scientific Research*, pp. 85–97.

The NDRC selected, farmed out to research establishments, supervised, and funded all projects through a contract system. In most cases, once a contract was approved technical aides for each division undertook the oversight of the work. Weaver defined the duties of AMP technical aides to include: "reading a large amount of report material, both British and American, visiting contracts, consulting on studies, suggesting material and contacts, and establishing inter-relationships between Panel personnel and the services." With her considerable charm, her aptitude for solving, not creating problems, and her skill at making people feel like valuable members of a team, Mina Rees was very well qualified for the job of technical aide.[52]

After Pearl Harbor, Rees had felt a great sense of frustration, believing she could be useful in the war, but not knowing how to go about making a contribution. Looking back she wrote that she had really wanted, "as most young people did, I think, at that time, to have some part in trying to save the world."[52] Fortuitously for her, Warren Weaver found he could not run the AMP alone, especially as he still maintained his position at the Rockefeller Foundation and was trying to juggle the two jobs. The AMP agreed that he needed somebody full-time to take care of central operations. Weaver immediately called Rees, offering her the dual job of technical aide to the panel, and executive assistant to himself. Rees knew that being a woman "it would be harder to get a job that would be really significant in the war effort," so she had no hesitation in accepting Weaver's offer. Assuming that Weaver had turned to her because of the extensive connections she had cultivated among mathematicians around the country, Rees began work on 1 August 1943, as soon as she was approved for a civil service appointment.[53] Her role at the AMP was succinctly described in a citation years later recognizing her deep involvement "in deploying and sustaining the efforts of this country's mathematicians in the war effort."[54]

Weaver's mathematicians, who eventually numbered several hundred, worked on AMP problems in groups set up at eleven universities across the country, including Princeton, Columbia, NYU, the University of California at Berkeley, Brown, Harvard, and Northwestern. Weaver was advised by an executive committee composed of some of the nation's leading mathematicians, including Richard Courant, Thornton C. Fry, Oswald Veblen, and Samuel Stanley Wilkes. Rees served as secretary to this group, and like everyone on the AMP had an identifica-

[51] Mina Rees Diary (hereafter Rees Diary), AMP Executive Committee Meeting (hereafter AMP ExCo), 31 Jan. 1944, box 1, AMP Gen. Recs., RG227, NA2; author's interview with Norma Kenigsberg, 15 June 2000, for insights into Rees's management style. Kenigsberg worked with Rees at City University of New York (CUNY).

[52] Rees interview, 1983–84, pp. 107–111, WFGOH40, SL.

[53] Rees interview, 1983–84, pp. 107, 111, WFGOH40, SL.

[54] "Citation for Mina Rees," Hunter College Commencement, June 5, 1973, typescript, "Awards and Honors," box 1, Rees Collection, CUNY Graduate School and University Center Archives, New York City.

tion badge reading "Mathematical Studies relating to Warfare."[55] By the end of the war the AMP had undertaken 194 studies, almost half of them the result of direct requests from the armed services.[56]

In the early days of the AMP, Rees sometimes had difficulty persuading scientists to accept panel contracts. She knew they were jealous of their freedom to pursue research independently of direction, yet in most cases during the war mathematicians had to solve other people's problems which was very trying for them. This forced technical aides to develop formidable skills as intermediaries; they were the government source of funding standing between the contractor (the scientists) and the client (usually the military), interpreting the project back and forth between them and making its completion possible.[57]

When problems came in from the military Rees transmitted them to the executive committee of the AMP after doing some preliminary work on them. She provided the background information with which the committee could make a decision. Generally this involved reformulating the problem in mathematical terms, and then seeing if there were people available who had the right kind of mathematical specialty to reach the answer to it. Rees was largely responsible for identifying a suitable person or group of people to carry out the work, so she needed to know what field people were working in and how busy they were.[58] She also had to keep current with all projects undertaken that might in any way involve mathematics – in the navy especially, but also in the army and in other OSRD divisions – in order to avoid duplication of effort.[59]

According to Rees, one of the strengths of the system thus developed was that many of the most able mathematicians in the country were identified with the AMP, either in the contract places or as members of the panel itself.[60] To be sure, both the army and the navy also recruited civilian mathematicians, while others were associated with British and Canadian research efforts. Still others held posts in industry. However, the NDRC, and especially its Applied Mathematics Panel, greatly influenced wartime mathematics thereby shaping postwar mathematics as well.[61]

[55] Mina Rees, "The Mathematical Sciences and World War II," in: *American Mathematical Monthly* **87**, No.8 (October 1980): p. 609; for the ID badge, Rees Diary, AMP ExCo, 11 Sept. 1944, box 1, AMP Gen. Recs., RG227, NA2. The Executive Committee had its first meeting on 27 Jan. 1943, before Rees was brought on board.

[56] Warren Weaver, *Scene of Change: A Lifetime in American Science* (New York: Charles Scribner's Sons, 1970), pp. 88–89; U.S., OSRD, NDRC, *Summary Technical Report of the Applied Mathematics Panel*, 3 vols. (confidential) (Washington, D.C., 1946) (hereafter OSRD, *Summary Technical Report of AMP*), vol.2, p. vii; "Meeting of the ExCo of AMP," 3 May 1943, box 1, AMP Gen. Recs., RG227, NA2.

[57] Weaver to Dr. Irvin Stewart, 9 Sept. 1943, box 8, AMP Gen. Recs., RG227, NA2; Rees interview, 1983–84, p. 131, WFGOH40, SL.

[58] Rees interview, 1983–84, pp. 108, 112–114, WFGOH40, SL.

[59] Rees interview, 1983–84, pp. 108, 112–113, WFGOH40, SL.

[60] Rees interview, 1983–84, pp. 110, 113, 118, WFGOH40, SL.

[61] Rees, "The Mathematical Sciences and World War II", pp. 608–609; Rees, "Mathematics and the Government,", p. 4, "Publications," box 1, Rees Collection, CUNY.

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One of the first problems the navy brought to the AMP was how to determine what kind of torpedo barrage to lay down against Japanese vessels to maximize the chance of hitting them. The navy had no information on how fast Japanese vessels could go in a straight line, how rapidly they could turn, etc. They, did, however, have very good photographs of many Japanese vessels. The people at NYU knew that in 1887 British physicist Lord Kelvin had established that the speed of a ship moving in a straight line is indicated by the spacing of the cusps along the bow waves. Most of the navy photographs, though, showed Japanese ships in the process of turning, so Lord Kelvin's analysis had to be extended to ships in turns. This was rather simply done and the data on the speed of Japanese ships was figured from pictures of their bow waves or wakes. A test of the mathematical results in an experimental run with a new destroyer off the coast of Maine found an extremely good agreement of theory and observation.[62] As Rees pointed out, "This and similar experiences won over the armed services to the notion that mathematics could be of great help to them."[63]

Rees noted that some of the tasks taken on by the AMP involved what was called "classical applied mathematics." At NYU, for example, work in gas kinetics concerned the theory of explosions in the air and underwater, which required extensive study of the kinds of shock fronts created by explosions. A Bureau of Aeronautics request for assistance in the design of nozzles for jet motors initiated Study No.137, an analysis of gas flow in nozzles and supersonic gas jets involving the development of jet and rocket theory. It was hoped to use rockets to assist in carrier plane take-offs. Rees remembers, in particular, one trip she made to Pasadena in 1944, accompanying Richard Courant and Kurt Friedrichs to check the problem Cal Tech was having launching their rockets. Courant and Friedrichs were able to make some suggestions and the experiments begun after their departure were successful.[64] By work of this sort AMP mathematicians gained expertise in new and important fields putting them at the forefront of postwar developments.

The Naval Research Lab frequently sought help for computations involving fire control experiments as did MIT physicist Philip Morse of the Anti-Submarine Warfare Operational Research Group for a number of probability problems concerning the lethal range of depth charges and airborne submarine searches.[65]

As technical aide to the AMP one of Rees's areas of responsibility was the effort to expand computing power, making use of all the various types of computing equipment including differential analyzers, relay computers, and other devices developed by National Cash Register and IBM. Rees also assigned projects to

[62] Rees, "The Mathematical Sciences and World War II,", p. 617; Rees Diary, AMP ExCo, 1 May 1944, box 1, AMP Gen. Recs., RG227, NA2.

[63] Rees, "The Mathematical Sciences and World War II,", p. 617.

[64] Rees Diary, AMP ExCo, 21 Aug. 1944, box 1, AMP Gen. Recs., RG227, NA2, for Study No. 137; for Courant in Pasadena, Rees Diary, ExCo, box 1, AMP Gen. Recs., RG227, NA2.

[65] Rees Diary, AMP ExCo, 1 May 1944, box 1, AMP Gen. Recs., RG227, NA2; "Diary of ExCo Meeting," 8 Mar. 1943, box 1, AMP. Gen. Recs., RG227, NA2; "Meeting of the ExCo of AMP," 3 May 1943, box 1, AMP Gen. Recs., RG227, NA2; "Notes on ExCo Meeting, 7 Jun. 1943," box 1, AMP Gen. Recs., RG227, NA2; Rees Diary, AMP ExCo, 27 Sept. 1943, box 1, AMP Gen. Recs., RG227, NA2.

Howard Aiken's Mark I at Harvard, where she heard of Grace Hopper for the first time. Rees thus became very familiar with the most up-to-date work in computers, helping to qualify her for her first postwar position.[66]

To be sure, Rees was not the only woman of science at the OSRD/NDRC, but there were not many others, and even fewer who were in positions as influential as hers.[67] Before going to the AMP, however, Rees had had little administrative experience and she watched Weaver closely, learning from his great skill in dealing alike with military officers, the Washington bureaucracy, and fellow scientists. In many ways her talents were very similar to his. Weaver wrote perceptively of himself that he "lacked that strange and wonderful creative spark that makes a good researcher." Rees, too, acknowledged that she did not have the kind of mathematical creativity that would have qualified her to do research for the AMP. Her job had been basically an administrative one, although it was one that also required a deep knowledge of mathematics. For their war work both Weaver and Rees received the King's Medal for Service in the Cause of Freedom from the British government, and Weaver received the Medal for Merit of the United States, while Rees was awarded the U.S. President's Certificate of Merit.[68]

Rees had joined the AMP in August 1943 and remained until its last meeting in April 1946. In a glowing letter Weaver wrote of her accomplishments that she had "made a large and distinguished contribution to the war effort."[69] She never returned to teaching, however. Her wartime experience had set her on the administrative path that defined the rest of her life. In 1946 Rees accepted an invitation

[66] Weaver to BuOrd, BTL, MIT, 23 Dec. 1943, box 25, AMP Gen. Recs., RG227, NA2; Mina Rees, "The Computing Program of the Office of Naval Research, 1949–1953," *Annals of the History of Computing* **4**, no. 2 (April 1982): p. 104; "Final Report of Committee on Computing Aids for Naval Ballistics Laboratory," 28 Apr. 1944, box 25, AMP Gen. Recs., RG227, NA2; Rees to Dr. A. N. Lowan, 4 Dec. 1945, box 26, AMP Gen. Recs., RG227, NA2; Rees Diary, AMP ExCo, 1 Nov. 1943, AMP Gen. Recs., RG227, NA2.

[67] There was, for example, Dr. Dorothy W. Weeks, of the OSRD Liaison Office, Dr. Gladys Anslow, head of the physics department at Smith College who was appointed to the Office of Field Service in 1944, and Dr. Gladys Anderson Emerson, a biochemist working for OSRD on the effects of vitamin deficiencies. There were also a few other very able women on the administrative side, like Margaret Moses and Dr. Louise Kelley in the office of the Chairman, NDRC. A number of prominent women scientists worked on the Manhattan Project, and among mathematicians there two very important statisticians working with Jerzy Neyman at Berkeley. One of them, Elizabeth "Betty" Scott, replaced him as chair of the department of mathematical statistics when Neyman retired. Margaret Moses to Rees, 26 Jan. 1944, and Rees to Moses, 28 Jan. 1944, box 23, AMP Gen. Recs., RG227, NA2; Minutes of Conference on Summary Technical Report, 30 Aug. 1945, box 3, AMP Gen. Recs., RG227, NA2; for Gladys Emerson see Edna Yost, *Women of Modern Science* (New York: Dodd, Mead & Company, 1959), pp. 140–155; Rees interview, 1983–84, pp. 139, 150–152, WFGOH40, SL; Rees to Dr. Dorothy W. Weeks, 8 Mar. 1944, box 23, AMP Gen. Recs., RG227, NA2; MR to WW, 29 July 1944, AMP Gen. Recs., RG227, NA2, for Weeks and Anslow.

[68] Weaver quoted in Mina Rees, "Warren Weaver, 1898–1978," National Academy of Sciences, *Biographical Memoirs* **57** (1987): p. 501; for Rees see Donald J. Albers and G. L. Alexanderson, eds., *Mathematical People: Profiles and Interviews* (Basle, Boston, Berlin: Birkhäuser, 1985), p. 258; Minutes of Conference on Summary Technical Report, 30 Aug. 1945, box 3, AMP Gen. Recs., RG227, NA2; Mina Rees c.v., box 1, Rees Collection, CUNY.

[69] U.S., OSRD, *Summary Technical Report of AMP*, vol 2, Foreword, v; Weaver to Pres. George N. Shuster of Hunter College, 29 Jan. 1946, box 8, AMP Gen. Recs., RG227, NA2.

to head the mathematics branch of the newly established Office of Naval Research (ONR). Building on the broad contacts she had made through the AMP, she took up the challenge to design and develop a mathematical program melding civilian and navy science in peacetime. With the end of the OSRD, the ONR became the chief government office to continue subsidizing scientific research after the war. A powerful incentive, of course, in the developing Cold War environment, was the awareness that applied mathematics was being vigorously pursued abroad, especially in Russia, Germany, England, and the Netherlands.[70]

The easy wartime availability of federal research dollars had irrevocably changed the scientific climate and Rees's war service had placed her on the ground floor of the new developments. With that head start she soon created a flourishing program at ONR.[71] Later, as chief of the Mathematical Sciences Division at ONR, Rees accomplished the distinction of being the only woman at division-head level in the navy's whole research program. In her final year at ONR, Rees became the deputy research director, responsible for the entire research activity.[72] For her work at ONR, Rees has been called "the architect of the first large-scale, comprehensively planned program of support for mathematical research; she pioneered its style, scale and scope." Both the American Mathematical Society and the Institute of Mathematical Statistics adopted resolutions of appreciation for her work at ONR.[73]

In 1953 Rees returned to New York as Dean of Faculty at Hunter College. She went on to a brilliant career as an academic administrator, eventually serving as the first president of the City University of New York Graduate Center. Questioning the timing of her move an interviewer asked Rees if she left Washington because Eisenhower came in. While not replying directly, she did admit "when Mr. Eisenhower was elected president, the budget was cut…the Republicans cut budgets."[74]

[70] Rees interview, 1983–84, p. 160, WFGOH40, SL; Rees, "The Mathematics Program of the Office of Naval Research: *Bulletin of the American Mathematical Society* **54**, no.1 (January 1948): p. 4; Reagan, *Science and the Federal Patron*, pp. 5–6, 264–266; Samuel S. Snyder, "Influence of U.S. Cryptologic Organizations on the Digital Computer Industry," 3, Special Research History – 003, box 4, RG457, NA2.

[71] Rees, "Establishment of CUNY," p. 6–7, box 1, Rees Collection CUNY; Rees, "The Mathematics Program of the ONR," pp. 2–3; Sapolsky, *Science and the Navy*, p. 8.

[72] "Who's Who in Naval Research," Office of Naval Research, *Research Reviews* (Feb. 1952): pp. 13–14, box 1, Rees Collection, CUNY.

[73] F. J. Weyl, who served with Rees at ONR is quoted in Grinstein and Campbell, *Women of Mathematics*, p. 176; Albers and Alexanderson, *Mathematical People*, p. 263; Rees, "The Computing Program of the Office of Naval Research 1949–1953," *Annals of the History of Computing* **4**, no.2 (April 1982): p. 119.

[74] Rees interview, 1983–84, pp. 230–231, 236, WFGOH40, SL.