Slide Rules and WWII Bombing: A Personal History

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Abstract

The history of the Computer Age is briefly surveyed from the early 1600s until today. We first summarize the development of mechanical calculators and slide rules before World War II. The slide rules are divided into general slide rules (primarily for multiplication and division of any two numbers) and special slides rules for solving specific problems. This is followed by a summary of the development of a World War II (WWII) programmable slide rule computer with considerable data storage that could quickly be changed from one special problem to another. The next section describes a planned WWII application of this slide rule as a SHOrt Range Aid to Navigation (SHORAN). The rule was developed at 20th Air Force Headquarters on Guam in response to a request in June 1945 by William Shockley to be used for the B29 bomber fleet's support of the planned invasion of Japan.

Calculators

The abacus, invented in Asia Minor in 2500 BCE, could be considered the earliest mechanical calculator for addition and subtraction. Around 1600 John Napier invented what has been called "Napier's bones" for multiplication and division [1]. In the 1640's, Blaise Pascal invented a more practical calculator that could add and subtract two numbers directly. It could also multiply and divide by repetitive operations.

Around 1672 Gottfried Leibniz invented the first calculator, using his Leibniz wheels that could automatically perform all four arithmetic operations. In the 1820's, these wheels became the heart of the first commercialized calculator, the arithmometer. Automatic mechanical calculators really took off in the 1870's with the manufacture of the pin-wheel calculator – originally invented by Leibniz! Further developments made compact mechanical calculators routinely available in World War II [1].

Slide Rules

John Napier also indirectly launched slide rule computers in the 1600's time frame [2]. His discovery of logarithms enables one to determine the product of two numbers by adding their logarithms and taking the anti-log of the sum. In 1620 Gunter took the next key step with his scale in which numbers from unity were inscribed at distances proportional to their logarithms from the unity index. He used dividers to perform graphical addition of lengths and to read the approximate product on this same scale. A few years later William Oughtred used two Gunter-like scales, first in a circular arrangement, then in a sliding arrangement to add logarithmic distances from indices on both the fixed scale and the sliding scale to obtain their product; e.g., $x*y = z$. Many other inventors, including such giants as Newton and Watt, generalized slide rules using scales with distances proportional to the logarithms of functions to get products such as $F(x)*G(y) = H(x,y)$.

Unlike mechanical calculators, the results of slide rule calculators are limited in accuracy by the inscribing precision of the scales and, to some extent, the user's skill in reading the rule. Furthermore slide rules intended for general multiplication or division relied upon the operator to fix the location of the decimal point of the result. In many respects this limitation was a blessing; the user had to focus on the magnitudes of the numerical inputs and gauge the output decimal place either by mental or "back of the envelope" calculation. With slide rules, the ability to cast the algebra into computable form was often the key to the successful solution of a practical problem and sometimes led to valuable intuitive insights.

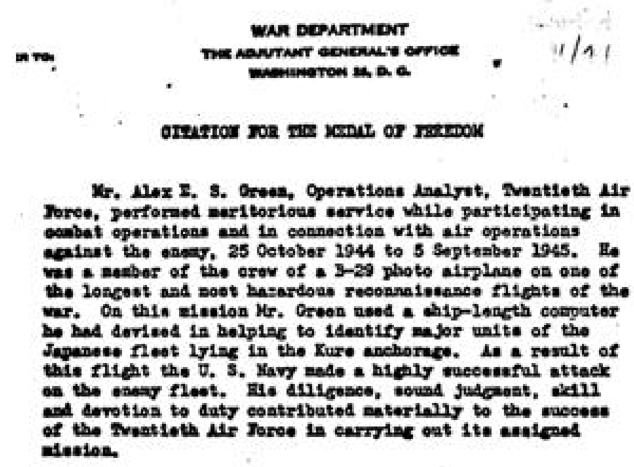
Soon after Oughtred's invention of slide rules for general multiplication and division, special slide rules were developed for specific calculations. For example, Wyman [3] describes slide rules developed to calculate taxes on alcoholic beverages. In such special applications the range of independent variables is usually constrained so that the decimal points can be identified on the logarithmically proportioned scales – a popular simplification. Commercial fabrication of general slide rules started in the mid-19th century with 10-inch products for most work, 20-inch slide rules for more precise work, and 5-inch "pocket" slide rules for quick-and-dirty engineering estimates. The first twenty volumes of the *Journal of the Oughtred Society* (JOS) describe many historic forms of these slide rules. A compact summary is available at the website of the Oughtred Society (www.oughtred.org). The recent articles by Shawlee [4], Sweetman [5], and

Koppany [6] describe a number of special slide rules made of cardboard and/or plastic that are still in production!

In summary, at the outset of WWII commercially-manufactured general slide rules had become the major calculating instruments of almost all engineers and scientists. Mechanical calculators were used when many digits of precision were needed; e.g., by business people and accountants. Soon after WWII the Space Age and the Nuclear Age were advanced mainly with the use of general slide rules. The designers of the hardware used in our travels to the moon used slide rules.

The 20th AF Slide Rule Computers

In January of 1945 Alex Green, an Operations Analyst with the 20th Bomber Command based in Kharagpur, India, was presented with the problem of determining the length of an enemy ship sighted during an overwater flight of B29 aircraft [7-10]. He developed a triangulation method in which the length L of the ship could be determined from the aircraft's altitude using the gunsight system to measure three angles. Finding the ship length required a special calculation involving a multiplication such as F(x,y)*G(z) = L where the x and y were not separable. To carry out this special calculation with a Mannheim-type slide rule, he used a wider slider and replaced the C scale with graphs of iso-contours of the two non- separable angle variables x and y. Details have been described in earlier JOS issues [7-10]. For the general use by the gunner, Green kept the traditional A and B scales for handy multiplication and division applications. Thus the "ship length computer" was a combination of a general and a special slide rule. This triangulation method was tested on March 12, 1945 in a photo-reconnaissance mission from Chengdu, China, that located the Japanese fleet (including the Yamato) anchored in Kure and Hiroshima harbors. For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CITATION FOR THE MEDAL OF FREEDOM

Mr. Alex E. S. Green, Operations Analyst, Twentieth Air Force, performed meritorious service while participating in combat operations and in connection with air operations against the enemy, 25 October 1944 to 5 September 1945. He was a member of the crew of a B-29 photo airplane on one of the longest and most hazardous reconnaissance flights of the war. On this mission Mr. Green used a ship-length computer he had devised in helping to identify major units of the Japanese fleet lying in the Kure anchorage. As a result of this flight the U. S. Navy made a highly successful attack on the enemy fleet. His diligence, sound judgment, skill and devotion to duty contributed materially to the success of the Twentieth Air Force in carrying out its assigned mission.

Figure 1. Citation for Truman Medal of Freedom

his role on this mission, in November 1947 Green received the award shown in Figure 1.

Shortly after this mission Green was reassigned to the 21st Bomber Command on Guam, where he received many requests for special slide rules. Several of these required multiplications such as F(x,y)*G(z,w) = H(x,y,z,w). To meet this need within the resources available at headquarters, he developed a programmable slide rule system. The system had four universal components: a 4 inch wide by 15.5 inch long aluminum metal frame with rolled over edges to serve as slider guides, a transparent plastic chart cover to anchor a replaceable chart, a glazed plastic slider with a hairline, and a sharp pencil with soft eraser. The essential 5th component was a replaceable precision computation chart specific to the problem at hand. These five component systems proved

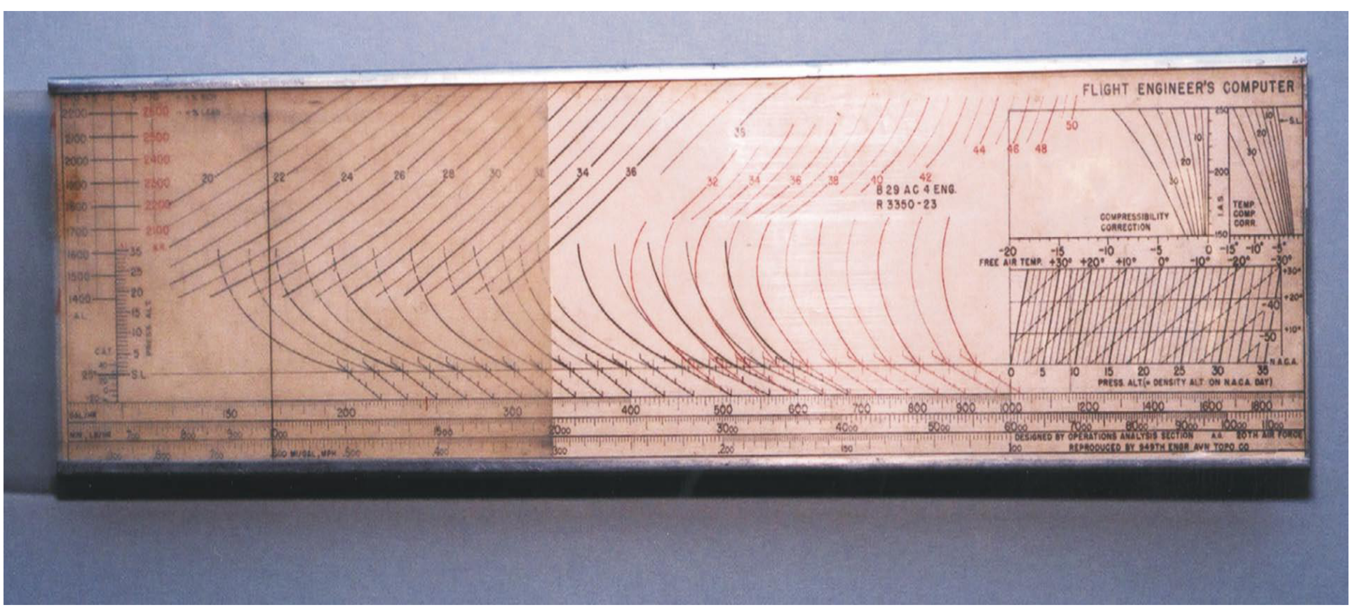


FIGURE 2. Flight Engineer's computer for predicting B-29 fuel consumption at various flight-control settings in nautical miles per gallon

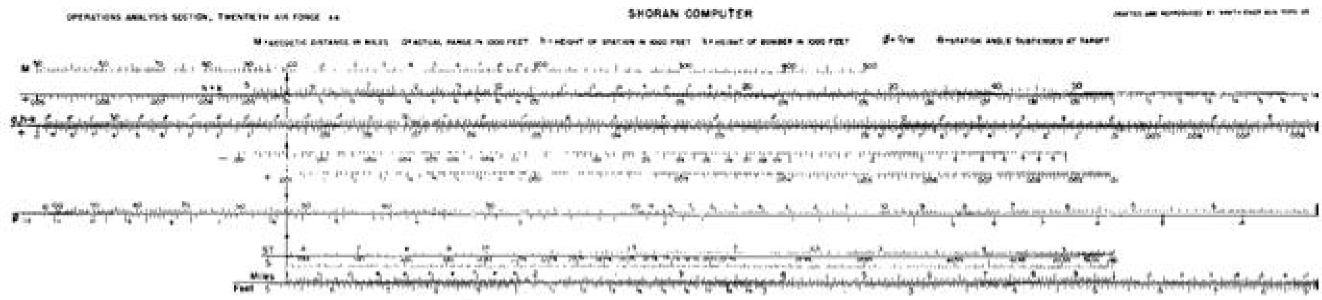


Figure 3. Computing chart for SHORAN Bombing corrections.

much easier to fabricate in the combat theater than conventional general slide rules or card board special slide rules. The charts could store considerable data and be used for more complex calculations than Oughtred slide rules. Furthermore we could solve many different problems by simply replacing the computing chart. Some 65 years ago Green called these charts "programs", analogous to those developed and used with desk type computers. Today he calls them "applications" or apps.

Figure 2 illustrates the general system with B29 Flight Engineer's Computer chart. This system was probably the most complex of the thirty or so types of special slide rules designed and produced during the war [7-10]. The precision charts were prepared by the service men-cartographers in the 21st Bomber Command's Topographical Company, whose regular role was to produce the maps for each B29 mission. They had access to advanced photographic reproduction and printing equipment. Green set up an efficient paperwork-free slide rule design and production service, whose fee was two bottles of the requesting officer's liquor allowance. These bottles were passed along to enlisted men in the map and sheet metal shops - most of whom were skilled soldier-craftsmen who appreciated the "spiritual" comfort. Somehow the work priority of Green's team was second only to the mission maps. By war's end they produced thousands of slide rule units for the most technical military campaign of WW II.

The SHORAN Bombing System

The versatility of Green's programmable system came to the attention of Dr. William B. Shockley Jr., who was involved with B29 radar bombing. He also had been in the new field of Operations Research and by 1945 was an expert consultant to the office of the Secretary of War [11]. His interests also included blind (i.e., poor-visibility) targeting during bombing runs. A possible solution was RCA's SHOrt Range Aid to Navigation (SHORAN) radar system operating at 300 MHz [12]. The basic elements of SHORAN were a pulse transmitter and a cathode-ray receiver AN/APN-3, both carried in the plane, and two precisely-located ground stations with equipment (AN/CPN-2) to receive and return the pulses from the plane. The receiver in the plane measured the round-trip transmission time and converted the result into distances, producing a visual indication on the cathode-ray-tube screen of position relative to the two ground stations. Relatively simple but precision calculations were required to achieve better than 100-foot bombing accuracy in converting time of flight to geometric distance over about 100 miles. In addition, rather complex calculations of small corrections to allow for the earth's curvature, atmospheric refraction, and some weather dependence were needed, but 2 or 3 place accuracy was adequate. When the first B29 equipped with a SHORAN bombing system arrived on Guam, Shockley contacted Green to develop the corrections calculator.

Figure 3 shows the computing chart developed by Green's team for insertion into his universal frame. Green's team also explored developing a computer chart that could meet the precision requirements of the geodetic calculation. We borrowed from the device of Fuller and Thacher who segmented extra long logarithmic scales on their cylindrical calculators [2]. In our case a logarithmic D scale from a 20 inch Keuffel

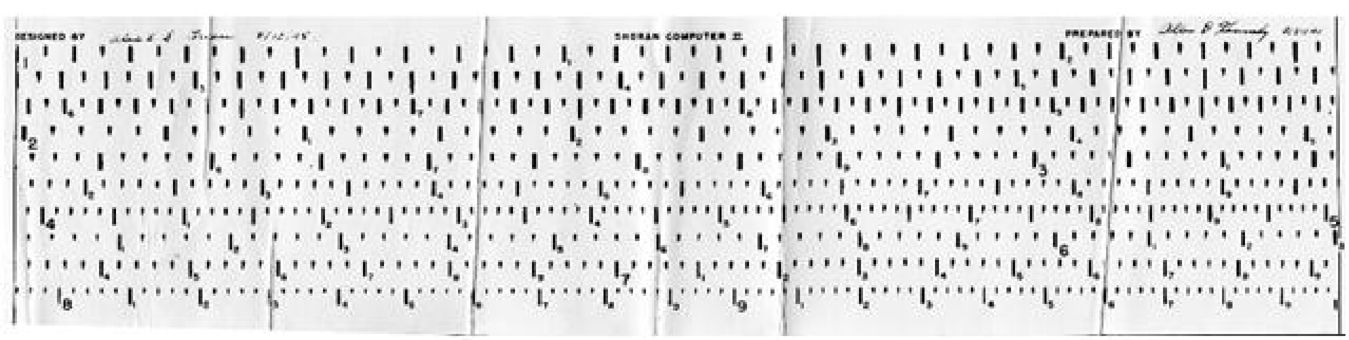


Figure 4. A segmented 12.5 ft logarithmic scale intended for the precision Shoran calculations

Figure 6. Author Alex Green (bottom row, second from right) and the SHORAN Project team on Guam, August 18, 1945, after returning from Manila

and Esser log log duplex unit was blown up and segmented photographically into 10 parts to give the equivalent of a 12.5 foot slide rule scale. Figure 4 shows our final attempt to adapt our 20 AF slide system to handle the precision Shoran calculation. Shockley was pleased with Green's Figure 3 product, but did not think the Figure 4 product would give sufficient accuracy. He recommended that Green serve as the Shoran calculator and that he use a mechanical calculator for the precision calculations and his first Shoran slide rule for the corrections.

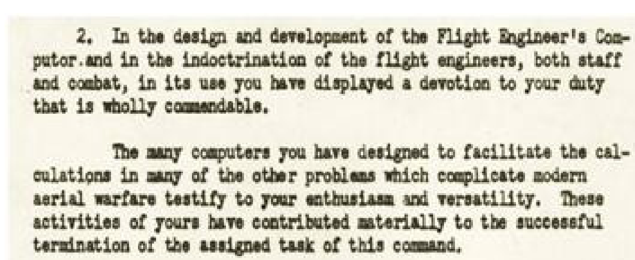
The plan was to have the few SHORAN-equipped planes drop marker flares that the rest of the bomber fleet would use with their Norden bomb sights to provide a protection zone for our invasion troops. In July 1945 Green joined the SHORAN Project team in its flight to Manila to work with the Navy team who would deliver the ground station equipment and personnel to two locations, each some 100 or so miles from the planned Kyushu beachhead. However, on August 6th the Hiroshima bomb was dropped and on August 9th the Nagasaki bomb was dropped. Also on August 9th the Soviets joined in the war with Japan. On August 15th Japan agreed to surrender. Figure 5 shows two computer-related paragraphs in a commendation from General LeMay that Green found upon his return to Guam. Figure 6 shows the first B-29 Shoran Project team upon their return to Guam.

SHORAN bombing was not used by B29s in World War II, but was used extensively in the Korean War.

Epilogue

Shockley's post-WWII invention of the sandwich transistor was probably the most important invention of the last half of the 20th century. The resulting invention of the integrated circuit and the microprocessor led to commercialization of transistorized hand and desktop computers that supplanted general slide rules and mechanical calculators in the 70s.

The continuing exponential growth of transistor-based microprocessors and data storage and advances in photolithography have led to the Computer/ Information Age. The rapid flow of information associated with the Internet, Artificial Intelligence, Informatics in Automation and Robotics, and such seemingly magical devices like iPads, all made possible by Shockley's invention of the transistor, are having consequences that are still unfolding.



2. In the design and development of the Flight Engineer's Computor and in the indoctrination of the flight engineers, both staff and combat, in its use you have displayed a devotion to your duty that is wholly commendable.

The many computers you have designed to facilitate the calculations in many of the other problems which complicate modern aerial warfare testify to your enthusiasm and versatility. These activities of yours have contributed materially to the successful termination of the assigned task of this command.

**Figure 5. Two paragraphs of Commendation from Major General Curtis LeMay dated July 31, 1945
Note the reference to "computers."**

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The Faber Manuals by Pickworth – Revised Chronology

Rodger Shepherd

Introduction

Between the late 1890's and the early 1920's Charles Pickworth authored several different slide rule instruction manuals for A. W. Faber. Unfortunately these interesting instruction manuals included no publication dates and no version designations. Nevertheless sixteen distinct versions have been identified; their sequence has been established; and preliminary dates of publication were reported in 2001 [1]. According to that chronology the first Faber manual by Pickworth was published in 1895. However, in 2011 a letter was discovered in the Faber-Castell archives, which clearly shows that this date was wrong [2]. That letter establishes that in March of 1896 the first version of the Faber manuals by Pickworth was still in the planning stage. This new evidence stimulated me to reexamine the chronology that I published in 2001.

Method

My first step was to seek access to copies of these manuals that included clues to date of acquisition. Therefore, in March 2011 I sent a letter to all the members of the Oughtred Society requesting their help in identifying copies of the Faber manuals by Pickworth that included: (a) presumed date of purchase or acquisition, (b) owner's name and address, and/or (c) a sticker or stamp indicating the original vendor's name and address. Several members responded to this request. They either provided the requested information from personal copies of Faber manuals by Pickworth or obtained such information from copies in libraries. As will be seen, some copies did indeed include enough information to help establish when the copy could have been acquired. This information was used to bracket plausible dates of publication.

Table 1

Versions of the Faber Manuals by Pickworth:

Original and Current Estimates of Publication Dates

Version *	Original Estimate	Current Estimate	Notes and References
1.1	1895	1896	[1], [2]
1.2		1897	[3], [4]
2.1	1901	1901	[5], [6]
3.5	1904	1904	[1]
4.1	1907	1907	[1]
5.1	1909	1909	[1]
6.1	1913	1913	[1]
7.1	1921	1921	[1]

*N.B. Until additional information is available, the publication dates of versions not listed must be estimated by interpolation.

Clues and Implications

Let us first consider Version 1.1. As indicated above, the letter in the Faber-Castell files clearly shows that publication the first version of the Faber manuals by Pickworth was still being planned in