

A PHYSICIST WITH THE AIR FORCE IN WORLD WAR II

This war story begins in 1935 at Brooklyn Technical High School, where my physics teacher, Simon Weissman, introduced me to most of the physics that I was eventually to use in World War II. My experience as an officer of Brooklyn Tech's radio club would prove to be quite helpful. Even more helpful, as it turned out, was my stint as president of the school's slide rule club.

Continuing my physics education at the City College of New York, I took courses from Clarence Zener, Hugh Wolfe, Walter Zinn, and other members of CCNY's outstanding physics faculty. After graduating with a BS in 1940, I started my graduate work at Caltech, taking courses from Robert Millikan, Carl Anderson, Fritz Zwicky, and other leading researchers. In June 1941, I received an MS and started on my PhD program in the x-ray laboratory of Jesse DuMond, who was away in Washington that year. In his absence, the laboratory was led by Wolfgang Panofsky, who was then in the final stages of his PhD thesis work.¹

After Pearl Harbor

After the Japanese attack on Pearl Harbor on 7 December 1941 brought the US into World War II, DuMond returned and his group, including me, joined the Caltech rocket development program. While working at Goldstone Lake in California's Mohave Desert, I took note of a British target rocket that was being used to simulate a fighter attack on a ground gunnery position. To score and improve the performance of the trainee gunners, I suggested attaching coils on the rocket's large tail and firing magnetized bullets at it. The induced voltage was to be transmitted by radio to the ground position and translated for the gunner into an immediate score.

The development of this idea was funded by the National Defense Research Council (NDRC), under DuMond's supervision, in mid-1942. Using a standard 30-caliber rifle to shoot magnetized bullets past our magnetic pickup coils at various distances of closest approach, we soon realized that the bullet's shock wave, by shaking the coil in the Earth's magnetic field, was generating a larger voltage pulse than the pulse induced by the magnetic field of the bullet.

Switching to an acoustic firing error indicator (FEI), we soon developed a small microphone that was very sensitive to shock waves, and an FM radio transmitter to tell the gunner by how much he had missed. The FEI project progressed rapidly, and field tests at military bases

Plucked out of graduate school after Pearl Harbor, a young physicist designed specialized slide rules for military aircraft. Trying them out aboard B-29s in the war against Japan, he had some hair-raising adventures.

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became my responsibility. Panofsky, DuMond, and I wrote up our results in several reports to the NDRC.

In the summer of 1943, I conducted air-to-air tests of two versions of the FEI system at the Flexible Gunnery Instructors School and Research Division (FGISR-D) of the Buckingham Army Air Force Base in Fort Myers, Florida. While

I was there, Major Nicholas Hobbs, head of FGISR-D, asked me to help develop realistic training methods. The objective was to prepare gunners for the costly attacks we were experiencing in the air battles over Germany. So I joined the project's planning and analysis unit, headed by biophysicist George Taylor. Hobbs later served as president of the American Psychological Society.

At FGISR-D, anticipating that FEIs would soon become available, I worked on developing a streamlined target, towed by airplanes, that could be maneuvered to simulate realistic fighter attacks while flying far enough below the tow plane to keep the plane safe from stray trainee bullets. In our first launch from a bomb bay, the target got jammed against the tow plane's fuselage in such a way as to prevent the bomb-bay doors from closing. So we couldn't land.

At the pilot's insistence (I will not repeat his heated words), I dislodged the target by jumping on it while hanging from a bomb-bay rack and wearing a parachute, just in case. After that experience, we mounted the target externally and soon had a usable offset tow-target system. I also worked on mathematical simulations of air-to-air gunnery engagements and ballistics. My first venture into theoretical modeling was republished by the NDRC Applied Math Panel.²

Join the army and see the world

In March 1944, the FGISR-D moved to Laredo, Texas. Two months later I received an induction notice from my Pasadena draft board. Noting the move to Texas, they assumed I had changed jobs. Fortified with letters from my Caltech professors and senior members of our planning and analysis unit, I began seeking an officer's commission and was making good progress.

At about this time, however, Taylor was commissioned as a lieutenant colonel to serve as an operations analyst with the 14th Air Force in China. On behalf of Army Air Force headquarters, he asked me to investigate the causes of combat losses of B-29 bombers by the 20th Bomber Command in the China-Burma-India theater, and to find ways of minimizing them. After my induction as a private at Fort Sam Houston in San Antonio, the Army Air Force placed me on inactive duty with the equivalent rank of major. I was flown to the 20th Bomber Command's headquarters in Kharagpur, India. There I reported to the operations analysis chief, Hamilton

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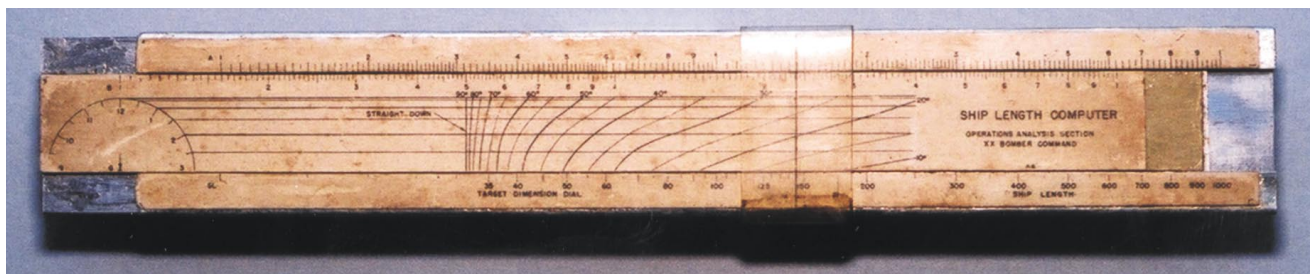


FIGURE 1. SHIP-LENGTH SLIDE RULE of the kind with which the author identified the 860-foot-long battleship *Yamato* hiding in Hiroshima Bay. On the slider, the horizontal lines from the clock face at left indicate the orientation of the ship on the water, and the family of curves they intersect is labeled by the vertical angle of the ship from the plane's horizon. The appropriate intersection, corresponding to a trigonometric function, is then multiplied by the gunsight target dial setting (in feet) on the bottom fixed scale to give the ship's length, also on the bottom scale.

Jeffers, a well-known astronomer.

Soon after arriving in Kharagpur, I flew over the Himalayas—the so-called Hump—to our advanced base in China's Ch'eng-tu area. The command pilot of our B-29 was General Curtis LeMay, head of the 20th Bomber Command. In China, the gunnery officers, intelligence officers, and crew members of B-29s briefed me on encounters they had seen, or learned about, in which B-29s were shot down.

After six weeks of data collection and statistical analysis, I completed my report. My analysis showed that, in attacks on our B-29s from the rear, it cost the enemy 70 lost fighter planes, on average, to shoot down one of our bombers. But in frontal attacks, the Japanese lost only three fighters for every B-29 they downed. This result differed starkly from the results of a massive combat simulation study, done back home, that had concluded that B-29s would be most vulnerable to attacks from behind! In light of the new findings, bomber formations and tactics were modified to bring greater firepower to bear against frontal attacks. These changes, together with some minor technical modifications, largely solved the problem.

Shades of the slide rule club

In January 1945, a navy liaison officer came to Kharagpur and complained about the quality of ship identifications made by B-29 crews in their flights over water. Knowing the B-29 gunnery system, I pointed out that the length of a sighted war ship could be calculated from measurements made with the bomber's gunsights. We used the target dial setting x needed to span the ship with the adjustable ring in the optical gunsight, the height h of the B-29, the depression angle d of the ship from the B-29's horizon and the "aspect angle" a of the ship's pointing direction relative to the plane's line of sight. I allowed for h by providing a paste-on scale for adjusting the gunsight's range handle. The crewman measured d with a protractor mounted on the gunsight yoke, and he estimated a by imagining the ship to be the hour hand of a clock.

The length l of the ship to be identified could then be written as $l = x F(d, a)$, where F is a complex, nonseparable trigonometric function of the measured angles d and a . To facilitate the calculation, I developed a special slide rule that used the general principle of multiplying two quantities by mechanically adding distances proportional to their logarithms.

In this case, I inscribed on the central slider horizontal lines of constant a and curves of constant d . Two such lines would intersect at a point whose distance along the slider was proportional to the logarithm of $F(d, a)$. This was multiplied, in the usual way, by the target dial setting

x , logarithmically inscribed on the fixed bottom scale to give the ship's length, also on the bottom scale. Figure 1 shows the 7.5-inch-long ship-length computing slide rule that we demonstrated during a B-29 mission over the Bay of Bengal.

Word of this solution reached Major Harry Allen, commanding officer of a B-29 photoreconnaissance unit based in Ch'eng-tu. He invited me to equip and train his unit and to test the method in combat missions. So, with the help of the 948th Engineering Topographical Company, we fabricated a number of such slide rules and gunsight adapters. After another flight over the Hump, I instructed the gunners of the photoreconnaissance unit on the use of the slide rules and the installation of the range dials and yoke protractors.

Look what we found!

On 11 March 1945, I joined the crew of Captain Alvin Coe on a reconnaissance mission to photograph military installations in southern Japan. After an uneventful flight from western China, we began photographing the southeastern coast of Honshu on Japan's Inland Sea. Quite unexpectedly, as we were flying at 28 000 feet over Hiroshima Bay and the Kure anchorage, we sighted the Japanese fleet whose whereabouts had been unknown to our forces since the Battle of Leyte Gulf in the Philippines five months earlier.

More than 70 warships were at anchor. We learned later that they were out of oil. The gunners and I used my slide rules to measure ship lengths and, with the aid of a chart that listed the dimensions of Japanese warships, we identified the 860-foot-long battleship *Yamato* and several other major ships.³

We continued northward along the coast of the Inland Sea to a point opposite Kyoto and then turned and headed southward along the Inland Sea coast of Shikoku. After that path had taken us past the Japanese fleet once again, we encountered a terrific headwind (later known as the jet stream) that slowed our ground speed to about 60 mph. Our modified B-29 bucked wildly in the turbulent air.

As the pilot and copilot were busy struggling with a turbocharger problem, the flight engineer informed us that we had consumed so much fuel flying against the headwind that we couldn't make it back to Ch'eng-tu. Capatin Coe had four choices: He could head for Vladivostok, the nearest allied airfield. But he dismissed that, because the Soviets (who did not declare war on Japan until August 1945) would have returned the crew but kept the B-29. He could also head for a fighter base in China still held by Chiang Kai-shek's Nationalist forces, or for the island of Iwo Jima, 800 miles to the southeast. The



FIGURE 2. CREW of the B-29 reconnaissance mission that found the missing Japanese fleet on 12 March 1945. The photo was taken after a harrowing emergency landing at a Flying Tiger base in Xian, China. Captain Alvin Coe is at the far right in the top row, and the author (with eyeglasses) is the second man to his right.

historic battle of Iwo Jima was still going on, but one airfield was in US hands. Our fourth possible destination was an enclave in China controlled by Mao Tse-tung's Communist forces, who were known to give good "walk-out" protection to US crews that bailed out.

Coe opted for the Nationalist fighter base, and we finally managed a skin-of-our-teeth landing at a field in Xian. This field was actually used by the Flying Tigers, American volunteer fighter pilots who had been fighting alongside the Nationalists since well before Pearl Harbor. Not only were our fuel tanks empty, but the field was completely surrounded by a stone wall that made landing a large bomber very scary. But, as figure 2 attests, we all survived.

In the citation for my Medal of Freedom, awarded in 1947, this mission was called one of the "longest and most hazardous reconnaissance flights of the war," as a result of which "the US Navy made a highly successful attack on the enemy fleet." After finally reaching our base in Ch'eng-tu, I was flown back over the Hump to Kharagpur. Because the 20th Bomber Command was closing out its operations in the China-Burma-India theater, our operations analysis unit was packing to go back to the States. I, however, was assigned to the 21st Bomber Command, headquartered on Guam in the Marianas.

The flight engineer's computer

After flying by military transport via Australia and the Philippines, I reported a week later to the operations analysis unit on Guam, headed by the physicist Donald Loughridge. Before taking on a new technical assignment, I visited other B-29 bases in the Mariannas and studied the operational procedures of the 21st Bomber Command. By contrast with the 20th, the missions of the 21st involved long flights over water and short penetrations over Japan. It became clear to me that most of their B-29 operations were highly technical, requiring specialized calculations for which they were using ordinary slide rules and data compilations in tabular or graphical form.

aluminum frame with bent edges to hold the chart in place and serve as a guide for the third component, a transparent plastic slider with a vertical hairline that could be slid along the computing chart. And, of course, there had to be a sharp pencil with an eraser at the ready.

When I returned to Guam, I received a request for a special slide rule from Fred Fennema, an aeronautical engineer with the 21st Bomber Command's operations analysis unit. The staff flight engineers, he told me, wanted a slide rule that could accurately estimate fuel requirements for forthcoming missions. Flight-control data from an extensive test program with an instrumented B-29 had been compiled into an unwieldy two-inch-thick data book.

After discussions with the staff flight engineers, we developed a slide-rule computer that encapsulated this massive body of data onto two 15-by-4-inch charts that were inserted in back-to-back metal frames with edges bent to hold the plastic sheets and sliders. One chart had a number of two-dimensional contour graphs that gave the optimal miles-per-gallon flight-control settings for the B-29's current weight and altitude. The other side, shown in figure 3, had a computational chart that used two-dimensional arrays of logarithmic curves and scales. These were used to calculate (by a kind of perturbation-theoretic approach) the fuel that would be consumed with the actual less-than-optimal settings required by the combat mission.

The staff engineers recommended that we equip all B-29s with this computer. Indeed, by the end of the war, almost every flight engineer in the 21st Bomber Command had one. Charts for operation with only two or three of the plane's engines, printed on the back side of the four-engine B-29 charts, could be quickly substituted if one or two engines were lost.

Lubricating with alcohol

Requests for special slide rules grew. To respond quickly, I set up a paperwork-free design and production service.

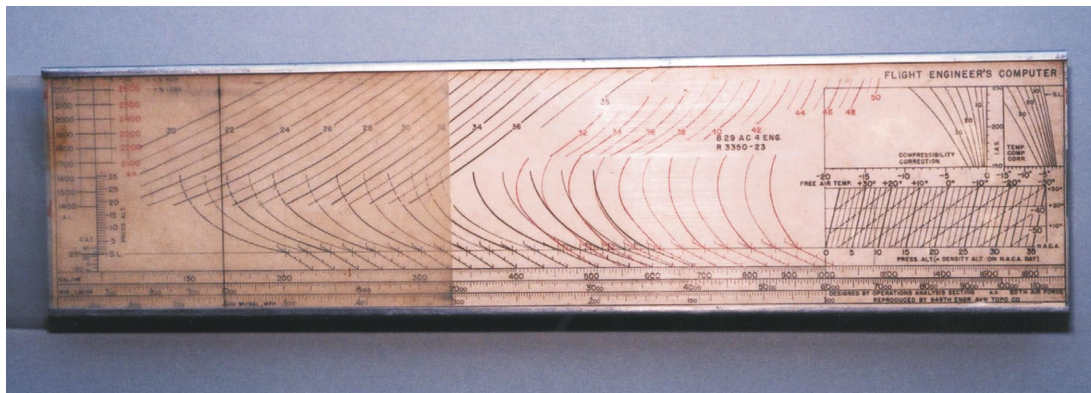


FIGURE 3.
FLIGHT ENGINEER'S
computer for pre-
dicting fuel con-
sumption at various
flight-control set-
tings on a B-29
bomber.

Our streamlined procedures took advantage of the fact that officers had a monthly liquor allowance but enlisted men did not. To secure a special slide rule, the requesting officer would pay with two bottles. I would pass these contributions along to the enlisted members of the 949th Topographical Company, who did the drafting, calculations, and reproductions. Somehow our service enjoyed a de facto priority second only to the production of mission maps.

As an example of the efficiency of our operation, I recall a colonel from the 73rd Bomb Wing on Saipan who came to Guam and posed the recurring problem of cloud or smoke obscuration of an intended target. In many cases, a site not far away would be visible and, by inserting appropriate false settings into the Norden bombsight, one could aim at the visible offset point and hit the intended but obscured target. But carrying out such last-minute calculations on a bomb run was very difficult, especially if the plane was experiencing enemy fire.

Our slide-rule team quickly worked up a two-dimensional design that incorporated the formula for the false bombsight settings and the ballistic characteristics of the bombs. The next day we had a prototype chart for 500-pound bombs ready for insertion into our universal aluminum holder. To test it, we took off for Rota, an island in the Marianas still held by the Japanese. Aiming at one end of their runway, we placed the bombs precisely at the other end as intended.

Back on Guam that night, the colonel and I ate in the command officers' mess. I found myself eating a steak at the same table as General LeMay. He had an engineering background and was interested in the what, why, and how aspects of our mission. The next morning we began production of offset charts for all bombardiers, incorporating the ballistic characteristics for all available bombs.

Dropping pumpkins

Bombardiers of the 509th Group on Tinian also requested a chart that incorporated the ballistic characteristics of their five-ton "pumpkins." Not until 6 August did I learn that these heavy pumpkins had been the 509th's practice bombs for the atomic bomb they dropped that morning on Hiroshima. The pumpkin charts could be used for offset bombing with atomic bombs.

When I needed a large supply of aluminum holders to meet the increasing demand for our slide rules in the spring of 1945, LeMay suggested that I arrange to have them fabricated in Hawaii. But, to avoid paperwork and delivery delays, I chose to have them made at the Harmon Field sheet-metal shop on Guam. At that time, there wasn't much combat damage to B-29s. So the repair crews readily gave up some of their beach time for a few bottles

of Old Granddad.

Early in the 21st Bomber Command's campaign, LeMay required B-29 crews to take bomb-strike photographs, to be used for competitive scoring of the various squadrons, groups, and wings. Unfortunately, taking bomb-strike photos required that the bomber fly straight and level for the duration of the bomb fall (typically 40 seconds for high-altitude releases). That, of course, increased the bomber's vulnerability to antiaircraft fire and fighter attack.

Happily, however, with a photograph of the bomb in relation to the ground only 10 seconds after release, we could use the laws of physics to calculate the precise impact point. That would spare the bomber and crew about 30 seconds of straight and level flight over the target. The problem was of double interest to the 509th Group. They needed to know where the atomic bomb would land but, to get away from its awesome shock wave, they needed to veer promptly after releasing the bomb.

By May 1945, most of Japan's major military targets had been substantially destroyed—except, ironically, for targets that were being "saved" for our atomic bombs. In the absence of massive missions to large targets, the operations analysis unit had to carry out tedious "force and bomb-load" calculations every day for four or five missions to small target cities. These calculations were needed to determine the number and types of bombs and planes required to accomplish the goals of each mission. So we developed a fast slide-rule computer that was used for this purpose on all subsequent B-29 missions.

Additional computer requests came in May and June, and they were filled in very short order. Our "radar resolution" slide-rule computer provided a quick means of determining the resolution of various radar systems under different conditions. It assisted staff radar officers in choosing suitable radar targets and reference points. We also designed a slide rule to calculate the time a bomber would need for a turn, and what wind displacement the turning plane would experience.

This "turn computer" proved useful 50 years later, when Edward Teller asked me, in hindsight, to investigate whether a humane high-altitude "demonstration" detonation of an atomic bomb over Tokyo Bay would have been feasible. The higher the detonation altitude, the less time the B-29 would have for turning away from the impending shock wave.

The Shoran computer

In early July 1945, the first Shoran-equipped B-29 came to Guam, accompanied by its project team and William Shockley of Bell Laboratories. The new Shoran bombardment system would enable the thousand-plane B-29 fleet

to give our troops close support in the invasion of Japan planned for November 1945. A few Shoran-equipped planes guided by ground- or submarine-based transmitters about 100 miles from the beachhead would drop bombs to establish reference impact points. All the remaining B-29s would use their standard bomb-sights in relation to the guide planes' impact points to form a bombing pattern for the protection of our invading troops.

A hand-cranked digital calculator was to be used for the six-significant-figure geodetic calculations. One also had to make last-minute atmospheric corrections that depended on the weather. But these corrections required only two-figure accuracy. Shockley heard of our slide-rule service and asked me to fabricate one for the atmospheric corrections. After we completed that slide rule, I was asked to carry out the operational geodetic and atmospheric calculations.

Shortly after I took on this Shoran assignment, orders came through from Army Air Force headquarters reassigning me to the operations analysis unit of the 20th Bomber Command, which was to be reestablished on Okinawa in support of a new Far Eastern Air Force under General James Doolittle. I was unhappy about this reassignment, because I thought my Shoran work was very important. I conveyed my displeasure to General LeMay and he initiated a battlefield commission that would allow me to continue the Shoran work.

I left Guam to go to Manila with the Shoran project team to undertake simulated air force-navy operations and to develop a protocol for combat applications. About a week later, on 6 August 1945, "Little Boy," the uranium bomb, was dropped on Hiroshima by the *Enola Gay* and, three days later, "Fat Man," the plutonium bomb, was dropped on Nagasaki by another B-29, named *Bocks Car*.

A week after that, our mission was canceled, and we returned to Guam. In 1990 I learned from Panofsky that refined versions of our old Caltech's FEIs had also been dropped by instrumented aircraft accompanying the *Enola Gay* and *Bocks Car* to measure the atomic bombs' energy releases.

When I returned to Guam on 18 August, my officer's commission had come through. However, since hostilities had effectively ceased on 15 August, I was permitted to decline the commission so that I could return to my doctoral studies. There was a rule requiring that operations analysts younger than 26 who had been on inactive duty were now to be called to active duty; those over 26 were to be mustered out. I had turned 26 in June.

Closure

Apart from my Shoran slide rule, which never made it into combat, my 21st Bomber Command slide rules "computerized" what was probably the highest-technology combat operation of World War II.⁴⁻⁶ The utility of these computers was recognized in personal commendations from General LeMay (see figure 4) and letters and citations from higher air force officials. Nonetheless, the personnel officer at the Washington, DC, area discharge center wrote the words "no active duty" on my discharge papers. That characterization nearly got me reintroduced, and it disqualified me from the GI Bill. This last injustice has, however, since been rectified. On 7 December 2000, I received from Randolph Air Force Base in Texas a revised discharge "from active duty," entitling me, at age 81, to the benefits of the GI Bill.

My air force slide rules were two-dimensional generalizations of the invention by the English cleric and mathematician William Oughtred in 1630. Slide rules remained

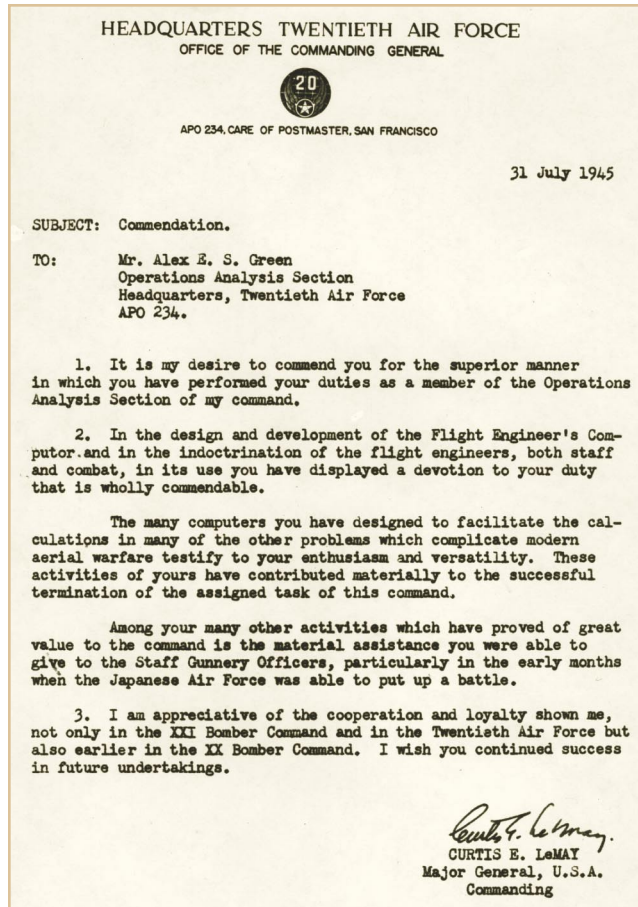


FIGURE 4. LETTER FROM GENERAL CURTIS LEMAY to the author, dated just a week before the atomic bombing of Hiroshima. LeMay commanded the 20th Air Force, which encompassed both the 20th and 21st Bomber Commands.

the dominant method of computation by scientists and engineers until about 1970. Our air force slide rules were, in effect, versatile computers with data storage and calculation capability. It is ironic that the Shoran computer, my last slide rule during the war, was made at the request of Shockley, whose invention of the transistor two years later has probably had the greatest impact of any invention since the war, eventually leading to the electronic computers that have made the slide rule a museum piece.⁷ I've sometimes speculated that Shockley didn't like my Shoran slide rule and therefore went back to Bell Labs to invent the transistor that put us out of business.

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6. A. Green, *Friends J.* (USAF Museum, Wright-Patterson Air Force Base, Dayton, Ohio) **23** (3), 11 (2000).
7. A collection of the author's air force slide rules, charts and manuals is available at the US Air Force Museum at Wright-Patterson Air Force Base near Dayton, Ohio. The pumpkin and flight engineer's slide rules are at the Smithsonian Air and Space Museum in Washington, DC.