The 20th AF Slide Rules of WW II

August 1944 to September 1945

by
Alex E. S. Green
Operations Analyst

When the Japanese attacked Pearl Harbor, I was working toward my doctorate in physics at Cal Tech where I joined the Cal Tech rocket development program.

While at Goldstone Lake in the Mohave Desert, I noted a British target rocket that was being tested to simulate a fighter attack on a ground gunnery position. Since there was no way to score the gunners, I suggested attaching coils on the rocket's large tail and firing magnetized bullets at the target rocket, an idea that was quickly supported by the National Defense Research Council. Using a standard M-1 .30 caliber rifle to shoot magnetized bullets at various distances from our magnetic pick-up coils, it soon became clear 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. This led us to switch to an acoustic type of firing error indicator (FEI). Drawing upon the then emerging frequency modulation (FM) technology we developed a small device, very sensitive to shock waves, that could transmit miss distance to the gunner. The firing error indicator (FEI) project progressed rapidly to the production prototype stage by early 1943. Field tests were my responsibility, and during many such tests at military bases, I became a technical gunnery expert.

In the summer of 1943, I was conducting air-to-air tests of miss distance and miss direction versions of the FEI system at Buckingham Army Air Forces Base Flexible Gunnery Instructors School and Research Division (FGIS & RD) near Fort Myers, Florida. While there, Major Nicholas Hobbs asked me to introduce the FEI system into their training program and also to take on some combat gunnery problems that had arisen in the European theater. Interested, I joined their Planning and Analysis unit headed by Dr George Taylor, as a federal employee with a War Manpower Deferment. Thus I became one of USA's first Operations Analysts, a scientist working with the military to deal with technical problems arising in combat beyond the training of staff officers. After WWII Operations Analysis evolved into Operations Research, Systems Analysis, Manufacturing Science, Risk Analysis and other important disciplines.

In March '44, the FGIS & RD was moved to Laredo, Texas. My draft board, assuming I had changed jobs, issued me an induction notice. About this time Dr Taylor was commissioned as a lieutenant colonel to serve as an Operations Analyst (OA) with the 14th AF in China. On behalf of Headquarters (HQ) USAAF, he asked me to take on an urgent assignment involving B-29 combat gunnery problems in the China-Burma-India (CBI) theater. While I also was seeking a commission, after my induction as a private, the USAAF HQ placed me on

Crew and debriefing officer at Xian, China (Green)

inactive duty with the equivalent rank of a major. I was assigned to investigate the causes of B-29 combat losses in the 20th Bomber Command (20th BC) and to find ways of minimizing them. When operations against occupied China and Japan began in June '44, we had more combat losses than had been anticipated. I proceeded to the 20th BC headquarters in Kharagpur, India, where I reported to Dr Hamilton Jeffers, a world famous astronomer.

Soon after arriving in Kharagpur, I went over the Himilayas (the Hump) to our advanced base in the Ch'eng-tu, area in a B-29 with General Curtis LeMay as the command pilot. The gunnery officers, intelligence officers, and crew members of B-29s briefed me on encounters they saw or had learned about in which these bombers were shot down. After six weeks of collecting and digesting data and a second round trip to Ch'eng-tu, I completed my analysis. It showed that we had shot down 70 fighters for each B-29 lost in attacks from the rear, whereas we shot down only three fighters for each B-29 lost in attacks from the front. This contrasted with the results of a massive combat simulation study carried out near Alamogordo, New Mexico, that had predicted the B-29 would be most vulnerable to rear attacks. The gunnery and intelligence officers endorsed my analysis, and LeMay modified our formations to bring greater fire power to bear against frontal attacks. With this change, some minor technical modifications, and other tactical changes, the gunnery problem was soon contained.

In January 1945, Navy Lt Benjamin Tator came to 20th BC headquarters with a complaint that sloppy ship identifications made by B-29 crews on their over-water flights led to fruitless Navy missions. I was assigned the problem, and my solid geometry analysis showed that the B-29 gun sight could actually measure the length (L) of an observed ship. This should greatly sharpen an identification since we had a Japanese ship identification chart that specified the lengths of various classes of Japanese warships. The ship length could be calculated from the height (H) of the aircraft the target dial setting (X) needed to span the ship in the retriflector gunsight, the angle of depression (D) of the ship from the aircraft's horizon and the aspect angle (A) of the ship. I allowed for H by providing a paste-on scale for adjusting the range handle on the gun-site. The depression angle (D) was measured with a protractor mounted on the gunsight yolk and the aspect angle (A) was estimated by considering the ship to be the hour hand of a watch. The length of the ship could then be determined by a formula L = G (D, A) X, where G is a complex trigonometric function of the observables D and A that could not be calculated with a standard slide rule. To overcome this obstacle I used two families of graphs so that the intersection of the D and A curves gave the factor G. This could be multiplied by the target dial setting X using graphical devices or with standard slide rule scales.

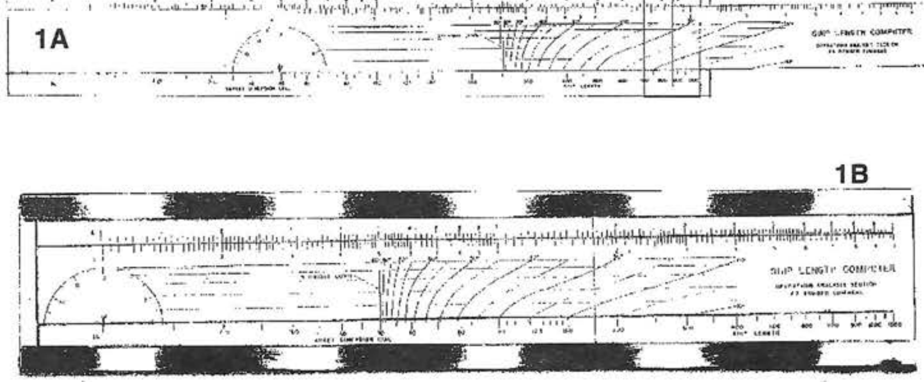


Figure 1. Ship length slide rule versions: Top(1A), 20th BC; Bottom (1B), 21st BC.

While I included a computing chart system in my report, I favored slide rule type solutions. With slide rules two quantities (say G and X) are multiplied by adding lengths proportional to the logarithms of these numbers. Accordingly, I developed a two dimensional variation of a standard slide rule in which the central slider had the array of D curves and A lines plotted on a logarithmic horizontal scale so that their intersection gave G on the lower slider scale. The gunner would (1) pre-set the aircraft height on the range dial paste-on, (2) place the central reticle dot on the nearest end of the ship, (3) adjust the fighter wingspan dial setting (X) until the reticle circle just spans the other end of the ship, (4) measure the line of sight depression angle (D) with a protractor on the gunsight yolk, (5) estimate the aspect (A) or o'clock position of the ship by considering it to be the hour hand of a watch, (6) set sliding scale index to X on the bottom scale, (7) set the hairline to intersection of the D curve and the A line, (8) read L, the ship length on the bottom scale under the hairline. Figure 1A shows: X = 49 ft, D = 25° and A = 2 o'clock giving L = 860 ft, the *Yamato*, the world's largest battleship.

Lt Tator conveyed my solution to Major Harry Allen, CO of Flight

C, B-29 Photo Recon Unit in Ch'eng-tu who requested, through channels, that I equip his gunners and go on a few missions to test the system's performance in combat. With the help of the 948th Engineering Topographical Company, we fabricated a number of slide rules, the special scales to set in the altitude on the range dial, and the paper protractors for the gunsight yolk to measure the depression angle.

Finding the Japanese Fleet

After clearances by USAAF HQ in the Pentagon, I went on my third trip over the Hump to this forward base. I instructed the gunners on the use of the slide rules and the installation of the range dial and yolk protractors. On March 11, 1945, placed on active duty and wearing my dog-tags and an enlisted man's insignia, I joined the crew of Captain Alvin Coe on their third reconnaissance mission, this time to photograph military and naval installations in southern Japan. They had recently been called up from the 58th Bomb Wing to replace the crew of Captain Arthur Humby whose plane was lost due to mechanical failure. After take-off at midnight, I slept in the tunnel between the forward and aft pressurized compartments until daybreak when I recall seeing the "Great Wall," which remained in sight for more than an hour.

After an uneventful flight across China and the East China Sea, we spotted some small warships and merchant vessels as we approached Kyushu and secured several reasonable ship-length measurements. We began photographing the southeastern coast of Honshu on the Inland Sea while flying at 28,000 feet when we sighted the Japanese fleet anchored in Hiroshima Bay and Kure anchorage. This fleet had been lost to our forces since the Battle of Leyte Gulf in October 1944. The gunners and I used my slide rules to measure ship lengths, and, in addition to the *Yamato*, I identified a big half carrier/half battleship, and many other large naval vessels. It was obvious that these were most of their surviving warships. We continued northward on the Inland Sea shoreline of Honshu until about Kyoto when we turned and headed southward on the Inland Sea shoreline of Shikoku. This path took us again past Kure anchorage where we encountered the Japanese fleet again and a terrific headwind (later known as the jet stream). It slowed us down to about 60 mph ground speed when our air speed was about 250 mph. Our F-13 bucked wildly due to turbulence while we had a turbocharger problem that Captain Coe struggled hard to control.

About this time our flight engineer informed us that we had consumed so much gasoline flying against the jet stream that we could not make it back to our B-29 base in Ch'eng-tu. The options Capt Coe considered were (l) heading for a Flying Tiger base in China still held by Chiang Kai-shek's Nationalist forces, (2) heading for Iwo Jima where the battle was still underway, but one airfield was in US hands, (3) heading for and bailing out at an enclave in China controlled by Mao Tse-tung's Communist forces. (With their protection, walkout survival rates were over 90 percent) and (4) heading for Vladivostok, the nearest Allied airfield. Unfortunately while the Soviets sent crews home, they kept the B-29s. Captain Coe chose the first option, and we headed back toward China, dropping down to 5,000 feet to save gas as soon as we cleared Kyushu.

We flew in clouds across the East China Sea and were uncertain as to our landfall when a break in the clouds revealed a Japanese military base in Nanking. Fortunately, the hole closed up before the anti-aircraft fire started. About two hours later we learned by radio that our intended emergency base was experiencing very heavy weather. At this time Captain Coe took a vote (I abstained) as to whether we should head for a Mao Tse-tung enclave. Our navigator, however, located a Flying Tiger base in Xian, which, although somewhat north of our course, was possibly within our fuel range. We climbed above some mountains and flew another hour or two to the northwest and descended carefully until we were below the low clouds. Thanks to the skill of our navigator, the ancient Chinese capital was within visual range.

Xian had a Flying Tiger fighter field that was completely surrounded by a stone wall. In our first landing attempt we were too high when we passed the front wall, and we all braced for a crash into the rear wall. Coe quickly pulled up the landing gear and gave the B-29 full power to make a second try. Fortunately the engines kept turning despite the fact that the flight engineer said we had no more fuel. On the second approach we touched down just after we cleared the front wall and thanks to Coe's skill we stopped some 20 feet before hitting the wall at the other end of the runway.

Our fleet sighting information was immediately coded and sent to headquarters from this fighter base. However, we were stuck in Xian until we collected enough fuel to fly our big aircraft another few hundred miles to Ch'eng-tu. Despite the fact that we were only 30 miles from Japanese lines and a killer squad was supposed to be after the crew of our giant airplane, some of us toured this beautiful city and sights. After two days in Xian we had enough fuel and made a successful takeoff.

Our flight to Ch'eng-tu was a lark, and I sat in the bombardier's position with its great view. I recall vividly the reception by the squadron and the kidding and horseplay that resulted. In effect they said, "You wanted to measure ships, so we showed you some." Major Allen told us that higher headquarters was very excited about the information we had turned in from what was then the longest reconnaissance mission over Japan on record.

I parted company with this photo reconnaissance unit the day after returning to Ch'eng-tu and flew back over the Hump in a C-47. When I reached Kharagpur, the 20th BC was closing out its CBI Operations, and our Operations Analysis unit was packing to go back to the States. I was reassigned to Guam with the 21st BC.

The Slide Rules of the 21st BC

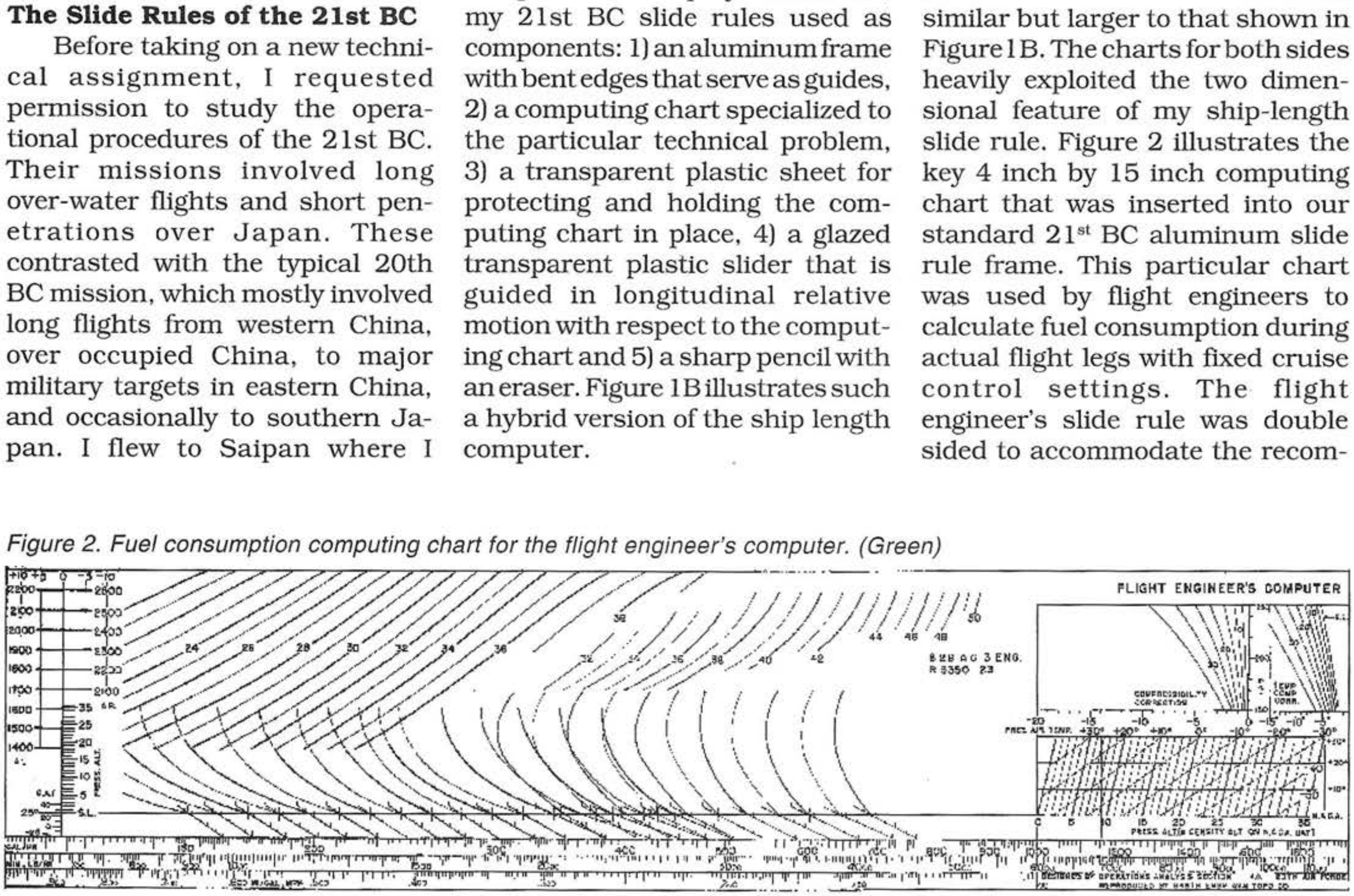
Before taking on a new technical assignment, I requested permission to study the operational procedures of the 21st BC. Their missions involved long over-water flights and short penetrations over Japan. These contrasted with the typical 20th BC mission, which mostly involved long flights from western China, over occupied China, to major military targets in eastern China, and occasionally to southern Japan. I flew to Saipan where I watched mission take-offs and landings of the 73rd Bomb Wing, and from a distance, those of the 313th Bomb Wing on Tinian. Facilitated by my boyhood friend Lt Lawrence Mayer, the lead navigator of the 497th Group, I had extensive discussions with crew members and staff. From these discussions it became clear that most B-29 operations were highly technical and required specialized calculations that were carried out with standard slide rules together with cumbersome compilations of data in tabular or graphical forms. This posed a challenge to me as to how to replace such laborious methods with versatile, easily fabricated, special computers. In my mind this soon took the form of a hybrid between a slide rule and a computing chart

My starting point was my 20th BC two-dimensional ship-length computer. To simplify fabrication, my 21st BC slide rules used as components: 1) an aluminum frame with bent edges that serve as guides, 2) a computing chart specialized to the particular technical problem, 3) a transparent plastic sheet for protecting and holding the computing chart in place, 4) a glazed transparent plastic slider that is guided in longitudinal relative motion with respect to the computing chart and 5) a sharp pencil with an eraser. Figure 1B illustrates such a hybrid version of the ship length computer.

Flight Engineer's Computer

When I returned to Guam following my information gathering tour, I received a request for a special slide rule by Fred Fennema, an aeronautical engineer also with the 21st BC OA unit. He was in communication with the command and wing flight engineers concerned with B-29 fuel consumption problems. For mission planning, they wanted a computer to quickly and accurately carry out all computations required while applying the principles of practical cruise control. They used data obtained in an extensive test program conducted in the Mariannas with an instrumented aircraft and incorporated into an Operational Engineering Data Book that was distributed to each flight engineer. Our flight engineer's computer encapsulated this massive body of data onto two charts held in back to back metal frames similar but larger to that shown in Figure 1B. The charts for both sides heavily exploited the two dimensional feature of my ship-length slide rule. Figure 2 illustrates the key 4 inch by 15 inch computing chart that was inserted into our standard 21st BC aluminum slide rule frame. This particular chart was used by flight engineers to calculate fuel consumption during actual flight legs with fixed cruise control settings. The flight engineer's slide rule was double sided to accommodate the recom-

Figure 2. Fuel consumption computing chart for the flight engineer's computer. (Green)



mended flight setting contour graphs on the back flight prediction slide rule. These graphs gave the recommended calibrated air speed, RPM, brake horsepower, cowl flap angle, manifold pressure, and the corresponding miles per gallon and fuel flow for the momentary weight and altitude. The system was a duplex slide rule. One side was for the solution of flight progress problems and made use of a number of two dimensional graphs on logarithmic scales. The other side, for the solution of flight prediction problems, used two dimensional graphs on linear scales. The computer side gave the fuel consumed during periods with fixed flight settings. The flight engineer summed these numbers and made sure that the calculated fuel consumed from base to target and back did not exceed the original supply of fuel. The charts on the prediction side of the computer gave the flight settings that yielded the best mileage per gallon of fuel.

Computing charts for three-engine and two-engine performance were printed on the back side of the four engine charts and could be substituted in a moment's time. The computer could be calibrated for a particular airplane if, after some test runs, the fuel use ship proved to be appreciably different from the standard plane. Detailed examples of operating procedures were given in our technical instruction manuals. By the end of the war, almost every flight engineer had one.

Offset Bombing Computer

The requests for special slide rules began to accelerate, and to respond quickly to these requests we set up a paperwork-free slide rule design and production service. To secure a special slide rule, the requesting officer, who had a monthly liquor allowance would pay with two bottles. I passed these along to the enlisted members of the 949th Topographical Company who did not have a liquor allowance. Most of these men had been drafted or otherwise selected for special skills, and being somewhat older than the average soldier, they appreciated this "spiritual" comfort. My slide rule design and production operation somehow got a very high defacto priority, second only to the 21st BC mission maps.

When I needed a large supply of aluminum holders to meet the developing demand, General LeMay suggested that I arrange to have them fabricated in Hawaii. To avoid paperwork delays, however, I had them fabricated on Guam at the aircraft sheet metal shop using a few bottles of Old Granddad for lubrication. About this time (May 1945) the damage to planes returning from combat missions was minimal, and the flight line repair crews had lots of free time.

As an example of the efficiency of this operation, a colonel from the 73rd Bomb Wing on Saipan came in one day with the problem of a cloud or smoke screen over the intended military target that they frequently encountered over Japan. In many cases an offset site was visible, and it was possible, by inserting appropriate false settings into the Norden bombsight, to aim at the offset point and hit the intended target. However carrying out last-minute calculations on a bomb run was very difficult, especially if the plane was experiencing enemy fire. With the help of Allen Kennedy, an enlisted man assigned to my work, I quickly worked up a two dimensional design that incorporated the formula for the false bombsight settings. We set our production system in motion and, the next morning, we had a prototype scale for insertion into our universal aluminum holder. We took off for Rota, an island in the Marianas still held by the Japanese, and aiming at one end of their runway, we placed the bombs precisely at the other end as intended. As soon as we returned to Guam we began production of scales for all bomb types and for all bombardiers.

By the end of the war almost every bombardier had this slide rule frame with a collection of charts for various bombs. The bombardiers of the 509th Group, who later dropped the atom bombs, also had one that incorporated the ballistic characteristics of the "Pumpkin," their heavy practice bomb. In view of the atom bomb's large radius of destruction, the ballistic characteristics of the Pumpkin were close enough so that the same charts could be used with the atomic bombs.

Bomb Plot Computer

Early in the 21st BC campaign, LeMay required the crews to bring back bomb strike photographs. These were used by staff to assign scores to various squadrons, groups and wings, and a healthy competition developed that substantially improved bombing results. Unfortunately to take bomb strike photographs, the bomber must fly straight and level for the duration of the bomb fall (typically about 40 seconds) thus increasing the bomber's vulnerability to anti-aircraft fire and fighter attack. However, with a photograph of the bomb, about 1,000 feet below the bomber, in relation to the ground, it is possible, using the laws of physics, to calculate the precise impact point. Doing it this way spared the bomber and crew about 30 seconds of straight and level flight over the target. This problem was of double interest to the members of the 509th group who were also concerned about the shock wave from the atom bomb blast.

The request for bomb plot computers came first in May, and scales for most of the available bombs reached the printed level by June '45. Calculations were moderately complex and required the two dimensional logarithmic plot feature of my ship-length computer.

Force and Bomb Load Computer

The need for the Force and Bomb Load computer arose in late May 1945, after most Japan's major military targets had been substantially destroyed. Virgil Proctor, 21st BC OA, who was responsible for mission calculations found it necessary to calculate four or five small missions instead of one massive mission. We developed a computer that mechanized the theory and procedures for determining the most efficient combination of bombs based upon the British experience in Europe. Practically all of the force and bomb loads assigned for the B-29 missions in June, July, and early August were calculated with this slide rule.

Three computer requests from 21st BC or wing command staff came in May and June of 1945 and were filled in very short order. They also used a multiplicity of logarithmic scales rather than two dimensional graphs:

A "Radar Resolution" computer provided a quick means of determining the resolution of the APQ 13 and/or APS 15 radar systems under various conditions. It assisted staff radar officers in selecting suitable radar targets or determining whether an object such as a river, bridge, or industrial plant would make a suitable radar check point or aiming point.

A "Turn" computer gave the time elapsed and wind displacement during a turn. It proved useful 50 years later when Dr Edward Teller asked the author to investigate the feasibility of an A-Bomb demonstration over Tokyo.

A "Slant Range" computer provided a simple conversion system.

Shoran Computer

In early July 1945, Dr William Shockley from Bell Laboratories came to Guam with the first "SHORAN" equipped B-29. This new bombardment system would enable the 1,000 plane B-29 fleet to give our troops close support in the planned invasion of Japan. A guide plane with SHORAN equipment was to fly a precisely determined circular arc about the master transmitter on a submarine or small island some 100 or so miles from the beachhead. The bombs would be released when the guide plane reached a precise distance from the second transmitter. All the remaining B-29s would use their standard bombsights in relation to the guide plane's impact point. A hand cranked digital calculator was to be used for the geodetic calculations that had to be carried out with six decimal place accuracy. Last minute atmospheric corrections were needed that depended upon the weather but only required two decimal place accuracy. Dr Shockley heard of our slide rule service and asked me to fabricate a slide rule for the atmospheric corrections.

After I completed this slide rule, I was asked to carry out the operational geodetic and the atmospheric calculations. My assignment was to determine the precise release point for each wing's SHORAN equipped bombers. Then the other bombers of each wing would use their regular bomb sight on the SHORAN determined impact points to form a bombing pattern to protect our invading troops.

I left Guam on the first SHORAN-equipped B-29 with the project team to undertake simulated AAF-Navy operations off Manila and to develop a protocol for combat application of the Shoran system. About a week later, on August 6, 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 *Bockscar*. After another week our mission was cancelled, and we returned to Guam. Shortly after taking on the Shoran assignment, orders came through from USAAF headquarters reassigning me to the 20th BC Operations Analysis unit, which was to be set up on Okinawa in support of the Far Eastern Air

B-29 "Shoran" crew (Green)

Force under General Doolittle. General LeMay sent a commendation letter summarizing my 20th AF service in connection with my impending transfer. I was unhappy about this reassignment because I thought my Shoran work was very important. I conveyed my feelings to General LeMay who initiated a battlefield commission that would placed me under 20th AF jurisdiction.

When I returned from Manila on August 18 my commission had come through. However, since hostilities had effectively ceased, I was permitted to decline it so that I could return to my doctoral studies. There was a rule in place at that time that operations analysts under 26 who had been inducted but placed on inactive duty were to be called to active duty, and those over 26 were to be mustered out. I had turned 26 two months earlier.

Impacts of 20th AF Slide Rules

My first 20th AF slide rule, the ship-length computer, developed in Kharagpur, India, involved me in some historic battle actions of the Pacific war. I was unaware of the consequences of our discovery of the Japanese fleet until an article appeared about it in the July 1945 *Air Force Magazine* identifying our flight as "one of the juiciest photo-reconnaissance flights of the war." The article noted that the sequel to our flight came on March 21 when Fleet Admiral Nimitz announced that a carrier task force had destroyed or damaged half the Japanese fleet where we had located it. Our sighting also triggered the early initiation of an aerial mining campaign that had been planned for over a year. In March the 313th Bomb Wing, based on Tinian, launched "Operation Starvation" by mining the Shimonoseki Strait, then the most important shipping channel in the Japanese Empire. Shortly thereafter mines were laid at the approaches to Hiroshima, Kure Harbor, and many other harbors and straits. These mines brought Japanese shipping and naval operations to a virtual halt.

Our siting helped the Navy task forces that hit Okinawa on March 25 to initiate the Okinawa campaign. Landing operations began on April 2. On April 7, the *Yamato*, the *Yahagi*, a light cruiser, and eight destroyers that had survived our naval assault on the Kure anchorage made a dash to the Philippine Sea. Given only a one way supply of oil, they were sent on a suicide mission to engage our Okinawa invasion fleet. They were spotted by a B-29 reconnaissance plane then tracked by a US submarine as they sailed along the coast of Kyushu. Finally, naval aircraft of Task Force 58 under Vice Admiral Mitscher sank the *Yamato*, the *Yahagi*, and four destroyers in the last major naval engagement of the war, effectively bringing an end to the Japanese Navy. With these victories, the highly effective B-29 fire raids, and the capture of Iwo Jima on March 25, the tide of our war with Japan turned dramatically in our favor.

Apart from my Shoran slide rule, which did not make it into combat, my 21st BC slide rules "computerized" and technically enhanced the 20th AF in what was probably the highest technology operation of WW II. The utility of these computers was indicated in General LeMay's letter, in personal commendations and citations from Generals Nathan Twining, Lauris Norstad, Carl Spaatz, the Secretary of War Robert P. Patterson, and in the citation for the Truman era Medal of Freedom presented to me in November 1947.

My 20th AF slide rules were two dimensional generalizations of the invention of Oughtred in 1630 AD, the dominant method of computation by scientists and engineers for three and one half centuries. The 21st BC slide rules, in effect, were versatile computers with data storage and data manipulation capability. It is ironic that the Shoran Computer, my last WW II slide rule, was made at the request of William Shockley. His invention of the p-n junction transistor in 1947, probably has had the greatest impact of any invention since WW II, eventually leading to electronic computers with vastly greater data storage and computing capability.

Forty-five years later, I learned from my Cal Tech colleague, Wolfgang Panofsky, that our firing error indicator (FEI) was dropped by instrumented aircraft accompanying the *Enola Gay* and *Bockscar* to measure the shock waves of our atomic bombs. Thus, for me, the beginning and end of WW II formed a closed loop.

Acknowledgments

I would like to thank the various people who requested these special slide rules and contributed so much to their designs. Also, thanks to the crews who tested them as well as those who relied on them for their combat needs. Contributions in Kharagpur of the 948th Topographic Engineer Unit and on Guam of the 949th Topographic Engineer Unit, the Sheet Metal Manufacturing Section of Harmon Field, the 35th Photo Technical Unit, and the OAS enlisted men were also very important. Finally, I would like to thank the USAF Museum at Wright-Patterson AFB for archiving a complete collection of my 20th AF slide rules and the Oughtred Society of Palo Alto, CA, an international society of slide rule collectors, for recently publishing a detailed technical account of these slide rules.