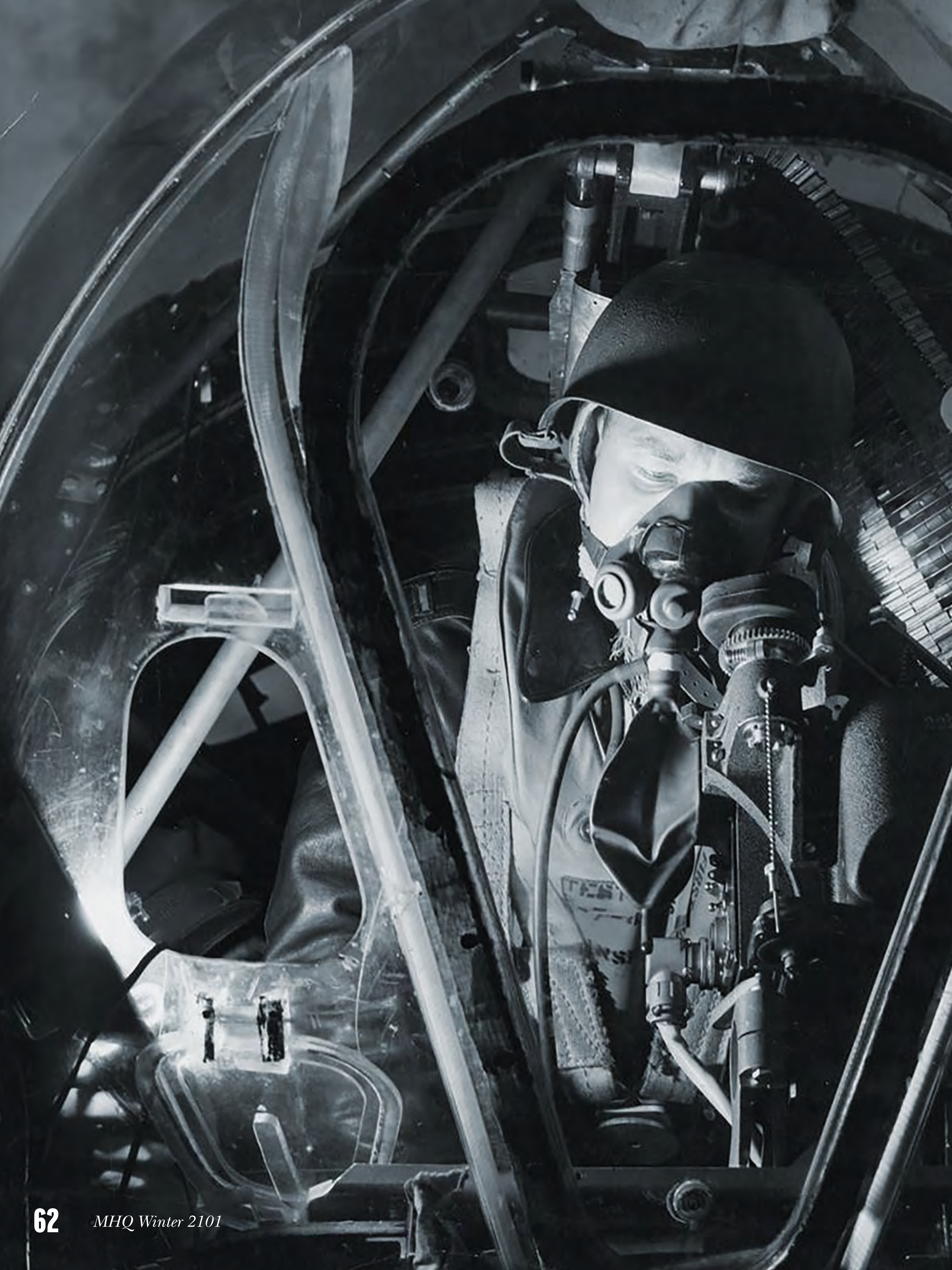
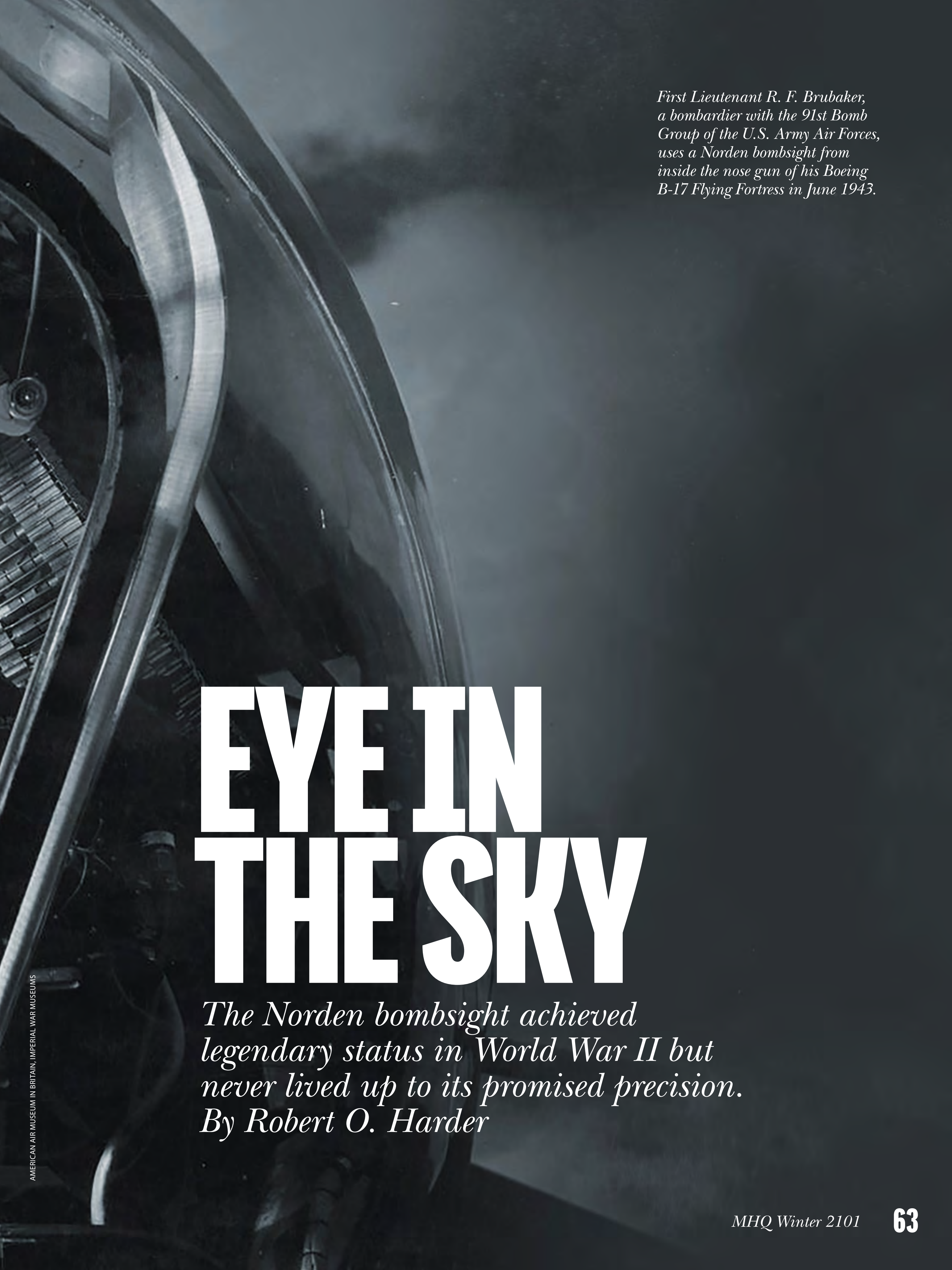




First Lieutenant R. F. Brubaker, a bombardier with the 91st Bomb Group of the U.S. Army Air Forces, uses a Norden bombsight from inside the nose gun of his Boeing B-17 Flying Fortress in June 1943.

AMERICAN AIR MUSEUM IN BRITAIN, IMPERIAL WAR MUSEUMS

EYE IN THE SKY

The Norden bombsight achieved legendary status in World War II but never lived up to its promised precision.

By Robert O. Harder

At 9:10 a.m. on Monday, August 6, 1945, Thomas Ferebee was hunched over his Norden M-9B bombsight, serial number V-4120. Ferebee, a 24-year-old major in the U.S. Army Air Forces, was the bombardier aboard *Enola Gay*, a specially modified Boeing B-29 Superfortress that was coasting in on Honshu, Japan's largest island. It was a beautiful, clear day—what flyers called CAVU, or ceiling and visibility unlimited. The plane, piloted by Colonel Paul W. Tibbets Jr., was still 9 miles south of its initial reference point, the city of Mahara. Ferebee, temporarily configuring his bombsight into extended vision mode, had already peered through his 3.2X power telescope and acquired his aiming point: the Aioi Bridge over the Ota River at Hiroshima.

Human history was about to change forever.

Extended vision—a feature of the X-1 Reflex Sight—was one of the more useful innovations in the final versions of the Norden Bombing System. By engaging the X-1 sight, Ferebee had raised the forward vision angle by another 20 degrees, enabling him to pick out the target from an astounding 75 miles away. The bombardier would stay in extended vision mode through the plane's inbound turn before switching back to the normal viewing configuration. *Enola Gay*'s three-minute bomb run was a complete success—"the easiest I ever made," Ferebee would recall. Mild winds, a well-defined aiming point, and the bombardier's skillful synchronizing of the crosshairs and accurate calculation of the airplane's 31,060-foot true altitude above sea level resulted in the bomb missing ground zero by 800 feet, a meaningless deviation.

The U.S. Navy aimed to build a precision bombsight that could target enemy ships.

"Little Boy" was the world's first atomic bomb. The strikes at Hiroshima and three days later at Nagasaki, which effectively ended World War II, would not have been possible without decades of work on sophisticated new bombsights. Much of that work was conducted in private and acquired legendary status before the first new, improved bombsight was ever installed in American warplanes.

The idea of dropping ordnance from flying machines came relatively late in their development. The mindset of army general staffs had long been that the airplane was useful only for reconnaissance—a better method than observation balloons. The first time a heavier-than-air flying machine dropped high explosives was in 1911, during the Italo-Turkish War, when Italian Sub-Lieutenant Giulio Gavotti, flying an Austrian-built Etrich Taube, bombed Turkish forces at the oases of Ain Zara and Tajura in western Libya. Gavotti simply tossed 17 Cipelli hand grenades from the cockpit as he passed over the enemy troops.

When the world exploded into flames three years later, it became clear that a more scientific approach to aerial bombardment was needed. Further, it quickly became apparent that gravity-propelled bombs also faced formidable atmospheric problems—the air beneath a bomber can be a virtual layer cake of wind patterns. It wasn't until 1915, the second year of World War I, that a British professor turned artillery lieutenant, Henry Tizard, developed a simple mechanical bombsight that used two rigid aiming bars mounted on the side of the plane's fuselage. The pilot sighted along them until they lined up with the target, consulted his stopwatch, and then tripped the release lever at the appropriate moment. While this was an advance over the previous eyeball and windage guesswork methods of 1914, the Tizard CFS-4 was still inadequate. But it was the most sophisticated option at the time, and several thousand of Tizard's bombsights were manufactured.

The Tizard was followed by the Mark I, the first reasonably effective mechanical bombsight. Developed by designer Harry Wimperis for the Royal Navy in 1917 and subsequently adopted by the U.S. Army Air Service in 1919, it marked the first time a bomb-aiming designer had seriously tried to compensate for groundspeed and drift. Unfortunately, the advance came with a serious drawback: Pilots had to crisscross the target at 90-degree angles to obtain usable readings. (Navigators later called the procedure a double drift.) Flying a warplane back and forth across a heavily defended target was not practical, to say the least. Further, it often took a great deal of ordnance to accomplish the job. In a 1921 test bombing, it took 65 bombs for American airmen, under General Billy Mitchell, to sink a stationary, captured German battleship.

Engineers made significant advances in bombsight development in the 1920s. Taking the lead was Carl L. Norden, a Dutch engineer who had immigrated to the United States in 1904 and worked for the Sperry Gyroscope Company in New York before becoming a consultant to the U.S. Navy in 1915. The navy asked Norden, who was known as "Old Man Dynamite" because of his explosive temper, to develop a precision bombsight capable of targeting enemy ships. Working alongside Norden were former U.S. Army colonel Theodore Barth, who had been in charge of gas mask production in World War I, and U.S. Navy lieutenant (later captain) Frederick I. Entwistle, the assistant research chief at the navy's Bureau of Ordnance.

From left: It took 65 bombs for American airmen to sink a captured German battleship in 1921; Enola Gay bombardier Thomas Ferebee with the Norden bombsight after the dropping of "Little Boy"; Carl Norden in 1944.

Before Norden's work, the vexing trigonometric difficulties in obtaining consistent bombing accuracy had defied solutions. How did one accurately place varying types of gravity-propelled weapons on specific earthbound targets when releasing them from fast-moving airborne vehicles operating in three dimensions? As any experienced bombardier could testify, it was a lot tougher than it looked on paper. The long list of variables included the size, weight, and shape of the bomb; the manner of releasing the bomb; malfunctioning bombs; broken bomb fins; defective bomb-aiming equipment; turbulence and wind drift; the aircraft's altitude and speed; ballistics computation errors; aiming errors; flak; and, of course, Murphy's Law.

Norden's answer was to design a completely new bomb-aiming system. It was built around an autopilot, a revolutionary concept in itself, and what today would be characterized as an optical-mechanical analog computer. It had two primary components: the removable sight head—nicknamed "the Football" (because of its shape) in Europe and "the Blue Ox" (after its code name) in the Pacific—and a stabilizer bolted to the airplane. Spinning gyros kept the Norden in three-dimensional equilibrium. These major hardware elements were supported by a complex array of knobs, dials, levers, cranks, cams, mirrors, tiny motors, and a multipower telescope.

After manually entering his ballistic calculations and other data into the Norden Bombing System and having departed the bomb run's Initial Point (IP), the bombardier would position himself over the bombsight and begin aligning the separately controlled crosshairs on the aiming point. Using the turn and drift knob and the rate and displacement knob (for range to target), he would manually crank the crosshairs until they were atop the aiming point. If his precomputation estimates (especially for wind) were off a little—they always were—he could "kill" the actual drift and speed differences by repeatedly dragging the hairs back to the aiming point, allowing the Norden's analog computer to neutralize the variations, thus stabilizing the crosshairs. This process of coordinating a vertical crosshair (course line—the plane's heading) with a horizontal crosshair (release line—perpendicular to course line) came to be called the "synchronous" method of bomb aiming. Considerable manual dexterity (all the synchronizing was performed with the right hand) and finesse were essential.

Once the bombardier was satisfied that he had acquired the target, he and the pilot would "clutch in," slaving the Norden bombsight to the C-1 autopilot and fully uniting the Norden Bombing System. The bombardier would continue to synchronize the two crosshairs on the target all the way through release, with the autopilot turning the airplane accordingly. Meanwhile, the To Go meter ticked down toward Bombs Away, which occurred when the Norden analog computer sensed that the sighting angle had intersected the dropping angle—about 70 degrees from the vertical at 30,000 feet, when the bombs automatically released. (As a frame of reference, it took 43 seconds after release from 31,060 feet for Ferebee's "Little Boy" uranium bomb to reach its planned airburst altitude of 1,890 feet, which caused more widespread destruction than a ground blast.)

Initial testing of the Norden prototype Mark XI was conducted at the U.S. Navy's proving ground in Dahlgren, Virginia. Pilots and bombardiers were unimpressed, complaining that the new device "demanded both hands, both feet, and their teeth" to make it work properly. Testing for circular error probable predicted that 50 percent of the bombs would fall within a 110-foot circle when dropped from a 3,000-foot altitude—an error of 3.6 percent, which actually was worse than existing systems. Despite the problems, in 1928 the navy awarded a $348,000 contract for 40 new bombsights to the newly created Carl L. Norden Inc.

Meanwhile, the U.S. Army was working on its own bombsight improvements. Swiss immigrant Georges Estoppey, a designer in its engineering division, came up with his Bombsight Type D-4, and Elmer Sperry, the inventor of gyroscopic-stabilized sensors that mitigated steamship wave action, developed the Sperry C-1 (gyro-stabilized) Bombsight. Estoppey's D-4 relied on mechanical stopwatch principles (lining up the target by viewing through a manually movable sight and timing the release with a stopwatch) much like those used by the Royal Navy's Mark I. Neither the D-4 nor the C-1, however, proved effective. A highly publicized target-practice bombing of a condemned bridge over the Pee Dee River in North Carolina in 1927 turned into an embarrassing five-day fiasco. It took U.S. Army Air Corps pilots of the 1st Provisional Bombardment Squadron, flying Keystone LB-5 bombers, more than 100 missions to destroy a middle section of the bridge.

Norden continued refining his designs, unveiling the Mark XV on paper in 1931. The first working prototype of the device appeared two years later, along with his company's greatly exaggerated claim: "It'll drop a bomb in a pickle barrel from 20,000 feet." While it took several more years to perfect, the Mark XV gyro-stabilized bombsight was the big breakthrough. The preliminary results of the precisely hand-machined prototypes so impressed U.S. Army Air Corps brass that for the first time, a dedicated bombardier station was installed in the nose of a production bomber—in this case the Martin B-10B, a twin-engine, retractable-gear, all-metal monoplane that entered service in 1934. The B-10's Norden system proved so successful that the air corps ordered it installed in all subsequent American medium and heavy bombers, a task that wasn't completed until 1943—years longer than anyone could have imagined.

"It'll drop a bomb in a pickle barrel from 20,000 feet," the breathless claim went.

Not surprisingly, the Sperry Company didn't take the news of this development lying down, especially once it learned that Norden had run into major technical difficulties that dramatically limited production. The most serious of these were obtaining satisfactory lubricants and achieving the extremely precise machining tolerances (to as fine as .0001 of an inch) the bombsight would require during mass production. On top of everything else, there was bad blood between Carl Norden and Elmer Sperry—during World War I, Norden had worked for Sperry until the two had a major falling out in 1915. When Norden's new sight came out in the early 1930s and its technical problems surfaced, Sperry promptly developed his own Sperry S-1 Bombsight, a knockoff of the Mark XV. The Norden sight had been married to the newly developed Honeywell C-1 autopilot (necessary for accurate and stable level bombing but not for dive bombing); Sperry joined the S-1 to its own A-3, A-4, and A-5 autopilots.

At the same time, Estoppey, sensing his own opportunity, developed the mechanical D-8 Bombsight, which did not require an autopilot. The D-8 was a big improvement over the earlier D-4 and much less complicated and expensive to manufacture than either the Norden or Sperry. For lower-altitude, slower-speed level bombing, the D-8 would come to occupy an important wartime niche. (Although Sperry had developed a rudimentary, one-off gyroscopic autopilot for Wiley Post's solo around-the-world flight in 1931, the modern autopilot was actually invented to support Norden and Sperry bombing systems, not to relieve pilot fatigue during long flights, which only later became a happy byproduct of the design.)

While the Mark XV concept had always been sound, formidable manufacturing difficulties continued to surface with disturbing regularity. As a consequence, by December 7, 1941, more of the rival Sperry S-1 bombsights had been installed in American bombers (though only a few hundred level bombers were operational). In fact, until 1943, when the Norden was fully perfected, the dirty secret in the air force was that many bombardiers preferred the less troublesome, easier-to-master Sperry S-1 to the Norden Mark XV and its descendants, the Norden M-Series Bombsights.

Even after going operational, the Mark XV had serious problems. First, its carbon brushes wore out frequently and had to be replaced, and carbon dust from the brushes would settle into the sensitive gimbal bearings, necessitating frequent cleaning and oiling. Second, accurate leveling of the vertical gyro required manual setting of two liquid levels, a process that took 510 seconds—a significant segment of any bombing run. Third, both the azimuth and range-operating knobs were on the right side of the bombsight, making simultaneous two-hand sighting of a target virtually impossible. Finally, the vertical gyro would tumble off its axis of rotation in rough air, losing its target.

Nevertheless, with each year Norden's manufacturing and technological capabilities improved, and fewer orders went to Sperry. By the beginning of 1944, the Sperry S-1 systems had been phased out of all U.S. bombers and replaced by the Norden. This was partly because the removable one-piece Sperry sight head–stabilizer weighed 75 pounds; the

Clockwise from left: An officer at the U.S. Army Air Forces Tactical Center in Orlando, Florida, provides a peek at the Norden bombsight in 1945; a Sperry bombsight undergoing evaluation in 1936; the Enola Gay in 1945.

LEFT: BETTMANN (GETTY IMAGES); RIGHT: U.S. AIR FORCE (2)

removable Norden sight head weighed just 35, with its stabilizer permanently bolted on the aircraft.The decision by the air corps (renamed the U.S. Army Air Forces in 1941) to eventually commit its higher flying bombers solely to the Mark XV was complicated by Norden's special relationship with the U.S. Navy. His breakthrough Mark XV had been specifically designed to function in the lower operating altitudes and slower speeds of flying boats, the navy's primary level bombing platforms at the time. As a result, to oblige the U.S. Army's sudden interest in the 1930s following the B-10B bomber's success, the XV would require significant modifications to accommodate the air corps' still-developing concept of high-flying, four-engine bombers. The problem was further exacerbated by the fact that Norden had already granted the navy an exclusive on all bombsight orders, forcing the army to order its bombsights through the navy, which wasn't even getting as many as it desired. Inevitably, the army sights actually delivered were not only too few but also unmodified for higher altitudes. The situation became intolerable, and the air corps turned to Elmer Sperry and his S-1 bombing system to fill the vacuum.

At this point Norden's president, Ted Barth, had stepped in, determined to maintain his firm's primacy in military procurement. While the Sperry company had conducted business without guile through the late 1920s and into the 1930s, Barth hadn't been above using backdoor tactics. His flamboyant salesmanship, extensive army and navy contacts, and brilliant "pickle barrel" public relations strategy would prove decisive. The Sperry Company inadvertently played into Barth's stratagems by keeping a low profile and remaining quietly professional. Even more damaging, Sperry was widely perceived to be tainted by its multinational status and prewar licensing agreements in Germany and Japan.

Sperry's own technical problems in the mid- to late 1930s helped tilt the growing momentum toward Norden. As soon as Norden's technical issues were solved and production was able to meet demand, the ax fell on Sperry. On August 4, 1943, Brigadier General Barney M. Giles, the chief of staff of General Headquarters Air Force (a separate organization within the air force), recommended that all bombsight production be standardized with Norden. That November, Henry H. "Hap" Arnold, the commanding general of the U.S. Army Air Forces, issued orders "to proceed immediately with the cancellation of all contracts for Sperry S-1 bombsights and A-5 autopilots." For the rest of the war the air force standard would be the Norden Bombing System—the M-Series bombsight and the Honeywell C-1 autopilot.

Not long after the first European bombing missions began in August 1942, bombardiers began openly sneering at the "pickle barrel" propaganda they had once more than half-believed. In a classic military training lapse, the first bombardiers had been instructed in twin-engine, lower flying Beechcraft airplanes, completely out of touch with the then-operational high flying Boeing B-17 Flying Fortress. Major Thomas Ferebee of the *Enola Gay* later said that he had never dropped a bomb from above 12,000 feet until his first combat mission in August 1942 at 20,000 feet. The degree of difficulty in obtaining acceptable bombing accuracy with the 8,000-foot altitude difference was enormous. What's more, at 20,000 feet the bombardier had to be harnessed to a clumsy oxygen apparatus to avoid hypoxia and, because of colder temperatures at that altitude, had to wear a heavy suit and thick gloves that made synchronizing the crosshairs on the aiming point very difficult. Further, multiple layers of wind shear that lay hidden below could blow the bombs off trajectory, and inherent aiming errors were magnified accordingly. Before World War II, a 200-to-400-foot circular error from a rated bombardier at an altitude of 12,000 to 15,000 feet was probably about average. In 1943, however, under combat conditions at higher altitudes, the average circular error was 1,200 feet and often much larger.

The U.S. Army Air Forces had drawn up its comprehensive European bombing plan with the understanding that the Norden would be the primary bombing platform. A single B-17 was believed to have a 1.2 percent probability of hitting a 100-foot target from 20,000 feet, meaning that 220 bombers would be needed for a 93 percent probability of one or more hits on a pinpoint objective like a factory. Air force leaders remained sanguine in the face of such dismal forecasts, and one can only wonder what they could have been thinking. As early as 1941, the British had understood that such low success rates against pinpoint targets were not likely to win the air war, which is why they turned to their brutal but more effective strategy of bombing cities, railways, harbors, industrial districts, and the like rather than purely military targets. Nevertheless, the American air force stuck to its guns, continuing to maintain that it could effectively strike individual targets through daylight bombing.

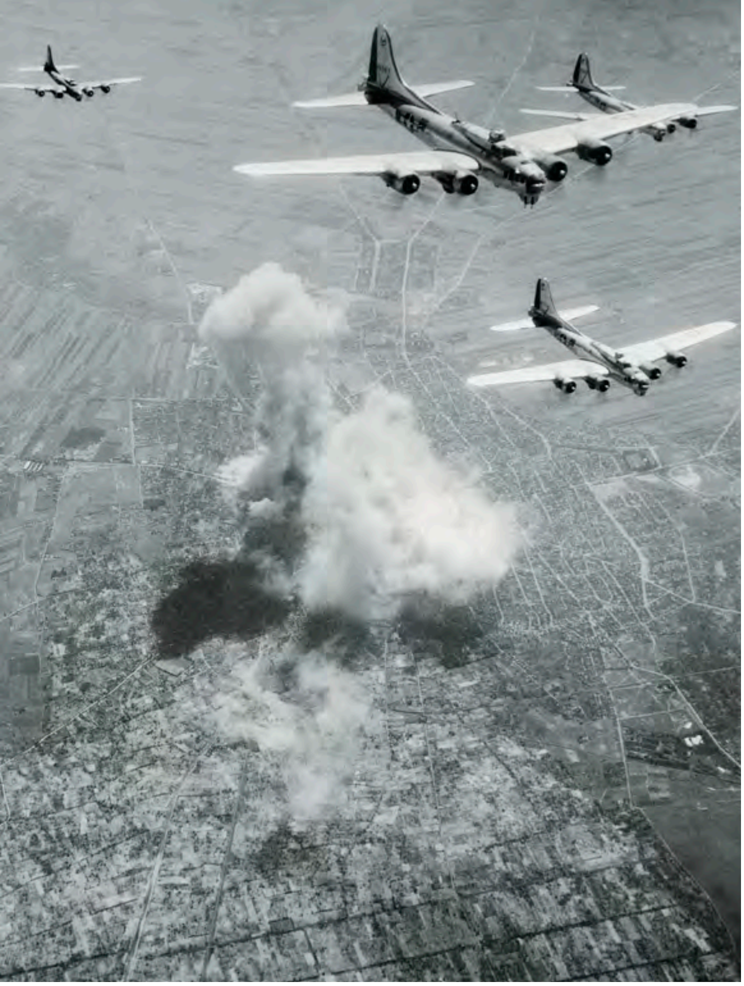
The Germans somehow managed to plant a spy in the Norden factory.

Throughout the war the American press functioned as a de facto publicity arm of the Norden company (egged on by air force brass, who desperately wanted to believe their own daylight bombing propaganda), printing favorable and often exaggerated reviews. At the same time, an aura of mystery and glamour surrounded the project: No photos of the new device were released, and even the name of the factory producing the sights was classified. The U.S. military developed an intricate system for shipping and handling the Norden sights, with armed guards escorting the sights to and from aircraft and monitoring special storage vaults between flights. There was, early in the war, even a written "bombardier's oath," which had the bombardier pledge to destroy the bombsight and himself if threatened with capture. Novelist John Steinbeck produced a U.S. Army Air Forces recruitment documentary, *Bombs Away*, in which he noted that the bombsight was never left unprotected. "On the ground, it is kept in a safe and under constant guard," he wrote. "It is taken out of its safe only by a bombardier on a mission, and he never leaves it. He is responsible not only for its safety but its secrecy. Should his ship be shot down, he's taught how quickly and effectively to destroy it." The 1943 motion picture *Bombardier* further exalted the Norden's deadly accuracy, with multiple shots of a bombardier hunched over the sight like a diamond cutter working on a priceless jewel, without ever providing so much as a glimpse of the instrument itself.

But the elaborate precautions taken to protect the secrets of the Norden bombsight were all for naught. It was grotesquely, almost hilariously ironic that the Germans found out details about the device even before World War II—through a Nazi spy in the Norden factory. Herman W. Lang, a German-born U.S. citizen, was a trusted Norden draftsman by day and a cunning agent-for-gain at night. In January 1938, he smuggled plans and blueprints of the device aboard an Atlantic steamer bound for Bremen, Germany. Later the same year Lang took a "vacation" back to Germany, ostensibly for a family visit but in reality to further assist Luftwaffe technicians in evaluating the Norden (and not incidentally collect his 10,000 reichsmark reward). Later in the war, Lang would be caught up in the arrest of the infamous German Duquesne Spy Ring—the largest espionage case in U.S. history that ended in convictions—and sentenced to 18 years in prison.

The subsequent German mock-up of the Norden was comparable to the Luftwaffe's own Lotfernrohr 7, or Lotfe 7, and similar in concept to the Mark XV, although in form it resembled the Sperry S-1. The Germans, who only used two-engine bombers that dropped weapons from about 15,000 feet, ultimately decided that their Lotfe 7 was simpler to use and less expensive to build. Consequently, they shelved the Norden plans for the balance of the war. In the end, only the Allied public remained in the dark about the "secret" Norden bombsight.

Norden M-Series Bombsight production totals compiled by various sources leading up to and during World War II vary dramatically. (Sperry and Estoppey totals are



A formation of Norden-equipped Boeing B-17G Flying Fortresses from the Fifteenth Air Force bomb a railway network near the Hungarian border in September 1944.

MONDADORI PORTFOLIO (GETTY IMAGES)

fairly consistent.) Sources also disagree as to the total number of men completing undergraduate bombardier training (award of basic wings), though here the reason becomes obvious after study. Most accounts count the same man two and even three times because he also graduated from advanced training (bombardier-navigator training, radar navigation training, and the like, for example). To arrive at a reasonable estimate of bombsights produced requires sifting through a great deal of material and weighing such factors as total level bomber production, total number of undergraduate bombardiers trained (approximately 50,000 men), and source reliability. The bombsight production numbers that Albert L. Pardini compiled in *The Legendary Norden Bombsight* (Schiffer Publishing, 1999) seem most reliable. During the war, Pardini was a supervisor at a bombsight repair and modification center and claims to have researched his highly technical book for nine years. Pardini's production totals were 52,083 Norden M-Series bombsights, 10,080 Estoppey bombsights, and 5,563 Sperry bombsights, for a grand total of 67,726. These were installed in seven major level bomber types totaling 59,974 aircraft: Boeing B-17 four-engine Flying Fortress, Consolidated B-24 four-engine Liberator, Boeing B-29 four-engine Superfortress, Douglas A-20 two-engine Havoc, North American B-25 two-engine Mitchell, Douglas A-26 two-engine Invader, and the Martin B-26 two-engine Marauder.

The U.S. military would continue to use the Norden well into the Vietnam War on older two-engine bombers like the A-26. (While Vietnam War B-52C and D Stratofortresses had similar optical sights, they were used only for post-release bomb damage assessment). The Norden was last used in combat by Naval Air Observation Squadron Sixty-Seven (VO-67). Flying U.S. Navy OP-2E Neptune twin-engine propeller patrol bombers under Operation Igloo, this unit gathered clandestine military intelligence by dropping electronic sensory devices along the Ho Chi Minh Trail. The unit was deactivated in July 1968. Though it was no longer used in direct combat operations, optical bombsight capability continued to be installed in American strategic bombers all the way through the B-52F Stratofortress, built in the mid-1950s.

The optical bombsight's demise was inevitable. All models had a built-in Achilles' heel: They worked only in daytime and clear skies. In the nuclear age, with all-weather jet bombers flying at near supersonic speeds, such limitations were simply unacceptable. The solution, which was already well on its way before the end of World War II in the Pacific, was radar aiming that used the same gyroscopically stabilized, though greatly enhanced, Norden-Sperry technology. Although radar bombing had been phased in to all American level bombers by the mid-1950s, that still left the intractable problems and inherent inaccuracies of gravity bombing. Developed after the Vietnam War era, "smart bombs" and GPS-directed weapons have since overcome those difficulties. While such technologies continue to be refined, looming on the horizon is perhaps the ultimate solution to the bombing problem: unmanned, artificial intelligence–driven weapon systems that combine standoff launching, pinpoint accuracy, and zero aircrew risk.

Today, visitors to the Steven F. Udvar-Hazy Center, the Smithsonian National Air and Space Museum's annex at Dulles International Airport near Washington, D.C., can view for themselves the brilliantly restored *Enola Gay* as it appeared on August 6, 1945. Sharp-eyed onlookers peering up through the bottom of the B-29's greenhouse glass nose will see V-4120, the truly legendary Norden bombsight, still in place, as if waiting for bombardier Thomas Ferebee to unleash the ultimate weapon on another disbelieving enemy and its unsuspecting people. MHQ

Robert O. Harder, a Vietnam War–era B-52D navigator-bombardier and an FAA-certificated flight instructor, is the author of *The Three Musketeers of the Army Air Forces: From Fortress Europa to Hiroshima and Nagasaki* (Naval Institute Press, 2015).