**Superbomber’s Achilles’ Heel**

*Long revered as the airplane that won the Pacific War, the B-29 was a cranky, complex machine with a fire-prone engine.*

Growing up during World War II, my vivid window on a world afire was *Life*magazine, the gritty, you-are-there, large-format photojournalism pioneer. “The Mighty Superfortress” became a star in *Life*’s firmament as soon as the big bomber flew its first combat missions in June 1944, and between the adulation of war correspondents and the near-weekly fullpage Boeing advertisements extolling the capabilities of its new superbomber, you’d have thought—well, certainly an 8-year-old would have thought—that four-engine, swoosh-tailed, polished-aluminum perfection had taken wing in Seattle.

It didn’t hurt that the B-29 was the most beautiful bomber ever built. What could possibly be wrong with an airplane that looked like it had been designed by Raymond Loewy? From the symmetrical cigar of a fuselage unbroken even by a conventional stepped windscreen to the tips of its impossibly long, gracefully tapered wings, the B-29 was the antithesis of the locomotive-like British four-engine bombers and the gawky German monstrosities. We had seen the future, and it worked.

Or did it?

In fact the B-29 was such a dangerous airplane that had it been peacetime, only one or two XB-29 prototypes would have been built before the U.S. Army Air Forces said, “No money for you, Boeing, come back in five years when you have something that’ll fly longer than an hour without becoming a bonfire.” But it was wartime, and never has as flawed and expensive a major weapons system—arguably the ultimate weapons system of the entire Pacific War—been knowingly deployed in as incomplete and imperfect a state of development.“We need it for this war, not the next one,” USAAF General Henry H. “Hap”Arnold at one point griped. At a point, in fact, when it looked entirely possible that he wouldn’t get the B-29 for *either*war; development, testing and production were going so badly that serious consideration was given to ditching the entire program despite the millions already spent.

The grim joke among B-29 crewmen was that more of them were being killed by Curtiss-Wright, the makers of the B-29’s big radial engines, than by the Japanese. Only it wasn’t a joke. Four hundred and fourteen B-29s were lost bombing Japan—147 of them to flak and Japanese fighters, 267 to engine fires, mechanical failures, takeoff crashes and other “operational losses.” Do the math and you’ll see that for every B-29 lost to the enemy, almost two were lost to accidents and crashes.

The Superfort was born back when civilians still thought the yellow-winged Martin B-10 was the bee’s knees. In the late 1930s, the Army General Staff was still made up of ex-artillery and -infantry officers who understood little about strategic warfare, but they believed we needed a “hemispheric defense bomber”—a very-long-range airplane that could defend the United States during a European war by launching from the safety of U.S. bases, since it was assumed that the British Isles would quickly fall to the Germans. It also needed to fly far enough to defend Alaska and Hawaii, well beyond the range of bombed-up B-17s, and there was also the thought that the Germans might try to attack the U.S. from bases in Africa and even South America.

The first round of responses to the War Department’s perceived need were designs like the Douglas XB-19 and Boeing’s own XB-15—gargantuan, vulnerable, underpowered inflations of conventional airplanes. It was a time when airframers paid out of their own pockets to engineer prototypes, hoping that maybe they’d get a production contract out of it. Boeing, in fact, was a small company on the ropes because the Army Air Corps had decided it only needed a few B-17s and had canceled plans for a large production run. If nothing else, however, the XB-15 did prove to Boeing engineers that they’d need to greatly reduce drag and increase lift if they were ever to build a superbomber.

Boeing bravely decided on its own to start serious work on just such an airplane. By August 1939, after seven major iterations of the design, the company had settled on the B-29’s predecessor, the Model 341. By December it had built a wooden mockup and had a substantial jump on the competition when the Air Corps issued an official request for very-long-range bomber proposals at the end of January 1940. Boeing needed to add self-sealing fuel tanks, increased armor and more and heavier guns—all as the result of lessons learned during the early air war over Europe—refining what became the B-29. One key to the design’s success was the veryhigh-lift, low-drag wing that Boeing developed—much like the Consolidated B-24 Liberator’s unique “Davis wing”—with sophisticated Fowler flaps, at the time a high-tech innovation, to make the wing work at takeoff and landing speeds.

Unfortunately, there was only one engine that potentially had the power and fuel efficiency to turn a B-29-size airframe into a contender, and everybody knew it. Lockheed, Douglas, Martin and Consolidated all specified the same engine in their ultimately unsuccessful superbomber proposals.

This seemingly ideal power plant was an 18-cylinder, two-row radial, the Wright R-3350, the highest-displacement production engine in the world at the time. The early 3350s were said to produce 2,000 hp at a time when half that horsepower was respectable for a production Rolls-Royce Merlin or Allison V-12, and the big radial seemed to be remarkably fuel-efficient. The famous Pratt & Whitney R-2800 would not run for another two years. Furthermore, it lacked the R-3350’s power and, particularly, its specific fuel consumption.

What could be more appropriate for a long-range, heavy-lift bomber? Nor was the R-3350 an overstressed variant of an existing design, but rather a new engine with considerable growth potential. In fact the Wright R-3350 would eventually put out a relatively reliable 3,400 hp in airliner service in the 1950s (3,700 in military applications), powering Lockheed Super Constellations and Douglas DC-7Cs, not to mention the Douglas AD and A-1 Skyraider, the dependable “Spad” of Korean and Vietnam war fame.

Curtiss-Wright had first run the R-3350 in 1937, and it had been casually tested in a number of low-altitude, low-load applications, but the company was far busier building R-1820s for B-17s and DC-3s as well as developing the twin-row R-2600 for a wide variety of wartime applications. Between 1937 and 1942, Wright managed to produce about two dozen running R-3350s, all with serious reduction-gear, cooling and exhaust-valve problems. The huge R-3350 at least initially became the company’s redheaded stepchild.

In the ’teens and 1920s, Curtiss had been a liquid-cooled engine pioneer, but by the 1930s, after its merger with Wright, the manufacturer of Lindbergh’s classic Whirlwind radial, Curtiss’ Wright engine division became an air-cooled company, designing and building R-1820s as well as smaller and larger radials for everything from trainers to torpedo bombers. The R-3350 seemed to be a natural part of this progression. But in 1939, for some reason, Wright Aeronautical got distracted and decided to develop the 42-cylinder, liquid-cooled Tornado, one of the most complex aircraft engines ever conceived. The Tornado had six in-line rows of seven cylinders each, arranged in an asterisk pattern around a central crankshaft.

The Tornado was intended for the Lockheed XP-58 Chain Lightning, one example of which finally flew in 1944, but with Allison V-3420 engines. Unfortunately, development of the Tornado sapped engineering talent from the R-3350. And then, when R-3350 development and production suddenly became the single most important aircraft engine program of the entire war, the same engineers were reeled back to the R-3350 project, thus dooming the Tornado to an early and well-deserved death.

The most notorious B-29 test flight crash was not caused by an engine fire, though there’s an urban legend to that effect. In February 1943, Boeing test pilot Eddie Allen was making his ninth flight in the number-two XB-29 prototype. Allen was that rare individual, an engineer who was also a test pilot. He was also the most experienced four-engine pilot in the country, probably the world, with substantial left-seat time in Boeing’s Model 314 flying boats, as well as the pressurized Boeing Stratoliner, of course B-17s and now the B-29. In fact he was the only person to have flown the Superfort as pilot in command.

Allen knew perfectly well what he was dealing with, which alone makes him one of the bravest test pilots ever. After the first flight of the XB-29, on September 21, 1942, his only public comment was, “It flies.”Perhaps he was being coolly reticent, but for a test pilot to be so apparently unenthusiastic might be the equivalent of saying, “I’ve flown worse, though I can’t remember when…” By the time of his fatal flight, Allen had already aborted one XB-29 test with an engine on fire and two more about to blow, choking smoke in the cockpit and a need to get on the ground fast enough that he landed downwind. The USAAF considered the situation so dire that Allen and his crew had every right to bail out, so it awarded him a rare civilian Air Medal for choosing instead to save the priceless prototype.

On February 18, Allen had already aborted the flight because of a by then routine engine fire—extinguished by the CO2 fire bottle—and was flying a conventional pattern and long, curving final approach when another fire started that blew off a large part of the left wing’s leading edge and rapidly spread throughout the wing. The accident investigation showed that faulty design of the fuel filler atop the wing could, in certain flight configurations, cause raw fuel to siphon down into the wing. On this day, it was ignited by a length of test-instrument manometer tubing that touched a hot exhaust manifold and created a slowburning fuse. The B-29 became uncontrollable on final and crashed into a meatpacking plant, killing 20 on the ground as well as Allen and his 10-man crew (three of whom had jumped, but too low for their chutes to open).

Boeing’s only other B-29-qualified pilot, who had flown as Allen’s right-seater, had seen enough. He quit the program.

Still, it was the Wright engines that were creating the real headaches for Boeing and the USAAF. Wright was trying to do—was being forced to do—in two years of powerplant development what typically took five. In April 1941, when military strategists concluded that the U.S. would never win the inevitable war against Japan without being able to seriously bomb the Home Islands, Wright suddenly found itself tasked with building more than 30,000 R-3350 engines, and the redheaded stepchild overnight became a squalling, tantrum-prone, 2,595- pound gorilla.

Wright’s unlikely star engine designer was an immigrant, Rudolph Daub, who had grown up in the classic German apprenticeship system that saw aspiring machinists carving camshafts out of solid billets by hand, with metal files. He was resented at Wright, perhaps because he was German, perhaps because he was damn good. When in the early 1930s Wright decided to build its first twin-row radial, the 14-cylinder R-2600, Rudy Daub’s design was accepted over all the company’s other proposals. The R-2600 power plant was so good that it forced Pratt & Whitney to develop the classic 18-cylinder R-2800, and the R-2600 went on to power the B-25 Mitchell, A-20 Havoc, PBM Mariner and TBM/TBF Avenger.

It also earned Daub the resentment of a lot of top Wright engine guys.

The R-3350 was Wright’s next project, and it was determined that it would be an R-2600 on steroids—nine cylinders per row rather than seven, but the very same cylinders with the very same bore and stroke. Who better to lead the project than Daub? He laid down the R-3350’s basic configuration but then got transferred to the ill-fated Tornado project, which badly needed his help, and the Wright people who took over R-3350 development removed many of Daub’s features.“Years later, after the troublesome debut of the R-3350,” wrote aircraft engine authority Kimble McCutcheon in *Torque Meter*, the quarterly journal of the Aircraft Engine Historical Society, “engineers faced with the challenge of fixing the engine’s many faults went back to Daub’s original layouts. In every case, putting back Daub’s original features solved the problem.”

For anybody familiar with General Motors’ stultified, bloated, internally competitive, hierarchical 1980s corporate culture, a snapshot of Curtiss-Wright in the 1930s and ’40s will look familiar. This was a company that apparently would rather have left bombers on the ground than license engine production to a competitor. At times, Curtiss-Wright seemed more concerned with its potential postwar competitiveness than it was with solving wartime problems. The company’s several divisions had no autonomy, and Wright had a bad enough reputation in the trade that it had trouble attracting top executive and engineering talent.

Wright executives “proved themselves not really up to running the company, which as part of its Curtiss-Wright parent company suddenly ballooned from an employer of a few hundred workers into a giant defense contractor with hundreds of thousands of employees in many states,” wrote Jacob Vander Meulen in his revealing book *Building the B-29*. “Its top executives refused or didn’t know how to delegate authority and allow managers in its various divisions to use their own initiative. Everything important had to be cleared through Curtiss-Wright headquarters in the skyscrapers of Rockefeller Plaza….”

In the summer of 1943, Congress—at the end if its patience with Wright—ordered General Arnold to convene a high-level committee to assess the company’s problems. The board included William Brennan (a future Supreme Court justice), William O’Dwyer (future mayor of New York) and James McDonnell (founder of McDonnell Aircraft). They found appalling managerial ineptitude and an utterly casual approach to the R-3350 project.

Nor was the workforce nearly as talented as the competition’s. New Jersey–based Wright Aeronautical decided to build its new R-3350 factory not far from New York City rather than, say, in Kansas, where there was a pool of aviation craftspeople with an old-school work ethic. They paid stingy wages—a starting wage of $9.40 an hour in 2011 dollars— and had to compete with New York shipyards in a region that had a high cost of living. The result was low morale, constant absenteeism, widespread slacking-off and poor worker retention. In the words of William Wolf in *Boeing B-29 Superfortress*, Wright used “the dregs of the workforce to manufacture the most complex piece of mass-produced machinery built at the time.”

Ultimately, the largest and best R-3350 factory was the huge one that had been built in Chicago by Chrysler and was operated by its Dodge division. During the war, Dodge-built B-29 engines became the gold standard…for what that was worth.

Much as Detroit did—to its regret—in the 1970s, Wright tried to automate the R-3350 manufacturing process as much as possible, making its workers monitors rather than craftspeople. One of the R-3350’s seemingly insoluble problems was constant, premature failures of the reduction gears that slowed B-29 propellers down to very efficient low-rpm speeds. Nobody bothered to analyze what was causing the reduction-gear failures, and Wright simply tried band-aid after bandaid. The same gearcase that would eventually successfully transmit 3,400 hp in Constellations and DC-7Cs proved unable to handle 2,200 hp for more than a few dozen hours, in some cases.

Finally, somebody actually measured tolerances in a production gear set and found that an automated gang drill press at the New Jersey factory that simultaneously bored the holes for a dozen planetary-gear carrier shafts was embarrassingly out of whack. A team of experienced machinists was put to work around the clock drilling the holes, and the reduction-gear problem went away.

Standard procedure for twin-row radials of the time was to have the exhaust ports of the rear cylinders facing aft and the fronts facing forward, with the front set of short, simple exhaust pipes leading to a big collector ring ahead of the engine. Unfortunately, this meant that the very first thing cooling air encountered as it flowed into the nacelle was a red-hot exhaust manifold—not a problem with lower-power engines but a serious detriment to cooling airflow on a ton-and-a-quarter furnace like the R-3350. (Pratt & Whitney designed its classic R-2800 with all 18 exhaust ports facing aft, and a single big circular exhaust manifold *behind*the engine.) Aircraft exhaust manifolds are vulnerable to leakage, cracks and vibration failures, and when this happened on a B-29’s R-3350, white-hot flames spewed back directly at the cylinder heads, resulting in valve failures and, sometimes, in catastrophic engine failure and an inevitable fire.

It’s not clear whether aft-facing front-row exhaust ports were part of Rudy Daub’s original concept for the R-3350, but they might well have been a “needless complexity” removed by other Wright engineers, since they required artfully bent exhaust pipes to snake through the gaps between the rear cylinders. Whatever the case, redesigning the R-3350 front-row cylinder heads with backof-the-head exhaust ports immediately solved some cooling problems. A few of these engines were installed in late-production B-29s built in 1944 and ’45.

There are photos of Japan-bound B-29 formations showing airplanes here and there with broad bands of sharp-edged, solid black atop a wing, directly behind a nacelle. A big invasion stripe? Nope: oil. B-29 engines were prolific leakers, largely as a result of vibration, and routine post-mission maintenance involved a lot of tightening of hose clamps, banjo fittings and compression nuts. And if an entire wing skin was wet, imagine the scene *inside*the nacelle.

Oil fires, not fuel, often created B-29 engine blazes, though the R-3350’s numerous large magnesium components fed the flames. A literally white-hot, wind-whipped magnesium fire quickly burned through a B-29’s ineffectual firewall—crewmen called them “tin pans”—and then melted the aluminum wing spar close behind the nacelle.

Another major cause of R-3350 fires was backfires due to poor mixture distribution, when a super-lean cylinder would burp flames back into the intake manifold. If this ignited fuel that had pooled in the poorly designed induction system, it could set alight the magnesium supercharger case.

The cure for this, engineered near the war’s end and later made standard for R-3350s, was direct fuel injection (DFI)—not into the intake ports upstream of the valves, as classic fuel injection works, but straight into the combustion chamber. No fuel ever enters the induction system, and DFI offers the added advantage of cylinder cooling from the spray of raw gas. Today DFI is being touted as the newest and latest automotive technology, but some B-29s had it in 1945. Curtis LeMay demanded that it be fitted to the “Silverplate” B-29s of the 509th Composite Bomb Group; he had no use for carburetors on the atomic bombers.

Two B-29 gunners were positioned in clear plastic blisters amidships, on each side of the airplane. From there, they remotely controlled .50-caliber turrets through analog-computer gunsights that calculated range, windage, target lead and even the ballistic drop of the bullets over the distance to the target. But since active gunning occupied only a small slice of time during each mission, the shooters were given a quite different primary duty: Watch the engines and report sudden oil leaks and fires. No other bomber, whether American, British or German, carried on-board fire marshals.

Despite the B-29’s troubled development, it’s worth noting that very few changes were made to the Superfort’s airframe or aerodynamics. Boeing got the bird basically right, out of the box. There were a few pressurization problems—gunner blisters occasionally blew out—but thanks to its prewar work on the Stratoliner, the company already had pressurization experience. Still, there were enough running systems and detail changes required that at peak production Boeing decided the hell with it, build the airplanes as-is at the four huge factories manufacturing them, then disassemble and modify them at its Wichita facility and other modification centers. It was later called the “Battle of Kansas,” and it involved thousands of technicians remanufacturing Superfortresses outdoors, during the bitter Kansas winter of early 1944, on Boeing’s windswept Wichita ramp.

Certainly not everything was Wright’s fault. B-29s were being flown in combat by young pilots and flight engineers who often had logged just several hundred hours and had come straight from twin-engine trainers. They were making overgross takeoffs from hot, coral-dusted island runways, and their engines were being maintained by kids in flip-brimmed baseball caps working outdoors, sometimes perched on oil drums instead of workstands. It’s no wonder that R-3350s were fortunate to survive for an average of 265 hours before being thrown away. (Some were overhauled, but many were simply junked, since Wright was cranking out plenty of replacements. Small mountains of trashed radials were standard features of B-29 bases in the Pacific.)

Five years later, R-3350s were thumping away for thousands of hours in Connies and DC-7s, but they were being flown by million-mile airline crews and maintained by professionals inside clean hangars. And they were loaded and carefully throttled up with one eye on the bottom line—airline economics.

Nor were B-29s easy to fly. They had the highest wing loading of any WWII airplane: 81.1 pounds per square foot by the time the Superforts took off for Japan, lifting huge loads. The bomber was so heavy that even taxiing was a task. Turns needed to be made cautiously, to avoid rolling the tires right off the wheels, and the B-29’s brakes were so marginal that they’d overheat if an anxious pilot taxied a bit too fast. Maximum ground-running time was 20 minutes, after which the engines were too hot for takeoff.

The climb to altitude was painfully slow, with one eye always on the cylinder-head temperatures, and once a B-29 got established in long-range cruise, typically at an indicated airspeed of 210 mph, flying became a delicate dance of slowly closing the cowl flaps to avoid too much drag yet not letting the heads get too hot. If an airplane began to fall back from its mates, a little more power was needed. But then the temps would rise. Open the cowl flaps some to compensate. But then the speed would drop even more from the added drag. Close the cowl flaps a little, but then more heat. In fact it was impossible to fly true formations in B-29s at altitude. Superforts flew in “streams” or loose groups.

Look at photos of B-29s flying missions over the Pacific and you’ll never see the cowl flaps fully closed unless the bombers are in a throttled-back descent. B-29 cowl flaps created such enormous drag that they couldn’t even be fully open for takeoff; the turbulent airflow they created over the wing could cause a huge loss of lift as takeoff flaps were retracted. Postwar tests showed that fully open cowl flaps created the same effect on performance as an engine failure with the cowl flaps closed.

The B-29 had a remarkably short combat career—just 14 months—and losses of one a day, every day, during that career. Its deficiencies remained so little understood by the public only because of creative spin by Boeing and Army Air Forces publicists and the existence of a captive press corps. Even the much-admired Ernie Pyle wrote a newspaper column headlined “Pilots Adore Cramped B-29,” and in it he gushed, “I’ve never heard pilots so unanimous in their praise of an aeroplane.”

It’s claimed that the B-29 won the war in the Pacific, though that’s only superficially true. If anything, the U.S. Marines, Navy and Army won the war by capturing the islands from which B-29s could reach Japan, since earlier attempts to bomb Japan from China with Superforts had proved ineffectual. But Boeing went on to ever-increasing greatness, while the R-3350 engine was the death of Curtiss-Wright. Though the complex radial soldiered on until the fast-approaching end of the piston-engine era, neither Curtiss nor Wright were invited to join the U.S. Air Force and Navy in the jet age.

*For further reading, frequent contributor Stephan Wilkinson recommends:*Boeing B-29 Superfortress: The Ultimate Look From Drawing Board to VJ Day*, by William Wolf;*Boeing B-29 Superfortress*, by Steve Pace; and*Building the B-29*, by Jacob Vander Meulen.*

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