Part I

What You Can Do When You Have To

During World War II, bomber production at Boeing Plant II and at Ford Willow Run "flowed like a river." Some of what we learned then — still useful more than 50 years later — was forgotten. But it's never too late to relearn and redeploy some of the timeless concepts that were discovered.

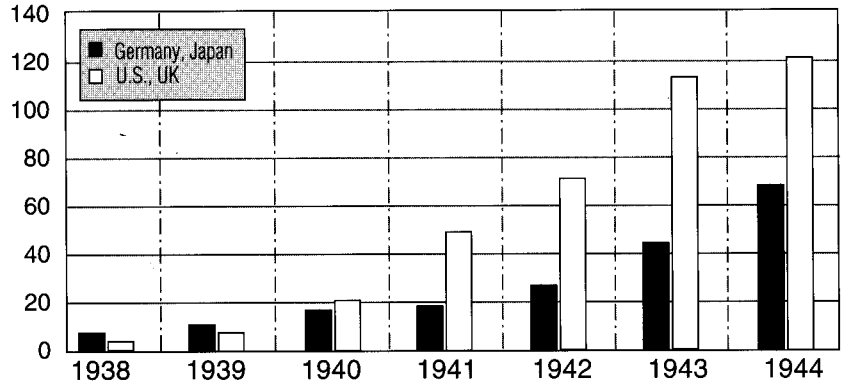
Bill Vogt

It was the war of the century — the big one — a war to win or lose through volume production. When it began in 1941, two four-engine heavy bombers designed in the mid-1930s, the B-17 Flying Fortress and the B-24 Liberator, were the biggest warplanes in the arsenal. Rapidly building armadas of these heavy bombers was one of the decisive strategies of that conflict. From 1941-45, the men and women engaged in it had the challenge of their lives building the largest, most complex, four-engine aircraft ever mass produced before. Figure 1 puts their achievement in context.

But what motivated them? Early on, it was a gut-wrenching fear of losing. By 1943, they sensed that they would win, so they had fire in the belly to get it over with as fast as possible. The word went out, "Get 'em flying." And they did what they had to do. Much of what they did had never been done before. Some of it hasn't been done since.

They invented, built, and ran what was, and perhaps still is, history's most efficient large-airplane production operations — Boeing's B-17 production run at

Total WWII Production of Military Aircraft (in 000s) by Major Powers



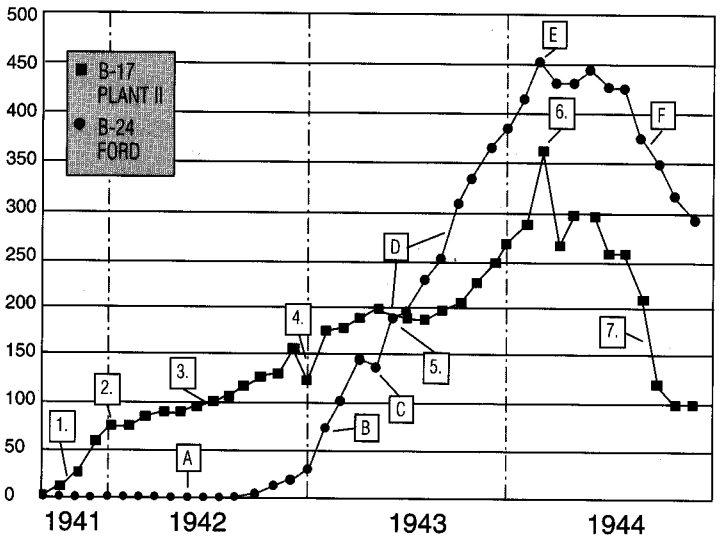
Year	Germany	Japan	U.K.	USA
1938	5.6	3.2	2.8	1.8
1939	8.3	4.5	7.9	2.1
1940	10.8	4.8	15.0	6.1
1941	11.8	5.1	20.1	29.4
1942	15.6	8.9	23.7	47.8
1943	25.8	16.7	26.3	85.9
1944	39.8	28.2	26.5	96.3
Totals	103.7	71.4	122.3	269.4

* From 1941-1944 the total aircraft production gap between the UK and the U.S. versus Germany and Japan widened until the advantage became so obvious that cutbacks began in 1944. Note that German and Japanese production continued to rise until the 1945 collapse, so it was a production race but they had nothing comparable to four-engine bombers like the B-17 and B-24. These were a much greater production challenge than twin-engine bombers. Some of the German twin-engine bombers carried a heavy bomb load, but few of those types were built. Together Plant II and Willow Run accounted for half of the 31,044 B-17s and B-24s built.

Source: *The Oxford Companion to World War II*, p.22 (Denis Richards) and p. 144-146 (David Dorrell).

Figure 1.

Aircraft Per Month from Boeing Plant II and Ford Willow Run



Explanation of the Chart

Plant II (number coded)	**Willow Run** (letter coded)
1. Finish building Plant II. Initial ramp up. Repackage B-17 design into modules. Invent multiline system. Quote 75 per month to AAF.	A. The colossus took shape. Redesign of B-24 into modules, machine & tool design, hiring & training. Operational by Sept. 1942.
2. Engine shortage. Fly 'em away, haul the engines back to re-use, and keep building.	B. Ramp up. Rapid learning on new fixtures. Green hires learn to build an acceptable B-24.
3. Intense training. Standard work. Great suggestion program. Constant revision of engineering and tooling to improve production.	C. Realization of the depth of the problem hiring and keeping workers. Begin to work out causes of Army "squawks" on finished birds.
4. Big snowstorm. People can't get to work.	
5. Flat spot. Labor shortage forces moving work to nearby feeder plants. Ramp up resumes.	D. "Taking the work to the workers." Out-source to feeder plants. Ramp up lifts off.
6. Peak production; March 1944. 362 B-17s flown away complete; about 17 airplanes per day, or one every 1.3 hours.	E. Peak production; March 1944. 462 B-24s accepted (some were knock down kits); about 18 airplanes a day, or "a bomber an hour."
7. B-17 orders tail off. Conversion to B-29; then all orders stop. Knowledge of methods of production begin to fade.	F. B-24 orders tail off. then stop in 1945. The players fade away. Willow Run becomes part of auto folklore but not seriously studied.
6981 Flying Fortresses produced.	**8685 Liberators produced.**

Figure 2. *Sources: The Boeing Archives. The Research Center, Henry Ford Museum and Greenfield Village, and Warren B. Kidder,* Willow Run: Colossus of American Industry, *KFT, Lansing, MI, 1995.*

Plant II, south of Seattle, and Ford's B-24 production run at Willow Run, near Detroit. The history of these distinctly different plants, summarized in Figure 2, shows how people can learn to build big airplanes (or any other large, complicated product) fast, efficiently, and with high quality. They did it with slide rules, telephones, teletypes, and drawing boards — and without computers.

Some of the practices at Willow Run and Plant II were similar; others were striking contrasts. Plant II was run by engineers who both designed and built B-17s. They knew airplanes, but not mass production. Hobbled by space restrictions, they had to self-discover lean manufacturing. They had a little help from here and there, but much of their system they created themselves to win the production race of the century.

By contrast, Willow Run was operated by engineers renowned for mass production, but who were not ignorant of airplanes. In the 1920s, Henry Ford designed and built the Tri-Motor airplane, pioneered the first commercial air service (between Detroit and Cleveland), and first used radio to guide a commercial airliner. However, Tri-Motor production halted eight years before ground was broken for Willow Run.[1] In effect, auto experts redesigned an advanced aircraft for mass production by automotive methods. They *knew* it could be done.

From beginning to end, Willow Run built B-24s in a glare of publicity. Still celebrated for "inventing" mass production, Ford wanted to prove that automotive methods and engineers could build airplanes faster than aviation companies. Because of that rivalry, and perhaps the publicity, aviation companies were not eager to learn from Willow Run.

Then and now, Willow Run captured more ink than Plant II, but at its peak, Plant II almost matched the actual output rate of Willow Run. The people of Plant II had to concoct some simple production methods that we now think are new.

The Airplanes to Be Built

By modern standards they weren't big, but in 1941, the B-17 and the B-24 were monsters, more complex than any previous aircraft. They had similar weights, wingspans, and payloads — and hundreds of thousands of parts. Each was powered by four 1200 horsepower engines. Although somewhat smaller than a 737, the planes resembled their modern commercial counterparts minus the electronic stuffings and customized interiors.

Although designed to win a war, not for decades of service, the durability of the B-24 wasn't bad, and the B-17 was legendary for flying home with horrendous battle scars. Into the 1980s, some B-17s served as slurry bombers on forest fires.[2] The last one retired as a crop duster in the early 90s. Today, 14 remain flyable as restored museum pieces.[3]

Among B-17 and B-24 buffs, debate continues on which one was better. Slightly faster and more maneuverable, the Liberator had a small edge over the B-17 in operating range, speed, and altitude. However, the more

stable, aerodynamic Flying Fortress was easier to hold in close formation in an English Channel fog. The B-17's large wings were designed with many redundant paths to carry stress loads around damaged areas, so a well-clobbered Fortress could keep flying — an attribute comforting to its crews.

Aircraft Comparison

	Boeing B-17G (Plant II)	Consolidated B-24J (Willow Run)
Wing span	103 ft. 9 in.	110 ft.
Length	74 ft. 4 in.	67 ft. 2 in.
Empty weight	36,135 lb.	36,500 lb.
Gross weight	65,500 lb.	65,000 lb.
Max. Speed	287 mph @ 25,000 ft.	300 mph @ 30,000 ft.
Cruise Speed	150 mph @ 5000 ft.	215 mph @ 8000 ft.
Ceiling	35,600 ft.	30,000 ft.
Range	2000 mi. w/ 6000 lb. bomb load	3300 mi
Engines (4 per)	Wright R-1820-97, 1200 hp each	P&W R-1830-65, 1200 hp each
Max. bomb load	9600 lbs.	8600 lbs.
Armament	Thirteen 50 cal. machine guns	Twelve 50 cal. machine guns
Crew	~ 10	~ 10
Part numbers*	~ 65,000 part cards	30,388 part cards
No. of parts**	~ 250,000	152,235
Designers	Boeing	Consolidated
Builders	Vega; Douglas; Boeing at Plant II at Seattle (three plants)	Consolidated at San Diego & Ft. Worth; Douglas at Tulsa; North American at Dallas, Ford at Willow Run (5 plants)
Planes built	Boeing Plant II: 6981 (54%) Total, all plants: 12,731	Willow Run: 8685 (47%) Total, all plants: 18,313
Cost per plane	Initially $242,000 in 1940 Finally $139,254 in 1944 Reduction: 57.54% in 32 months	Initially $238,000 in 1942 Finally $137,000 in 1944 Reduction: 57.56% in 24 months

* Both counts are believed to be for active part numbers.

** Not counting rivets; rivet estimates of around 300,000 for both B-17 and B-24.

Figure 3. *Sources: O'Leary, Michael, "Mission with the Classics,"* Air CLassics, *Oct. 1982, p. 35; Burk, Clarence S.,* Production Acceleration Case Study: Boeing B-17, *(TSZLA-7/FWF/ew), Los Angeles AAF Procurement Office, July 22, 1946, p. 1.; West, H. Oliver, "What is the Multiline System?"* Boeing News, *March, 1943; Redding, Robert and Bill Yeene,* Boeing: Planemaker to the World, *Brompton Books, Greenwich, CT, 1989; The Research Center, Henry Ford Museum and Greenfield Village, Part count estimates from the materials department as reported in Plant Data, Feb. 18, 1944, Accession 435, Box 40; and Kidder, Warren B.,* Willow Run: Colossus of American Industry, *KFT, Lansing, MI, 1995.*

The Liberator's high-aspect ratio Davis wings were small relative to their bodies. With fewer redundant loading paths to reroute stress, a solid hit would crumple a B-24 wing. B-24s were also less crash worthy. A belly landing often cracked a B-24 fuselage into two or three pieces, and if the impact of ditching at sea collapsed the bomb bay doors, a B-24 sank fast. When a sturdier B-17 ditched, the plane usually stayed afloat until the crew escaped in rafts. Some floated for days.

However, Eighth Air Force records show a crew loss rate of only 13.4 percent for B-24s versus 15.5 percent for B-17s, so among veterans the debate lingers on. "Well now, the B-24 could fly above the flak, while the B-17 flew more often without fighter escort ..." The two planes are shown in the cover photo, B-17 in the foreground, B-24 in the background. Their comparative statistics are in Figure 3. From a production and engineering viewpoint, they were nearly equal challenges.

Wings were, and still are, the crucial structures of an airplane. The engines mount to them and the fuselage attaches to them. They are "the platform" that holds a plane together in flight. That's why the wings became the centerpieces of production flow in each of the two plants. One of the major design differences between the planes was that the single wing of the B-24 penetrated all the way through the fuselage, which was suspended from it, while the two wing halves of the B-17 attached to the lower fuselage.

Once upon a time, when we had to, we designed highly producible aircraft and created simple systems to build them. Boeing did it one way; Ford did it another. Both achieved the desired result — huge volumes of quality aircraft. We can still learn from what our grandparents did.

1. Lacey, Robert; *Ford: The Men and the Machine*, Ballantine Books, New York, 1986, p. 257.
2. Holien, Mick; *Missoulan on Line*, Thursday, Sept. 24, 1998, http://www.missoulian.com/news/docs/news5.shtml.
3. "B-17s: Where to Find Them," *Aero Vintage*, http://www.aerovintage.com/b17loc.htm.