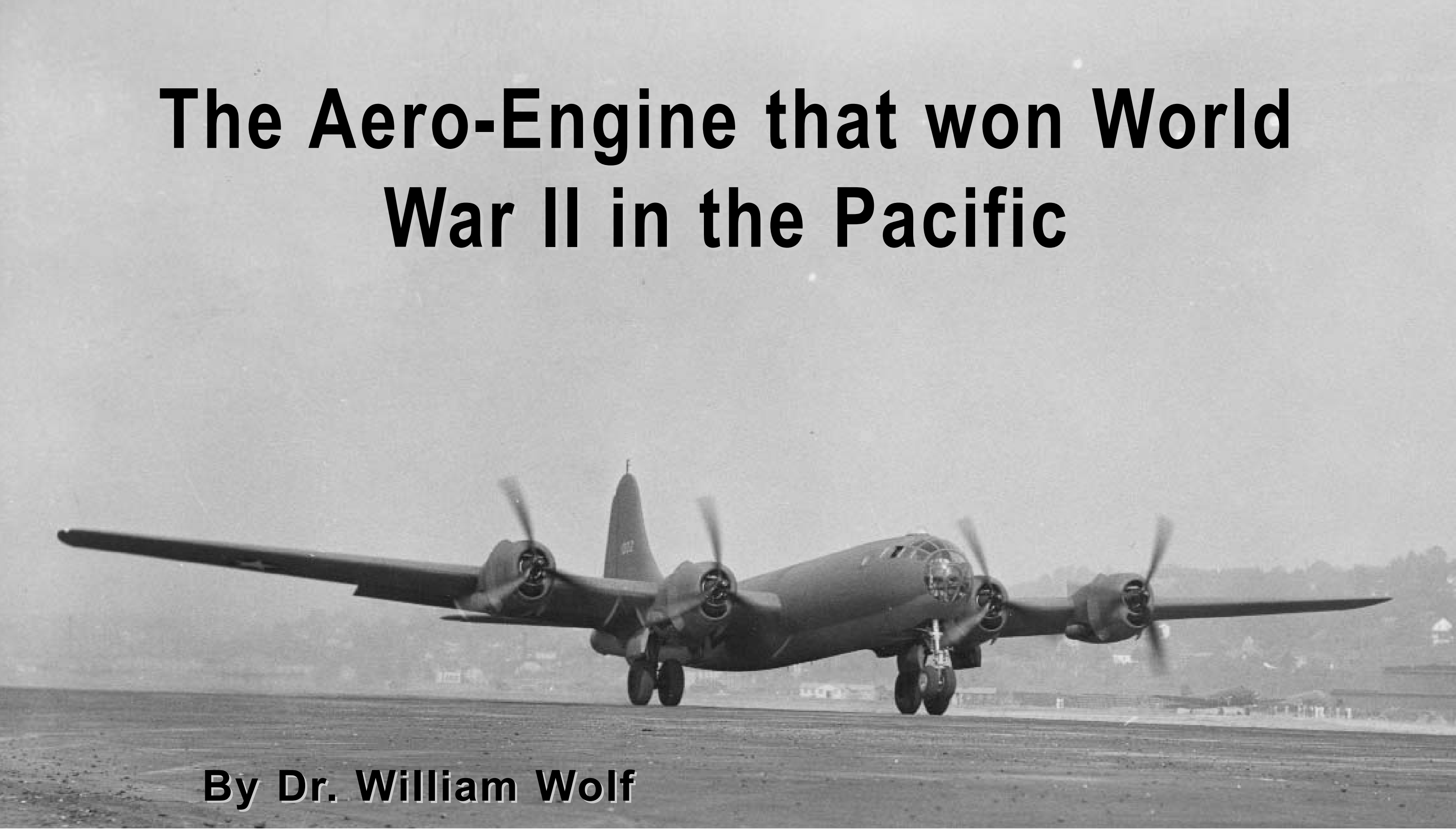
The Aero-Engine that won World War II in the Pacific



By Dr. William Wolf

Boeing XB-29 takes off on its maiden flight on September 27, 1942. Powered by four Wright R-3350 engines, this design would play a key role in the war against Japan. (Boeing photo X22 from the Ed Stoltz collection, AAHS # P000144)

The success of the B-29 program and ultimately the conduct of the Pacific war hinged on the timely development, subsequent dependability, and mass-production of the 2,200-hp Wright R-3350 *Cyclone* engine designed by the Wright Aeronautical Division of the Curtiss-Wright Company of Paterson, N.J.

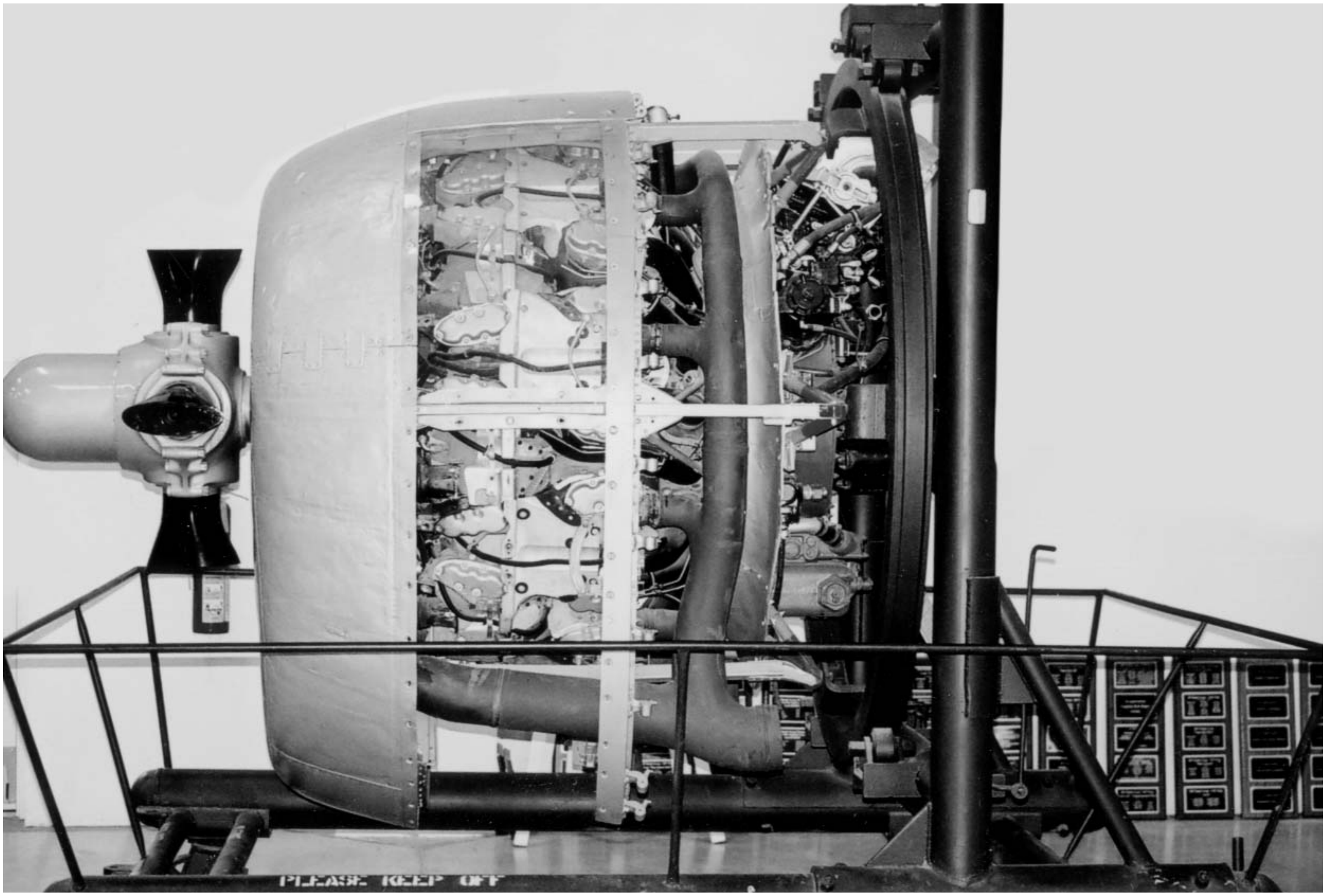
Wright R-1820 and R-2600 *Cyclone* Engines

At a time when Pratt & Whitney dominated American aircraft engine manufacturing with its *Wasp* and *Hornet* engine series, Wright initiated its *Cyclone* engine series in 1923 with a Navy contract for two of the new radial engines. In 1929 Wright merged with Curtiss and by 1932 the two engineering departments collaborated to produce the outstanding 9-cylinder 1,000-hp *Cyclone F* designated the R-1820 that were to power the Douglas airliners and the B-17 bomber. Work on a 14-cylinder engine began in November 1935 and use the hard-learned lessons in the development of the R-1820. The 14-cylinder 1,600-hp Wright R-2600 *Cyclone* was the company's first successful two-row air-cooled radial engine. It was used to power the Boeing 314 Clippers and would become a major wartime aircraft engine used in the AAF B-25 and A-20 medium bombers and the Navy's TBM/TBF and SB2C carrier bombers.

Wright R-3350 *Cyclone* Development

A larger engine was needed to power the B-29 and the Wright engineering department's developmental objective for the R-3350 was to produce one horsepower for every pound of weight. Wright engineers mounted two 9-cylinder *Cyclone* engines together at a 90-degree angle from each other to form a "V" with its open ends facing toward the line of flight to yield a displacement of 3,640 cubic inches. Power from each engine was transferred through a common gearbox that combined the power of the two engines and directed it into the propeller main shaft. While single *Cyclone* R-1820s had flown reliably over millions of airline and military miles the new combined engine presented Wright engineers with a number of problems. The gearbox added weight and there was two of every engine accessory: two carburetors, two superchargers, two air scoops, and dual fuel and oil lines. Although the dual engine was the standard 55 inches in diameter its cowl needed to be much wider to facilitate cooling.

Wright engineers soon realized that the inherent problems of a combination engine were significant and went back to the drawing boards to design an entirely new 18-cylinder 3,350-hp flat engine that would become the company's financial backbone until well after the end of the war. Initially, Wright didn't have enough engineers to devote to the R-3350 project as they concentrated on the R-1820 and its employment in the prewar DC-2 and DC-3 commercial market that would reach 70 percent and the military market for the B-17. Also, at the time the potential and marketability of the R-2600 engine was thought to be greater than the R-3350. The company didn't assign a large number of engineers to it until 1942 when it was compelled to do so by the awarding of the large B-29 contracts.



When Wright engineers began R-3350 development in January 1936 they incorporated as many of the established Cyclone *engine attributes as possible into the new engine following the design and construction details of their successful R-2600. The R-3350 was an air-cooled, duplex engine that had 18 cylinders with two radial rings of nine cylinders positioned around the crankshaft. (Author/Pima ASM)*

As Wright and its parent company, Curtiss, rapidly expanded into huge manufacturing entities Curtiss did not allow Wright management to make high-level decisions. The fact was that Wright executives weren't qualified to assume undertaking a project of the magnitude of the R-3350 and consequently failed to support the project as forcefully as they should have. In the late 1930s under the Army Air Corp's prototype developmental contract system there was no monetary motivation for airframe builders such as Boeing and engine builders such as Wright to hurry the development of their products. Any improvement or innovation in the developmental process was expensive and Wright had to assume these costs knowing that there was no guarantee that the AAC would purchase the engine once it was ready. Wright could expect no financial help from its parent company, as Curtiss had not been profitable in the 1930s. It was not until 1940 when Congress allowed cost-plus contracts that engines could be developed and produced without as much financial risk.

Nonetheless, work went ahead and Wright engineers incorporated as many of the established *Cyclone* engine attributes as possible into the new engine. When it began its development in January 1936 the R-3350 followed the design and construction details of the R-2600. During 1937 and 1938, Wright engineers upgraded and hand-built the new engine in the experimental machine shop. The engine integrated traditional *Cyclone* steel-barrel cylinders with aluminum heads that increased the cooling area. They kept the *Cyclone*'s strong steel crankcase and strong, light magnesium nose and supercharger sections. There were two banks of nine cylinders each with one master rod and eight articulated rods directing piston power into a three-piece crankshaft. A 20-pinion reduction gear directed power into the propeller shaft at efficient speeds and at a weight scarcely over one pound per horsepower. The R-2600 and the R-3350 had the same bore and stroke with the additional displacement gained by adding four additional cylinders (in two rows of nine). The R-3350 was an air-cooled, duplex engine that had 18 cylinders with two radial rings of nine cylinders positioned around the crankshaft. The cylinder heads of the two cylinder rings radiated outward to be cooled by the air stream from the huge propellers. The R-3350 was rated at 2,000 hp for cruising and 2,200 hp for takeoff. The engine was twice as powerful as the

The R-3350 mounted Hamilton-Standard (a division of United Aircraft Corp.) 16.67 foot steel four-bladed, hollow, electric, hydromatic, constant speed, full-feathering propellers, which were the largest fitted to an American production aircraft. (Author/Pima ASM)

R-1820 of the *Flying Fortress* yet its 55-inch frontal engine exposure was the same size as the B-17 and provided equivalent cooling!

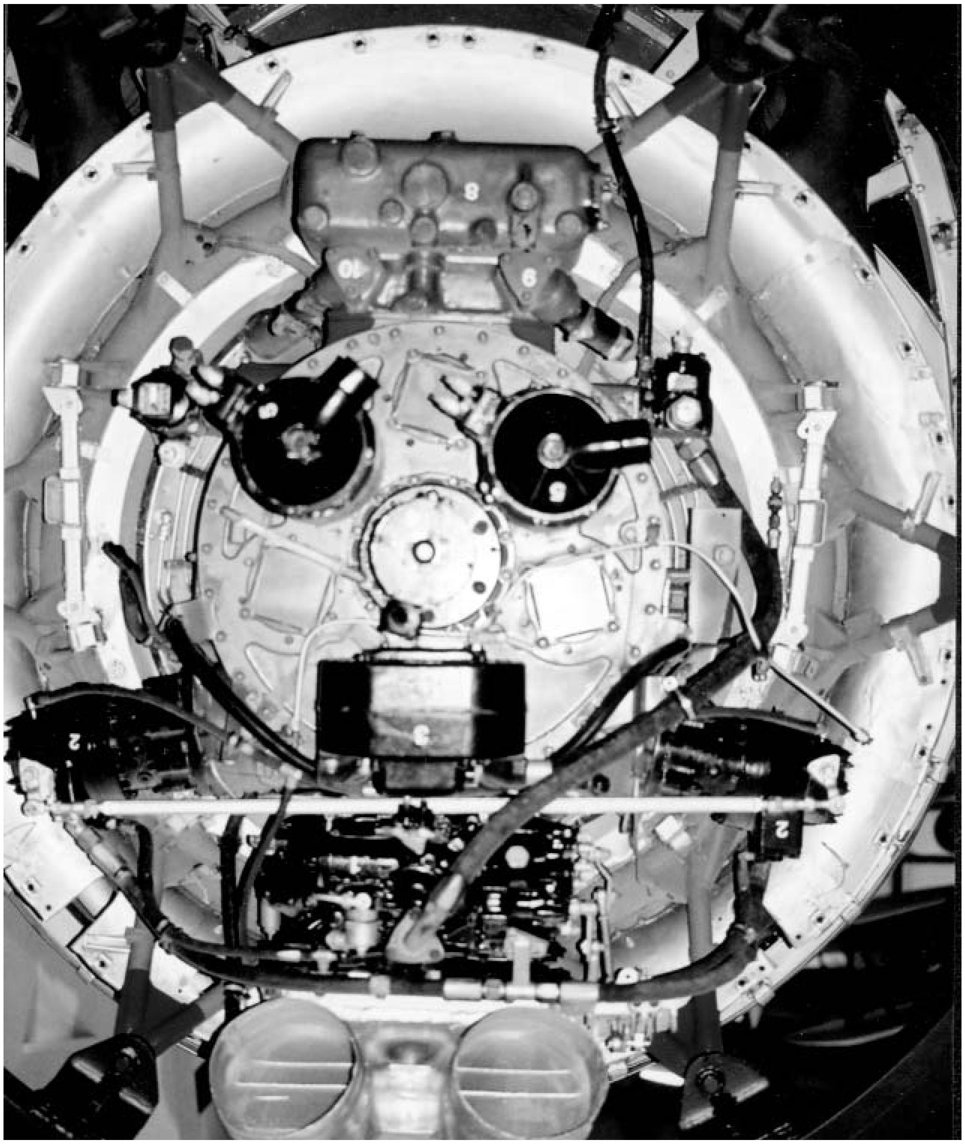
As mentioned, during the late 1930s the R-3350 was a low priority for Wright as the company centered its attention on expanding its R-1820 and R-2600 *Cyclone* engine production. The R-3350 developed slowly from the foundries to the machine shops, to assembly, and finally to the test cells. The testing and development of the Wright engine was very limited and there was no significant production as from 1936 to 1939 Wright delivered only seven R-3350-5s to the Air Corps. When Wright tested the first R-3350 in 1937 the initial problems arose. After running for 135 hours on a test stand the engine's reduction gears failed and this problem was to continue until 1943. In 1939 two new problems with the exhaust valves and the cooling system occurred that also would never be fully remedied during the war. Initially, the R-3350 was scheduled to power the Martin *Mars*, the Lockheed *Constellation*, and the Boeing Model 341 (Boeing B-29 precursor) but it was not until May 1939 that it was first flown in the Douglas XB-19 and tests continued in that aircraft through the summer. In September 1939 the war in Europe began when Hitler invaded Poland and the French and English demand for Wright *Cyclone* 9s and 14s increased dramatically. Wright was faced with a glut of orders for its proven R-1820 and R-2600 engines and in less than two months it built new machine shops to accommodate these orders. These facilities almost equaled the size of the main Wright plant and were in production by early 1940. The continued high engine demand prompted Wright to buy vacant silk mills in the Paterson, N.J., area and these mills were quickly renovated and expanded into six plants and a new foundry to build more R-1820 engines. Wright expanded its main plant Cincinnati, Ohio, that would build 50,000 wartime R-2600 engines and also built its Lockland, Ohio, plant that would be the largest single floor factory in America to exclusively manufacture the R-1820. Later, Studebaker was licensed to build the R-1820 and it eventually built 60,000 to power the B-17.

The B-29 Program

In the Air Force's R-40-B bomber design invitations of January 29, 1940, all five bidding aircraft companies offered their proposed aircraft to be powered by the Wright R-3350 engine: Boeing XB-29, Lockheed XB-30, Douglas XB-31, Consolidated XB-32, and Martin XB-33. The engine had been under contract by the AAC since 1936 (XB-19) and by the Navy from 1937 (for the Consolidated Model 31, Boeing XPBB-1, and Martin *Mars* XPB2M-1). All five bidders had experimental aircraft in development using the R-3350 engine. The reason was that the displacement of the R-3350 was the largest of any contemporary engine and had the potential for the greatest development. There were no other large contending engines under development at the time except the Pratt & Whitney R-4360 and Allison's large liquid-cooled 1,600-hp Allison XV-3420-1 24-cylinder in-line engines. These engines were dropped from consideration as they were in development, were too large and heavy and did not provide any increase in power. So by default, on April 15, 1941, the Air Force issued contract No. AC-18971 to Wright for a future production of 30,000 R-3350 engines, which was the largest and highest priority engine production program of the war.

The R-3350 is put into Production

Wright received its first production order for the R-3350 in May 1941 when the AAC ordered 185 for its XB-29s and YB-29s. With all of the fundamental design changes Wright did not have the engine available at that time and would not have one until December 1941. The R-3350 design was nowhere near ready for the foundries, cutting equipment, and tooling that had been ordered and thus, the government gave Wright a low priority to receive the machine tools and strategic metals that all defense contractors were clamoring after. Fortunately, the War Department continued to support the Wright engine program and the exigencies caused by the Pearl

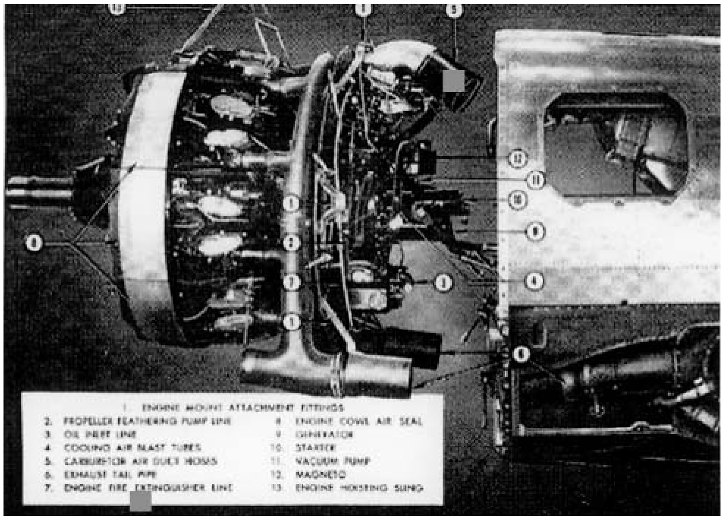


A rear view of the 18-cylinder 3,350-hp flat R-3350 engine that would become the company's financial backbone until well after the end of the war. (Author/Pima ASM)

Harbor attack benefited both the R-3350 and the B-29 programs. To meet the obligations of the R-3350 contract, Wright built a new plant at Woodridge, N.J., exclusively to build the engine and its entire Cincinnati factory production was also converted to the engine. In January 1942, the Chrysler Corporation and its Dodge Division were awarded a $314 million, 6 percent cost-plus-fixed-fee contract to build 10,000 R-3350 engines plus spare parts. When Dodge was awarded its contract there was the opportunity for the company to convert the cylinder head design from the forged to the better cast design but due to delays in the delivery of tooling the existing cast design was continued. In March this contract was increased to 17,653 engines worth $594 million and Chrysler was to construct a new factory on the west side of Chicago.

In the meantime, the B-29 program was in jeopardy and no one wanted to take responsibility. AAC and engine industry reputations and careers were at risk. Curtiss-Wright, the holding company for the engine, had swelled in size from 10,000 employees in 1939 to 140,000 in 1943 and was still expanding to become the second largest American military contractor after General Motors. But in the expansion Curtiss-Wright continued its archaic centralized management practices that controlled the 1939 company. The company's many divisions were not allowed

Consolidated XB-32-CF, 42-108471. The B-32 Dominator *was ordered as a backup in case the B-29 program ran into insurmountable problems. The bomber also was powered by the R-3350 but ran into far fewer engine problems as the B-29 program, which had a higher priority status in development and testing, and the delayed B-32 program benefited from the previous B-29 engine problem solving. The B-32, however, suffered delays due to significant problems resulting from its initial tail design. (USAF photo from the Ed Stoltz collection, AAHS # P000144)*



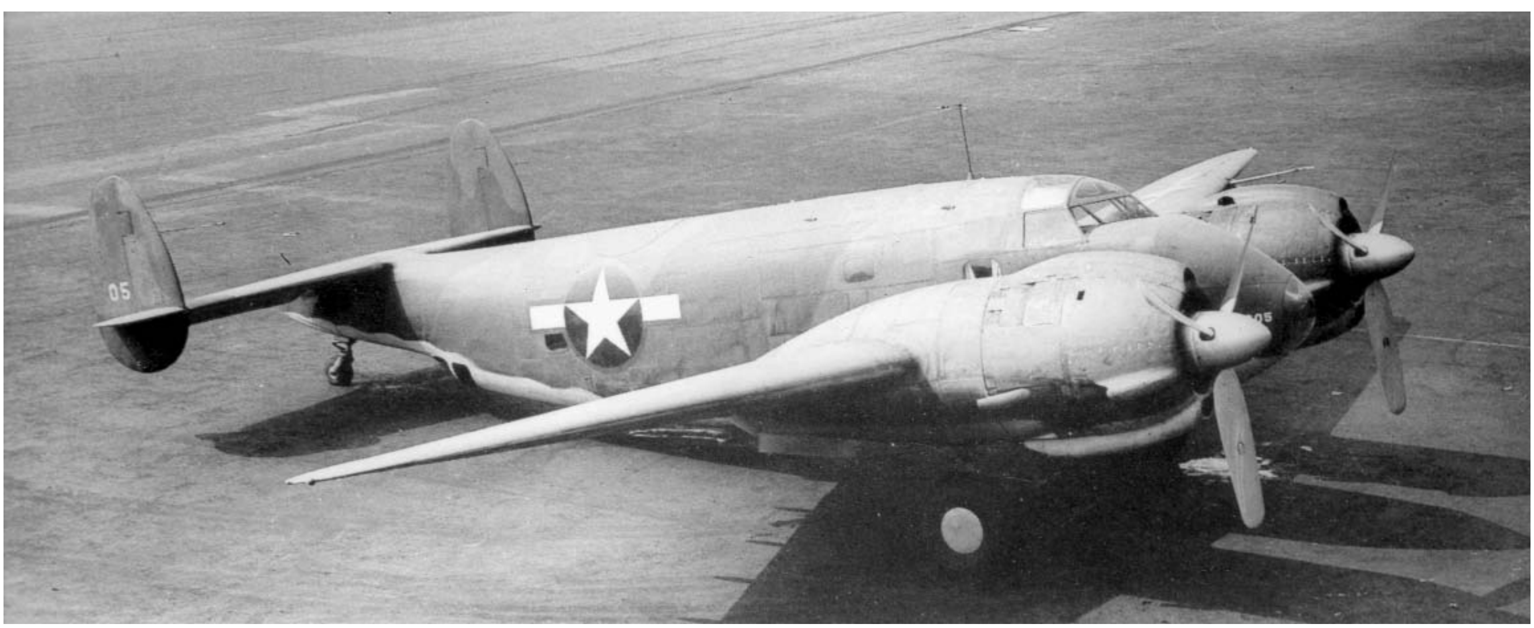
Engine installation into the cowling from official Boeing/USAAF Erection and Maintenance Manuals. The engine was twice as powerful as the R-1820 of the Flying Fortress *yet its 55-inch frontal engine exposure was the same size as the B-17 and provided equivalent cooling! It was the increased gross combat weight of the B-29 that caused the R-3350's cooling problems. (Boeing/USAAF via Pima ASM)*

any autonomy and all decisions were to be made through corporate headquarters in New York. Curtiss-Wright chairman, Guy W. Vaughn, and top executives and investors were concerned over losing control of the company during its rapid wartime expansion as they were looking to the postwar when its military contracts would be canceled and peacetime endeavors would have to be pursued to stay in business. Consequently, military divisions like Wright Aeronautical found it difficult to draw top-flight executives and managers to fill what would be temporary war industry positions.

R-3350 Test Programs and Problems

In September 1942 three flight test programs commenced using the first 25 Wright R-3350 engines. The Consolidated XB-32 first flew on September 7 and was followed two weeks later by the XB-29 while Lockheed flew its two-engine test aircraft called the "Ventillation" at the end of that month. Very little is known about the "Ventillation" except that it was a specially modified twin-engine *Ventura* bomber that was the seventh *Ventura* on the original British contract. It was kept at the Lockheed factory to test nacelle configurations for the Lockheed *Constellation* airliner, thus the combination of names. The *Ventura's* nose had to be shortened so it was cleared by the large diameter propellers. Over the next four months Wright furnished 65 engines for these three programs.

Due to the small number of test hours of the early lower powered engines problems, some major and many minor, soon appeared with the cooling system, reduction gear, and piston rings. The Wright service units spent many hours in the field making changes at Consolidated, Boeing, and Lockheed. Among the long list of problems were instances of extremely high oil consumption on the XB-32 and XB-29. All engines shipped before October 1, 1942, had to have all cylinders removed and lapped. During takeoff the propellers developed runaway rpms measuring in the hundreds. Hamilton-Standard, the propeller manufacturer, and Wright discovered the problem was due to low oil pressure and a stopgap remedy was to set the propeller stop at lower maximum rpms. The final fix was larger internal oil passages and increased oil pressures that would only come with a newly designed, larger engine nose section. Moisture, particularly during rainy periods, was forced into the ignition by outside and inside pressure differentials, and interfered with normal function. To solve this problem Wright used filled harnesses and changed the materials in the ignition components. When the engines were shut down large quantities of fuel were leaked and caused a fire

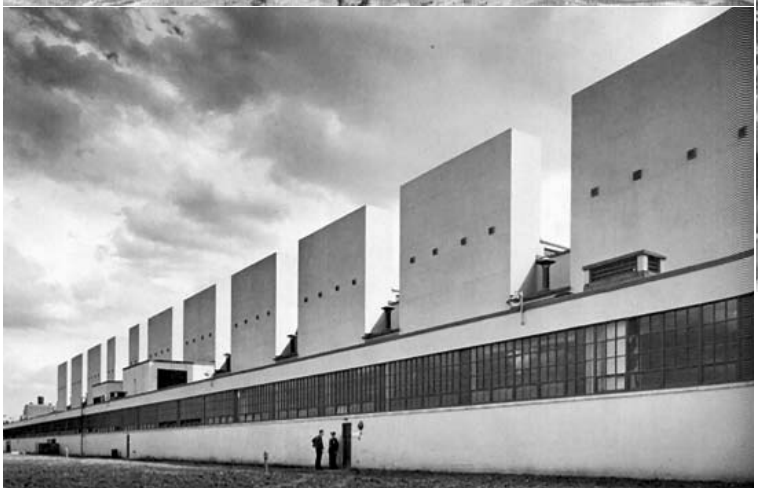


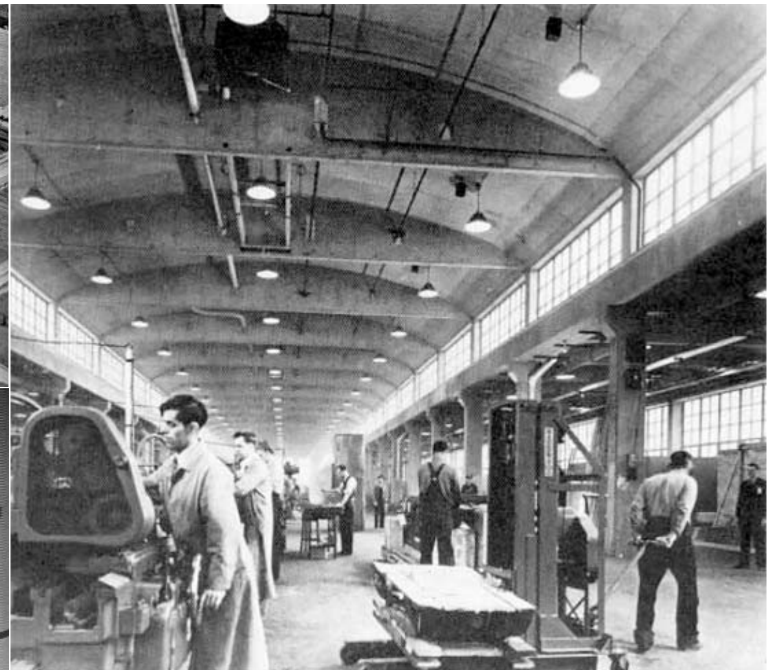
Very little is known about the "Ventillation" except that it was a specially modified twin-engine Ventura *that was kept at the Lockheed factory to test R-3350 nacelle configurations for the Lockheed* Constellation*, thus the combination of names. The* Ventura's *nose had to be shortened so it was cleared by the large diameter propellers. (USAAF)* danger but this problem was remedied by minor field changes. Also, after engine shutdown, oil could leak past the pistons and cause a hydraulic lock at the bottom of the cylinders that could cause damage on the next engine start and special instructions were issued for start-up procedures. There was heat build up caused by the design of the nacelles and from the two external superchargers that could cause exhaust fires. The original carburetor supplier could not maintain its contract numbers and other manufacturers were contracted. Most of these problems were no more than annoying and were usually easily corrected. However, a more serious problem soon emerged, as the aircraft were unable to climb to altitude as the oil pressure decreased to unsafe levels and high altitude tests had to be suspended until an answer could be found. The solution was to increase the size of the external oil line from the rear of the engine to the nose, reducing oil pressure loss. But this fix would not come for four months, and finally on December 31, 1942, the Boeing XB-29 finally reached 25,000 feet. The engines went through several configurations. Two reduction gear and two supercharger ratios were tested, as were several different compression ratios, and two different master rod locations. By the end of 1942, Wright engineers and designers and their counterparts at component subcontractors had solved many problems but in the meantime solving these problems had reduced the total flight testing times on the 26 engines involved in all three manufacturers test programs to only 365 hours and 10 minutes: Boeing XB-29 #1 - 99:35 hours; Boeing XB-29 #2 - 2:08 hours; Consolidated XB-32 - 131:12 hours; and the Lockheed "Ventillation" - 132:00 hours.

The XB-29 #1 required 17 engine changes to reach the 99:35 total hours and the highest flight time for any of its engines was only 19:35 hours. During the test period the aircraft had encountered three total reduction gear failures and one partial failure along with a fractured engine nose section on a ground test engine. The XB-32 results were better because Consolidated used Boeing's engine experience gained earlier in the year. The XB-32s used eight engines to accomplish the 131:12 testing hours and suffered only one reduction gear failure but the maximum XB-32 engine time was also low at 19:34 hours. The Lockheed tests were much better as the same two engines were used for the entire 132 hours of testing and no major problems were encountered during testing. This significant difference between the two-engine Lockheed and four-engine Boeing and Consolidated test models was due to having each XB-29 and XB-32 engine fitted with two external superchargers for each engine nacelle causing a concomitant increase in heat and mechanical complexity. Since the B-29 program had a higher priority status in development and testing the delayed B-32 program benefited from the B-29 engine problem solving, and thus had fewer engine problems during its testing although it had significant early problems resulting from its tail design.

Wright-Woodridge Plant

By the summer of 1943 the Wright-Woodridge Plant #7, near New York City, was built in seven months to exclusively manufacture the R-3350 engine (Dodge-Chicago was nowhere near geared up). Despite the supposedly "exposed" east coast location to possible enemy air attack the large new 1.5 million square foot facility was chosen by Under Secretary of War, Robert Patterson, Chief of Staff, George C. Marshall, and Assistant Secretary of War, Robert Lovett. They chose the site because of the availability of the nearby experienced labor pool and the availability of electric power in the area. By the end of 1944 $70 million had been invested in the Woodridge plant and machinery. Plant #7 was scheduled to build 850 engines per month with the first production engines slated for May 1943 but the first engines were actually shipped in July 1943. The plant was unusual in that it was built entirely of poured concrete from the floor to the supporting pillars to the roof. The first Woodridge engines were hand-built on a single "pilot line" incorporating changes as they went. Wright engineers reasoned that once the design was frozen the final mass production assembly lines could be easily duplicated from the pilot lines. The first engine was built and tested in July 1943 and it was anticipated that by November all the changes could be incorporated into additional pilot/production lines and relatively large numbers of combat engines could be turned out for the first B-29s coming off the Wichita production lines. But during the summer and into the fall R-3350 production met one delay after another and there weren't enough engines to go around for the B-29s that were now going into an intensive training program over Kansas. The uproar reached Congress that demanded to know why the R-3350 project fell so far behind schedule. Gen. Arnold was on the hot seat again with the B-29 project and he made the R-3350 engine the top priority of the Air Force. He ordered a new board to investigate the engine program. Members of the board included future Supreme Court Justice, Col. William Brennan, future mayor of New York, William O'Dwyer, and founder of McDonnell Aircraft, James McDonnell. The board found widespread managerial ineptitude and indifference, and shortages in the labor force. Wright-Woodridge Plant #7 was scheduled to have 8,000 workers on the production line but had only 3,300. Like other companies in the aircraft industry, Wright had problems attracting workers and then holding them after giving them extensive training. Wright's reputation as an employer in the area did not help matters. It had broken a machinist's union strike in 1931 and throughout the 1930s fought the unions and used every means to keep wages low. Wright had planned to attract workers from the New York Boroughs and Newark but a starting wage of $0.60 per hour, the long commute, and better paying jobs in shipyards closer to New York and Newark left Wright with the dregs of the workforce to manufacture the most complex piece of mass produced machinery built at the time. To cope with this unskilled workforce Wright broke down as much production and assembly as possible into procedures that could be done by machines and watched by workers. Other jobs such as testing and inspection were simplified to the lowest common denominator. Wright did little to supervise or train their workers but there was little work to do until the engine design was finalized. Low pay, an ineffective union, and little or no work led to low morale and excessive wasted time, loitering,





The Dodge-Chicago engine testing facility (far left end of the complex in Upper Right photo and Lower Left) had 50 test cells in which each engine underwent evaluation. Every month 2.25 million gallons of fuel were used for testing the engines but most of the power generated by the engines was recaptured by means of a unique power-recovery system which resupplied a quarter of the electric current used by the entire Chicago facility. At the time the facility was built, it was one of the largest (square footage) buildings under one roof. (Chrysler)

absenteeism, and a high quitting rate. By September 1943 the situation at Woodridge became so bad that the War Department sent in advisors to turn things around. An improved training program was established and workers were made to appreciate the importance of their jobs in the building of the engine of the super bomber that would win the war. Unskilled women and Negroes were also accepted into the workforce and Wright transferred 300 skilled workers from other plants and the AAF sent men to train new workers. Interchangeable engine parts were to be manufactured by new subcontractors, at the Dodge-Chicago plant, and at government–financed Wright plant conversions at East Patterson and Fairlawn, N.J., and Lockland, Ohio. Gen. Arnold campaigned to have the government raise starting wages to \$0.70 per hour with raises for time on the job and bonuses for work produced. Perks such as child day care; bus transportation to and from New York City; and cafeterias, banks, and stores also attracted new workers. In October the company hired 1,000 new workers to bring its total to 9,700 of the goal of 13,200. In November it seemed that 800 engines per month could be produced starting in January 1944 and the War Department withdrew its advisors and allowed Wright to manage the project at Woodridge. However, with their departure the problems did continue and production lagged in the spring and early summer after which the production lines finally churned ahead at the scheduled production rates.

Chrysler was to begin engine delivery in March 1943 but there were start-up difficulties in buying the land, contracting the architects, and then construction that did start until June 1942. Chrysler then had problems obtaining engine blueprints and other data from Wright and crucial metals such as aluminum, steel and magnesium were in high demand and short supply. Chrysler President K.T. Keller (shown with Gen. Henry Arnold) was forced to ask for a July 1943 delivery date extension. (Chrysler)

Dodge-Chicago Plant

The Navy had two important flying boat projects consisting of 500 planes each scheduled requiring their variant of the R-3350 engine. The Consolidated XP4Y-1 was to be built at a new factory at New Orleans while the Boeing XPBB-1 was scheduled for its new plant at Renton, Wash. There were discussions on using the Navy engine but Boeing and

A Boeing Company PR photo of an exploded B-29 demonstrating the component structure. Powered by four Wright R-3350s the bomber was truly an innovative air weapon, a true superfortress, as it was the first heavy bomber produced to include a tricycle landing gear, autopilot, tandem bomb bays, pressurized crew compartments, and remote central fire control. It was the forerunner of today's "systems" aircraft. (Boeing via Pima ASM)

Consolidated were unable to make the necessary engine installation changes to use them on their bombers. It was determined that the new Dodge-Chicago engine plant could get tooled up to supply these Navy engines without jeopardizing its initial production schedules. However, the Navy engine production total was finally reduced and the personnel were diverted to the B-29 program.

Chrysler was contracted to build a new factory complex on 450 acres on the west side of Chicago. The George A. Fuller Co. broke ground in June 1942 for 19 buildings covering 6.3 million square feet. Plant #4 that housed the assembly areas and machine shops was the largest individual building in existence. At four million square feet it was larger than the Pentagon. The building was remarkable containing over 1,000 work bays measuring 30 x 38 feet, and located underground were 10 acres of lavatories, nine cafeterias, kitchens and other services connected by two lengthwise and one cross tunnel. The complex also had the world's largest parking lot that was a block wide and a mile long and was capable of parking 8,000 automobiles. The other buildings contained administration, tool and die shops, magnesium and aluminum foundries, light and heavy forge buildings, a heat treating building, two powerhouses, and oil and chip recovery facilities. By 1944, $750 million had been spent on the Chrylser-Chicago development including $175 million on the land, construction, and equipment. Chrysler was to begin engine delivery in March 1943 but there were difficulties in starting up: buying the land, contracting architects, and then during construction. Chrysler then had problems obtaining engine blueprints and other data from Wright that had few to give as the engine was under development. Crucial metals such as aluminum, steel, and magnesium were in high demand and short supply and Chrysler President K.T. Keller was forced to ask for a July 1943 delivery date extension.

Dodge-Chicago continued to run into problems and delays in the fall of 1943. Chrysler was tooling up before the engine had passed its type test and as a consequence suffered an enormous 48,500 engineering changes that, of course, affected production schedules. The immense plant had been finished in April at a cost of $100 million but shortages of machine tools, the relentless engineering changes, and problems in the exchange of technical data with Wright prevented Dodge-Chicago from setting up so much as a pilot production line. After most of the design problems had been eliminated the first Chrysler engine was finally produced in January 1944. The production line was fully equipped and manned and from that point the engine manufacture moved efficiently turning out 18,500 R-3350s by the end of the war. The Chicago operation was enormous with an average of 33,000 workers, 16,000 on the production line (8,800 on the day shift, 6,600 on the night shift and 600 maintenance workers in the morning) and 17,000 on the managerial staff. Women comprised 36 percent of the labor force and Negroes, who toiled mostly in the hot, grueling foundry, comprised 20 percent. The plant commonly surpassed production quotas, building not only engines but also thousands of vital parts for the Wright Woodridge and Lockland plants. In November 1944 the plant turned out a high of 1,079 engines. Dodge-Chicago's initial cost estimate for the R-3350-23 was $25,314 per engine plus a fee of $1,519. By the end of 1944 this figure was lowered to $14,500 plus a fee of $580 and further decreased for late model B-29s/B-32s to $11,537 for the –23 engine and $12,954 for the –57 fuel injected model despite its numerous engineering changes.

The number of new engines that did not survive hours of testing (called "penalty engines") dropped from 31 percent in early 1944 to two percent a year later. So good was the tooling set up at the Chicago plant that its parts were interchangeable with those from the Woodridge plant. When the Woodridge plant production faltered in the spring and early summer of 1944, the Chicago plant made up the deficit. Subcontractors supplied the electrical components such as the carburetors, generators, motors, magnetos, spark plugs, and wiring.

In the Dodge-Chicago plant, the engine production moved from the forge buildings, to the die shops and heat treating building, to the foundries, to the machining, and then to the assembly buildings. The forge shop contained 41 hammers that weighed up to 35,000 pounds and were able to strike with a force of 56,000 pounds to shape rough steel forgings such as crankcases, master and articulating rods, and cylinder barrels. From the forge shops the slowly cooling forgings were moved to the heat treating building where they were subjected to heating, cooling, and an oil bath.

On February 18, 1943, the XB-29 flown by Eddie Allen (shown) crashed due to engine fires that killed its crew and 20 people on the ground. A disgruntled Gen. "Hap" Arnold grounded all XB-29s, and ordered that the special Echol's Board be formed to investigate the engine's problems, conduct tests, and recommend changes. The Air Force Power Plant Laboratory at Wright Field was also assigned to investigate the causes of engine failure and it compiled an extensive inventory of 82 instances of engine problems occurring between October 1941 and the end of February 1943. (Pima ASM)

The Chicago magnesium and aluminum foundries poured more metal than any other plant in the world at capacity. Just as Wright had received its engine contract and was expanding its facilities the company was beset by shortages in strategic materials that threatened to jeopardize the program. The East Coast foundries required core sand that was supplied from abroad and at the time German U-boats threatened the shipment of the supply. A search for alternative domestic sources was conducted but none could supply the volume or quality needed and the foreign sand was scrupulously rationed. Other strategic materials used in engine manufacture were either threatened or in short supply so Wright was forced to develop substitute materials and once developed these materials required many hours of engine proof testing. The aluminum foundry produced intricate castings of finned cylinder heads in sand molds. Originally, Chicago was scheduled to tool up to produce forged cylinder heads that were preferred for greater high altitude cooling but was unable to do so because of the delays they would cause. Wright produced their cylinder heads by forging. Each die was half a cylinder head that was placed into molding sand that was placed into the molding machine that compressed and vibrated the sand around the head die. The die was carefully removed, leaving its form in the sand. A binding liquid was sprayed on the delicate sand mold and then the mold was placed on a slowly moving conveyor that moved it through a furnace for baking to harden it. The hardened mold was inspected and then burned with a blowtorch to keep the poured metal from adhering to the sand. The other half of the cylinder head mold was fitted to its opposite and the two were clamped together. About a 100 steel pins (1,400 in first production molds) were placed in the mold to keep it from breaking during metal pouring. The clamped mold then had aluminum poured into it and after it cooled the clamps were removed and the mold was pried open with a bar. The finned casting was removed from the mold and rough machined, inspected and ready for fine machining and assembly in these automated plants.

The magnesium foundry produced the supercharger housing and the engine nose section. Caution had to be observed in the magnesium foundry due to the metal's inflammability and the magnesium pouring pots were connected to temperature gauges that were constantly monitored. The molds had to be pumped full of sulfur gas and sprinkled with sulfur to keep oxygen away to prevent flare ups.

The main building contained the automated machining and assembly functions. The raw castings were machined and polished and fabricated into subassemblies and moved onward for final assembly. The completed engine was moved off the line on special mounts and run on test cells for several hours. The Chicago engine testing facility had 50 test cells where each engine underwent evaluation. The engines underwent preliminary "green" tests that gradually ran the engine up from 1,400 rpm to full takeoff throttle at 2,800 rpm. Initial green tests lasted seven hours but by 1945 after the engines became more reliable this was reduced to 3.75 hours. Any failure of an engine or its auxiliaries during the green test caused the engine to be transferred for repair and then it was put through the "penalty" tests. After the engine passed the green test it was returned to the factory for disassembly and detailed inspection of every part. It was then reassembled and then retested for another 3.5 hours (later reduced to 2.75 hours) before it was shipped to one of the B-29 factories for installation. Every month 2.25 million gallons of fuel were used for testing but most of the power generated by the engines was recaptured by means of a unique power recovery system which resupplied one-quarter of the electric current used by the entire Dodge-Chicago facility.

The B-29 Program Continues to have Problems

The B-29 program was hindered by the R-3350's problems and consequently slowed its development during all of 1943 and into 1944. On February 18, 1943, the XB-29 flown by Eddie Allen crashed due to engine fires that killed its crew and 20 people on the ground. A disgruntled Gen. "Hap" Arnold grounded all XB-29s, XB-32s, and the Model 49 Lockheed *Constellation* prototype which first flew on January 9. He ordered that a special committee be formed, named the Echol's Board, to investigate the engine's problems, conduct tests, and recommend changes. The Air Force Power Plant Laboratory at Wright Field was also assigned to investigate the causes of engine failure and it compiled an extensive inventory of 82 instances of engine problems occurring between October 1941 and the end of February 1943 on test aircraft in flight (31 problems) or test stands (51). Individual engine problems were examined and Wright suggested a solution and then considered the urgency of the change and its effect on production. Most of the engines suffered high oil consumption but the major problem was with the reduction gear (23 problems) and exhaust system fires (11) along with assorted problems associated with exhaust valves and guides (7), cylinders and pistons (7), and the supercharger drive (7).

The Douglas XBT2D-1, BuNo 09085. This design would evolve into the ubiquitous A-1 Skyraider *powered by the R-3350 and proved itself an effective propeller-driven jack-of-all-trades in the jet age aerial warfare over Korea and Vietnam. (USAAF)*

The Wright Labs concluded that the R-3350 engine design was viable and that in time with some basic suggested engineering changes and given higher priorities it would be dependable and could be put into mass production. Most failures occurred in the reduction gears or nose section of the engine and these had to be corrected to attain high altitude operation and acceptable propeller rpm control at takeoff. The nose casting had thicker walls in some areas requiring larger internal oil conduits, a larger oil pump and sump, and changes to the torque meter. The reduction gear required a new pinion carrier with closer tolerances, which was a very difficult manufacturing process. The study also determined that the new Woodridge plant with its new personnel and machinery and the complexity of R-3350 engine manufacture would require the strict maintenance of quality control and this led to the superlative R-3350 aero engine. The machine tools and mass production assembly lines could not be set up until the suggested changes were completed and the engine design frozen. The parts for the first 13 engines shipped from the new Woodridge plant in July 1943 were machined by only one very skilled machinist working long shifts. There were over 2,000 changes made between January and November 1943 of which nearly a quarter caused expensive and time-consuming revisions in tooling that precluded any mass production.

After the installation of the dual turbo-superchargers in each engine the major potential problem of engine cylinder cooling especially at high altitudes emerged and the lack of time prevented a resolution. The problem was exacerbated when the bombers were made combat ready and their gross weights increased by five to eight tons. Also, each engine had a difference in drag that was caused by opening the cowl flaps to bring down its particular cylinder head temperatures to operating levels. These large differences in the drag of each engine and concomitantly the drag of each aircraft made formation flying very difficult. The Wright Engine Committee had anticipated this problem as it had been remedied in the B-17 powered by R-1820 *Cyclone*s during its high altitude missions over Europe by replacing cast with forged cylinders. The Committee recommended the same change from cast to forged cylinder manufacture in the Wright R-3350 but there was insufficient forging capacity in the country to meet both B-17 and B-29 requirements and the B-29 was sent into operational testing with this critical defect. The XB-32 was a much lighter aircraft and at the time was not encumbered with combat equipment and therefore its R-3350 engines did not have any significant cooling problems. The production B-32s had an empty weight of 60,000 pounds compared to the B-29's 78,000 pounds and gross weight of 100,000 pounds compared to the B-29's 135,750 pounds.

In the spring of 1943 there were only 32 R-3350s available to Boeing-Wichita but they could not be used as Gen. Arnold banned their use after the Eddie Allen crash of the XB-29. The first production B-29s rolled out of the factory without engines. The empty nacelles had cement blocks hung below them to balance the aircraft. The Wright Engine Committee decided that these 32 engines could be modified to "flight status" and the Boeing-Wichita plant made a concerted, round-the-clock effort and by June 29, 1943, the first production test flight was scheduled. For the test flight, work was temporarily halted at the Wichita factory when Boeing employees and Wichita locals came to watch from a hill near the field. The impressive bomber was towed out and the engines thunderously run up in preparation for takeoff. Just after the bomber lifted off smoke billowed out from one engine and the flight had to be quickly aborted. Inspection on the ground showed the problem to be from a tiny oil leak around a small gasket in the engine nose section that flowed back over the hot exhaust and caused the heavy smoke. By July 23, 1943, 143 engines had been shipped but only 12 were the –21 "combat" engines. Fifty of these engines were grounded because their Ceco carburetors needed to be reworked and another 29 were in the Wright service shops

The Lockheed Constellation *- here a Braniff L-049, N2521B, c/n 2082 - was another benefactor of the Wright R-3350. The prototype Model 49/C-69 first flew on January 9, 1943, but was grounded in February after the crash of the B-29. (Photo from the Robert Hufford collection, AAHS # 32953)*

for modification. Once modified only 10 of these engines were declared "combat" ready and were parceled out for flight (six to the Martin Navy program and four to Bell). Sixteen were deemed only suitable for "school" use and ground testing and the other three were used for training or flight spares.

On August 16, 1943, a meeting was held at Boeing-Wichita to analyze and discuss the recent R-3350 tests, particularly the comprehensive cooling tests that had been conducted using the "combat" type R-3350-21s on the XB-29 #1. During ground testing problems were uncovered that would later occur in combat: burnt pistons and discolored, charred, burned, or seized engine parts. Flight tests established that the cowl flaps needed to be wide open for all ground running and partially closed during takeoffs. A revised takeoff procedure, considering the bomber's increased heavy gross weights, was tested and instituted called the "War Emergency Rating." With the increased combat gross weights normal cruise power was not sufficient for climbing and a much higher power setting was necessary and with it came the cylinder cooling problem, even with an auto rich mixture. A minimum climb rate of 180 mph and a 1,400 rpm limit was established to maintain temperature limits.

Problems are solved at Boeing and Wright

But by October 1943, the constant modification orders for both the engine and aircraft put everyone concerned with the programs under great pressure to meet the original date to get the B-29 into combat. Aircraft available for flight training were behind schedule with only 21 B-29s delivered to combat units. The average flight time on these aircraft was about 70 hours (only one plane had 200 flight hours) and only seven had flown with "combat" engines (the highest time on any combat engine was 73 hours). Hap Arnold backed by Secretary of War Robert Lovett went to the White House and the War Department to bolster the B-29 program, promising increased effort and top echelon changes. A major change was the appointment of Gen. William Knudsen, a past president of General Motors, to coordinate the B-29 project. Under Knudsen and with Arnold's influence there would be tangible progress in the B-29 program.

If it were not for the Boeing-Wichita plant's ability to quickly and efficiently incorporate changes in their assembly lines and increase productivity to turn out quality bombers the B-29 program could have become the failure predicted by a few. Boeing made changes on a "routine" basis (e.g., the shortest time without interfering with the schedule) and production was rapidly increasing. Wright was also able to make major engine changes that were accompanied by changes in the model "dash" designation so that it could be easily identified in the field. The first prototype XB-29 used the R-3350-5 that delivered 2,000 hp at 2,400 rpm and was later fitted with the –13 model rated at 2,200 hp at 2,800 rpm. Because of the delays in getting the B-32 into production the first B-29s off the line were equipped with the improved Model -21 and -23 R-3350s. A total of 162 R-3350-21s that also delivered 2,200 hp at 2,800 rpm were ordered for the YB-29s (B-29 service test models), the XB-32s (the Consolidated backup bomber to the B-29), and the XC-97s (Boeing cargo spin-offs of the B-29). The –21A (2,200 hp/2,800 rpm) was installed on the YB-29s and the early B-29s. The first R-3350 to be built in quantity was the R-3350-23 of which 1,366 were ordered. Early B-29 production models used the R-3350-23 model built by Dodge-Chrysler that delivered 2,200 hp at 2,600 rpm. Once the problems of the –23 engine were remedied it was replaced by the –23A "War Engine." These -23A engines differed from the plain –23s as they had aluminum cooling fins pressed into the cylinder barrels instead of the machined steel fins. A total of 22,385 R-3350-23As also built by Chrysler, were ultimately ordered. Late production B-29s and B-29As used the improved R-3350-57 engines that delivered 2,200 hp at 2,800 rpm. The evolution of the R-3350 engine was slow and arduous and was the major factor in influencing the development of the B-29. The problem with the Wright engine was not with the engine design as much as the accelerated time constraints it was placed under as part of the B-29 project to solve the problems that were inherent in the development of any new engine.

By the fall of 1944, the Chrysler and Wright plants were exceeding the demand for the R-3350, not only for the B-29 but also for the other aircraft mounting the engine: the Martin *Mars* Flying Boat, Lockheed's *Constellation* transport, and the Douglas BTD-1 *Destroyer* carrier borne attack plane which was the precursor of the AD-1 *Skyraider*. Ultimately there were so many engines produced that it was easier and less expensive to replace a worn engine with a new one than to overhaul it. By August 1944 R-3350 production had to be decreased as engines had to be stored as the supply outstripped the demand. In all, Wright and its licensees produced over 281,000 engines of all types by the end of the war. Dodge-Chicago supplied the majority of the R-3350s manufactured in WWII, 18,413 as compared to Wright's 13,791.

The B-29/Wright R-3350 Legacy

While USAAF B-17s and B-24s and RAF *Lancasters* pulverized German cities, they did not have the same effect on the outcome of the European war as did the B-29s powered by Wright R-3350 engines on the Pacific war. Despite its numerous teething problems, from the time of its first test flight on September 21, 1941, until its first combat mission over Bangkok on June 5, 1944, the *Superfortress* had one of the shortest gestation periods of any combat aircraft, fighter or bomber. Although the B-29 forever will be linked to the atomic bombings of Hiroshima and Nagasaki as the "A-Bomber" and be given credit for ending the Pacific war, the bomber's missions from the Marianas had previously devastated the Japanese homeland to the brink of submission. The B-29s of the XXI Bomber Command were responsible for severely damaging or almost totally destroying 65 major Japanese cities; destroying 178 square miles of industrial urban areas; destroying 83 percent of oil production; destroying 75 percent of aircraft engine production; leaving 330,000 Japanese killed and 476,000 wounded (direct civilian casualties in the concentrated 10 month span of B-29 attacks were more than Japanese military forces suffered in three and half years of war); leaving 8.5 million civilians homeless; and 21 million displaced.

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This article was excerpted from my recent books in which a complete bibliography for this article may be found:

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About the Author

Dr. William Wolf was a dentist for 22 years in Fort Lauderdale, Fla., before retiring at the age of 45 to pursue his aviation interests and outdoor pursuits of hiking, mountain climbing, road and mountain biking and sea kayaking. But Wolf's lifelong hobby has been WWII aerial combat and over the past 35 years he has collected over 15,000+ books and magazines, 10,000+ photographs, along with hundreds of reels of microfilm, and over 800 videos on the subject that are housed in his enclosed, air conditioned garage (while his wife's car sits in the hot Arizona sun). He probably has nearly every book written on WWII aviation and complete collections of every aviation magazine published since 1939. Also included in his collection are many hundreds of aviation unit and pilot's histories, crew manuals, aircraft technical, structural and maintenance manuals. His microfilm collection includes vintage intelligence reports, USAF, USN and USMC group and squadron histories, complete Japanese Monograph series, U.S. Strategic Bombing Surveys as well as USAF Historical Studies. Over the years he has been fortunate to meet many fighter aces, other pilots and fellow aviation buffs who have shared stories, material and photographs with him (he has over 5,000 photos of fighter aces alone). He has made many multi-day expeditions to various military libraries, museums and photo depositories with his copy machine and camera, accumulating literally reams of information and thousands of photographs. He also developed thousands of rare photos from microfilm negatives and from other sources. Over the past six years, in particular, he has made a concerted effort to use this information and has had five books on WWII air combat published by Schiffer Publishing.