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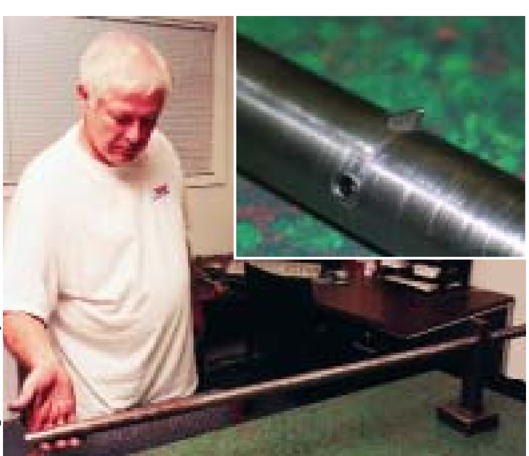
The Wright Stuff

To commemorate the 100th anniversary of flight, a company has replicated the Wright brothers' 1903 airplane engine—and their machining techniques.

On Dec. 17, 1903, the Wright brothers accomplished the world's first flight of a piloted, powered aircraft. The key to their success was mastery of aerodynamic control. Years of experiments with kites, gliders and a homemade wind tunnel, as well as numerous hours spent watching birds fly, convinced Wilbur and Orville Wright that powered flight required active control in three dimensions. The year before, they had successfully built a glider that had a front elevator to control pitch and a movable tail to dictate yaw, and it employed wing warping to handle roll.

To complete their aerodynamic achievement, they required a light, reliable source of power. The Wrights calculated that the engine should weigh less than 200 lbs. and produce at least 8 hp. When requests to a dozen or more manufacturers for such an engine went unfulfilled, the Wrights turned to their bicycle shop "mechanician," or machinist, Charlie Taylor. Together, the three designed and manufactured a 180-lb. aluminum monoblock gasoline engine with four cast iron cylinders set horizontally.

Possessing a 4"×4" bore and stroke, the engine displaced about 200 cu. in. and produced about 12 hp at 1,000 rpm. Connecting rods were made of steel bicycle tubing with bronze ends. Inlet valves were spring-loaded and suction-activated. A chain-driven camshaft operated the exhaust valves. The water-cooled engine had a tall radiator between the wings. The cooling system worked by thermal convection without a water pump.



All images: B. Kennedy

Hesler displays the 5' boring bar he used to align-bore the engine block. Inset: Closeup of a section of the bar showing the carbide bit.

There may have been a rudimentary oil pump, but splash feed provided the majority of the lubrication. Carburetion was a "hot-tube" system in which fuel dripped from a small overhead tank, through a tube, into a plenum and onto the engine's hot water jacket. As the heat vaporized the fuel, it was sucked into the cylinders; there was no throttle.

After a battery provided the ignition voltage for starting, a low-tension magneto supplied power to breaker points within each combustion chamber. When a cam opened the points, the resulting spark ignited the gas vapors.

The engine ran hot, noisy and rough. As it ran, its power decreased. The engine's longest in-flight running time was 59 seconds, on the fourth and last flight of that historic December day. After that flight, a gust of wind toppled the airplane, damaging it and the engine.

The broken motor was cannibalized for parts, and later rebuilt, with different parts, for display purposes. Although crude by today's standards, the engine was innovative for its time and accomplished the goal of its developers.

Anniversary Replica

In recognition of the 100th anniversary of the Wright brothers' triumph, organizations worldwide are producing replicas of the Wright 1903 Flyer. One of the groups, the Dayton, Ohio-based Wright Brothers Aeroplane Co., was founded in 1999 by woodworker, author and aviation archeologist Nick Engler. The nonprofit WBAC has constructed replicas of the kites and airplanes the Wrights made between 1899 and 1905, and displays them at presentations for schools and other groups.

While building a replica of the 1903 airplane, Engler obtained a set of castings for the engine block and other components from Sand Castings of (Shapleigh) Maine, a metalcasting job shop. He asked machinist Terry Hesler to look at the castings and determine if he could machine them, fabricate other parts and produce a working engine. "I needed a good machinist to help me build the Wright engine," Engler said, "Terry stepped up to the plate and said, 'I'll do it.'"

Reverse Engineering

The first problem Hesler faced was a lack of accurate drawings. The Wrights and Taylor designed the engine piece by piece, sketching each component and pinning the drawing above the workbench. When a part was completed, the sketch was thrown away.

It wasn't until 1928 that a full set of engine drawings was made by the Kensington Science Museum in England. Those drawings, however, were done without completely dismantling the engine (which, as noted, was not totally original to begin with), so many of the dimensions were inaccurate. Other sets of drawings followed, but these were adapted from the first set or based on later-model engines.

The lack of accurate drawings made Hesler an ideal machinist for the project. In addition to rebuilding machine tools and making production runs of parts, Hesler Machine Tool, Dayton, also provides reverse-engineering services to recreate components for which drawings no longer exist.

The Mechanician's Role

One of Hesler's resources was a book by retired machinist and master model maker Howard DuFour. DuFour spent 14 years researching and writing "Charles E. Taylor: The Wright Brothers Mechanician." In addition to telling the absorbing story of a life that stretched from just after the Civil War until the Jet Age, the biography describes in detail Taylor's work to build the engine with only limited technology.

The Wrights' bicycle shop did have a 14" Putnam lathe, a 20" Barnes drill press and a 26" Crescent bandsaw. As a result, the Wrights and Taylor designed

Wright Brothers Aeroplane Co.'s replica of the Wright 1903 Flyer on display at Carnegie Mellon University in Pittsburgh.

Closeup of one cylinder's connecting rod and crankshaft journal. At the top is a cylinder that was threaded and screwed into the engine block.

the engine to suit the lathe they had to use to produce it. "That's why it was a laydown engine," said DuFour, "so it could go on a lathe."

DuFour explained that Taylor used riser blocks to lift the lathe's headstock and tailstock to increase the capacity to more than 24". Taylor also specified that the engine block be cast with 15⁄16" holes in the crankcase directly opposite the cylinder bores. When the block was mounted horizontally on the lathe, a shaft could pass from the headstock to the tailstock directly through the crankcase and a cylinder. Essentially, the lathe became a horizontal mill. Taylor used this setup to machine the block to accommodate the cast iron cylinders and to thread the block so the cylinders could screw into it.

Replicate vs. Duplicate

Other builders of replica engines sought to exactly duplicate the 1903 original. Hesler took a slightly different approach. He said the original engine was "not very sophisticated; this was 1903." It would run, he said, only a few minutes at full power. "When it was fired up it had 12 hp, by the time it began flying it had about 10 hp and when it quit it had 8 hp."

Early gasoline engines mimicked steam engines, and the 4"-dia., long-skirt cast iron pistons were heavy. "With all that weight flying around on the crankshaft, they generally blew rods," Hesler said.

Although Hesler wanted to keep the engine as authentic as possible, "inside we made it a little better so it can run longer," he said. Accordingly, he put aluminum automotive pistons in his replica.

Hesler also upgraded from the 1903 engine's poured-babbitt crankshaft bearings. With the early method of creating bearings, molten lead-based babbitt was poured around the crankshaft journal, half the diameter at a time. After the babbitt cooled, the crankshaft was removed and the bearing was scraped to achieve the required clearance.

"Taylor put the liquid babbitt [around the journal], set in the crank and lined it up the best he could to get it to run straight with the rods," Hesler said. To ensure exact crankshaft alignment and bolster his engine's reliability, Hesler align-bored the block and installed bronze bearings.

Building the Block

The original block was cast in an aluminum-copper alloy. Considering today's growing market for near-net-shape castings, it is notable that the 1903 block was cast to final size. The reason, according to DuFour, was that turn-of-the-century metalworkers did not have machine tools advanced enough to remove much excess material.

Frank Mekkelsen, owner of Sand Castings, said producing the block casting was a challenge right from the start. As others had found, the measurements were off in the existing engine drawings. Mekkelsen had a toolmaker redo the drawings, then had match plates, or mold forms, CNC machined from plastic.

When creating the sand molds, Mekkelsen said, the biggest problem was "getting the metal to go where it was supposed to go. There were so many cores in the mold, and some of the plates on this casting were as thin as ⅛". I had to have special gating in the mold, and it took me about three tries until I got a good one."

Mekkelsen cast the block in an A-356 aluminum alloy, which pours easily. He said he doesn't supply machining recommendations for short-run products like the block because every one is different. But Helser noted that the alloy was quite machinable.

Boring Precision

Recalling Taylor's horizontal machining setup, Hesler machined the block using a right-angle attachment on a manual Bridgeport with a 54" table.

To align-bore the block, he made a boring bar from 1¼"-dia. round steel stock, measuring 5' long. A hole drilled in the middle of the bar held a carbide bit, adjustable with a setscrew. A carriage supported one end of the bar, and the other end was chucked in the right-angle attachment.

Hesler bored the block in a series of steps. "First, I barely skimmed the journals, just enough to get them straight," he said. For each pass, he moved the setscrew about a quarter of a turn, "maybe 0.003" to 0.005"." Passes were repeated until the casting marks disappeared, producing a 1.400"-dia. bore. Then, with extenders, Hesler drilled the bore with a 1.480"-dia. drill.

Next, an HSS reamer, also on an extender, reamed the journals to 0.005" under 1.5". Then Hesler honed the bore with a bar consisting of a 4'-long piece of 1½"-dia. stock with stout handles welded onto it. He put a lapping compound on the bar and tightened the bearing caps until the bar was hard to move. He pushed the bar back and forth until it moved freely, then further tightened the caps.

Lapping continued until the honing bar slid in and out fairly easily with the bearing caps fully tightened. "You have

Side view of the engine showing the combustion chambers, the can-like opening for the hot-tube fuel intake system and the suction-activated intake valves on the top, and the cam-operated exhaust valves below.

to remember that 1½" round stock is generally 0.001" to 0.0015" undersize," Hesler said, "and that your bearings always come in about 0.002" oversize."

When the bar moved easily, the bore was the right size for the bearings.

Fitting the Bearings

Hesler said he used an "old machinist's trick" to fit the bronze main crankshaft bearings. The engine required five bearings, but Hesler bought 10 with a 1½" OD and 1⅛" ID. He bored them to a 1.216" ID. "The journals on the crankshaft were machined to 1.212", giving me around 0.004" clearance, 0.002" per side, which is pretty good," he said.

After the bearings were bored, they had to be cut so one half could be mounted in the block and the other half in the bearing cap. However, Hesler pointed out, if he simply cut the bearings in half they would no longer be 1½" in diameter, "because you're going to lose your cut. That's why I bought 10. I cut them off-center. Then we milled [the larger 'halves'] exactly to ¾", ±0.001"." Hesler discarded the 10 smaller halves, but milling the other 10 produced five 1½" OD pairs to match the holes he had bored in the block.

Fabricating Cylinders, Crankshaft

Hesler didn't have cast iron castings for the cylinders, so he fabricated them from 5½"-dia. 1018 steel tubing with ¾"-thick walls. He welded a top on each cylinder and threaded the outside so it could be screwed into the block.

Like Taylor, he machined the block horizontally to accept the cylinders, applying a special carbide boring tool. Then, with a hand-made steel 5½"-dia. tap, Hesler cut threads in the block to match those on the cylinders. He hand-turned the tap with a 6'-long breaker bar.

Another instance where Hesler varied from Taylor's methods was in fabrication of the crankshaft. Taylor made his crankshaft from a solid piece of 1⅝"-thick, 6"-wide and 30"-long steel. He marked the shape of the crank on the steel and "chewed" out the excess material with a drill press.

According to DuFour, Taylor held the crankshaft with offset bars on the lathe and turned the journals.

Hesler said he couldn't afford to spend that amount of time on the crankshaft, so he welded it from 1018 steel, using three pieces of 1¼"-dia. round stock and eight pieces of 4"×1½"×⅞" flat stock. He bored 1¼"-dia. holes through each 1½" end of the flat stock, assembled the parts and welded them.

Removing the round stock between the connecting rod journals produced a flat crankshaft with four connecting rod journals and five main bearing journals. After being ground and nitrided, the crankshaft was ready to accept the rods.

In the 1903 engine, cast bronze rod ends were threaded onto steel sleeves, which were then slid into steel tubing and brazed. "We did it the same way," Hesler said, "except I welded mine … because there are going to be some guys flying in this plane, even if they are not going to be far off the ground."

Getting It Running

Hesler made many other components necessary to complete the engine, including the exhaust and ignition cams and the ignition breaker points. He scrounged other parts. The intake valve springs, for example, were steel coils—purchased at a flea market—originally used in a car's gas filler neck to prevent siphoning.

Hesler and a staff member test-run the engine with a dummy wooden propeller.

After assembly was completed, the challenge became timing the engine. "Because we were doing it as much as we could in the same way Taylor did it, we ran into the same problems he did," Hesler said.

Using a degree wheel on the camshaft gear, Hesler said timing by trial and error took about a week. Overall, the engine building process consumed about 6 months, with interruptions dictated by the shop's normal workload. Hesler estimated that he has spent about $20,000 on materials and shop time for the engine, not including Engler's cost for the castings.

The Wrights were excellent aerodynamicists, managers and practitioners of the scientific method—not master machinists. But, as DuFour said, "Genius begets genius, and Charlie Taylor was a genius in his own right."

Engler concurred that, "The Wrights probably could not have done it without Taylor. He did not design the engine, but he probably made it work."

Like the Wright brothers and Taylor, certain people get together and make history. In this case, Hesler and Engler got together and replicated one of history's landmark machines.

The following companies contributed to this report:

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