Supercharging a Comanche 400 (May 2004)

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The quest for speed is very addicting and sometimes illusive. I have a nasty (and fun) habit of making airplanes go fast. (Ask my wife how fast her Comanche 180 is now!)
In my quest to make my Comanche 400 faster, I started a project two years ago to install a belt driven supercharger on my Lycoming IO-720. Two weeks ago, I finished the final flight tests and transferred all data to an Excel spreadsheet with some interesting results.

My goal was to reach 300 mph TAS at altitude. But because of a few surprises, the airplane would only go 281 mph TAS at 16,000 feet. At no time was the engine pushed past 30 inches of manifold pressure. Nor was the indicated airspeed past the structural limits of the airframe. At altitude, the indicated airspeed was well below the 250 mph Vne of the airframe. Part of the fun of flight-testing in the flight levels was watching my ground speeds vary between 300 to 350 mph as I would catch the big tailwinds aloft. I could easily cross a state line or two pretty quickly.

One of the biggest challenges on this project was to engineer the changes such that I could have three different variations of engine/cowl configurations.
(1) A supercharged version with the extended nose bowl and composite prop;
(2) a normally aspirated configuration with the extended nose bowl and composite prop, and;
(3) one with the original Piper nose bowl and Hartzell prop.

I fabricated all parts so they could be quickly interchangeable.
Before I started the project, I met with the FAA in Wichita several times to work out an acceptable plan for putting these components on my airplane. I know you have heard the stories about working with the FAA. However, from the beginning, I have had nothing but praise and admiration for the Wichita FAA. They have worked with me beyond belief and have helped with direction of the project many times. I also have many thanks to Hans Neubert and Bob Weber for their help and support on this project.

Three years ago, I began planning the installation of the supercharger. Just as I was about to start the project, I ran into a couple of guys from North Las Vegas who had just finished installing a supercharger on their Lancair Legacy. They had the resources to build the mounts and other system components. So instead of duplicating all their work, I joined with them to install the system on my Comanche.

Because the supercharger was mounted on the front of the engine, it was necessary to extend the nose bowl and prop hub four inches to provide the required clearance. The supercharger was mounted high so the oil could gravity-feed back to the engine. If the supercharger were to be mounted low, a sump pump would be needed to pump the oil back to the engine crankcase. A new nose bowl had to be built from scratch. We started with a Lancair IV-P nose and cut it to fit my 400, then produced a mold, which allowed us to build a carbon-fiber nose bowl final product. The new nose bowl has round inlets that are half the volume of a stock 400 nose bowl.

Previous improvements I made to Piper's cowl, especially in the exit air area, allow the greatly reduced inlet area to work well with no heating problems to cylinders or oil temps. The improvements worked so well that the cowl flaps can stay closed in all flight profiles. Once the nose bowl was fitted, the next task was to extend the propeller.

The propeller was the biggest challenge of all. Hans calculated that the Polar Inertia Moment of the Hartzell propeller was very bad with a 4-inch extension. I had not heard of Polar Inertia Moment until Hans brought up the subject. Extending the prop 4 inches with an extension could result in blade separation! So now the project was dead without a new prop.

I called Hartzell several times about building and testing a new, lighter prop for my 400 and they were mostly rude and, in so many words, told me to go away.

I found a couple of composite companies that were willing to work with me, but didn't have the equipment for the very important vibration test, which is a requirement for FAA approval. Then I met

Gerd Muehlbauer, president of MTPropeller, and after several long conversations, we worked out a plan for developing and testing a new prop. From the beginning, the plan was to fly NAA speed record runs in the flight levels with the supercharger. So I asked Gerd to build a prop that would be efficient at FL250. The funny story about that prop was when I took it on its first test flight, the plane would barely climb.

On a 4,000-foot runway I could barely clear the trees at the end. Anyone who knows the Germans knows they are very precise at everything they do and take you literally on what you say. I called Gerd to express my concerns on the lack of climb rate and he said, “You told me you wanted a prop that was efficient at 25,000 feet and it is!”

I told him I assumed the prop would climb and he reminded me I didn’t request that. He was gracious to build me another prop and install it free of charge. He also sent a team of engineers over from Germany to do the prop vibration test on my 400. The prop passed the vibe test and was approved in Germany; the paperwork is now in the United States waiting on the final FAA flight test in Wichita. MT-Propeller has been a wonderful company to work with and has gone beyond the call of duty to approve this prop. How nice it would be if we had more composite props and fewer Hartzells on our Comanches. The prop is 78 inches in diameter, scimitar shaped and 30 pounds lighter than the Hartzell. Flare to landing is much better with reduced weight on the nose. I actually started making several good landings in a row with the lighter prop!

The composite prop also has no ADs and no service requirements other than the normal leading-edge inspections. If a rock dings the stainless steel leading edge badly, the cost to repair it is one-third the cost of a Hartzell. Another big plus is that my rate of climb increased from 1,500 fpm to 2,000-2,500 fpm normally aspirated, and the takeoff roll was much shorter. Baffling was another big challenge. The nose bowl was extended 4 inches to accommodate the supercharger. This created a large cavity between the nose bowl and engine. Hans informed me it was a huge source of cooling drag. When Hans talks, I listen.

So I built a carbon fiber air inlet on the co-pilot’s side and baffled it in. Then I baffled an air “path” over the supercharger. Since the supercharger is belt-driven, it’s impossible to stop all the air from passing around the belt into the nose bowl cavity. However, I baffled it tight enough that most of the air would be stopped.

In the normally aspirated configuration, another set of baffles had to be made to fit where the supercharger was installed. All versions came out very nice – just like factory.

Several flight tests were scheduled with different supercharger and normally aspirated configurations. I had a choice of three pulley sizes on the supercharger to spin it slower or faster to make more manifold pressure. And I had two configurations of flight-testing normally aspirated – one without ram air and one with ram air.

Initial flight tests produced some disappointing surprises, especially at low altitudes. Takeoff roll was much longer and rate of climb was reduced by 1,000 fpm. After a few more precise flight tests, it became obvious that the horsepower to turn the supercharger was more than reported. As a matter of fact, it takes 100-plus horsepower to spin the supercharger. I did some comparison flights at different altitudes to compare normally aspirated numbers to supercharged numbers. My speed with the supercharger was 25-plus mph slower with equal manifold pressure numbers normally aspirated, and my fuel burn was up 8 to 10 gph.

Also, the original air inlet box from the North Las Vegas guys was restrictive; the manifold pressure would never peak. So I built a new version of the air inlet box and solved that problem. However, I had an engine miss from both air boxes that I finally diagnosed as compressor stall. I’ll talk a little more on that subject later in this article.

Next, I installed temp probes in the supercharger discharge air and found that the discharge temps with the 3-inch pulley were in the 230-degree range on climb and descent and in the 200-degree range in cruise depending on altitude and OATs.

With the 3.5-inch pulley the discharge temps were in the 190- to 200-degree range in climb and descent and approximately 170 degrees in cruise depending on altitude and OATs. The 3-inch pulley spins the supercharger at approximately 45,000 rpm and the 3.5-inch pulley spins it at about 36,000 rpm. I had a 2.5-inch pulley that would spin the supercharger 56,000 rpm, but found my speed numbers were going backward with the extra load of turning the supercharger. The more the supercharger spins the more manifold pressure I can make.

With the additional inlet heat from compression, the engine was letting me know it was unhappy with high CHTs, high fuel flows, and a feeling that the engine was in a real strain. If I wanted to regain lost power due to heated inlet air from the compressor, I would have to install an intercooler. It was previously reported that supercharger discharge temps would only be 80 degrees F above ambient, but that turned out to be false, too.

At 17,000 feet with an OAT of 36 degrees F, my supercharger air discharge temps were in the 195-200 F degree range in cruise.

As you know, there is a limited amount of space under the cowl of a Comanche 400. Therefore, an airto- air intercooler with associated plumbing was out of the question. I had to find a product that would fit. I then could engineer the plumbing around it. I found a block charge cooler (11-inch by 4-inch by 4-inch) and built the inlet and discharge manifolds in such a way that the intercooler fits between the supercharger and the engine. I welded the over-boost valve onto the air-charge cooler, along with some pressure ports for upper deck pressure and temp probe ports.

The whole unit weighs 7 pounds, and is much more efficient than an air-to-air intercooler. The pressure drop across the core is .25 psi. Anyone who understands intercooling knows that on some air-to-air intercoolers the pressure drop is sometimes 3 psi. And 1 psi equals 2 inches of manifold pressure. That relates to a lot of manifold pressure drop on an air-to-air cooler!

Since I didn’t have the luxury of having twin blowers (like dual turbo chargers), I had to find a way to keep the performance at peak with my one blower (supercharger), and the air-to-water intercooler I designed was perfect for the job.

The intercooler system works as follows: There is a 15-gpm in-line water pump (weighs 3 pounds) that circulates the water from the expansion tank to the intercooler. From the intercooler, the water goes to the secondary heat exchangers (two small radiators) and back into the expansion tank. The total water/ glycol mix in the system is about 2 gallons. The water temperature stabilizes at a specific temperature and continues to circulate.

As far as power management, it looks like for every 14-15 degrees F, the intercooler cools the inlet temperatures from ambient; the power should be pulled back 1-inch manifold pressure to maintain equivalent percentage of power.

As far as overall weight and balance, since the propeller is 30 pounds lighter, the overall weight difference is estimated to be +15 to +20 pounds for the whole project. Putting that into perspective, the original STC for twin turbochargers on the Comanche 400 allowed for +56 lbs on the nose.

I tried two different versions of the heat exchanger – one in the tail and one in a P-51 style belly scoop. With the belly scoop installed, the airplane lost 10 mph and didn’t give me much more cooling efficiency than having the heat exchangers in the tail. It took quite a bit of work to get the flow rates and heat exchangers working efficiently. Thanks again to Hans for the technical input. The belly scoop really looked cool on the 400!

With all the systems in place and working well it was time to do some final flight testing. With the large pulley (3.5-inch) I was able to achieve 281 mph TAS at 28 inches manifold pressure. I then installed the intermediate pulley (3-inch) and gained an additional 7 inches manifold pressure! I climbed higher so as not to exceed 30 inches and the end result was a loss of speed. The power to turn the supercharger was more than the power gained.

There is so much to write about this project that it couldn’t possibly fit in a couple of articles. Another problem that developed was an engine miss. After checking the normal things like pressurized mags, plugs, wires, etc., I found the miss to be compressor stall. After reconfiguring the air inlets to the supercharger, 98 percent of the miss went away. Needless to say, that was a very hard problem to solve.

The last problem was with the metering of fuel from the Bendix servo. It seems that when there is pressure ahead of the partially closed servo butterfly, the system meters in more gas. I'm sure there was a fix for that but it was getting beyond my goal of having everything easily interchangeable. And having to recalibrate the Bendix system every time a change was made is not easy.

In light of all the data, I found the supercharger to be mission specific. That is, it's good for high altitude only if I can figure out a way to clutch it. Since the supercharger has an internal 4:1 ratio, the clutch would be turning 14,000 rpm's. The rotating mass would have to be designed carefully! And keep in mind that if I am able to work out the other problems and keep the supercharger on the airplane, fuel burn is still another 8-10 gph! That's almost unacceptable. I'll be going faster but I won't be able to make it to my longer destinations without stopping for fuel.

On the other hand, a few good things came out of this project. As far as I know, 281 mph TAS is the fastest any Comanche has gone and my 350 mph ground speeds at altitude should be a new world record. With the new prop and nose bowl, my normally aspirated speeds are up about 5 mph. For instance, at 8,000 feet with my ram-air system, I can make 24 inches manifold pressure and TAS is 245-247 mph at 23-24 gph. At 16,000 feet, my TAS is 235-238 mph at 19 gph!

With comfortable speeds like that, the wear and tear of supercharging and extra fuel burn doesn't make any sense. And the Comanche 400 airplanes will have another choice of props soon, with or without the 4-inch integral hub extension; complete with spinner and bulkhead. The prop without the hub extension will be an exact replacement for the Hartzell.

In hindsight, if I had been given accurate information on supercharger loads and discharge temps to begin with, I would have focused on modifying the existing turbo system for the Comanche 400 and installed my air-to-water intercooler system to eliminate the power restrictions. Without the extra load of turning a supercharger I think I could have reached the 300 mph mark.

Did I have fun on this project? You bet I did! And I have good hard flight data to back up any stories. One of my quotes throughout the project was, "I'll be satisfied with whatever speed I get out of this, as long as it's as fast as I can go!"

For now, I have my good ole' normally aspirated Comanche 400 back; only a little better and a little faster. And above all, I still have the power!

What's next you ask? A coast-to-coast speed record run is still planned for the beginning of next year. Anyone wanting to know about supercharging, intercooling or boosting our Comanches, I'll be glad to share the details with interested ICS members. Contact me by e-mail at com400@mindspring.com.