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The Bigger BANG Theory

The Quest for More Power

Photo by H. Dean Chaimberlain

This highly modified P-51 **Mustang** *Reno Air Racer uses supercharging well beyond normal operating ranges to produce massive horsepower.*

"This airplane has too much power," said no one ever. Okay, maybe it's possible someone at some point in recorded history has uttered that phrase — but it seems unlikely.

One of the best ways to go faster in your airplane or your car is by adding more horsepower. There are several ways to accomplish this goal. Since horsepower is essentially a measure of work done over time, increasing either the size of the "bang," or the number of bangs per unit of time, will increase horsepower. The easiest way to upsize your "bang" in both automotive and aviation applications is to add displacement, i.e., engine cylinder volume. A larger engine generates more power but the current initiative to improve fuel economy and reduce emissions is pushing engine manufacturers away from the tried and true "there's no replacement for displacement," motto.

Another option for more power is for the engine to run faster. A higher revolution per minute (rpm) generates more power by increasing the number of bangs per a given unit of time. This approach has worked quite well in cars, but doesn't work as effectively in airplanes due to the requirement for a reduction gearbox to lower the rpm to a more manageable range for propellers. Cars naturally have these gearboxes (transmissions), but smaller GA airplanes generally don't, with a few exceptions like the Cessna C-175 *Skylark*. Since neither of these options is that great, how is a tried and true power junkie able to increase power?

Take a Deep Breath

Allow me to introduce the magic of forced induction. To increase the size of the bang without increasing the size of the engine or the speed at which it turns, we need to find a way to get more fuel into the cylinder. By itself, this extra fuel will cause the engine to run too rich, so we need to balance it with more air. By cramming both extra air and fuel into the cylinder, we can get a bigger bang or maintain a certain bang size at a higher altitude than would be possible without forced induction. This action is carried out by a pump on the front of the engine that compresses the intake air. The pumping can be accomplished in one of two ways.

Superpower Supercharger

The first method is with a good old-fashioned supercharger. This is a compressor — sometimes called a blower — that is driven by the engine just like an alternator, air conditioning unit, or any other accessory. The advantage to this method is that it requires less plumbing and doesn't experience any lag or spool time (more on that later). The main disadvantage is that the energy used to power the compressor is drawn from the engine. This drag on the engine means that a supercharger is more about net gains than absolute. In fact, some superchargers can require well in excess of 100 horsepower to run. Even though your supercharger may be capable of adding 400 horsepower to a given engine, you effectively lose a percentage of that output to power the compressor. So if your 400 horsepower supercharger took 50 horsepower to run, you'd net 350 horsepower to your overall total. While it's still very much a net positive, it's not as efficient as it might be. For these reasons, among others, supercharging has fallen out of favor since the Second World War. This leads us to our next form of forced induction.

Terrific Turbocharging

Turbocharging is similar to a supercharger in that it helps deliver more air to the induction system. It differs in how it powers the compressor. A turbocharger uses the exhaust gas from the engine to turn the compressor in a way that is very similar to the cold and hot sections of a jet engine. In this system, however, the compressed air is being delivered to an internal combustion engine rather than straight into a combustion chamber. The key advantage of turbocharging is that it captures "free" or otherwise wasted energy from the exhaust gases.

The engineers out there are probably screaming "there's no such thing as free!" — and they are right. The downside is that turbocharged engines tend to run hotter and harder than their normally aspirated counterparts. Another disadvantage of turbocharging is that to compress the air, you must first have sufficient exhaust gas flowing through the turbine to run the compressor. This creates a phenomenon known as "turbo lag." Turbo lag occurs when the power delivery is delayed while the turbos spool up in response to the increased exhaust gas flow created by advancing the throttle. This creates issues in aviation, but it is more noticeable in automotive applications.

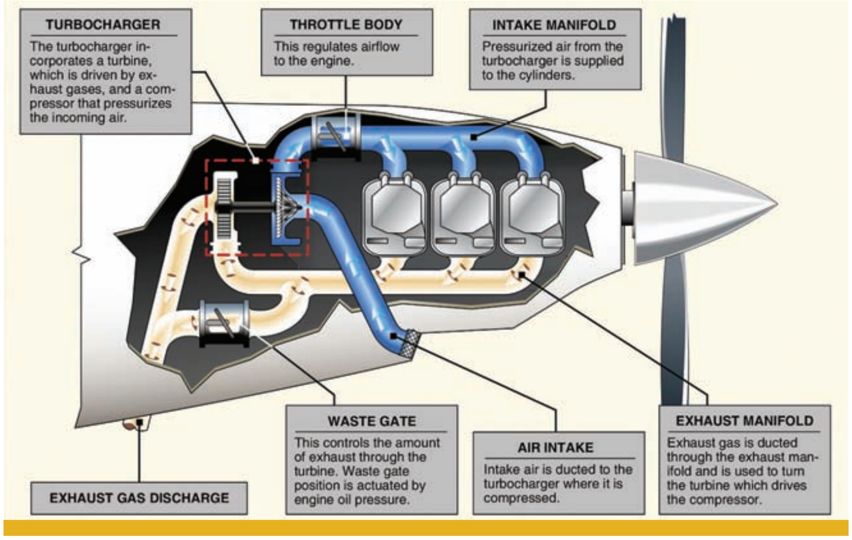
Turbocharged engines also require more discipline from the pilot. Depending on the setup, rapid throttle movements could potentially damage or destroy an engine. Turbochargers also require a cool down period after flight. Because the turbines spin at very high rates — at times in excess of 80,000 rpm — they require significant cooling and lubrication. This requirement is accomplished by circulating engine oil through the bearings. If you were to shut down the engine before the turbos have properly cooled, the flow of engine oil would also stop and the oil left in the turbos would literally cook, causing hard carbon deposits to build up on the bearings. This, in turn, restricts future oil flow and leads to more issues.

Give Me a Boost

Before we get too deep into the technical discussion, let's look at how this technology can be applied, because it can make a big difference. On a standard day at sea level, a normally aspirated aircraft would produce about 30 inches of mercury (inHg) in manifold pressure, which is another way to measure engine power produced by a piston engine with a constant speed propeller. (We'll round the pressure up from 29.92 to make the math easier.) In reality, the number would be lower due to losses in the intake system. So that normally aspirated airplane's engine would decrease in performance as atmospheric pressure dropped, by 1 inHg per 1,000 feet, to the point where at 5,000 feet, the theoretical maximum would be 25 inHg.

In the first form of turbocharging, we would look to boost the incoming manifold pressure significantly. This could be to 35 or 40 inHg while at sea level, which allows us to generate more power with a smaller engine. Turbocharging in this way can create fantastic power. Great examples include the turbocharged Formula One engines of the mid 1980s, which at their maximum power settings ran something more than 160 inHg and turned out around 1,300 horsepower from a tiny 1.5 liter engine. For an aviation equivalent we turn to the Reno Air Racers, which pull anywhere between 70 and 130 inHg. However, these planes use superchargers rather than turbochargers on engines ranging between 27 liters and nearly 55 liters of displacement.

These applications are an example of "boosted turbocharging." This approach does allow the generation of massive horsepower numbers, but forced induction can be hard on the engine. In fact, the highly boosted Formula One cars could only sustain



Turbocharger components


Photos by George Soteropoulos


Photos by Anne X Graham

The P-38 **Lightning** *(left) and P-47* **Thunderbolt** *(right), along with the B-17* **Flying Fortress***, are a few of the rare turbocharged WWII airplanes.*

maximum boost for two to three laps before giving up the ghost, and it is a similar story for our air races. That is why most boosted engines run much, much lower levels of boost. Throttle movements need to be made deliberately to avoid over-boosting these engines.

The New Normal

The other way to turbocharge an airplane engine is called turbo-normalizing. This is where a turbocharger is used to maintain sea level pressure up to a critical altitude. After that point, the manifold pressure drops off at the same one inch per 1,000 feet. This allows the aircraft to fly higher and faster by making more power at altitude (than with normal aspiration) and having less drag due to lower air density. Essentially, the engine is performing as if it's at sea level while your airframe gets to take advantage of the thin air. This approach is generally easier on the engine, because it imposes less stress and lets it run at a lower temperature than the boosted approach. Many manufacturers (retrofit and OEM) even state that there is no reduction in time between overhauls for their turbo-normalized engines when compared to their normally aspirated counterparts.

Keeping Your Cool

One of the key control mechanisms for a turbocharging system (turbo boosting or turbo-normalizing) is a waste gate. The waste gate is a valve in the exhaust system that limits the amount of boost generated by controlling the amount of exhaust gas that flows to the turbine. In essence, the waste gate is a bypass valve that allows exhaust gases to skip the turbine when open. When closed, it allows all the gases to pass through the turbine. The waste gate can

Additional Training Required?

If you are considering flying or owning a turbocharged airplane, here are a few training options you may need in addition to aircraft specific training:

High Performance

Under 14 CFR section 61.31, any aircraft with an engine with more than 200 horsepower is considered high performance and requires training and an endorsement from an authorized instructor to act as pilot in command. A turbocharger alone would not render the aircraft high performance by definition, but most turbocharged aircraft fit into this category.

Complex Airplane

Also under 14 CFR section 61.31, training and an endorsement are required to operate a complex airplane. This is defined in 14 CFR section 61.1 as an airplane that has a retractable landing gear, flaps, and a controllable pitch propeller, including airplanes equipped with an engine control system consisting of a digital computer and associated accessories for controlling the engine and propeller, such as a full authority digital engine control; or, in the case of a seaplane, flaps and a controllable pitch propeller, including seaplanes equipped with an engine control system consisting of a digital computer and associated accessories for controlling the engine and propeller, such as a full authority digital engine control. Again, a turbocharger is not considered part of a complex airplane by definition, but many turbocharged airplanes meet the criteria in other ways.

Pilot Ratings

Since the turbocharged (or turbo "normalized") engine often allows an airplane to fly higher, the pilot must be instrument rated to operate the aircraft when flying above 18,000 feet.

be opened, closed, or anywhere in between to generate the commanded boost pressure. Most systems nowadays use an automated control mechanism to manage the waste gate, but some older retrofit systems have a manual controller the pilot must actuate. This arrangement makes setting power a more detailed process than just pushing the throttle forward. Even with the automated systems, a more deliberate pace in throttle adjustment is recommended because these systems rely on engine oil to manage them. They can lag slightly in some conditions, which could cause momentary over-boost situations. Knowing what kind of waste gate system the aircraft has is important to how to correctly operate the aircraft.

A natural side effect of compressing a gas is increased heat and pressure. There is no way around basic physics. Too much intense heat and pressure in an engine is bad for any number of reasons, but one is the possibility of detonation, the spontaneous combustion of fuel in the cylinder. This is why most turbocharged engines have a lower compression ratio than their normally aspirated counterparts. Another way of dealing with this side effect is an intercooler, which is like a radiator for the compressed intake air. The air gets cooled as much as possible, and it reduces the risk of detonation while potentially improving performance. Intercoolers are a nice bonus, but they aren't a strict requirement of a turbocharger system.

The Air Up There

With the rise of turbocharging, especially in the turbo-normalized form, GA pilots are able to access airspace like never before. That access adds flexibility in planning by opening up more cruising altitudes to avoid icing or adverse winds. But remember the engineers' warning that nothing is free. With access to higher altitudes come other restrictions, such as the requirement for supplemental oxygen (14 CFR section 91.211). To take the greatest advantage of a turbocharged airplane, you will likely need a supplemental oxygen system.

With Great Power Comes Great Responsibility

Turbocharging can be a great tool to expand the usefulness of your aircraft. While the tales of rampant engine explosions are largely unfounded, knowing how your system works and what that means is absolutely critical. As with any more advanced system, turbochargers require an advance in your aeronautical skills.

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