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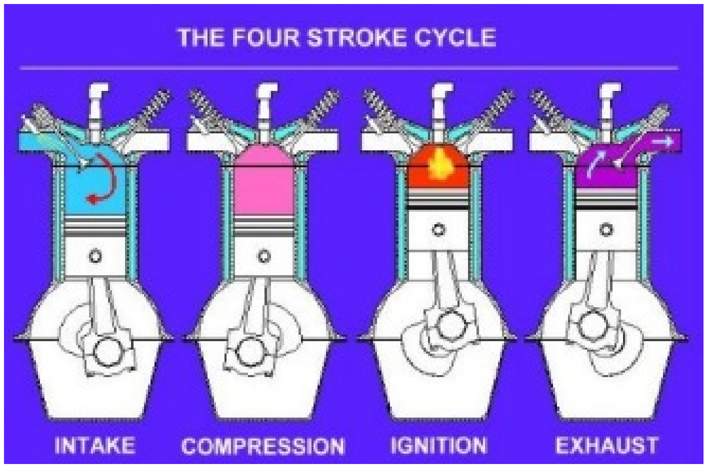
It seems that everything is getting the word “turbo” attached to it these days; “turbo” has become a sort of buzzword to denote something fast, whether it be modern electronics such as the Droid Turbo, or even tax software such as Intuit’s TurboTax. In the context of automobiles, many ordinary passenger cars have a “turbo” version or trim level. This “turbo” indicates an engine equipped with a turbocharger, which is often sportier and more luxurious. Almost everyone must own and regularly drive a car at some point in their lifetime; some see cars as something to be enjoyed, and others see them as an appliance to be used simply as transportation. Regardless, turbocharging improves a car’s ability to fulfill either requirement; it increases both fuel economy and performance. This essay explores the technology of turbocharging and its increasing presence in the automotive industry.

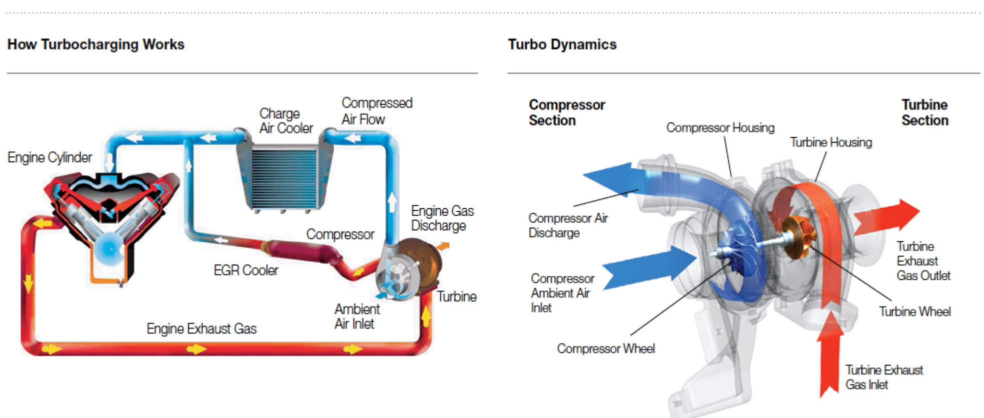
In order to understand turbocharging, a technology designed to increase an engine’s performance, it is helpful to understand exactly how a car’s engine works. A turbocharger works to increase the amount of air and fuel in an engine, which generates more power and does so in a more efficient manner. A car engine is an internal combustion engine, meaning it combusts a mixture of fuel and air to generate power and subsequent rotational energy to spin a car’s wheels. A turbocharger improves this by increasing the amount of air (and subsequently, the amount of fuel) per engine cycle, in turn providing both an increase in power and an increase in fuel efficiency, which improves the experience for nearly all drivers. In detail, a car engine operates on “engine cycles”, which are made up of four “strokes”. Each stroke is one movement of the piston, which is connected to the crankshaft via a connecting rod. The piston moves up and down, and it rotates the crankshaft with each cycle; this transition to rotational movement is what enables a car to spin its wheels.



The first part of an engine cycle is the intake stroke, in which the piston is moving down, drawing air into the cylinder via a valve at the top. At the same time, fuel is injected into the same combustion chamber, formed by the sides of the cylinder and the top of the piston. After that is the compression stroke, during which the valve is closed and the piston moves up, compressing the air/fuel mixture. When the piston reaches the top of the cylinder, the air and fuel are ignited by the spark plug during the ignition stroke. The force of this combustion forces the piston down, causing the crankshaft to rotate; as it rotates, the then-rising piston forces all of the spent exhaust gases out of the engine through an exhaust valve at the top of the cylinder. In all of these steps, air plays a critical role. Dr. Evangelos G. Giakoumis is a professor of mechanical engineering and oversees the internal combustion engine laboratory at the National Technical University of Athens. Succinctly, he says of gasoline engines: "it is the incoming air-supply that plays the most critical role for the engine response." (Giakoumis 2016). Without air to compress, the engine would simply be lighting gasoline on fire, which creates no combustion and thus no energy.

A turbocharger works to bring more air into the cylinder. According to BorgWarner, a major turbocharger manufacturer, "In exhaust gas turbocharging, some of the exhaust gas energy, which would normally be wasted, is used to drive a turbine… which draws in the combustion air, compresses it, and then supplies it to the engine." (BorgWarner, n.d.). Dr. Jianqin Fu of Hunan University in Changsha, China conducts research at the Research Center for Advanced Powertrain Technology, and he describes the process in more detail: "Because the IC engine exhaust gas has a high temperature and high pressure (compared with ambient pressure), it still contains lots of energy which could be recovered by exhaust turbine. In the exhaust turbocharging system, exhaust gas is used as the working medium of turbine, while turbine acts as the power output device of boosting pressure system. During the exhaust gas expansion process, part of exhaust gas energy is recovered and transformed into useful work. Then, the useful work is used to drive the compressor". (Fu et al. 2014).

The turbocharger acts as an intermediate step between exhaust and intake; the exhaust gas, which is normally routed out of the engine and through pipes out of the back of the car, is routed through the turbocharger. This turbocharger acts as a compressor, using the exhaust gases to spin a turbine that compresses the new air coming into the engine during the intake stroke. Since the air going inside the engine is already compressed, "the oxygen molecules are packed closer together. This increase in air means that more fuel can be added for the same size naturally aspirated engine." (Cummins, 2016). Dr. Giakoumis, the aforementioned professor of mechanical engineering and internal combustion engine expert, says of exhaust gas turbocharging: "By so doing, the air-supply that enters the cylinders is increased accordingly, enabling efficient burning of



proportionately higher amount of fuel. The obvious benefit here is the direct increase in the engine power; at the same time, down-sizing of the engine is possible" (Giakoumis 2016). Below is a graphic showing air routing through an engine and turbocharger system, as well as specific air routing through the turbocharger itself.

Turbocharging improves engine performance by increasing efficiency, which impacts one's life more than is immediately apparent; with both an increase in power and an increase in fuel efficiency, the experience is improved for nearly all drivers. More efficient engine operation results in improved fuel economy and reduced emissions, and improved engine operation can lead to other benefits. "[Turbocharging] generates increased mechanical power and overall efficiency improvement of the combustion process. Therefore, the engine size can be reduced for a turbocharged engine leading to better packaging, weight saving benefits and overall improved fuel economy." (Cummins, 2016). Jason Cammisa, an automotive journalist for *Road & Track*, a leading auto magazine, said, "[Turbochargers] are the right way to reduce emissions without sacrificing performance." [Cammisa 2015]. On the other end of the spectrum, high performance vehicles are often turbocharged in order to achieve high amounts of horsepower and torque.

Rather than using the increased energy efficiency of a turbocharger to decrease engine size and minimize the amount of fuel used, high-performance turbocharged engines use the extra air and fuel provided by a turbocharger to further increase the power generated by an engine already tuned for high performance applications. The cars produce more horsepower, and more torque generated at a lower RPM, meaning that the power is easier to access for the driver; a turbocharged engine makes more power, sooner. Cammisa also says of supercar brand Ferrari: "Modern Ferraris do what you ask, when you ask, how you ask. They are pretty much perfect… their forthcoming turbocharged replacements will almost certainly be faster." (Cammisa 2015). In the sense of power generation and performance, an exhaust gas turbocharged engine "has many advantages, such as higher specific power, smaller displacement, and larger torque. As a result, [exhaust gas turbocharging] has been widely applied in automotive gasoline engines in recent years," (Tang et al. 2016). In the sense that large amounts of horsepower and torque are benchmarks for high-performance engines, turbochargers help achieve that goal. Additionally, they do so without disregarding secondary goals, such as limiting emissions and fuel consumption. Oftentimes, initiatives to heighten performance sacrifice nearly all other goals in order to maximize power output. These conventional methods of making power are single-faceted; they lack the ability to contribute to multiple goals of an engine. Giakoumis says, "A distinctive advantage of a turbocharged engine is its capability to operate more efficiently compared to its naturally aspirated counterpart, hence, produces proportionately less CO_2 " (Giakoumis 2016). Though Giakoumis specifically talks about carbon emissions, he makes the point that reduced emissions stems from more efficient engine operation. More efficient operation means less fuel consumption, less oil use, and less carbon and soot particle emissions.

Turbocharging increases the energy efficiency of an engine by using exhaust gas, an energy source that is nearly free. Exhaust gas, without a turbocharger equipped, would leave the exhaust pipe at the rear and be effectively wasted. Harnessing the exhaust gas energy through the use of a turbocharger is harnessing an incredible previously untapped power source. The exhaust gas is very hot and moves relatively fast; it "contains a lot of thermal energy, thus exhaust gas energy recovery becomes an effective way to improve engine fuel efficiency and power performances." (Tang, et al. 2016). To Dr. Fu, "exhaust turbocharging engine has more advantages, e.g., higher thermal efficiency, for the compressor power comes from exhaust gas energy recovery becomes an effective way to improve engine fuel efficiency and power performances." (Tang, et al. 2016). To Dr. Fu, "exhaust turbocharging engine has more advantages, e.g., higher thermal efficiency, for the compressor power comes from exhaust gas

energy rather than IC engine," (Fu, et al. 2014). Fu's differentiation of the compressor's power source as being the exhaust gas is important because he explicitly highlights the effectiveness of using that free energy source to improve efficiency.

The rising presence of turbocharged engines in the automotive industry indicates a shift towards more efficient methods to increase both fuel economy and performance. Since a car's engine is an internal combustion engine, it combusts a mixture of fuel and air to generate power and subsequent rotational energy; a turbocharger allows for larger amounts of both, and in turn for more efficient engine operation. Efficiency in operation is pertinent not only to issues of fuel consumption and emissions, but also to issues of performance. Nearly everyone drives a car, and a turbocharger has such an impact on the behavior of a vehicle that it directly impacts the experience the driver has with the car. The application of a turbocharger is one that contributes to both of these goals; it doesn't neglect one in favor of the other. With regard to the constraining of emissions and the maximizing of both fuel economy and horsepower/torque, automakers are consistently turning towards turbochargers with great success.

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