CorkSport Performance Drop-In DISI MZR Turbocharger

White Paper

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Introduction

In a market that is constantly pushing for the most power and the fastest Mazdaspeed, it's easy to overlook the "little guys" or sometimes even forget them all together; most of the time only reasonable performance gains with direct fitment are desired. CorkSport has set out to fill the gap between stock and big turbo with a performance drop-in turbocharger for the Mazdaspeed platform.

Historical Overview

It's Not all about Crazy Power:

Scanning through social media and forums you will quickly see that "big turbo" builds are a popular subject amongst enthusiast. A lot of us dream of an epic build with all the bells and whistles, but we also realize that a big turbo setup is not ideal for our needs and goals with the vehicle. In fact, most people are quite happy with the OEM equipped turbocharger, but it is also a ticking time bomb is bound to go zoom-zoom-boom sooner than later.

Figure 1: Assumed mazdaspeed market break down for consumer's power goals.

Looking at the Mazdaspeed market, it is safe to assume that the consumers can be broken down into three major power levels. The few members of the 500whp+ group that will go to great lengths to achieve maximum power, the 375-500whp group that will rely on bolt-on's and some custom modifications, and a majority of enthusiasts in the stock-375whp range due to the much lower difficulty and price point as shown in Fig 1.

What is "Drop-In" and Why is it important?

There are a handful of turbochargers available for the Mazdaspeed platform that will sit in the OEM location; modified OEM K04's, GT28 frames, GT30 frames, and GT35 frame turbochargers just to name the typical options. These options all fit on one of the three levels shown in Fig 1, but all of them except the modified K04 lack one very important feature. This feature is what defines the difference between a "bolt-on" turbocharger and a "drop-in" turbocharger.

A bolt-on turbocharger will have the OEM style turbine inlet and outlet flanges so it can be bolted to the OEM exhaust manifold and use the OEM downpipe, but this is where the similarities end. The drop-in turbocharger will not only have the correct turbine inlet and outlet flanges, but also the OEM size compressor inlet and outlet, oil and coolant hookup points, and will be able to reuse the OEM heat shields and support brackets (if applicable).

So why is the drop-in goal so important? The drop-in turbocharger is the only item needed to install and operate it. It is not required to purchase new coolant lines, new oil lines, or a new intake system. That is a savings of $300-$400, not to mention you can still use the OEM heat shields which ultimately improves the efficiency of the turbocharger and keeps engine bay temperature's in check. The end result; the performance drop-in turbocharger is more cost effective for you, the customer.

Anatomy of a Turbocharger

The purpose of this section is to provide a brief description of the components that make up a typical turbocharger. The most common terms are turbine housing, compressor housing, and center housing rotating assembly (CHRA). An assembled CorkSport turbocharger is shown below in Fig 2.

Figure 2: Assembled turbocharger kit

Turbine Housing

Exhaust gases flow through the turbine housing from the exhaust manifold and are forced through the turbine wheel. This converts the thermal fluid energy of the exhaust gas into mechanical shaft energy. The CHRA and downpipe sides of the turbine housing are shown below in Fig 3.

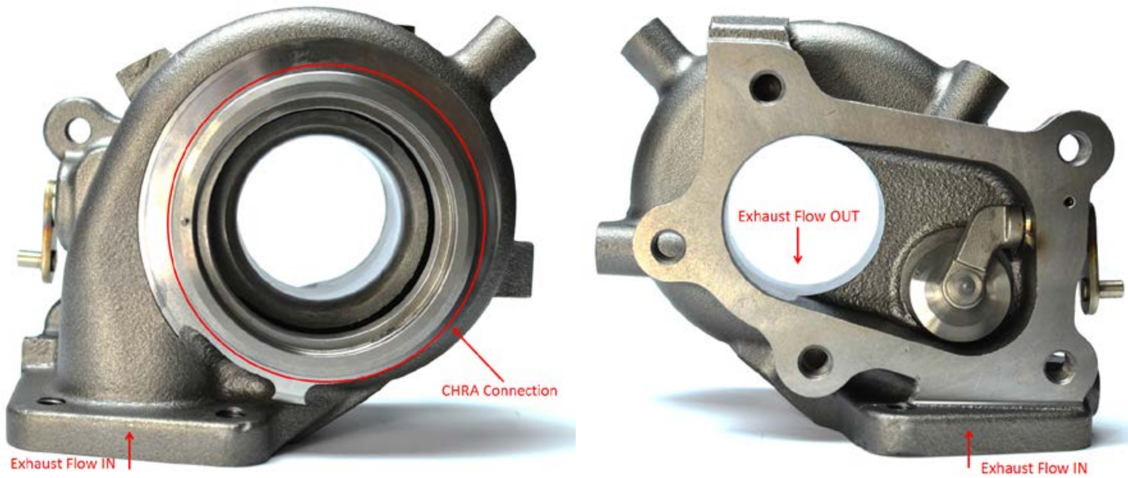

Figure 3: The CHRA connection side of the turbine housing (left) and outlet side (right).

Compressor Housing

Clean atmospheric air is pulled into the compressor housing and then compressed by the compressor wheel. The mechanical shaft energy from the turbine wheel is converted back to fluid energy as pressurized (boosted) air. The flow through the compressor is shown below in Fig 4.

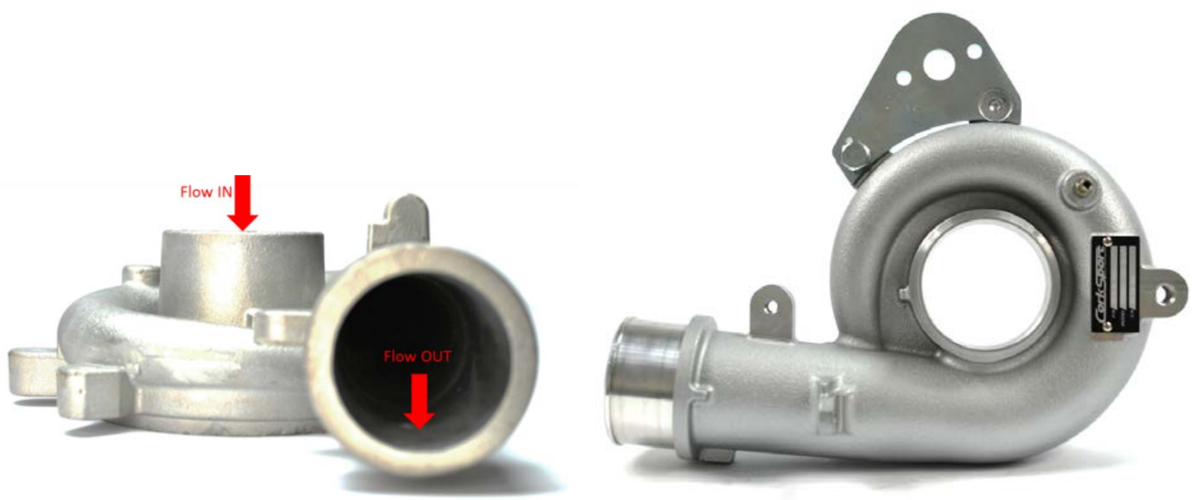

Figure 4: Compressor housing before and after finish machining.

Center Housing Rotating Assembly

This is the heart of the turbocharger containing the bearings and shaft which are connected to the turbine and compressor wheels. The CHRA also contains and routes the oil for the bearings and the coolant through the housing and around the bearings. An assembled CorkSport CHRA is shown in Fig 5 below.

Figure 5: Assembled CorkSport CHRA.

Turbocharger Design Considerations

Journal Bearing vs Ball Bearing:

There are two types of bearing systems commonly used in the CHRA; journal bearings and ball bearings. The design of these bearing systems can vary between manufacturers, but the designs below in Fig 6 and Fig 7[1] are a good representation.

Figure 6: 360 degree axial bearing (left) and typical journal bearing (right).

Journal Bearings have been used for years in CHRA's and have not fundamentally changed since their invention except for a couple minor improvements including: 360 degree axial bearing vs 270 degree axial bearing and improved journal bearing design. Journal bearings consist of two different types of components; the radial bearing and the axial bearing commonly known as the "thrust" bearing. Journal bearings are typically manufactured from brass or another semi-soft material. Journal bearings depend heavily on the oil to create a dynamic fluid barrier between the turbo shaft and the bearing. This is why journal bearing turbochargers have a small amount of radial shaft play while not in operation. Journal bearings are an old technology, but are reliable, cost effective and easily rebuild-able.

Figure 7[1]: Cartridge style ball bearing.

Ball Bearing technology has only recently become prominent in the turbocharger industry due to the extreme conditions in which the turbocharger functions. Ball bearing systems typically perform better than a comparable journal bearing system for a few reasons. The turbocharger's response speed (time needed to build boost) can be improved 10-15% as well as being more durable due to the improved shaft dynamics control. The increased control comes from the improved design. Ball bearing systems utilize an inner and outer race with rollers or balls between the two races. The inner race is pressed onto the turbo shaft and the outer race is pressed into the CHRA. The rollers or balls replace the oil's "job" of controlling the turbo shaft's orientation, but do still need to be lubricated. This improved design does come at a cost though. Ball bearing CHRA's are 15-35% more expensive than a comparable journal bearing CHRA and are not easily rebuild-able.

Internal vs External Wastegate:

There are two types of wastegate setups used in a turbocharger system; internal (IWG) and external (EWG). The wastegate vents off excess exhaust gas away from the turbine wheel effectively controlling the boost pressure. The design and application of these varies greatly with IWG and EWG each having their pro's and con's.

Figure 8: Typical internal wastegate design (left) and typical external wastegate design (right).

Internal wastegate systems consist of the waste port, wastegate flapper, the wastegate flapper arm, and actuator (not shown). As assumed by the name, the IWG functions from inside the turbine housing opening and closing the waste port to the control exhaust gas flow through the turbine wheel. IWG's are common in OEM applications and in performance turbochargers that are not excessively larger than OEM. These systems are typically more cost effective to manufacture and operate as well as are much easier to package. However, IWG setups do have limits and can be ineffective in controlling boost with large turbochargers in high power setups.

External wastegate systems consist of the wastegate port, wastegate piston (like the IWG flapper), and the actuator. Likewise, the EWG functions outside of the turbine housing with extra exhaust gas piping. EWG's cost more, require a more complicated boost control system and are much more difficult to package. However, EWG setups do typically control the exhaust gas flow faster and more efficiently than an IWG setup. For that reason, EWG's are more prevalent in high horsepower applications such as racing where performance trumps packaging and cost.

Determining the Housing Area Ratio (A/R):

The area/radius (A/R) ratio defines the volute characteristics of both the compressor and turbine housings. The A/R is a measurement of the cross-sectional area of the inlet volute divided by the distance (radius) from the area centroid to the wheel centerline, shown with the left side image in Fig 9. Basically, the A/R determines how quickly the gas expands out of the compressor wheel and how quickly the exhaust gas is forced into the turbine wheel.

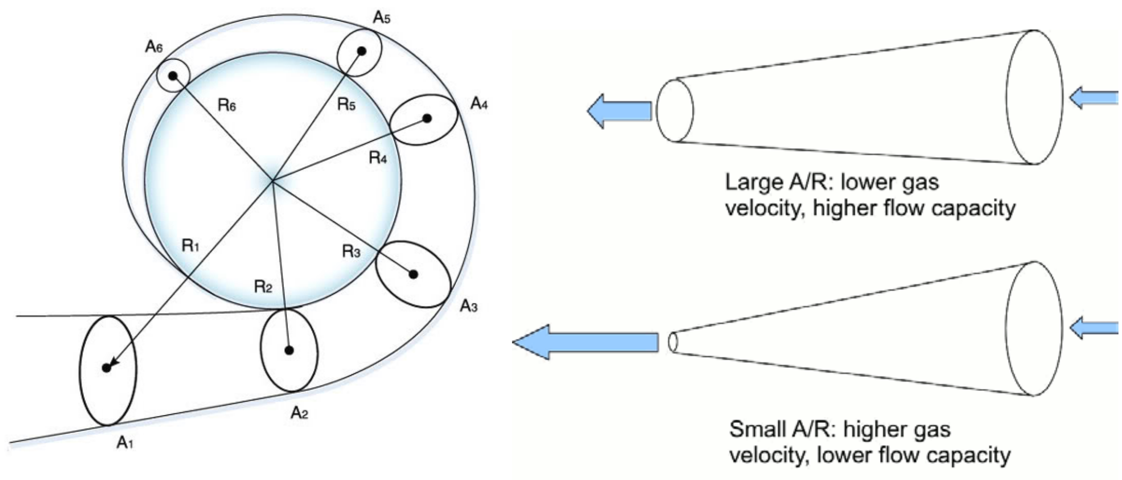

Figure 9: How to measure the A/R of a turbo housing (left) and the visual aid of how A/R effects the gas velocity (right).

The compressor A/R is not typically changed to define the characteristics of the turbocharger because it has little effect. As a rule of thumb smaller A/R housings are used in high boost applictions whereas larger A/R are used in low boost applications, but commonly there is only one A/R option for the compressor housing.

$$Cross\ Sectional\ Area\ of\ Volute\ at\ \text{"n"}\ location\ = A_n$$

$$Distance\ (Radius) from\ CHRA\ Centerline\ to\ A_n\ Centroid = R_n$$

$$A/R\ Ratio = \frac{A_n}{R_n}$$

However, the turbine housing A/R greatly effects the characteristics of the turbocharger without modifiying the CHRA or wheel sizes. The turbine housing A/R directly effects the flow capacity of the turbine. A larger A/R results in a lower exhaust gas velocity entering the turbine wheel; this allows the gas to enter the wheel in a more radial angle which is more effiencent. A smaller A/R results in a higher exhaust gas velocity entering the turbine wheel;this forces the exhaust gas to enter the wheel in a more tangential angle which is less effiencent.

A real world effect of the A/R design brings us to the concept of turbo lag. Imagine two identical vehicles with identical turbochargers; one has a 1.00 A/R turbine housing and the other has a 0.50 A/R turbine housing. The larger A/R is designed for peak horsepower therefore will not begin to build boost until higher in the rpm range. This would make for a great setup in a dedicated racecar because it is always ran in the higher rpm's. The smaller A/R is designed for low-end torque and improved turbo response, but this compromises peak horsepower performace because the turbine housing can become a restriction on the engine if too small.

Determining Wheel Trim:

Wheel trim is the ratio between the inducer and exducer of either the compressor or turbine wheel. For both the compressor and the turbine wheels; air enters through the inducer and exits through the exducer. A diagram of inducer and exducer is shown below in Fig 10.

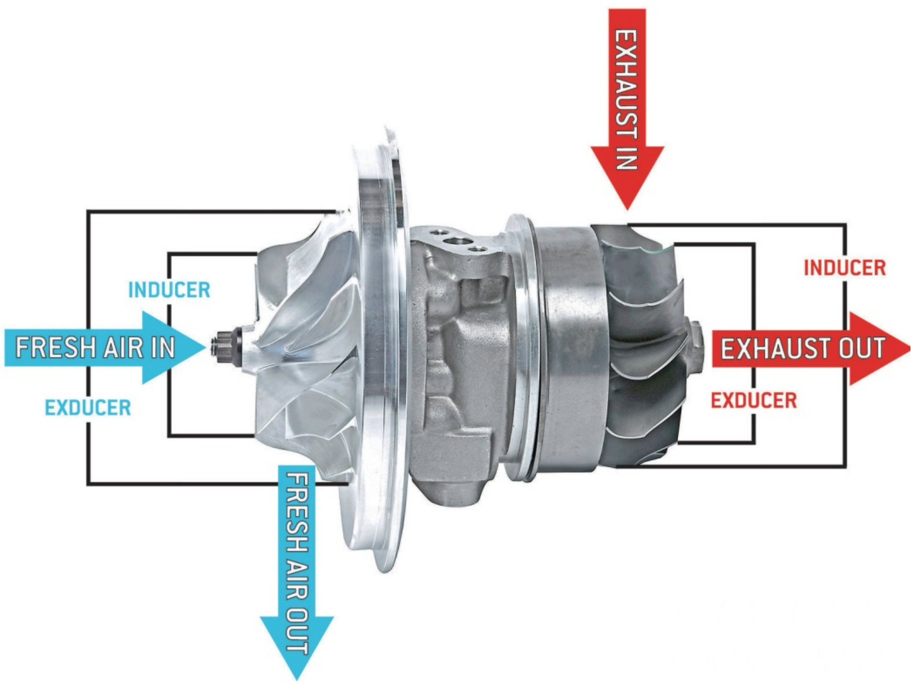

Figure 10: Visual description of the inducer and exducer of both wheels.

Wheel trim ratios can be changed without changing the blade design of the wheel to adjust the characteristics of the turbocharger. This allows greater flexibility when designing a turbocharger that can excel in many different applications. In general, a larger trim wheel will flow more peak volume, but is efficient in a smaller flowrate and pressure ratio range. With a higher flowrate yet more specific operating range the larger trim wheel would excel in a dedicated racing application. There is also a point when the wheel trim becomes too large. Once too large, the turbocharger is subject to increased lag and a higher chance of compressor surge.

Conversely, a smaller trim wheel may not have as high peak volume, but is efficient over a larger flowrate and pressure ratio range. With a larger more efficient operating range the smaller trim wheel is better suited for daily driving where good turbo response is desirable. The smaller trim also reduces the risk of compressor surge because it has a higher pressure ratio capability without significantly increasing flowrate. Below are the equations for calculating wheel trim:

$$Compressor\ Trim = \left(\frac{Inducer^2}{Exducer^2}\right) * 100$$

$$Turbine\ Trim = \left(\frac{Exducer^2}{Inducer^2}\right) * 100$$

Wheel Design:

Turbine Wheel: Blade Count and Materials

Some of the greatest improvements in turbocharger technology have come through improved turbine wheel design and material. The thought process used to be “more is better”, but the theory has changed drastically in recent years. You can see an obvious difference between the two turbine wheels shown in Fig 11. On the left is the standard 12-blade turbine wheel and to the right is the high flow 9-blade wheel.

Figure 11: Standard 12-blade turbine wheel (left) and high flow 9-blade turbine (right).

There are a few key improvements beside three less blades that make the 9-blade wheel superior. The blades have a more “scooped” profile that aids in high flowrate efficiency and the overall blade height is taller, allowing the turbine wheel to “extract” more energy from the exhaust gases. However with improved flow usually comes more lag, but that’s not the case with this new turbine wheel. To reduce lag and improve boost response, the turbine wheel features a smaller diameter center shaft that reduced the weight by 21% and increased the overall surface area of the blades. Combine all these improvements and you have a faster responding, higher flowing, and overall more efficient turbine wheel.

Along with improved designs come improved materials. Turbine wheels used to be manufactured from steel alloys because it was cost effective and easier to manufacture, but that proved troublesome from a reliability and durability standpoint. The steel alloys could not handle the high stress combined with the extremely high operating temperatures. Eventually the turbine wheel would break apart in an explosive matter without warning. Today, turbine wheels and sometimes turbine housings are manufactured from “super alloys” that are designed to handle extremely high operating temperatures. These super alloys are typically inconel (nickel chromium iron alloy) or titanium alloys and can actually improve the thermal efficiency of the turbine wheel.

Compressor Wheel: Cast vs Billet vs Forged Billet

Compressor wheel design has come along way with the advancement of manufacturing technology and materials. With the advancements in manufacturing abilities producing stronger, lighter, and more complex designs has become capable and ultimately improves the effieciency of the compressor wheel. Below you can see the difference between a standard cast aluminum wheel and a performance forged billet wheel with extended tip technology.

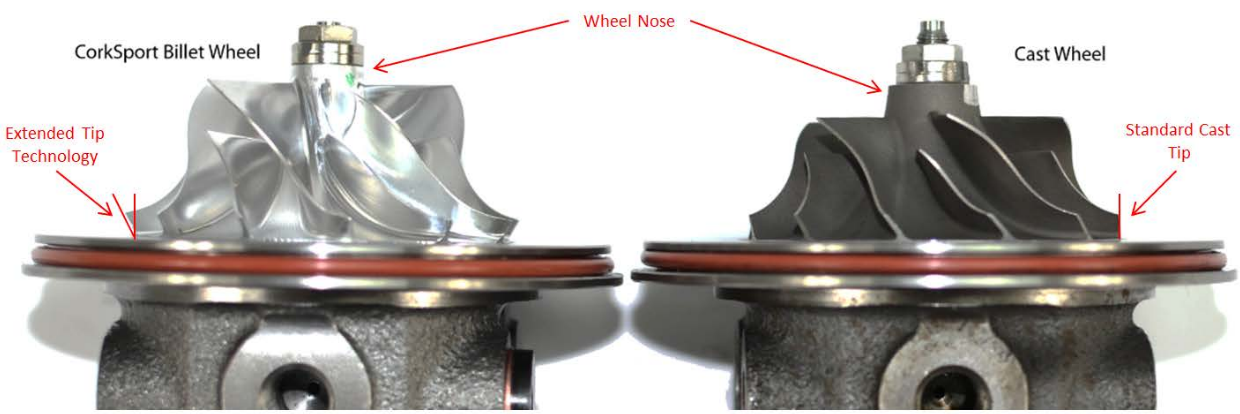

Figure 12: CorkSport performance billet wheel with extended tip technology (left) and comparable standard cast wheel (right).

Cast compressor wheels are the standard for good reason. They are reliable, perform adequately well, and are cost effective to manufacture, but when the goal is to squeeze every ounce of power out of a turbocharger they just don’t cut it. However, some billet wheels improve performance in basically every aspect, but do tend to cost more to manufacture. Cost aside let’s look at the benefits. There are two types of billet wheels typically used; a standard billet wheel machined from a solid block of aluminum and then there is the forged billet wheel. For the sake of simplicity we will focus on the forged billet variant.

The key to the forged billet wheel comes down to strength at the molecular level. Billet in general does not have the issue of metal porosity (bubbles) like casting can have. Forged billet takes it a step further. Forging is the process of pressing non-molten metal into a desired shape. The result is a molecular grain structure that closely follows the desired shape and a higher density grain structure. With this added strength, the compressor wheel can push the design limits even further. Looking at the cast wheel in Fig 12, you can see that the wheel "nose" that the nut presses against is larger in diameter than the forged billet wheel to the left. This is a result of lower strength and casting capabilities. With the smaller diameter nose the wheel becomes lighter and increases the maximum flowrate capability by effectively increasing the blade width. Also, the blades can be machined thinner than the cast counterpart without fear of blade straightening or complete wheel failure at high pressure ratios and RPMs.

Material and manufacturing are not the only things that set the forged billet wheel ahead. The blades are 22% taller and the exducer utilizes "extended tip technology". The added height increases the blade surface area that can do more "work" to the air. This means more volume is moved per wheel revolution. Extended tip technology (ETT) is a great addition to the compressor wheel as it adds all the great qualities of a small trim wheel without the negatives. ETT improves the wheel's anti-surge capabilities while increasing flow capacity and high-boost capability at safe turbo RPM speeds.

Turbocharger Maps:

Understanding Compressor Maps:

Compressor maps can look overwhelming at first, but are quite easy to understand once broken down into their components. The compressor map consists of six components shown in Fig 13. The vertical axis represents the pressure ratio. The pressure ratio is the ratio of the compressor inlet and outlet pressures.

$$Gauge\ Pressure = PSIG$$

$$Absolute\ Pressure = PSIA$$

$$Pressure\ at\ Inlet = P_{in}\ (PSIG)$$

$$Pressure\ at\ Outlet = P_{Out}\ (PSIG) = P_{MM} + P_D$$

$$Mesured\ Manifold\ Pressure = P_{MM}\ (PSIG)$$

$$Pressure\ Drop\ from\ Turbo\ to\ Manifold = P_D$$

$$Atmospheric\ Pressure \approx 14.7\ PSIG$$

$$Pressure\ Ratio = \frac{P_{Out} + 14.7}{P_{in} + 14.7}$$

The horizontal axis represents the mass flowrate in lb/min which can be converted in grams/sec for comparison. The nearly vertical line at the left side of the map represents the compressor surge limit. Surge can happen two ways; suddenly closing the throttle body or when the compressor is flowing more air than the engine can use.

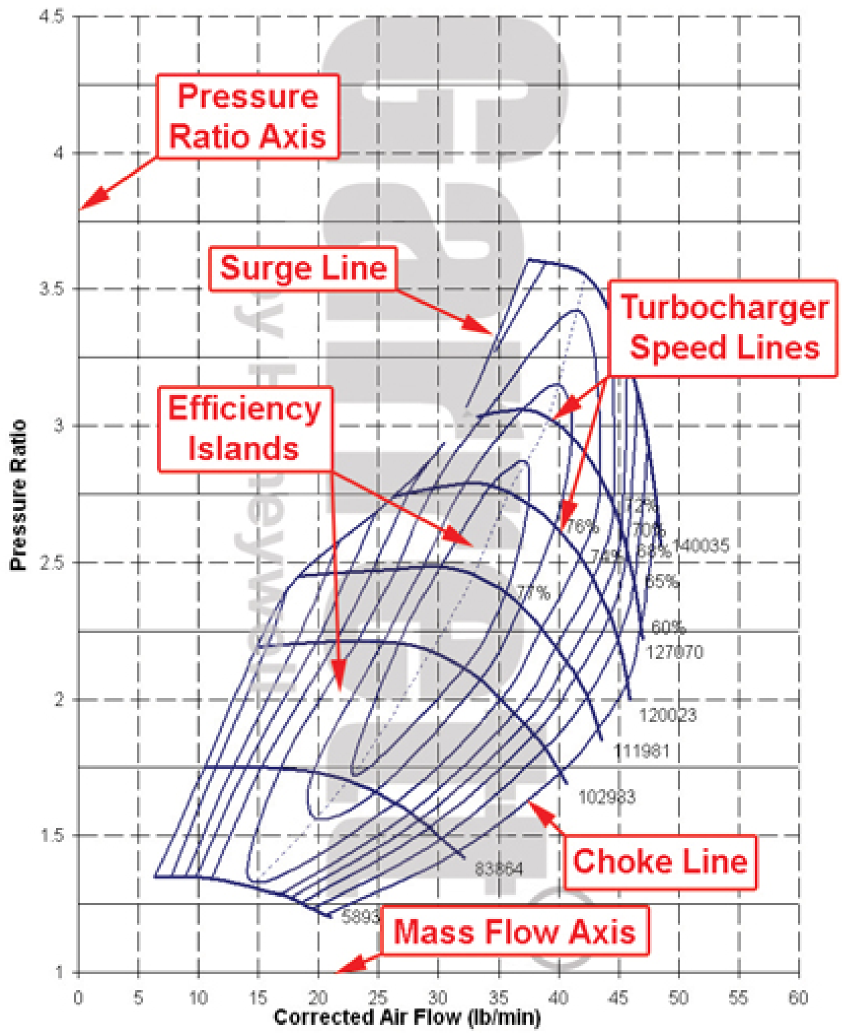

Figure 13[2]: A typical compressor map with component descriptions.

The somewhat vertical line at the right side of the map represents the choke limit of the compressor. The choke line position is an obituary choice by the manufacturer, but is typical marked at the 50-60% efficiency range. The dark lines that run across the map represent the turbo shaft speed. These typically range in the 50k-150k RPM range to be efficient. The remaining lines that are lighter represent efficiency lands. The center land/area represents the most efficient region for the compressor wheel and is also labeled with a percent efficiency; typically the highest is around 78-80%. Then, as you move in any direction the compressor becomes less efficient.

Understanding Turbine Maps:

Turbine maps are far simplier to read and understand compared to a compressor map. The vertical axis represents the corrected flowrate in lb/min and the horizantal axis represents the pressure ratio that functions like the pressure ratio on the compressor map. The different color lines represent different A/R housings. Also worth noting is these lines are not a perfect representation, but are an average of the pressure ratio steps that are actually measured.

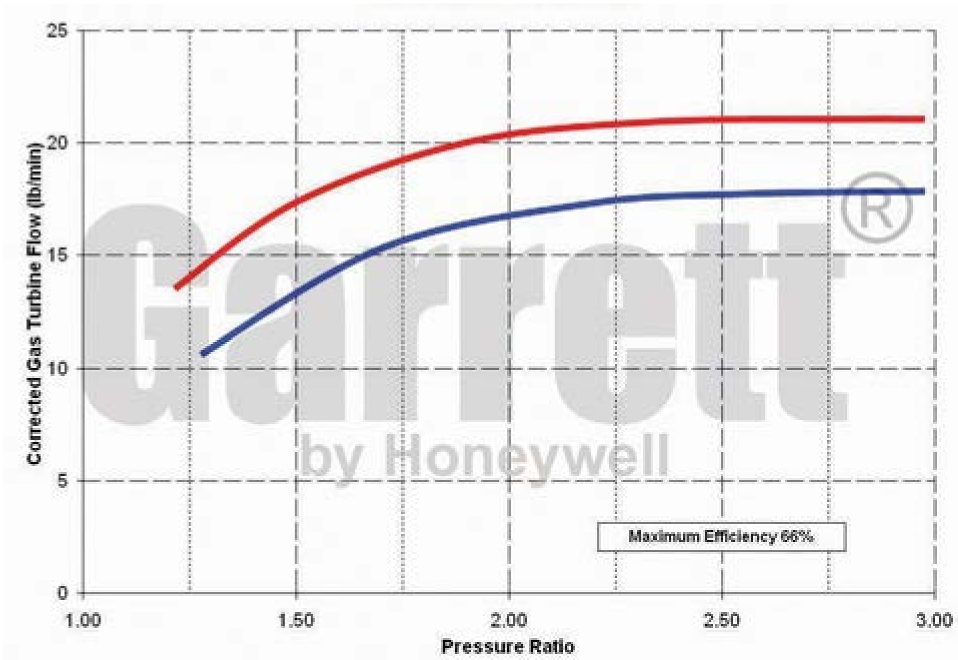

Figure 14[2]: A typical turbine map with two A/R housings shown.

CorkSport Drop-In Turbocharger

The R & D Process:

The "Research & Development" process sounds glamorous, but is really just a fancy way of saying "The Problem Solving" process because that's what it truly is. When an idea is taken from conception to proven product there are bound to be roadblocks and hurdles to jump over, but this is also why we spend countless hours testing and developing products of this scale. The goal is the best performing product for the customer.

Unlike some of the available performance turbochargers for the DISI MZR engine, the CorkSport performance drop-in turbocharger was designed from the ground up utilizing a Mitsubishi CHRA. It is not based off the OEM K04 turbo charger in any way other than OEM hook up points.

3D Printed Prototype:

Like any new project, there are prototypes before there is a final product. The first prototype came in the form of a non-functional 3D printed turbocharger with a functional CHRA and wastegate actuator which can be seen in Fig 15.

Figure 15: A non-functional 3D printed prototype turbocharger.

The 3D printed prototype allowed us to test the fitment in the engine bay and make changes to the housing design before the expensive cast molds were manufactured. The end result is a better performing and more cost effective product for you. Some of the changes made through test fitting the 3D printed prototype included the following: The wastegate actuator was moved closer to the turbine housing to improve clearance between the actuator and the coolant lines. The turbine outlet opening was enlarged to maximize exhaust flow through the turbine wheel and around the wastegate flapper. In Fig 16, you can see the line that the turbine outlet was increased to.

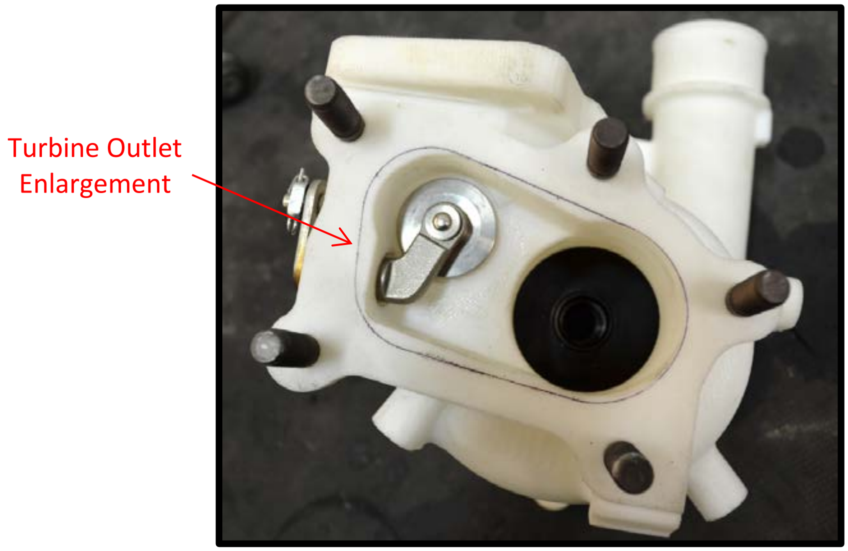

Figure 16: 3D printed prototype with turbine outlet enlargement marked.

Lastly, the internal wastegate port was increased to a 24mm diameter to improve the wastegates ability to control boost pressure and the wastegate flapper was reduced to 28mm in diameter to further improve the exhaust flow around it while still providing ample sealing surface. With these changes confirmed it was time for a functional prototype to begin testing.

Functional Prototype:

The first functional prototype (and argueably the most exciting) was immediately subjected to multiple dyno runs. Initial dyno testing showed a 50hp gain at the same boost pressure, 20psi tapering to 17psi. The prototype was still far from customer worthy at this point. There were a handful of problems to solve: First, the OEM upper coolant line would not fit and asking a customer to bend it to fit was out of the question. The idea of using a flexible braided coolant line with -AN fittings was appealing, but this is also the cheap and easy way to solve the problem. With OEM fitment in mind we designed a new coolant line that is CNC bent and mounts like OEM retaining the OEM banjo bolt. The CAD model of the CorkSport coolant line can be seen below in Fig 17.

Figure 17: CorkSport CNC bent coolant line designed and manufactured to fit like OEM.

Second, the large OEM turbine heat shield would not fit around the wastegate actuator rod, inhibiting its movement. We tried trimming the shield, but that was not solving the issue nor did it seem like a good idea to ask a customer to do the trimming. With that, a new heat shield was designed to replace the OEM piece while still providing as much coverage. The CorkSport heat shield is shown below in Fig 18.

Figure 18: CorkSport Turbine heat shield.

Third, we realized on some car models, the wastegate actuator was rubbing against the firewall. This forced us to rethink the design of the actuator for both fitment and performance. The ports were moved to a secondary chamber to improve the flow and the flat cut on the side of the actuator was added to improve fiment in the vehicle. All this can be seen Fig 19 below.

Figure 19: CorkSport billet wastegate actuator.

Lastly, was the restrictor pill which is only needed when running bleed setup boost control. We could have bypassed the restrictor pill in the testing and design only allowing for interrupt setup. With a drop-in replacement as the goal, it was important that the turbocharger was able to function in bleed setup which is how the OEM boost control functions. Four sizes of restrictor pills were tested to find the optimum setup for the turbo. Comparing the boost curves for each pill it was clear that the 0.030" pill was the best compromise for spool and response without over-boosting. The graphs for each restrictor pill can be seen in Fig 20 and Fig 21 below.

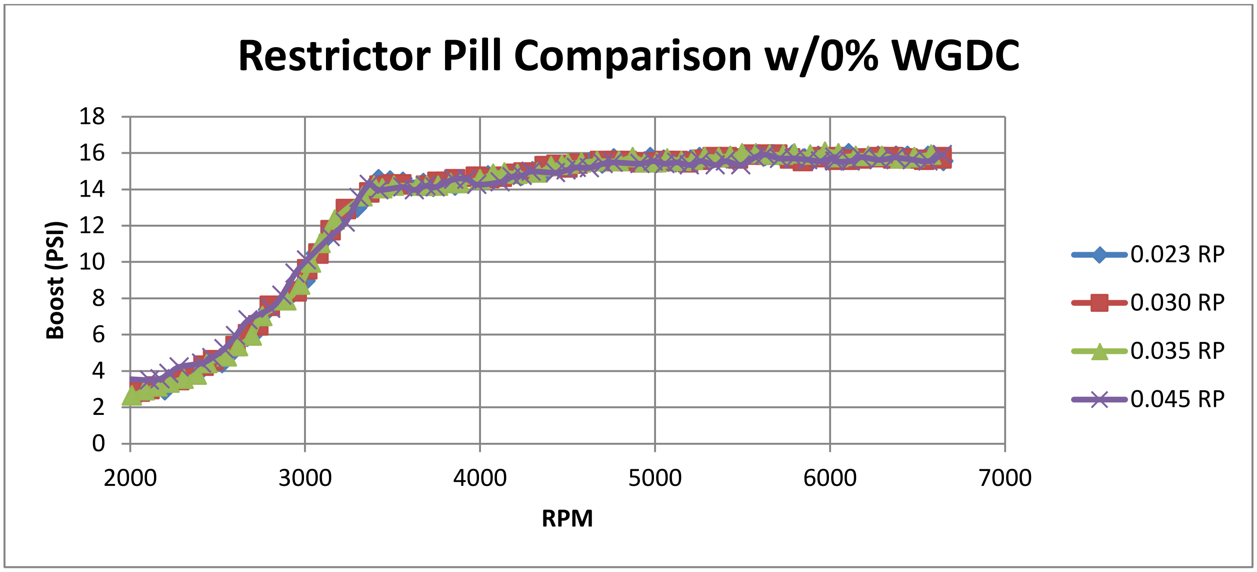

Figure 20: Comparison graphs for the tested restrictor pills.

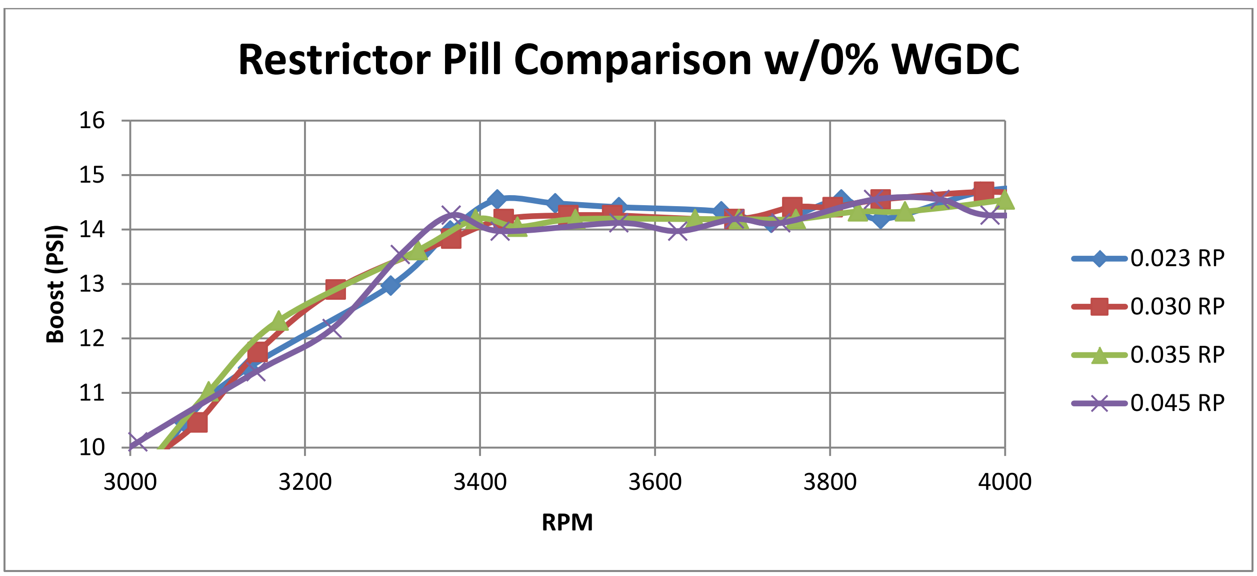

Figure 21: Comparison graphs for the tested restrictor pills zoomed in to show response difference.

With these problems resolved, testing moved forward. The turbocharger was showing good gains while still being very daily driver friendly. The spool time was nearly like stock, building 20psi by 3200rpm with a CorkSport TMIC, CorkSport catted downpipe, and CorkSport Stage 2 intake system.

Compressor & Turbine Wheel Combinations:

At this point in the testing the CHRA was equipped with the standard wheel combination consisting of a standard profile cast compressor wheel and 12-blade turbine wheel. This combination is tried and true, but leaves some performance on the table. We began exploring new wheel combinations in an attempt to squeeze the most out of the turbocharger. We tested multiple compressor and turbine wheel combinations eventually satisfied with the performance forged billet compressor wheel and high flow 9-blade turbine wheel. This combination proved to excel with faster spool and more top end power. The design and details of these wheels can be found above in the knowledge base and below in the turbochargers features chart.

CorkSport Performance Drop-In Turbocharger Features:

Performance Drop-In Turbocharger Design & Specs

Component	Feature	CorkSport Turbocharger	OEM Turbocharger
CHRA	Manufacturer & Model	**Mitsubishi TD05H-18G**	**KKK K04**
	Bearing System	Heavy Duty Journal Bearing w/360 Degree Thrust Collar	Standard Journal Bearing w/270 Degree Thrust Collar
	Lubrication & Cooling System	Oil & Coolant	Oil & Coolant
	Serviceability	100% Rebuildable Without replacing the Center Section Housing	Not Worth Rebuilding
	Balancing Procedure	Compressor Wheel Balanced	Unknown
		Turbine Wheel Balanced	Unknown
		Assembled CHRA Balanced	Unknown
Compressor	Wheel Material	Fully Machined Forged Billet T6 Aluminum Alloy	Cast Aluminum Alloy
	Wheel Design	50.5mm Inducer 55 Trim 6x6 Blade Design w/Extended Tip Technology	45mm Inducer 64 Trim 6x6 Blade
	Housing Material	Cast T6 Aluminum Alloy	Cast Aluminum Alloy
	Housing Design	0.53 A/R w/OEM Size Inlet & Outlet	Unknown A/R w/OEM Size Inlet & Outlet
	Maximum Flowrate	660 CFM (50 lbs/min @ Sea Level)	Not Enough
Turbine	Wheel Material	Inconel 718 Super Alloy: Extreme Heat Tolerance	Unknown
	Wheel Design	49mm Exducer 76 Trim High Flow 9-Blade 21% Lighter than 12-Blade Design	44.5mm Exducer 79 Trim 12-Blade Design
	Housing Material	High Silicon Molybdenum: Resistant to Heat Cycling Cracks	Cast Iron Alloy
	Housing Design	Single Scroll 0.71 A/R (9cm^2) w/OEM Hook Up Points	Single Scroll Unknown A/R w/OEM Hook Up Points
Wastegate Design	Port Size	24mm Port: 12% Larger than OEM	21.5mm Port
	Actuator	Large Diaphram Billet Housing w/Adjustable Rod	Small Diaphram Stamped Steel Housing Non-Adjustable
	Internal	Internal Wastegate Design: 28mm Flapper Valve	Internal Wastegate Design: 27.5mm Flapper Valve
	Turbine Outlet	Increased Outlet Size Improves Flow Around Wastegate Port	Non-Optimized Outlet Restricts Flow Around Wastegate Port
Installation	Drop-In	**CorkSport Turbo Kit Includes:**	OEM
		OEM Style Coolant Line w/M14 Copper Crush Washers	
		Turbine Gaskets	
		Turbine Studs & Crimp Flange Nuts	
		Turbine Heat Shield	
		Oil Feed Banjo Bolt w/M12 Copper Crush Washers	
		Replacement Hardware & Fasteners	
Quality Control	Balancing	Turbo Technics CHRA Balancer up to 250,000 RPM	Unknown
Warranty	Coverage	Limited 1 Year/Unlimited Miles	Mazda Powertrain

Conclusion:

When a performance drop-in turbocharger first became an idea the goal was to create an easy to install, cost effective, and performance driven turbocharger that would fulfill the power goals from the novice enthusiast to the track running extremist. We designed the largest turbocharger you can operate that will still be compatible with OEM components that fills the gap between the OEM K04 and the big turbo builds. The CorkSport Performance Drop-In Turbocharger is packed full of the latest technology to provide you, the best value for your hard earned money.

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