

BorgWarner EFR Turbocharger Technical Training Guide



Table of Contents

Foreword	pg.3
Product Introduction	pg.5
Aerodynamic Selections	pg.11
Compressor Wheels	pg.12
Turbine Wheels	pg.13
Turbine Housings	pg.16
Open vs. Divided Turbine Housings	pg.20
Wastegate System	pg.25
Wastegate Canister Selection	pg.30
Boost Control Troubleshooting	pg.31
Bearing Systems	pg.33
Oil Restrictor and Inlet Fitting	pg.37
Oil and Water Connections	pg.39
Gamma-Ti Turbine Wheels	pg.42
Compressor Stages	pg.46
Turbine Housings	pg.53
CRV (Compressor Recirculation Valve)	pg.61
BSCV (Boost Control Solenoid Valve)	pg.62
Speed Sensor Accessory	pg.64
Turbo Orientation Features	pg.69
Oil Connections and Lubrication	pg.74
Housing Connections	pg.75
EFR Feature Summary	pg.79
Turbo Installation Notes	pg.81
Wastegate Preload Adjustment	pg.81
CRV Hose Connection	pg.84
BSCV Hose and Electrical Connection	pg.85
Thanks and Acknowledgements	pg.87
Appendix: Misc. Pictures and Data	pg.88
Kit Descriptions and P/N's	pg.88
Super-Core Descr. and P/N's	pg.93

Fastener Tightening Torques	pg.95
Oil Drain Orientation Angle	pg.95
BorgWarner Match-Bot	pg.101
BCSV Operation	pg.103
CRV Operation	pg.104
Speed Sensor Connector	pg.104
Turbo Outline Drawings	pg.105
Compressor Maps	pg.113
Turbine Maps	pg.119
Product Matrix and P/N's	pg.120



Foreword

The first thing worth explaining is the strong connection between this exciting line of aftermarket turbos and our OEM commercial vehicle products. Commercial/industrial turbo products have extreme requirements for durability, reliability, and aerodynamic performance. Turbo sizing for the performance user more resembles what's in the commercial realm as compared to what comes from our (and others') OE passenger car developments. Since modern passenger car applications use turbos smaller than 55mm turbine wheel diameter, it's the larger components used on commercial applications that are more applicable to high-power aftermarket performance use. Commercial engines often utilize high boost pressures. Gage pressures of 45+ psi [3+ bar] are quite common even while retaining extreme durability.

Also required is resistance to abusive thrust loads, vibration, and robustness for a wide range of lubrication and cooling conditions. Our OE product validation standards are very tough, and many of these same practices were employed during the development of the EFR products.

That was the commonality, now here are the differences. Unlike commercial applications, high performance users want lightweight, compact, versatile designs. They also deliver the turbocharger very high exhaust gas temperatures and have high expectations for fast response. They also place value in cosmetic appearance and want integrated features that aid the installation process and remove the need for other accessories.

So, what happens when you combine all these requirements?

Something new is required, something that really changes the game.

Before a team was assembled, I selected the aerodynamics for the product line -- a range using only optimized combinations that would give our users turbo solutions anywhere between 200 and 1000 horsepower capability per turbo. I also made a list of every great design feature I could think of -- everything I had ever seen or heard of, new ideas that had never been taken from paper to hardware, and permutations of these that had never been integrated. Ninety percent of this content "stuck" and it was only the truly exotic that was excluded; features that would either take too long to develop across the size range or would be so expensive that nobody could afford them. Then, the program proposal was pitched to three of our top management staff. They got excited about the vision of giving this segment something remarkable and approved proceeding with the project. So, to them we all owe thanks.

After that, a talented and enthusiastic team was assembled and the rest of this text shares the detail of the design, development, and production launch process that followed.

The result is the new EFR Series of turbos from BorgWarner, and it's our sincere hope that you enjoy them.

A handwritten signature in black ink that reads "Brock S. Fraser". The signature is written in a cursive, flowing style.

Brock Fraser
Global Director, Application Engineering
(Chief Engineer & Team Leader of EFR Project)
BorgWarner Turbo Systems



Chapter 2: EFR Product Introduction

Aerodynamic Selections

As mentioned, the primary goal was to provide optimized solutions for people in the 200-1000hp per turbo segment. Thankfully, this covers just about everyone except the hardcore drag racers. For those specialized customers, we still offer the highly popular S400SX and S500SX product lines. For the EFR products, the compressors range from 62mm OD (~50mm inducer) to 91mm OD (~68mm inducer). From this, the 70mm through 91mm compressors are designed for high-boost (40+ psi) capability. Born from our work in highly-boosted highly-efficient commercial engines, these compressors are top-shelf in terms of efficiency, range/width, and of course pressure ratio (boost) capability. On the turbine end of the machine, the range is from 55mm OD to 80mm OD. These turbine shapes are the newest “superback” and “fullback” designs from our work in high-boost high-efficiency applications. These are low-stress designs capable of high speeds and offering excellent efficiency. The compressor and turbine “pairing” is what it should be to maintain the best turbine inflow incidence, and the turbine housing A/R’s are selected to also optimize turbine stage efficiency. A team has this kind of flexibility when you design a product line from scratch and aren’t limited by availability of what already exists.

Wastegate System

Everyone knows that high performance applications need wastegating, and typically lots of it. This industry has been relying on external wastegates for many years out of necessity. As part of our “clean sheet” approach, we wanted to make internal wastegates that were capable of handling the flow requirements of high performance applications. This meant very large valve sizes (36mm and 42mm valve

head) and aerodynamically-efficient porting. When you look at these designs, you won't see harsh corners, fabricated edges, or other losses. When as much as 40% of the flow needs to pass through the wastegate at maximum power, a flow-optimized solution is needed. You also won't see "fuse points" such as flexible diaphragms that have metal-to-metal contact with hot exhaust parts. In this industry, when an internal wastegate was employed for performance application, it was typically a housing inherited from prior diesel use (with a low wastegate flow demand) and so it had to be a pretty special case to be able to flow enough exhaust and also a special case to be able to have enough orientation flexibility for the actuator canister. We hope you'll agree that the EFR product line changes this. Three actuator specifications are offered: low boost, medium boost, and high boost. Choosing the right actuator is the coarse adjustment and then the fine tuning can be done through a very handy rod-swivel joint.

Bearing System

Even though we have been long-time proponents of efficient journal bearing systems, for this product line we opted to use rolling element (dual row, ceramic ball) bearings. Once you have reached target boost, ball bearings offer little or no advantage in performance at full throttle. But, we absolutely recognize the benefits of getting up on boost quickly and having torque response that feels tightly linked to throttle movements. Ball bearings also reduce parasitic loss at low turbo speed and in the few (but growing!) instances of people who care about both fuel economy and performance, a benefit will be seen in consumption. Amongst OE's, this and other efficiency-enhancing tricks will be popular in coming years when coupled with engine downsizing. Ball bearings also offer greatly improved thrust capacity and can live with a lesser oil supply. Lastly, our EFR bearing system includes the latest in sealing technology, improving both resistance to oil leakage at light loads and intrusion of boost and exhaust pressures into the bearing housing while under heavy loads. The bearing housings are water-cooled for those who choose to (or are able to) plumb a water supply. Water cooling is

recommended where possible to do so.

Turbine Wheel

The most exciting technology in the EFR package is the turbine wheel material. EFR turbine wheels are made from titanium aluminide. It's not the first time this material has been used, but it's the first time that it has been offered to the public across a range of size options.

Titanium aluminide (or Gamma-Ti, for short) is a strange compound. One of those nice examples of the result being greater than the sum of the parts; this compound has temperature capability far in excess of aluminum and titanium as individual elements. Very difficult to cast, this compound is actually an inter-metallic which means that it's not quite ceramic and not quite metal. One major delivery of this project has been to commercialize this material to be able to introduce it at an acceptable price point. The technical advantage is very simple: low inertia. Since Gamma-Ti has roughly one-half the weight of a typical turbine wheel, the reduction in inertia is substantial *especially* on the larger wheel sizes such as 64mm and above. The turbine wheel is so light, it is very nearly the same weight as the compressor wheel that is on the other end of the shaft. When you feel one of these parts in your hand, it's hard to believe it's a turbine wheel. Then you drive the car and you feel what's been accomplished. When paired with the ball bearing system, it yields a turbocharger that has no rivals in terms of boost response.

Compressor Stage

As mentioned above, the series of compressors is from 62mm to 91mm OD which satisfies a wide range of applications. The compressor wheels are all FMW (forged milled wheels). We selected forged milled wheels not because they are pretty (even though they are) but because they do offer a strength improvement over cast wheels and because it provides speed and flexibility to the design process by not having to make casting tooling. Most high performance users won't benefit from the strength improvement because these applications are generally low

turbo rotational speed and of relatively short mileage lifetime as compared to a commercial application. But, for the endurance racer or the uber-boost drag racer, the material might save your day. The compressor covers have been given our latest flow-range enhancement tricks such as treatment to the recirculation slot and optimization of the diffuser pinch and width.

Turbine Housing

When you look at the external appearance of the EFR product line, the first thing you will probably notice is the turbine housing. Unlike a milled compressor wheel that stays hidden inside, this outward-facing turbine housing looks like jewelry when installed. It's not all looks, however. The material is 300-series stainless steel for high temperature performance and corrosion resistance. The wall thicknesses are very thin, much thinner than a conventional casting, yielding low installed weight and low thermal mass. The manufacturing process is investment casting, which yields a cast surface that rivals a machined surface finish both inside and out. On the inside, this means lower gas friction losses. On the outside, this means people staring in your engine bay with jealousy. However, the housings are all-business when you get right down to it. With the initial product launch being comprised of four castings (with many machined variants), we are serving a variety of customers: wastegated or not, divided (twin scroll) or not, and of three different industry-standard mounting flange shapes. A v-band discharge flange comes standard. And, as mentioned above, they are aerodynamically designed as matched pairs with the turbine wheel choices.

Integrated Features

Why buy an external BOV? Why buy a boost control solenoid? In addition to buying these items separately and spending more money in the process, the user has needed to mount these parts which gives hassle and headache. The BorgWarner EFR turbos have these parts as integrated features. The CRV (compressor recirculation valve) vents

boost quickly and efficiently when the throttle closes, and it is internally-recirculated to keep turbo speed high during the shift and to keep engine control systems (especially those with a MAF sensor) satisfied. The boost control solenoid valve (BCSV) is a convenience feature. Integrating the mounting of these valves onto the compressor cover is a trend we observed from the OE passcar side of the business. As such, you can trust that these are proven solutions that have worked for millions of customers for many years. For those that prefer an external blow-off valve, that's fine too. We will sell a block-off plate that disables the internal CRV.

"EFR" Name

Now that you have read the "EFR" letters a few times, you might wonder what the letters stand for or where the series name came from. Believe it or not, the process of determining the name was one of the more controversial elements of the program, but that just shows how much passion was put into this project by the team. Originally the name was derived from a contest entry held amongst BorgWarner's Asheville North Carolina facility (where the product is engineered and produced) employees. EFR² stood for Earth Friendly Race Ready series of turbochargers. The name struck a chord because it aligned with BorgWarner's strategy of being a technology leader in reducing fuel consumption and harmful emissions but also shows that they are well-heeled in the performance and racing scene. Many of the features in this product line will also migrate towards our OEM customers, especially those seeking the highest level of performance, efficiency, and feature content. Many of these customers are striking a healthy balance between powerful (fun) engines, yet also achieving extremely clean emissions and low fuel consumption. The name was later shortened to "Earth Friendly Racing" for a simpler look. After revealing the name within the organization and with some external advisors, it was apparent that tying "Earth Friendly" and "Racing" didn't go over well with many people. While many of the racing leagues are trying to produce a more "green" image, the vast majority of the performance

market doesn't make a connection, at least not yet.

The EFR acronym remained the official name but it now more aligns with the true intent of the program. To find the name we needed only look back to the reason we started this project; to give the performance market a turbocharger that was engineered from a clean sheet with them in mind. Through the course of doing the work, we came to appreciate that the name "Engineered For Racing" (a.k.a EFR Series) would be known as the turbocharger that redefined the market's expectations.

Summary

All combined, the EFR turbocharger line is at the pinnacle of what can be done with the current state of the art while maintaining affordability. It raises the bar in every respect: performance, response, installation, appearance, and value. It is quite simply the best aftermarket turbo that money can buy, and we will continue to raise that bar and provide additional housing and feature options going forward.



Chapter 3: EFR Aerodynamic Selections

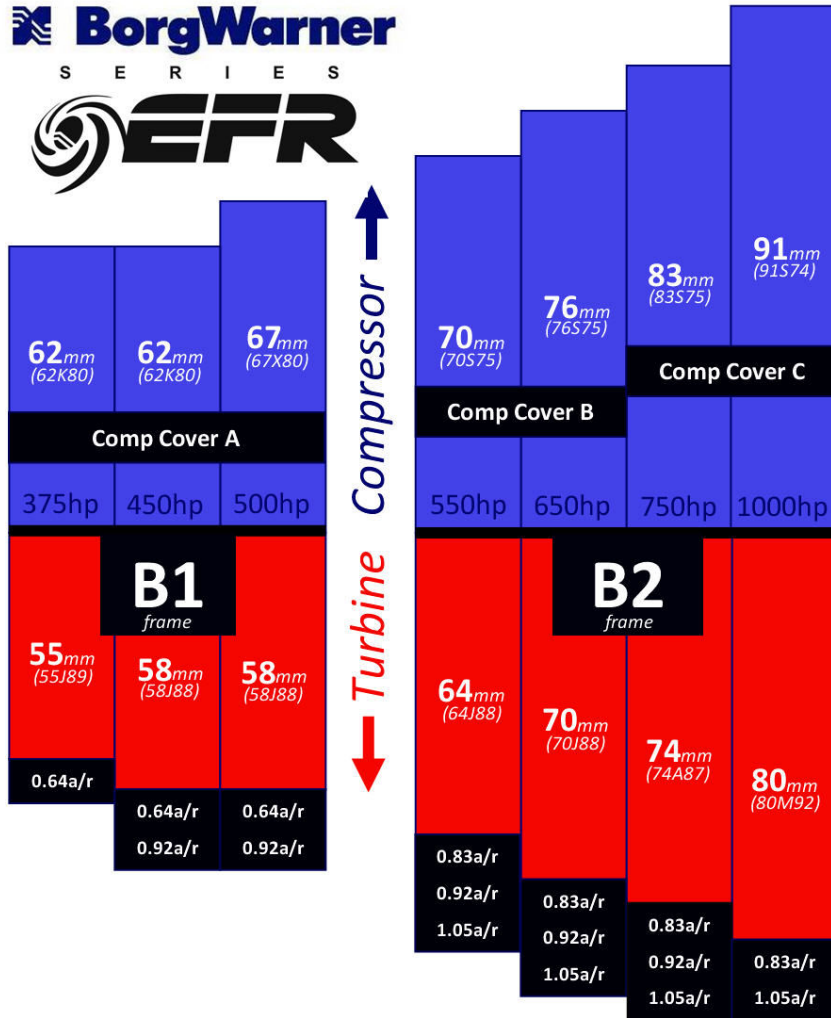


Figure 1: EFR Aerodynamic Options

Compressor Aerodynamics

There are six compressor wheel sizes within the EFR product range. 62mm, 67mm, 70mm, 76mm, 83mm, and 91mm.



Figure 2: Compressor Wheels 62mm-91mm

The two smallest wheels (62mm and 67mm) offer very large map width while still enabling high-boost operation. Very important for small engines striving for peak torque at streetable engine speeds, these compressors offer surge line positions that are far to the left on the map without needing a cover recirculation slot and cavity. The wheel itself is designed to not *need* an inducer recirculation slot, but furthermore it helps solve packaging problems due to the 2.5" inlet hose connection. Through a high backsweep angle on the blade outlet and our Extended Tip Technology on the exducer tip, these wheels offer excellent range (flow capacity) while still being capable of high boost at reliable turbo speeds. Both the 62mm wheel and 67mm wheel employ a large 80% inducer trim (64% on an area basis).

The rest of the compressor wheels (70mm through 91mm) are of a different design. These Extended Tip Technology wheels are very unique in that they are our highest-boost capable wheels but still give outstanding map width and flow capacity. The compressor cover treatment includes an inlet recirculation groove for maximum width and anti-surge characteristics. A new trim set was developed for this program on these wheels, which is 75% trim (56% on an area basis). This large trim gives up a very small amount of efficiency but for a

significant gain in flow capacity. The only trim exception is the 91mm version. This part is released at 74% trim as to maintain an inducer diameter that is compliant to some specific drag racing class rules.

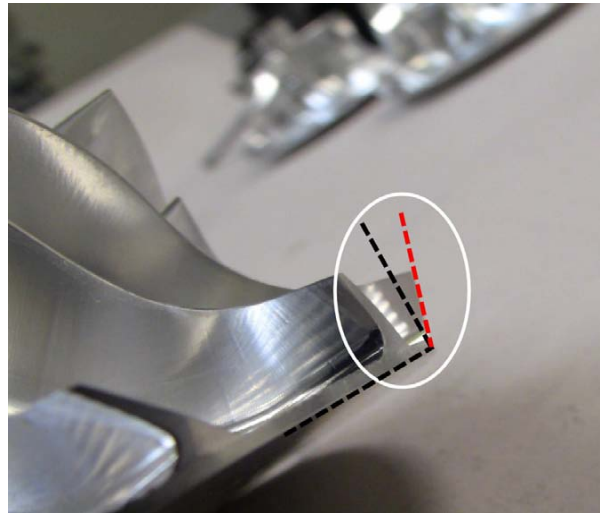


Figure 3: Extended Tip Technology

Turbine Wheel Aerodynamics

There are six turbine wheel sizes within the EFR product range. 55mm, 58mm, 64mm, 70mm, 74mm, and 80mm.



Figure 4: EFR Turbine Wheels 55mm - 80mm

The 55mm and 58mm turbines are targeted at street applications that need maximized boost response through smallest diameter and lowest inertia. Still capable of 350-450hp when mated to the 62mm and 67mm compressors, they are a potent combination of quick response and respectable power capacity. The 58mm turbine offers superior efficiency to the 55mm and when in doubt, should be the chosen one of the two. The 55mm is offered for those people wanting the ultimate in small-rotor response, especially those who are used to 45-50mm turbos (such as our K03 and K04 products) who still want that “feel” but with a lot more top-end capability.

The 64mm and 70mm wheels are descendants from the same family of blade shape as the 55mm and 58mm, but are simply larger in size. All four of these wheels use an 88-89% trim diameter, a good choice on this wheel for efficiency, flow capacity, and durability.

The 74mm wheel is of a very similar theme of those smaller sizes. This wheel is a very potent performer and is used heavily in some of our most efficiency-focused applications on the OE side of the business. It is cut to an 87% trim diameter.

The 80mm wheel really means business. Made from our highest-flowing blade shape, this wheel is designed for maximum flow in view of our highest-power EFR customers. This wheel has delivered the goods for up to 1000whp (per turbo) and comes with a 92% exducer trim.

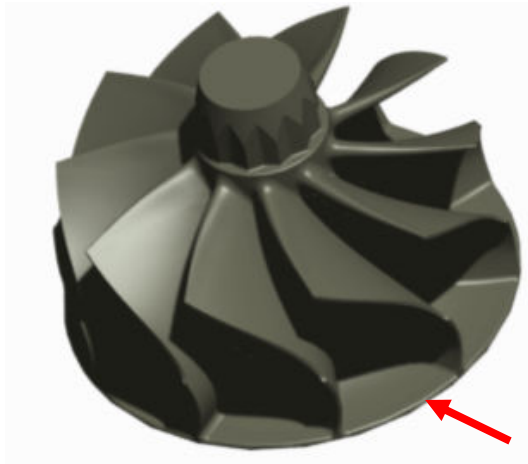


Figure 5: EFR Turbine Wheel, Showing “Fullback” (Full Diameter) Back Disk

All six turbine wheels use our latest hub shape definition. These hubs have a full aerodynamic back-disk, meaning that the hubline extends all the way to the inlet tip. Intuitively, this feature allows very smooth guidance of flow out of the housing and into the blade channels and this is exactly what is achieved. Impossible in the past due to material stress limitations, this exciting new “fullback” design is enabled by also having a “superback” on the part. Very similar to the curved surface on the backface of modern compressor wheels, the “superback” reduces centrifugal stress in the wheel by moving the locus of stress outwards from the core of the wheel. These two features work in concert to allow best possible efficiency, high speed capability, and durability.

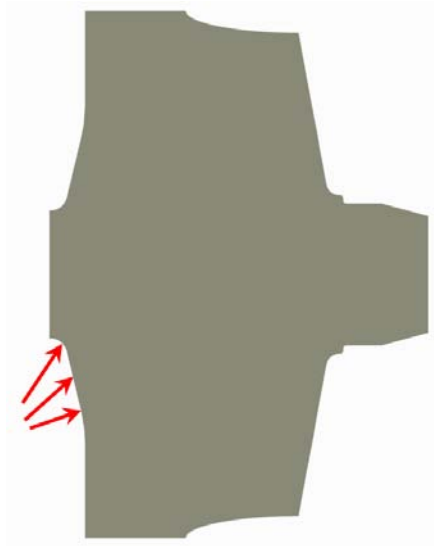


Figure 6: Turbine Wheel "Superback"

Turbine Housing Aerodynamics

Some of the most difficult program decisions were what design shapes to use for the turbine housings. The external features (and the decisions that led to them) will be discussed in a later chapter but here we will focus on the internal (volute) attributes. Every turbine wheel has a "sweet spot" in terms of what it likes to see for flow incidence angle. Keeping in mind that the wheel is always spinning, the incidence angle is formed by the rotational speed of the wheel and the angle of the gas leaving the turbine housing. Think of a garden hose that is spraying on a spinning paddle wheel. The wheel will achieve highest speed (greatest reaction) when the hose is pointed at the correct angle. It's tempting to think that the outflow from the housing volute dumps into one location, at the small end of the volute near the tongue (like the garden hose example). However, the actual purpose of the volute is to deposit an even distribution of flow (around the perimeter) leaving the volute and entering the wheel. Keep these principles in mind while we discuss a/r selection and the topic of "sweet spot".

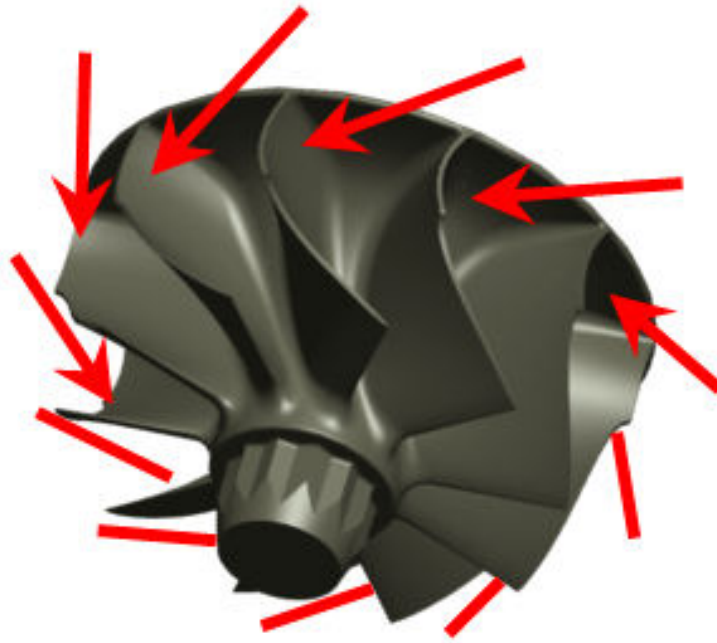


Figure 7: Turbine Wheel Inflow from Turbine Housing

Another important definition is the phi parameter. The phi parameter is nothing more than a numerical representation of the stage (wheel + housing) swallowing capacity. The number is calculated by knowing the mass flow, temperature, and pressure of the incoming gas.

$$\text{Turbine Flow Parameter (Phi)} = \frac{\text{mass flow} * \sqrt{\text{absolute temperature}}}{\text{absolute pressure}}$$

Figure 8: Phi Equation

Knowing the phi parameter for the stage and comparing that number to the engine exhaust manifold outlet conditions will describe whether or not the turbine can swallow what the engine is emitting. Any flow above and beyond the phi capacity must be wastegated. If the flow is less than the phi capacity, then the turbine is oversized and the boost target will not be achieved at that engine speed and load. This

numerical comparison (point by point) is what is referred to as turbine matching and is substantially more involved than compressor matching. For that reason, turbine maps are often not published and sizing decisions are often based on rumor and tribal knowledge.

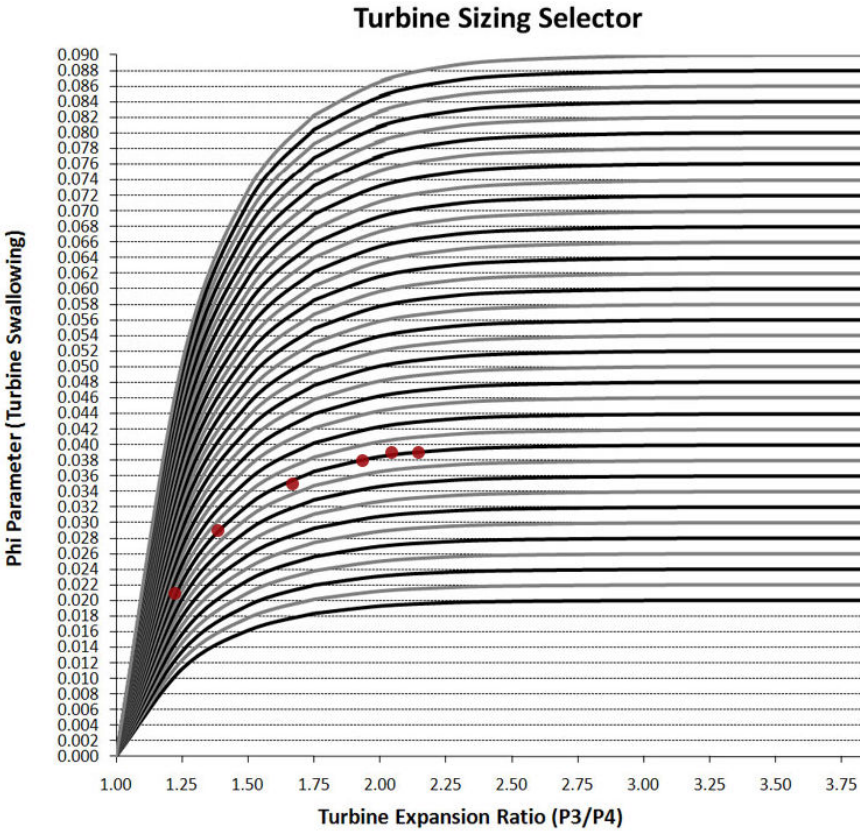


Figure 9: A Series of Phi Curves, (on which the operating points must fall, excluding the wastegate fraction)

The smallest housing in the EFR range was called "A" during the development phase and is optimized for the 55mm and 58mm turbine wheels. It uses a 0.64a/r which generates a volute outflow angle that is right in the sweet spot for these wheels. It is a suitable compromise of flow capacity while staying somewhat small and responsive. It has a large internal wastegate (31mm port, 36mm valve) which has flow

capacity for roughly 38-40% of the turbine flow conditions for engine matches in the 350-450hp range.

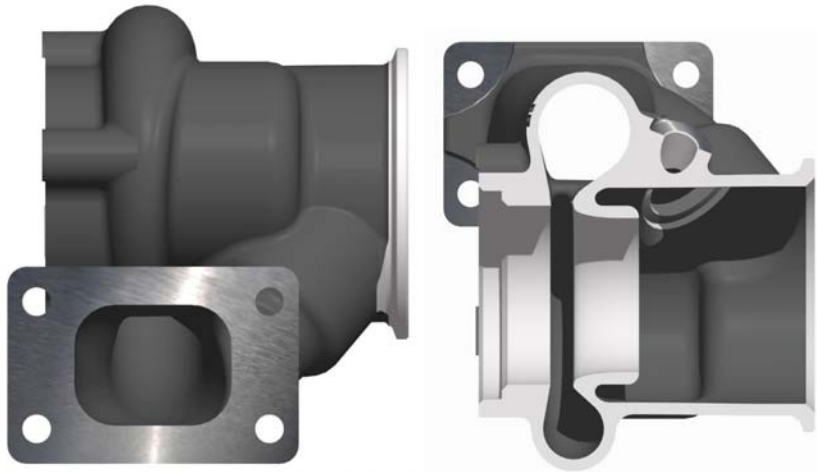


Figure 10: Turbine Housing "A": 0.65a/r wastegated

The second housing "B" in the EFR range is similar in function to the "A" housing but designed for larger wheels. This housing has a 0.83a/r and is optimized for the 64mm, 70mm, 74mm, and 80mm wheels. This span of wheel diameters (16mm) yields a range of 8mm per side (at the tip radius) and the housing tongue position is designed for optimized yet durable positioning across this size range spectrum. This housing also has an internal wastegate, but is a bit larger in size than the "A" housing's wastegate due to being targeted at the higher-power users. This wastegate has a port diameter of 36mm and a valve head diameter of 42mm which is the largest internal wastegate ever employed at the time of this writing. Wastegate flow fractions of 40-45% are possible with this design and combined with the range of wheel sizes, this housing is capable of very high power levels. The "B" housing does not have a divider wall, in other words it is a single-scroll design that will serve customers with non-divided manifolds.

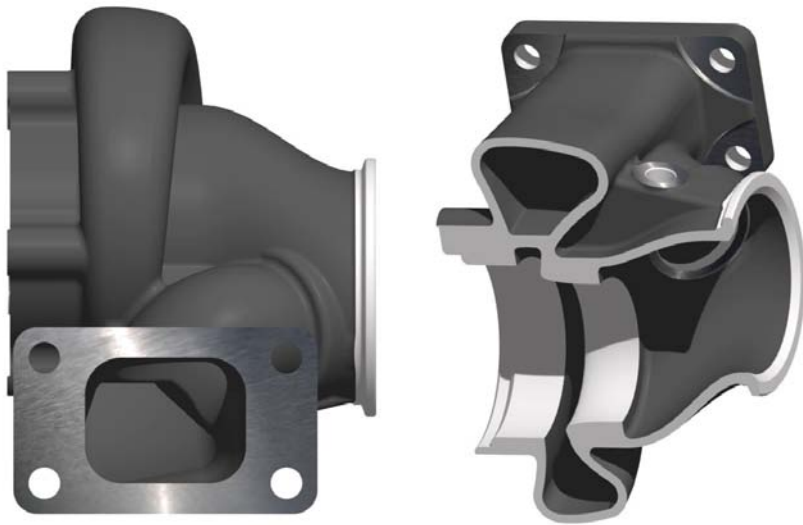


Figure 11: Turbine Housing "B" - 0.83a/r wastegated

Let's pause on the EFR housing descriptions and spend a few moments on the subject of twin-scroll (divided) turbine housings. Twin-scroll housings are becoming very popular for performance use, and for good reason. By dividing the manifold and turbine housing into two flow paths, the engine firing order can be made to "alternate" the flow all the way to the turbine wheel inlet. The engine blow-down pulse is generated when the exhaust valve opens. During the blow-down, the engine power cylinder is still at very high pressure as a residual of combustion and the power stroke. This initial "pop" of energy travels at very high speed down the manifold runner, through the volute, and impacts the wheel. For this reason, the stream is very much a "pulsed flow" and the divided nature of the system simply amplifies and arranges those pulses. The engine firing order creates a "one-two" (alternating) punch on the wheel, keeping the pulses evenly spaced and in rapid succession. As the engine speed increases, this becomes a blur and the alternating nature loses its value. Hence, twin-scroll housings only benefit the low and medium speed operation of an engine. Within this range, it is a very effective way to improve turbine effectiveness. The wheel loves the high velocity evenly-spaced pulses of gas, and as

long as they are “slow” enough in succession and duration, the wheel can make good reaction usage of the energy. What results is an improvement in “effective” efficiency, and at lower engine speeds more turbine power can be generated. The obvious result is quicker spool and better low-end boost response. As mentioned, the top-end operation is not improved, everything else being equal. Put into practice, a single-scroll housing of sufficiently large size is the recipe for a user that is seeking only top-end power optimization. That said, a very potent combination is a twin-scroll divided system that works to retain good low speed boost response, while sizing it large (aerodynamically) for the best top-end power. It’s the best of both worlds, in many cases.

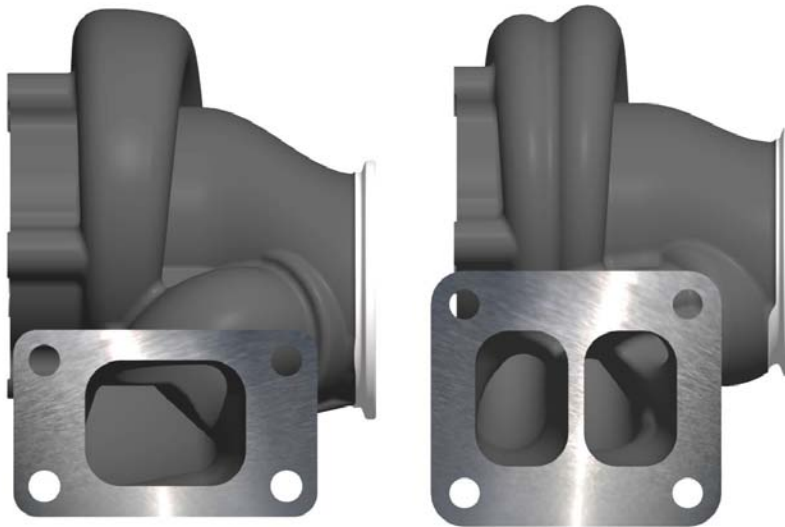


Figure 12: "Open" versus "Divided" Turbine Housings

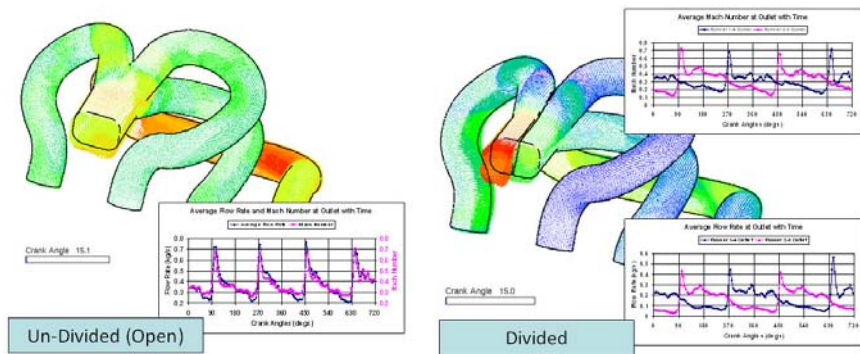


Figure 13: Open vs. Divided Manifold Pulsation (Courtesy: Ford Motor Company)

EFR turbine housing “C” is a very intricate part since it is not only a divided (twin-scroll) housing but is also internally wastegated. From a casting standpoint, this is quite difficult to do because the core shapes must not only divide the volute but also divide the wastegate path all the way up to the valve head. On OE diesel style housings, this can be accomplished with simple shapes and sometimes dual-valve arrangements but these are not good solutions for the performance application due to the limited wastegate flow capacity and high port flow losses. This “C” housing has a $0.92a/r$ and is optimized for the 58mm, 64mm, 70mm, and 74mm turbine wheels. Like on the “B” casting, this span of wheel diameters (16mm) yields a range of 8mm per side (at the tip radius) and the housing tongue position is designed for optimized yet durable positioning across this spectrum.

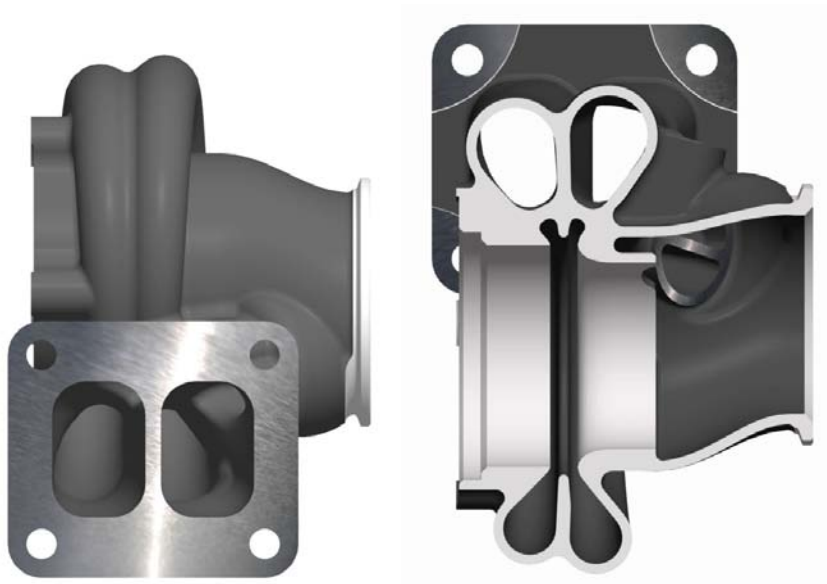


Figure 14: Turbine Housing "C" - 0.92a/r Wastegated

EFR turbine housing "D" is also a divided (twin-scroll) housing but is not wastegated. Targeted at those who are comfortable using two external wastegates or are already set up in such a configuration, this part will likely be the most popular on dedicated drag race machines. It is constructed with a larger volute than the "C" housing, this one being 1.05 a/r. It is also adjusted so that it can accommodate the largest of EFR wheel sizes, the 80mm. It is also offered for the 64mm, 70mm, and 74mm wheels. The housing has a very short axial length and is designed to be a "drop-in" for customers already running a T4-inlet divided housing with external wastegates.

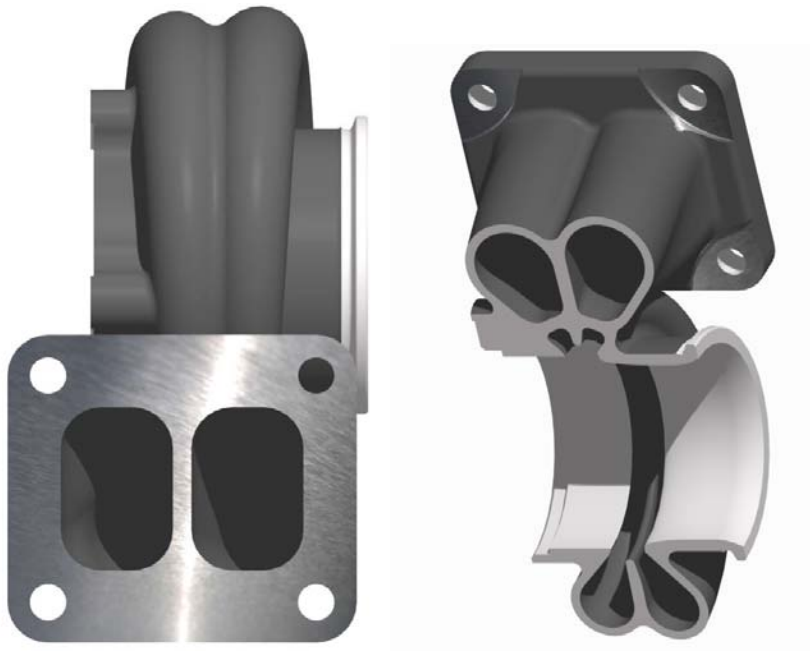


Figure 15: Turbine Housing "D" - 1.05a/r Non-Wastegated

Summary

Turbine and compressor aerodynamics are truly “top shelf” in the EFR product line. Choices have been made that embody the current state of the art and include the latest and greatest techniques also being offered to our OE customers today. Combined with the other features like ball bearings, the compressor cover refinement, and Gamma-Ti turbine wheels (to be further discussed in other chapters), it has been our intention to maximize the performance of these turbos in every possible way.

Chapter 4: EFR Wastegate System

As mentioned in the introduction, internally-wastegated housings of the past have usually been castings that were handed down from prior diesel applications. As part of offering a diverse “performance” product line, it’s logical to make use of any casting that is available and might be of use to someone. However, these housings have had limitations. They have almost always had small wastegate ports that were quite suitable for diesel use but often not sufficient for “gasoline” levels of wastegating. Material specification has also been an issue, with most of these housing made from ductile cast iron of one flavor or another but rarely of a material truly suited for high-temperature operation. This is particularly noteworthy for wastegated housings, since the wastegate seat can be the “fuse” for thermal fatigue failure.

As part of our “clean sheet” approach, we wanted to make internal wastegates that were capable of handling the flow requirements of high performance applications. We use matching calculations that predict the level of wastegate flow required for any given match. By using a conservative flow coefficient assumption, we can predict how much flow will pass through a wastegate port of a specified diameter, motivated by the expansion (pressure) ratio across the turbine stage. Using this method, the wastegate can be sized on a match-by-match basis. This procedure was followed for a wide range of matches (displacements, power levels, engine speed ranges, turbo sizing) at the beginning of the project. It was decided that a 31mm port (36mm valve head) would be sufficient for the smaller turbine housing, and a 36mm port (42mm valve head) would be used for the larger housings. 36mm may not sound that much larger than 31mm but in fact it’s 35% more flow area.



Figure 16: Large Internal Wastegate

There are downsides with going too large, so we knew that we were walking a fine line. A wastegate that is too large can be fickle to control since a very small valve opening can then result in a very large increase of flow. In other words, if only 50% of the rod stroke is used for max wastegating flow need, then the control resolution is half of what it could have been. Also, packaging dimensions (housing physical size) suffers as the wastegate valve head grows in size.



Figure 17: Wastegate Valves - 36mm and 42mm

The wastegate valve, shaft, bushing, and lever materials are investment castings of premium materials. The valve heads have anti-rotation tabs to prevent vibration-induced skidding wear. Lever arm kinematics were selected to be a match with available rod stroke, yielding approximately

50 degrees of valve motion – sufficient to achieve maximum port flow. Another nice mechanical element is the lever’s swivel-block due to the easy adjustment. The wastegate canister has an output rod and the end of this rod is threaded. The thread is M6 x 1.0 which means that each full turn of the nut equals a 1mm change in extension. By tightening the nut one turn at a time, a known preload (1mm) can be applied to the rod and canister spring. As preload is added, the spring inside the canister compresses and exerts more force to hold the wastegate flap closed. The downside of added preload is loss of stroke. In other words, the rod travel that is consumed by preload setting is no longer available for rod stroke motion (during use). The valve will not be able to open as far, so maximum wastegate valve flow will be limited.

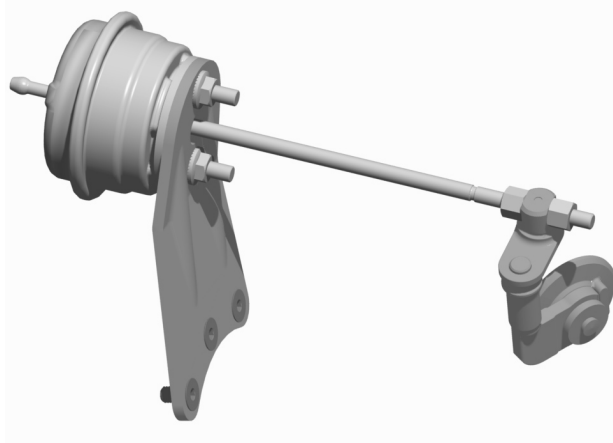
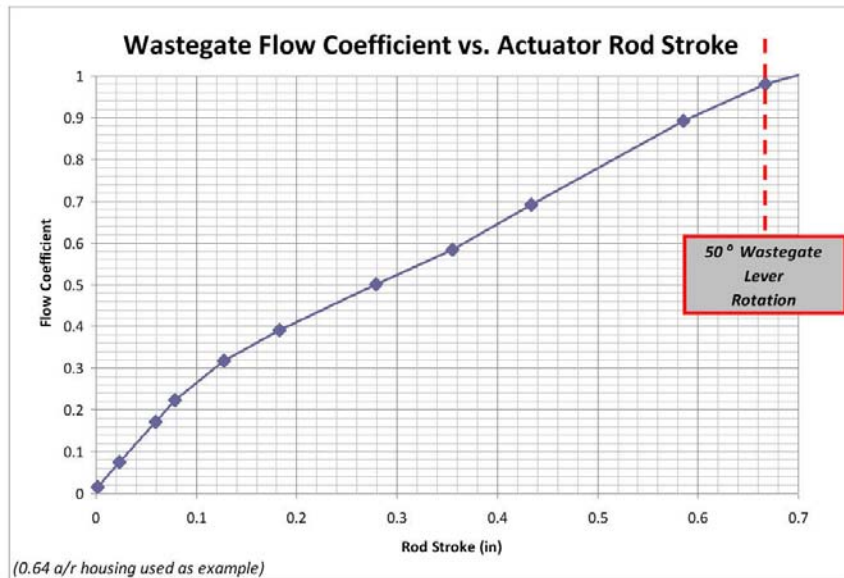


Figure 18: EFR Wastegate System



The flow coefficient is a measure of to what extent the wastegate port area is being used. When a pressure drop is applied to any orifice, orifice flow equations can be used to calculate what the theoretical maximum flow is through the hole. If the flow coefficient reaches 1.0, then that means that the port is being fed efficiently and that the port area is being used to the maximum extent. In this example, once the lever angle reaches about 50 degrees, the valve is sufficiently out of the way and the port is flowing at the max capability. From studying this plot, you can see why achieving a large stroke from the canister is important if the wastegate is being used for a large fraction of the total exhaust flow. This is particularly important with low-boost applications since higher wastegate flow fractions are required. More highly-boosted applications require less WG flow fraction since more work extraction (read: more turbine wheel energy) is required to power the compressor.

Figure 19: Wastegate Flow versus Opening Angle (Rod Stroke)

Turbine housing porting was also done with care, giving as much attention to the gate channel(s) as given to the rest of the volute entry throat. This is a compromise with outer elements such as overall housing height and stud/nut wrench access, but given these constraints the ports were smoothed, blended, and sized generously. Of particular challenge is integrating a smooth pair of wastegate channels into a twin-scroll housing. The “C” housing is of this type and requires bit of twist on the volute throats in order to wrap both wastegate channels towards the outlet, heading towards a Siamese (double-D) valve seat.

This is a superb housing for users of “divided” systems (with twin-scroll housing) since it avoids the need to buy, mount, and plumb two external wastegates.

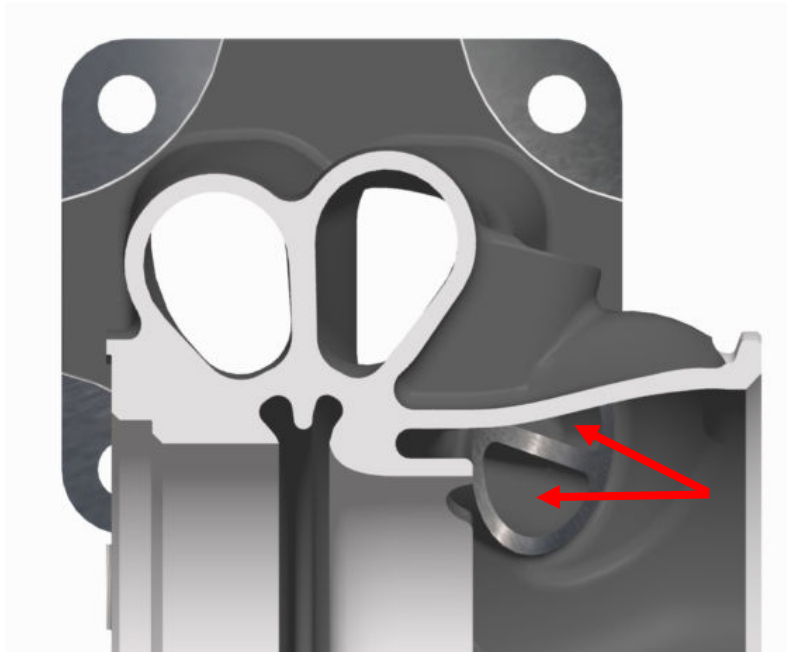


Figure 20: Turbine Housing "C" (0.92a/r) with Dual WG Passages

Wastegate behavior is tuned in two ways. First, the wastegate canister is selected. Second, the rod preload is set. There are three canisters offered, simply called “low boost”, “medium boost”, and “high boost”. As you would expect, the “low boost” actuator requires a low pressure to be applied before cracking the wastegate open. It is also sprung quite softly, so as canister applied pressure increases, the amount of rod movement increases quickly. This actuator is meant for vehicles running low boost pressures (less than 10psi) or vehicles running medium boost (10-15psi) that have an electronically-controlled spill valve (e.g BCSV) on the actuator line. The “medium” boost actuator is the default on EFR turbos and is targeted at the user running 12-18psi boost pressure straight off the supply hose or with mild amounts of electronic spill control. The “high” boost actuator is quite stiffly sprung

and is reserved for those running 20-30psi boost (or higher, when using spill). The rod preload is the fine-tune adjustment, and as mentioned above it's easy to count turns and know how much preload (rod extension) is being added. Graphs are supplied that gives wastegate canister stroke response as a function of preload and applied pressure.

Rod & Spring Preload (mm / nut turns)	Full Stroke Capability inches (mm)	179282, 179420, or 179285		179283, 179421, or 179286		179284, 179422, or 179287	
		Low Boost WG Canister		Medium Boost WG Canister		High Boost WG Canister	
		Crack-Open Pressure (psi)	Full Stroke Pressure (psi)	Crack-Open Pressure (psi)	Full Stroke Pressure (psi)	Crack-Open Pressure (psi)	Full Stroke Pressure (psi)
0	0.67" (17mm)	4.0	13.7	8.8	20.6	16.8	32.3
1	0.63" (16mm)	4.9	13.8	9.6	20.6	17.3	32.3
2	0.59" (15mm)	5.7	14.0	10.8	20.6	17.6	32.3
3	0.55" (14mm)	6.1	14.1	11.2	20.6	17.8	32.3
4	0.51" (13mm)	6.8	14.3	11.9	20.6	17.9	32.3
5	0.47" (12mm)	7.3	14.4	12.3	20.6	18.1	32.3
6	0.43" (11mm)	8.0	14.4	13.2	20.6	18.6	32.3
7	0.39" (10mm)	8.5	14.6	14.0	20.6	19.0	32.3
8	0.35" (9mm)	9.1	14.6	14.3	20.6	19.3	32.3
9	0.31" (8mm)	9.6	14.7	14.8	20.6	19.4	32.3
10	0.28mm (7mm)	9.9	14.7	15.9	20.6	19.6	32.3

Figure 21: Actuator Preload and Available Stroke Chart

The best control is achieved by using an electronic spill valve. This valve “vents” pressure from the wastegate canister’s signal port. The net effect is that the canister can have a non-linear response to applied pressure and a more precise opening point and opening rate. When using a spill valve such as the one supplied with EFR turbos, the canister selected should be relatively softly-sprung. Why? With a valve, you can always lower the pressure making its way to the actuator, but you can’t raise it. Also, the valve can vent all the signal pressure until it’s time to open the wastegate. If you want a real punch in the mid-range, this is how to achieve it. The limiting factor for selecting a “softly sprung” canister (low boost) is the risk of premature wastegate valve opening. While not damaging in any way, it will soften up the boost response and can actually be a useful attribute on cars that are having traction problems when boost hits. Premature wastegate opening can be overcome by adding preload in most cases, but if extreme, the wastegate valve will blow open when exposed to turbine inlet pressures prior to when it is commanded to open by the actuator. The EFR actuators are sold separately, so if an alternate choice is needed, it’s an inexpensive and easy swap.

EFR Wastegate Canister Selection Guide			
Core Assy	0.64a/r TH	0.83a/r TH	0.92a/r TH
6255	179282, 179283, or 179284	N/A	N/A
6258	179282, 179283, or 179284	N/A	179420, 179421, or 179422
6758	179282, 179283, or 179284	N/A	179420, 179421, or 179422
7064	N/A	179285, 179286, or 179287	179285, 179286, or 179287
7670	N/A	179285, 179286, or 179287	179285, 179286, or 179287
8374	N/A	179285, 179286, or 179287	179285, 179286, or 179287
9180	N/A	179285, 179286, or 179287	179285, 179286, or 179287

Figure 22: WG Actuator Canister Matrix

The most common problems occur at each end of the extreme:

Lazy boost onset or wastegate blowing open

- Canister spring too soft (use “medium” or “high”)
- Not enough rod preload (tighten nut to add preload)
- No electronic intervention (spill valve can block pressure signal getting to WG can, hence delaying the opening)

Boost creep (overboost at high engine rpm’s)

- Canister spring too stiff (use “low” or “medium”)
- Too much rod preload (loosen nut to allow more rod stroke)
- Actuator/preload/spill combination not allowing full rod stroke at full boost condition
- Solution: Make sure actuator rod is achieving full stroke at max boost and high RPM (video-record, if required)

In extreme cases, the EFR wastegate port will not be large enough. It is sized to provide capacity for up to 40% of the engine mass flow to bypass the turbine wheel. However, on applications using very low boost pressures on large engines, little turbine power is required to satisfy the boosting task and as a result the need for wastegate flow is extremely high. In this type of scenario, there may be no other solution than a very large external wastegate. There are many on the market and the keys are to plumb the flow well and to buy a quality product. Keep in mind that these devices have an elastomer of some kind (either an o-ring or a diaphragm) that is in close proximity to exhaust gas heat. It's for this reason that we shy away from external wastegates, but if you do need one, buy the best you can afford.

The last topic is wastegate canister mounting. The canister bracket connects to the front face of the bearing housing, on the compressor end. This is a relatively cool location and keeps heat conduction (to the actuator) to a minimum. Furthermore, both the bracket and the output rod are stainless steel which further reduces the conducted heat. The bolt pattern on the bearing housing face is drilled in 15° increments which maximize the canister mounting options. Since the actuator mounts to the bearing housing, the bracket location will have to be adjusted simultaneously when the turbine housing to bearing housing orientation is adjusted.

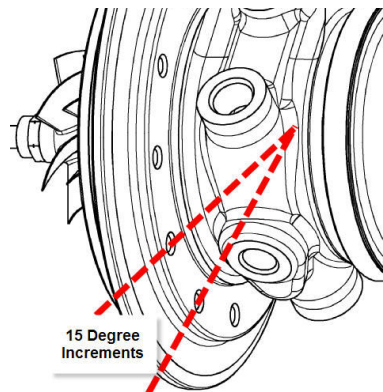


Figure 23: Actuator Bracket Able To Be Rotated in 15° Increments

Chapter 5: EFR Bearing Systems

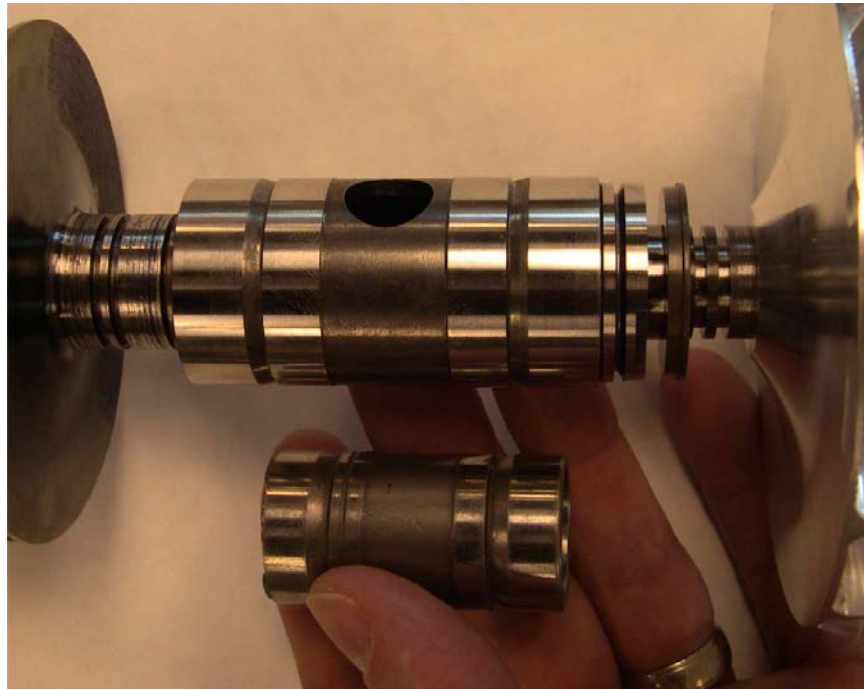
The barrier for widespread use of turbocharger ball bearings continues to be cost. While the pricing is coming down amongst the global supply base, this is the primary reason as to why journal bearings continue to dominate worldwide OE turbo production. Current state of the art in rolling-element turbo bearings is to use ceramic balls and specialized race materials. EFR turbos use these premium materials and are designed and tested with commercial-duty longevity in mind.



Figure 24: Ball Bearing Cartridge



Figure 25: Bearing Disassembled; M50 Races, Metal Cages, Ceramic Balls



*Figure 26: Which Would You Rather Have Supporting Your 500hp Application?
(BorgWarner B2 vs. Competitor)*



Figure 27: Competitor's Plastic Cage and Steel Balls

Ball bearing systems reduce friction losses as compared to their journal bearing counterparts. These friction losses are measurable on a combustion gas stand and are quantified by a gain in calculated turbine efficiency. Because it is difficult to separate the effects of mechanical efficiency (from the bearing system) and turbine efficiency, the SAE convention is to report the two as a “combined” efficiency. The combined efficiency is simply the multiplication of the thermodynamic turbine efficiency times the mechanical (bearing system) efficiency.

The friction loss is considerable at low turbo speeds and low shaft power. At these conditions, the power required to overcome friction is a larger fraction of the total power such that when reduced with ball bearings it accounts for a large improvement in combined efficiency. At higher speed and shaft power, the savings are a much smaller percent of total such that they become negligible. For this reason, the efficiency enhancement from a ball bearing system benefits the spool-up period and the light-load (low boost) regions of operation. The effect is most noticeable on a street machine coming in and out of boost and not as much at the drag strip. Using a drag race vehicle as an example, once it leaves the line it’s always up on boost. Once on boost, the advantages of ball bearings erode so most drag race applications won’t see much performance advantage from ball bearings. It’s for this reason that our large S400SX and S500SX drag race turbos will likely retain conventional bearings for the foreseeable future.

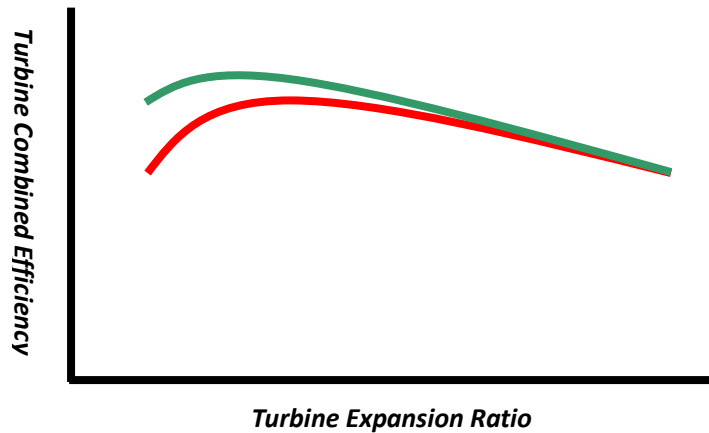


Figure 28: Low-End Efficiency Gain (Green) From Ball Bearings over Conventional System (Red)

The ball bearing system can survive substantially higher thrust loads than a hydrodynamic thrust bearing. The ball bearing is much better at surviving abuse such as compressor surge, marginal oil quality, low oil pressure, and harsh acceleration. The thrust capacity of a ball bearing is believed to be about 10X that of a conventional thrust bearing but to be honest we don't know the exact figure because our thrust load test rig cannot currently develop enough force to overload one. We do know that it has at least 5X the capacity. Unlike the conventional system where higher axial load capacity comes at the expense of friction losses, the thrust capacity of a ball bearing is "free", by comparison, when it's not heavily loaded.

Oil flow requirement is another key distinction. The ball bearing system does not require much oil to function properly. We have integrated an oil restrictor into the bearing housing so an external orifice SHOULD NOT BE ADDED. The oil does provide a cooling function in addition to keeping the ball raceways lubricated, so the oil flow will continue to be 25-50% of that required for a conventional system. A -4AN male fitting has been provided on the EFR turbo and a -4AN (1/4")

line is sufficient as long as the engine supply pressure is healthy and the line(s) are kept short. If the line is longer than about 18" then it's advised to step up to a -6 supply line. This is most critical for people living in cold climates.

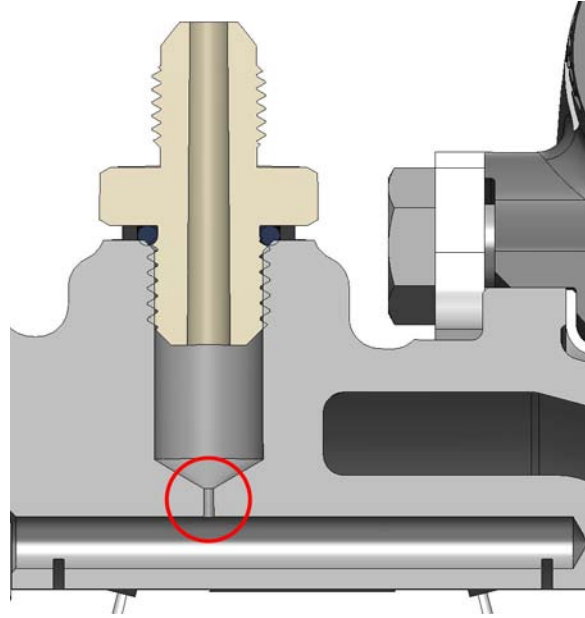


Figure 29: Oil Restrictor Integrated Into Bearing Housing



Figure 30: -4AN Oil Inlet Fitting (Supplied)

The EFR turbo also uses our top-shelf sealing system which includes two compressor piston rings placed in separate grooves as well as two turbine rings also placed in separate grooves. These features along with other geometric techniques provide a very effective oil sealing function as well as good blow-by resistance. Blow-by (the boost and exhaust pressure gases entering the bearing housing) has been reduced by 50% over the levels seen in prior generations of turbos. This sealing system along with the extended bearing span (for added stability) do make the center section quite long, and is the only drawback of the EFR internal component selections. This is a clear example of priorities: function and durability comes first.

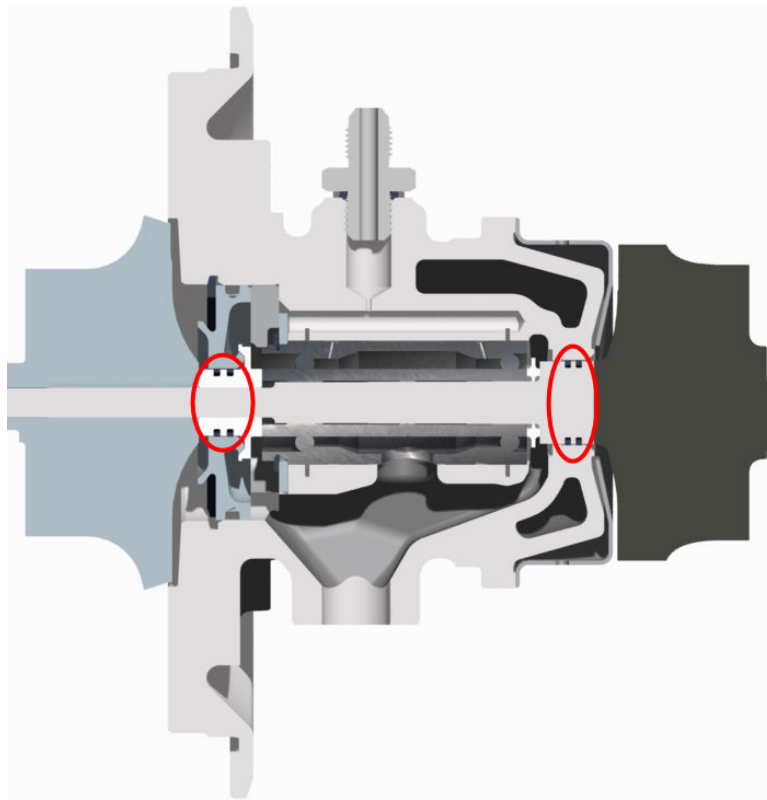


Figure 31: Dual Compressor and Turbine Piston Ring Seals

The bearing housing oil drain is machined for two connection types. The oil drain port is tapped with 3/8-NPT threads for those who want to install a fitting. A fitting with 3/8-NPT on one end and -8AN on the other makes for a very nice solution. The through-bore of such a fitting is about 0.42", which then spills into a 0.5" ID drain line. For those wanting to install a gasketed flange, two M8 holes are provided with a centerline span of 1.5".



Figure 32: Oil Drain Pad Machined for Gasket and 3/8 NPT Fitting

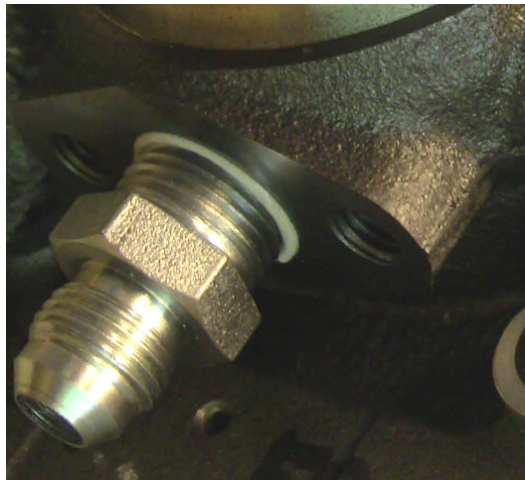


Figure 33: Oil Drain Fitting Installed (-8AN)

The bearing housing castings are water-cooled, and four M14x1.5 ports are provided. Two plugs are also provided so that the ports not being used can be capped off. It does not matter which side of the bearing housing gets the inlet flow and which side gets the outlet flow, but the flow must be diagonal across the housing. Also, the inlet port needs to be on the bottom and the outlet port needs to be on the top. This is to encourage evacuation of air bubbles as well as to encourage auto-siphoning (flow movement through natural convection) during the shut down's heat soak.

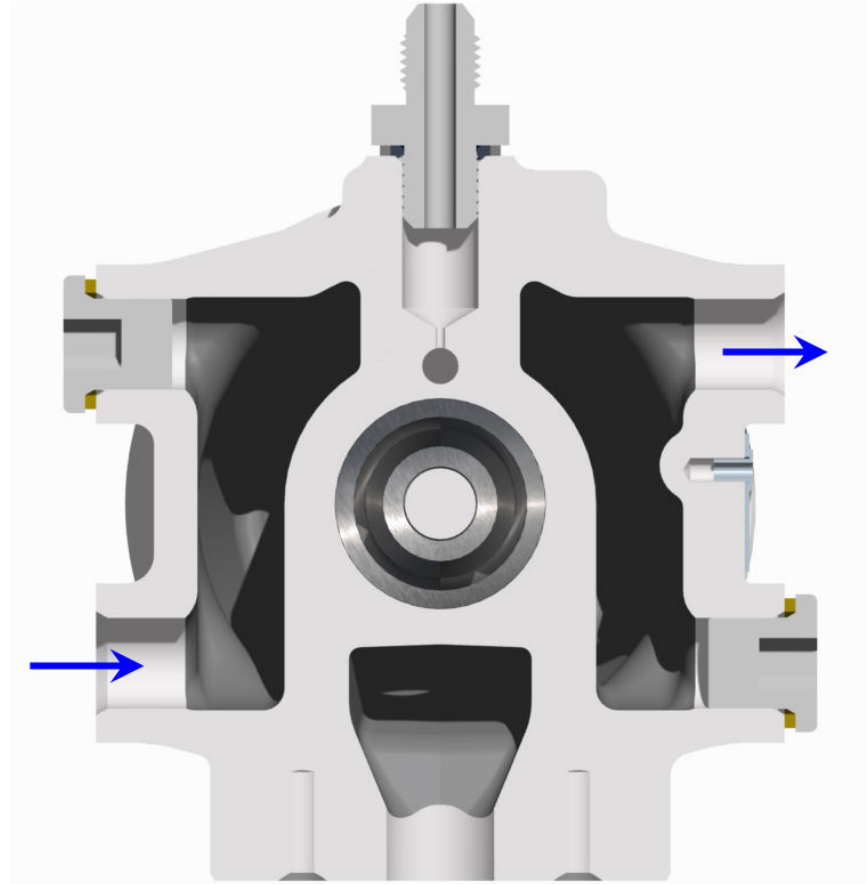


Figure 34: Cross-Flow (Bottom to Top and Side to Side) Nature of BH Water Cooling Plumbing



Figure 35: Series EFR Bearing Housings, B1 (back) and B2 (front)

Chapter 6: EFR Turbine Wheels

The most exciting (and challenging) element of the EFR program has been the creation of a new line of titanium-aluminide turbine wheels. The biggest challenges of titanium aluminide (also called Gamma-Ti) are getting a sound casting and achieving a secure joint with the shaft. Due to being poor-flowing in the liquid state, it is difficult to fill a wheel mold all the way out to the blade tips and also avoid a centerline shrink void. Machining the material is a challenge due to the high hardness and it also emits an interesting bright light when cut, not unlike the characteristic of burning magnesium. Once the backwall area of the wheel is machined, it can be joined to the shaft. A typical nickel-based wheel (e.g. Inconel) can be welded to the chromoly shaft, but Gamma-Ti cannot be welded. Instead, a proprietary connection method is used. Following connection, the shaft and wheel assembly (SWA) requires post-processing on lathe, grinder, and balancing machines. Some of these process parameters are the same as with Inconel wheels, but many are newly formulated for Gamma-Ti.



Figure 36: Gamma-Ti Turbine Wheels (55mm and 74mm Examples)

As mentioned in the introduction, Gamma-Ti is an inter-metallic compound. It's not quite metal and not quite ceramic. It is comprised

primarily of titanium and aluminum (with other trace elements), yet the compound exhibits material properties well in excess of the constituents. Gamma-Ti lacks toughness at room temperature (another one of the manufacturing challenges) yet at higher temperature it gains ductility and takes on excellent strength properties. It also has a very high stiffness-to-weight ratio and good damping.

The benefit of using Gamma-Ti as a turbine material is the low mass. Having roughly half the density of Inconel, it makes for a turbine rotor that has extremely low inertia. In fact, the turbine inertia is not much higher than the inertia of the compressor paired with it. The benefit of low inertia is improved turbo transient response. Since it requires less energy to spin up (accelerate) the wheel, higher speeds can be reached sooner and as a result the on-engine boost response improves.



Figure 37: Best of Both Worlds; Ball Bearings + Gamma-Ti Turbine

The effect is most dramatic with larger rotors but we have released the technology all the way down to the 55mm size. The entire EFR turbine line is 55mm though 80mm outer diameter. You really won't believe how light the larger ones are.

The base geometry of the EFR turbine wheels comes from high-performance blade families. These wheels have the characteristic of very high efficiencies and have been paired with our "Superback" and "Fullback" back-disk shapes. The Fullback shape extends the hub deck all the way to the OD of the wheel. By doing this, the turbine flow leaving the housing volute is better guided into the wheel blade cavities. The Superback shape adds a curved profile to the backdisk and has the effect of lowering centrifugal stress and permitting higher rotational speeds. The combination of these two shapes is a significant step forward in turbine geometry, with the only downside being the space required to package the Superback's added axial length. Flow capacity has been maximized by using large trims: 87-92% on a diameter basis (76-85% on area basis) depending on wheel size.



Figure 38: Gamma-Ti Shaft and Wheel Assembly (Superback + Fullback)

The combination of this top-shelf geometry and the exclusive titanium aluminide material significantly raises the bar for performance aftermarket turbochargers. Combined with our ball bearing technology, it is the most responsive range of turbos that are available anywhere, at any price.



Figure 39: Gamma-Ti Wheel at End of Successful Thermal Durability Test

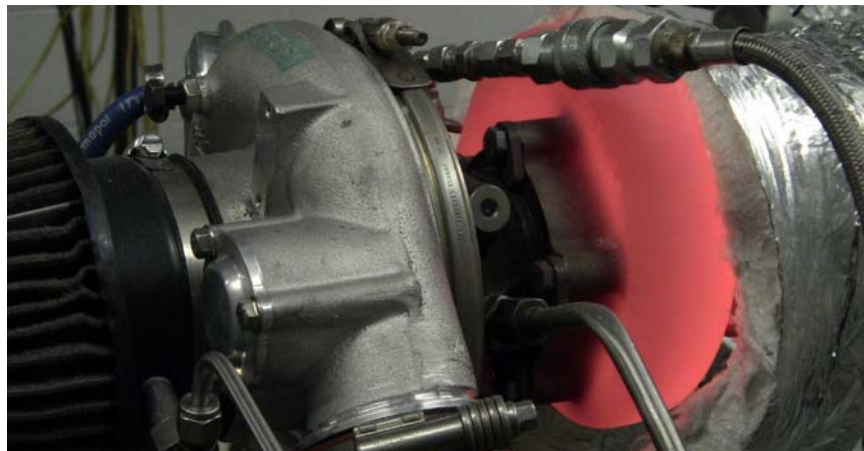


Figure 40: Torturous Thermal Durability Test (175 hrs)

Chapter 7: EFR Compressor Stages

The EFR product line features compressors ranging from 62mm OD (~50mm inducer) to 91mm OD (~68mm inducer). From this, the 70mm through 91mm compressors are designed for high-boost (30+ psi) capability. The smaller 62mm and 67mm wheels are from a different design family, used for “medium” boost but very large flow range. Due to their small size, paired with other technologies like the Gamma-Ti turbine and ball bearing system it yields an extremely responsive system specifically targeted at small engines or twin-turbo installations.



Figure 41: Forged Milled Comp Wheel (FMW) Lineup for EFR; 62 to 91mm

The material chosen for all 6 compressor wheel sizes is forged aluminum, fully milled. Also known as “billet”, these wheels are as amazing in appearance as they are in function. Cut from custom forgings, their strength exceeds that which is available from typical bar-stock and also exceeds the material properties of an aluminum casting.

The 62mm and 67mm wheels feature an 80% diameter trim (64% on an area basis), giving them a very high-flow characteristic. They are uniquely capable of having this trim while still having acceptable stress levels, blade frequencies, and boosting capability. The 70mm, 76mm, and 83mm wheels have 75% diameter trim (56% on an area basis) which gives them optimized flow, strength, and high boost capability. The 91mm wheel is trimmed slightly smaller (74% diameter; 55% area) to fit within some specific drag racing class rules.

All six EFR wheels feature our Extended Tip Technology. Just as on the S200SX, S300SX, S400SX, and S500SX lines, this feature amplifies the boost pressure and flow capabilities for a given wheel size. This BorgWarner feature has been a segment-leading technology for many years and it is continued here with the EFR series.

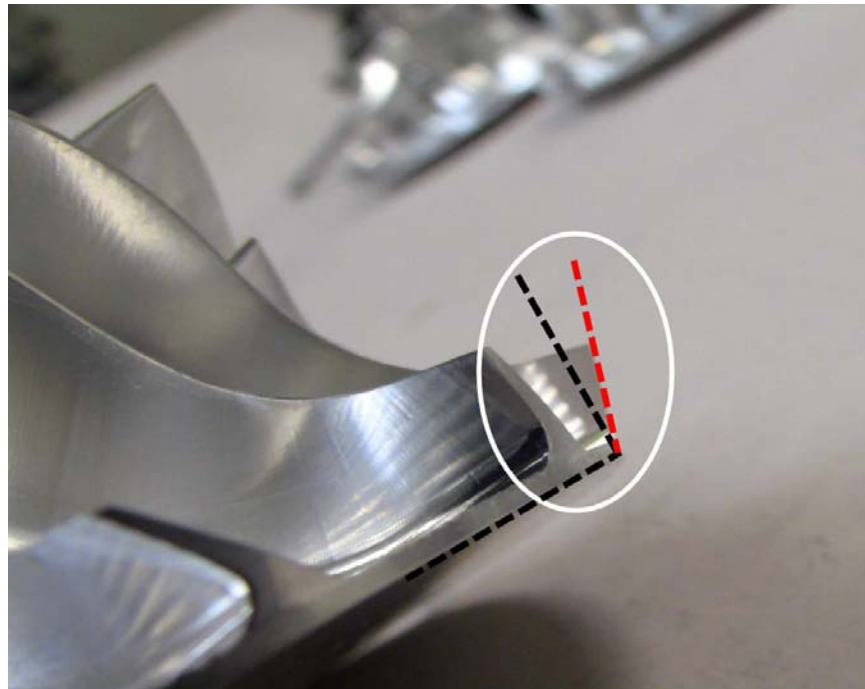


Figure 42: Extended Tip Technology (ETT) on EFR and Airwerks Product Lines

We investigated the use of an abradable coating on the compressor cover and got mixed results. Sometimes it yielded an efficiency and boost pressure gain but other times it did not. It also had mixed effects during the startup and cut-in process; effects that are all in need of further study. This feature will continued to be evaluated by the BW team and might be released at a future date either on EFR or Airwerks products, or perhaps both.

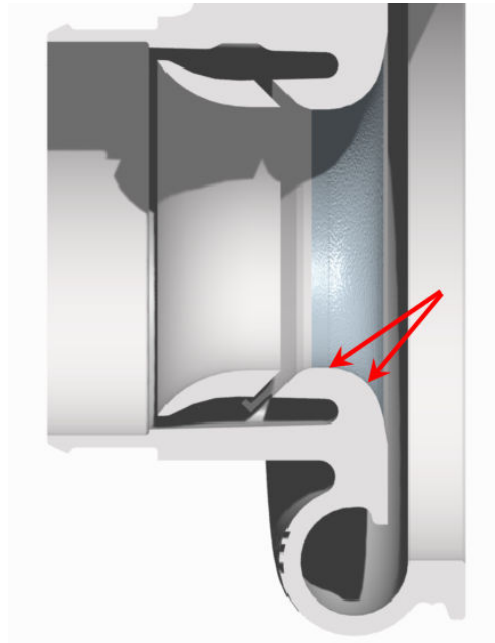


Figure 43: Abradable Coating (Shaded Blue) – Not Used With Initial EFR Product Launch, But Present On Some Pre-Production Prototypes

Three all-new compressor cover castings have been created for the EFR product line. For the purposes of this text, let's call them "A", "B" and "C". All three have some common features: First, they are retained to the bearing housing with a v-band which helps for easy orientation adjustment. Second, they have integrated CRV (Compressor Recirculation Valve) ports and mounting. Third, they provide a

mounting pad for the boost control solenoid valve (BCSV).

"A" Compressor Cover

This casting is used with the 62mm and 67mm compressor wheels and has a compact non-recirc inlet size. Designed for smaller packaging spaces, a 2.5" inlet hose connection is used. The outlet is machined for a 2" hose connection. As mentioned above, the CRV and BCSV mounting features are included. The volute a/r is 0.46.

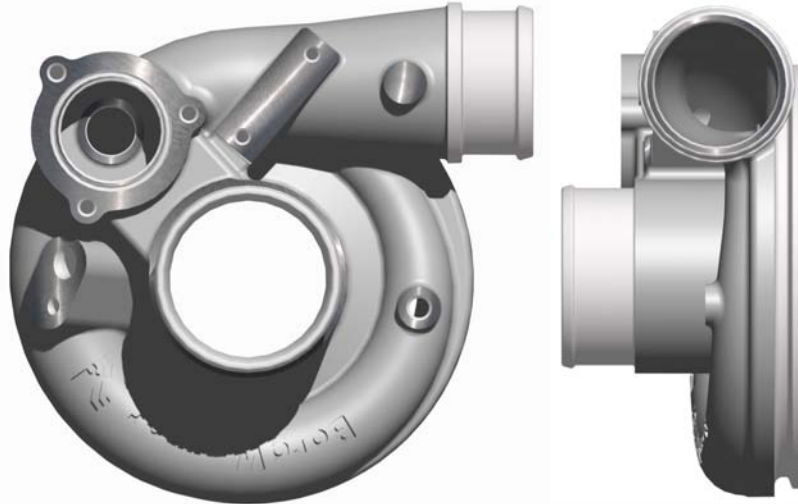


Figure 47: Compressor Cover "A" for 62mm and 67mm Wheels (0.46a/r)

"B" Compressor Cover

This casting is used with the 70mm and 76mm compressor wheels and features a recirculation ("recirc") groove. This groove surrounds the leading edge of the compressor wheel and provides an escape path for air on the tip of the wheel. In the process, the surge margin is extended when operating on the left side of the compressor map. On the right side of the map the operating range is also extended. In this zone, air is admitted through the port and into the wheel. The function of the recirc groove is very different than that of the CRV. The recirc groove is in operation all the time. The CRV operates only during a

throttle-closing event and helps prevent compressor backflow and related compressor surging. The inlet connection on this cover is sized for a 3.5" hose and the outlet is for 2" hose. Otherwise, it's very similar in size and shape to the small cover. Again, the CRV and BCSV features are integrated. The volute a/r is 0.5.

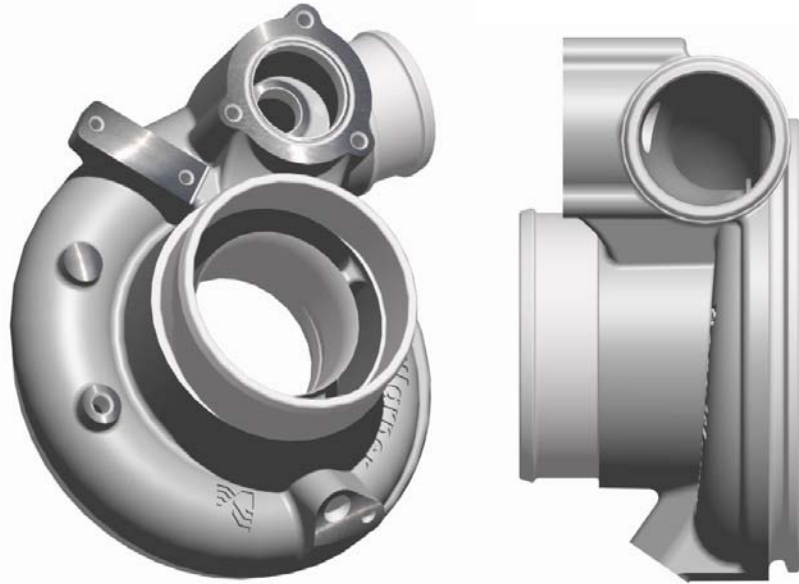


Figure 48: Compressor Cover "B" for 70mm and 76mm Wheels (0.5a/r)

"C" Compressor Cover

This casting is used with the 83mm and 91mm compressors and also features a recirc groove and cavity. Due to the larger size wheel bore, a 4" hose connection is used. The outlet connection is also larger, being sized for a 2.5" hose ID. This outlet is unique because it can also be modified for a v-band connection. The hose connection can be cut off and then a hard-mount piece (such as an elbow or tube assembly) can be clamped on. The 0.57 a/r volute shape of this cover is one of our long-time staples, having been also used in our popular S300SX and S400SX lines. Again, the CRV and BSCV mounting features are integrated.

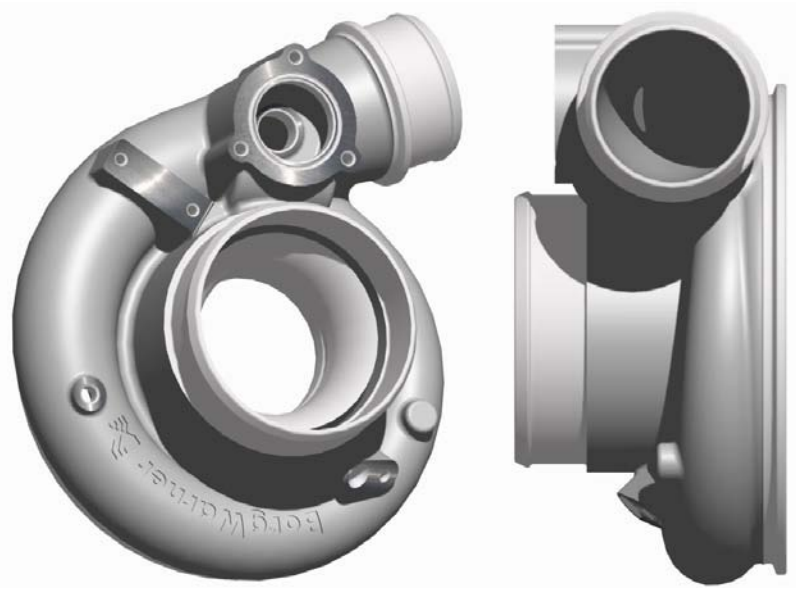


Figure 49: Compressor Cover "C" for 83mm and 91mm Wheels (0.57a/r)

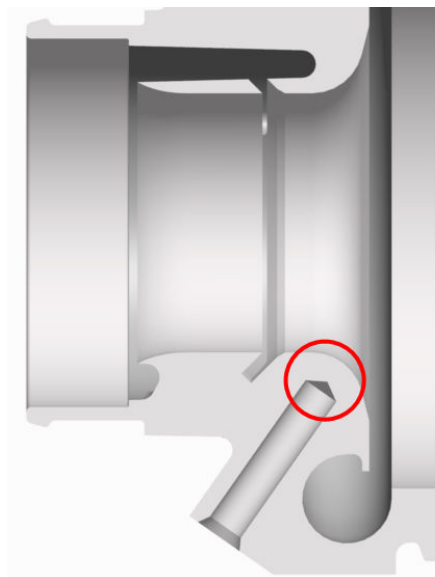


Figure 50: All EFR compressor covers come equipped with a speed sensor port. The bottom of the port gets drilled through the rest of the way (by the user) if an optional speed sensor is installed.



Figure 51: Compressor Covers "A" (top left), "B" (top right), and "C" (bottom)



Figure 52: All EFR Compressor Covers Come Equipped With A Compressor Recirculation Valve, Which Can Optionally Be Disabled.

Chapter 8: EFR Turbine Housings

The EFR series uses the most premium materials and processes for the turbine housings that are currently available. The material is HK30 cast stainless steel which is extremely crack-resistant. Having OE-level durability when used in conjunction with gasoline exhaust gas temperatures means never having to give your turbine housing any worry of failure. It is truly fit for purpose whether that's street use, road racing, or even endurance racing.

Another feature of these housings is the investment casting process. This process is the same as what is used for jewelry-making, yielding intricate detail and fine surface finish. The resulting turbine housing is beautiful inside and out. On the outside, it gives a show-quality finish unlike that of a sand casting. On the inside, the turbine flow enjoys a reduction in flow friction due to the smooth surface.



Figure 53: The EFR Turbine Housings Are Investment Cast Stainless Steel and Exhibit an Outstanding Level of Craftsmanship and Function

The part can be easily polished if desired, and either way (as-cast or polished) has a very nice color once heat-cycled. It is naturally corrosion-resistant.



Figure 54: Jewelry That Your Engine Can Wear

All that being said, the design of these housings is all business. There are four castings that make up the initial release of the EFR series, with more to come. The smallest three of the four are wastegated housings. Two of the four are divided (twin scroll) housings. These four castings can be trimmed for the various turbine wheel options yielding a total of 16 turbine housing combinations.

These 16 combinations span a PHI range of 0.020 to 0.048 (see BorgWarner Match-Bot turbo matching tool & catalog for details) to give maximum turbine flow options.

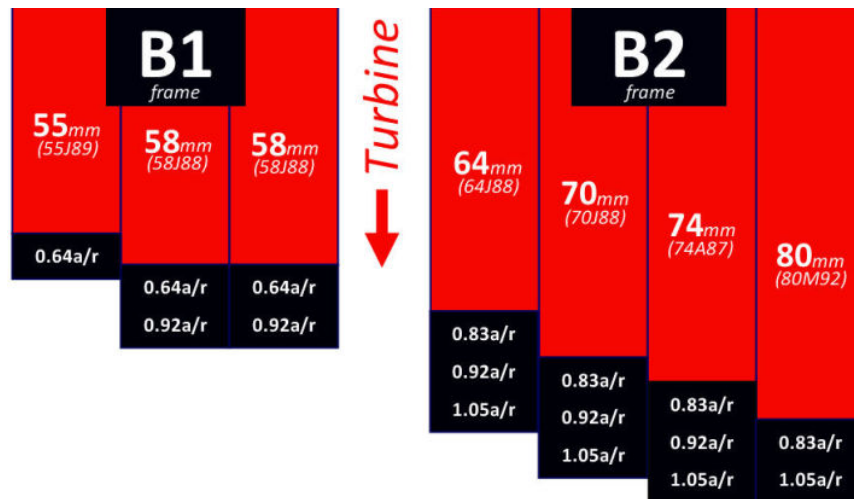


Figure 55: Sixteen EFR Turbines (Six Wheels & Four Turbine Housing Types)

0.64a/r Wastegated (A-Type)

The A-Type housing is designed for use with our smallest wheels in the range, the 55mm and 58mm. It uses a “T25” inlet flange shape that is industry-standard for this size. The flange is very compact to the body of the housing in the sprit of making the housing easy to package especially on twin-turbo installations. This tightly-coupled flange requires the use of a manifold-mounted stud through the most confined mounting hole. This hole is closest to the wastegate port and due to the compact size makes for a tight squeeze. The stud can’t be too tall emerging from the manifold or it will interfere with the housing’s surface. The nut must be tightened during the process of lowering the housing onto the manifold. The other three are easy to access (by comparison). The housing volute has a 0.64a/r which is nicely optimized for these two smaller wheels. The wastegate port is a generous 31mm port (36mm valve head) which is significantly larger than virtually all aftermarket housings that came prior. The targeted audience is the owners of smaller “street” engines (1.6L – 2.2L) or users installing a twin-turbo system. All four EFR housings have outlet machining that is designed for use with a 3” v-band. The v-band isn’t

actually 3" in diameter, but it's the common size that is used in conjunction with 3" downpipe tubing. The joint is "half Marmon" meaning that half of the flange is on the turbine housing and the other half of the flange (the other angle) is welded to the downpipe.



Figure 56: Turbine Housing "A" (0.64a/r) with T25 Flange

0.83a/r Wastegated (B-Type)

The B-Type housing is designed for the 64mm, 70mm, 74mm, and 80mm wheels. It uses a "T3" inlet flange shape that is standard for this size. The housing is the "big brother" of the A-type and is very similar in design theme, only larger. The a/r is 0.83 which is within the sweet spot for these wheels and is a balance between response and efficiency performance. The B-Type housing has a very large wastegate: 36mm port and 42mm valve head. This wastegate is truly designed for high flow, even for the big-power users. Gone are the days of needing to buy expensive and bulky external wastegates. This is a real "value" feature of the EFR program. A controversial feature of the "B" housing is the offset outlet. This outlet shortens the axial length of the housing by bringing the outlet down and towards the wastegate port. It also tightens the packaging by putting the downpipe closer to the manifold runners. It also has a functional reason: it favors the wastegate flow and makes that an ultra short and direct shot. So, what's controversial? It looks unusual, and it appears that it would hurt turbine wheel flow. The housing has been tested with and without the outlet offset and results show that no loss results from it. Keep in mind that 30-40% of

the flow is through the wastegate port during high-flow conditions.



Figure 57: Turbine Housing "B" (0.83a/r) with T3 Flange

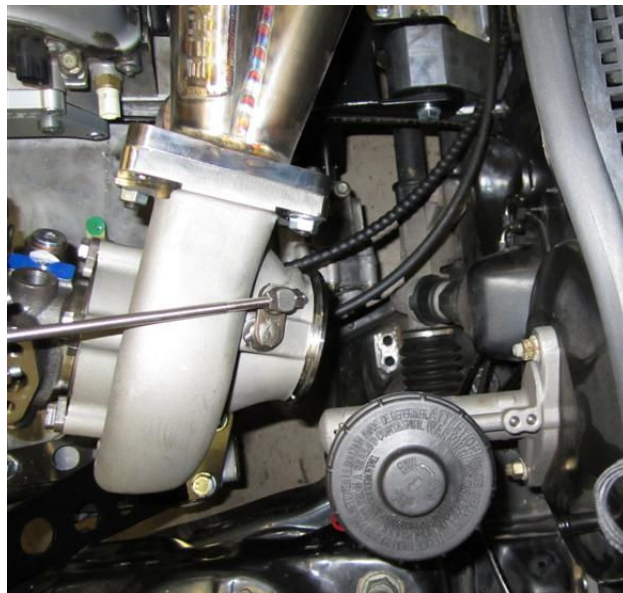


Figure 58: The TH Outlet Offset Saves the Day by Clearing the Brake Master Cylinder (photo courtesy Full-Race Motorsports)

0.92a/r Wastegated (C- Type)

The C-Type housing is designed for the 58mm, 64mm, 70mm, and 74mm turbine wheels. It uses a "T4" divided inlet flange shape that is standard for this size. The a/r is 0.92 which is also within the sweet

spot for these wheels. Being a twin-scroll, it is a little larger than the B-Type sibling. Higher flow is the result but the low-end response is retained (and surpassed) due to the divided nature. As discussed in a previous section, the twin-scroll housing and manifold preserves pulse energy all the way from the engine exhaust blowdown event to the turbine wheel, resulting in low-rpm boost response amplification. The C-Type housing also has a very large wastegate: 36mm port and 42mm valve head. This wastegate seals both branches of the twin-scroll volute since each volute has a wastegate channel leading to the Siamesed outlet port. The C-Type also has an outlet offset, but somewhat less than the B-Type housing.



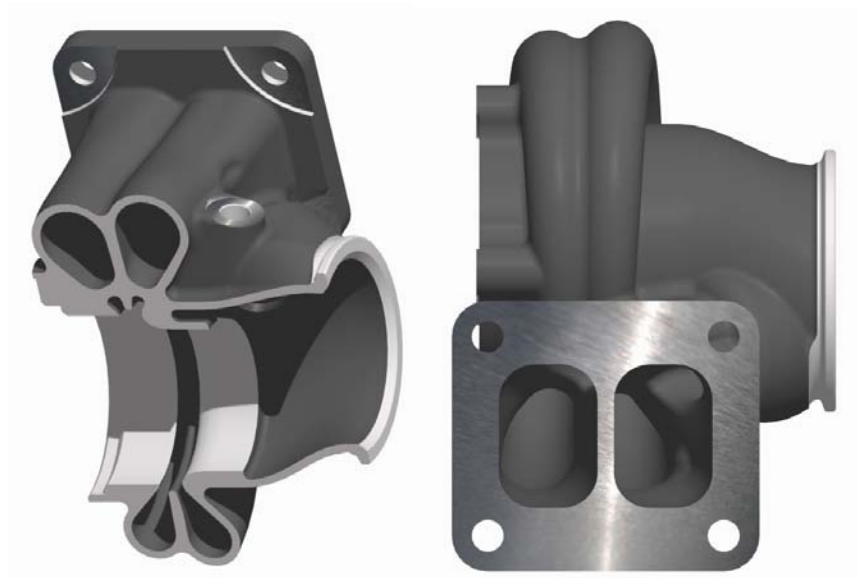


Figure 59: Turbine Housing "C" (0.92a/r) with T4 Flange

1.05a/r Wastegated (D- Type)

The D-Type housing is designed for the 64mm, 70mm, 74mm, and 80mm turbine wheels. It uses a "T4" divided inlet flange shape. The a/r is 1.05 which is on the high end of optimum and is targeted at the big-power users who want maximum flow yet still very high efficiency, especially in the pre-wastegated operating region. Like the C-Type housing, this part is divided (twin scroll) for the best combination of low-end response and top-end power. The D-Type housing is not wastegated, and as a result the outlet length is very short and without any offset. Like the others, it uses a 3" tube downpipe v-band connection.

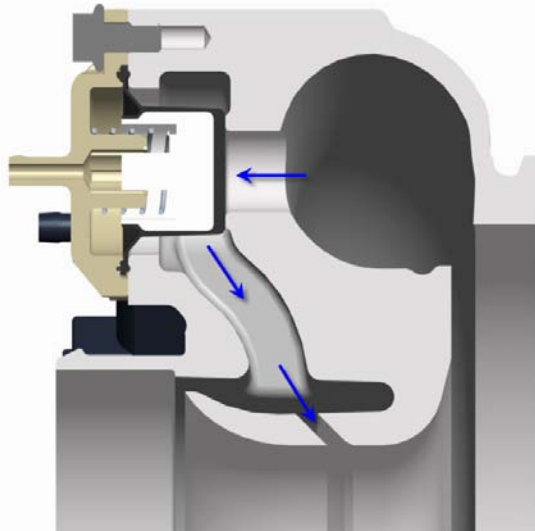


Figure 60: Turbine Housing "D" (1.05a/r) with T4 Flange

Chapter 9: EFR Installation Features

CRV

We have had great success with integrating the compressor recirculation valve (CRV) into the compressor cover for quite a few years on OE gasoline engine applications. The major benefits are of course the underhood packaging space that is freed up by not having an external device and the cost savings from integrating it into the turbo assembly. Recirculating the flow back into the compressor inlet helps keep MAF engine management systems “happy” and also helps keep turbo speeds high during the shift. The only downside of this feature is the fact that it makes the compressor housing about 1” longer in axial length. For the users that opt not to use the internal valve, we offer a disabling cover plate. This cover plate installs in place of the plastic cover and uses the original diaphragm to seal the port. As a service replacement item, spare plastic cover plates (with hose nipple) are sold as part of a CRV service kit. An external valve (BOV) can be used in place of, or in addition to, the BorgWarner CRV if desired.



*Figure 61: Integrated CRV (Compressor Recirculation Valve) and Air Flow Path
When Open*

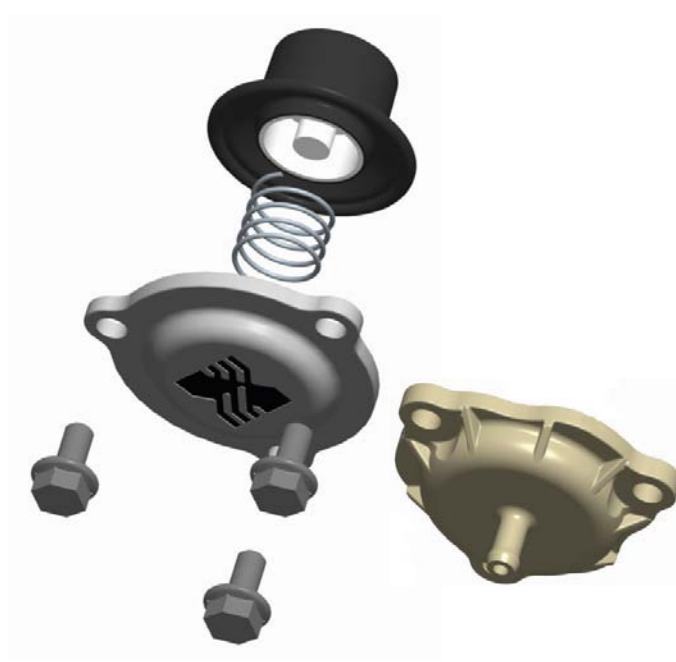


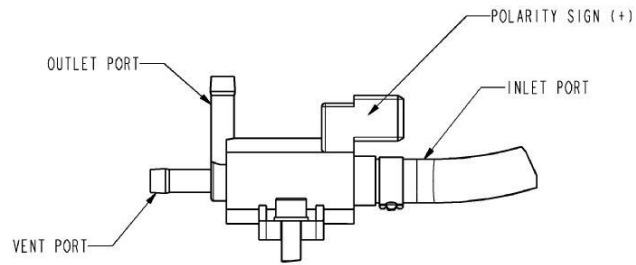
Figure 62: Contents of Optional CRV Kit Shown, Including Block-Off Plate and Repair Parts

BCSV

Integrating the boost control solenoid valve (BCSV) onto the compressor cover is another feature that has been widely used for a few years on OE applications. Any user of electronic boost control will need a solenoid valve. We use the highest quality part with OE-level robustness for this application. It is a value to the customer to buy it as part of the assembly so that they save money overall as well as have a tidy mounting solution. Loose BCSV's will also be sold as a service item in case the original one is damaged. The solenoid valve uses an "injector type" connector, and the BSCV connector itself is marked with a polarity symbol. There are two connections, +12V and ground. The valve is pulsewidth controlled and the wave frequency should be less than or equal to 32 Hz. The resistance of the BCSV coil is 23 Ohms.



Figure 63: Contents of Optional BSCV (Boost Control Solenoid Valve) Kit



SOLENOID SPECIFICATIONS:

CONNECTOR:

EV1 INJECTOR TYPE
 E.G. DELPHI CONNECTION SYSTEMS:
 12196895: CONNECTOR BODY
 12157740: TERMINALS (X2)
 15324982: SEALS (X2)

ELECTRICAL DATA:

NOMINAL VOLTAGE: 12V
 CURRENT CONSUMPTION: $\leq 0.72A$ AT 12V, $-40^{\circ}C$ AND 100% DUTY CYCLE
 RESISTANCE: $23.0 \pm 1.2 \text{ Ohm}$
 CYCLE FREQUENCY: $\leq 32Hz$ AT 13.5V
 OPERATING TEMPERATURE: -30 TO $130^{\circ}C$

Figure 64: BCSV Specifications and Connections (Pneumatic and Electronic)

Speed Sensor

Turbo speed sensors are of course not new technology, but the installation procedure has often (or perhaps always) been difficult for the end user. Competing products require the customer to remove their compressor cover and take it to a machinist. This machinist then has to set up the cover at a compound angle to precisely drill the speed sensor bore while carefully hitting the contour area of the wheel bore and at the right angle.

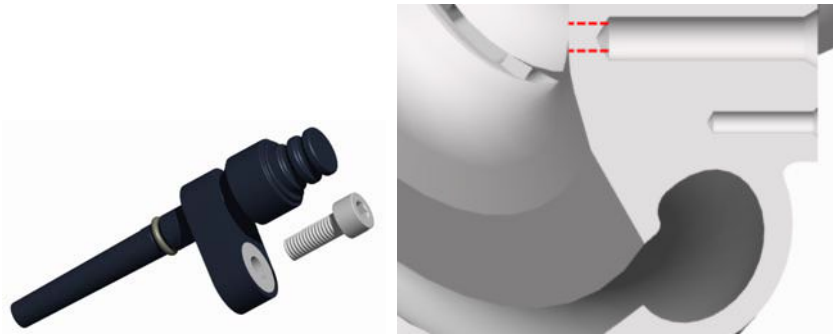


Figure 65: Speed Sensor Kit (Left) and Hole Drilling Schematic (Right)

The BorgWarner EFR solution provides this precision machining already done to the compressor cover. The hole stops short of protruding into the compressor wheel bore. If a user decides to buy a speed sensor as an upgrade accessory, they can remove the compressor cover and extend the hole the rest of the way through to the wheel bore using a hand drill. A 1/4" drill bit is used and the length required to be drilled is quite short. This hole allows the tip of the sensor to come flush with the contour surface. The hole does not have to be precise, as no sealing takes place in the small hole that the user just created. The hole should be de-burred where it pierces into the wheel bore. The goal is to make sure that there are no sharp edges remaining in the wheel bore that the compressor can become snagged on. Installation steps:

1. Remove compressor cover from turbo (CAREFULLY)
2. Place cover on a table, with some kind of backing so that it won't slide while being drilled
3. Equip a hand drill with a 1/4" drill bit
4. Drill out the bottom of the speed sensor bore while being careful not to nick the side-walls of the bore where the speed sensor o-ring will seal.
5. De-burr the hole where it protruded into the compressor wheel region.
6. Lubricate the speed sensor o-ring
7. Install the speed sensor into the bore and check for a good fit.
8. Use a file on the mounting surface if the sensor needs to protrude further into the bore. The sensor tip should be nearly flush (within 0.5mm) with the edge of the hole.
9. Tighten speed sensor hold-down bolt.
10. Re-install compressor cover on turbo and verify that the compressor wheel spins freely.



Figure 66: Drilling the 1/4" Hole



Figure 67: De-burring the Edge of Hole with Sandpaper



Figure 68: Lubricate O-Ring, Install, Check Depth, and Tighten Bolt



Figure 69: Example of Sensor Tip that is Not Sufficiently Deep

The speed sensor is powered by a +5V supply, and the return signal is a variable frequency square wave that has maximum amplitude of 5V and has a 50% duty cycle. The frequency of this signal depends on the speed of the wheel. Each passing blade creates a pulse, and all the EFR wheels have 14 blades except for the 67mm (which has 12 blades). The sensor embedded electronics divides the blade-pass frequency by 8, and then the resulting count forms the output waveform. Here is an example:

$$\begin{aligned} 100,000 \text{ rpm} & * 14 \text{ blades/rev} & = & 1,400,000 \text{ blade pass counts per minute} \\ 1,400,000 & / 60 \text{ sec/min} & = & 23,333 \text{ blade pass counts per second (Hz)} \\ 23,333 & / 8 \text{ count divisor} & = & 2,917 \text{ Hz output frequency} \end{aligned}$$

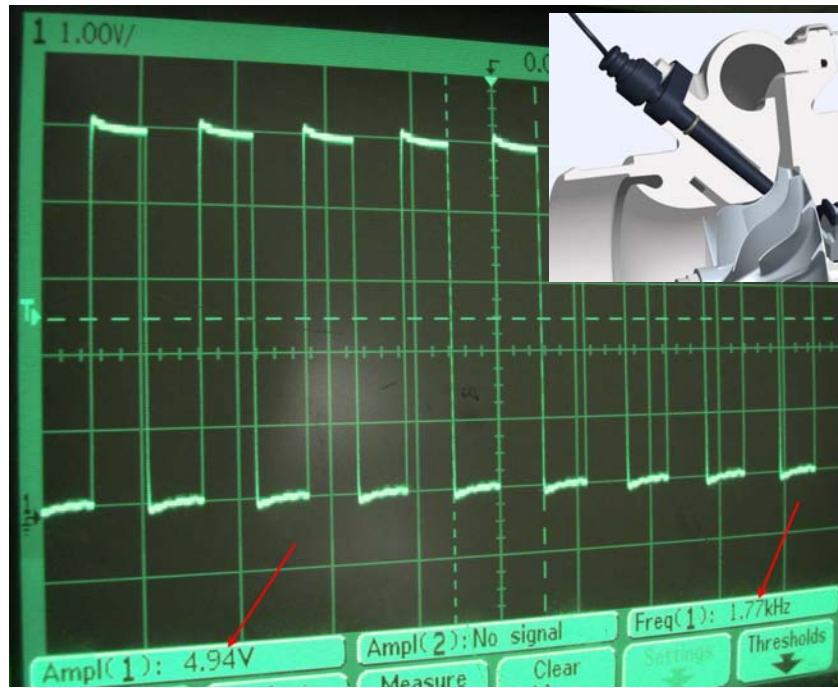


Figure 70: 0-5V Frequency Output Waveform (this example is 1770Hz, which is 60,686 rpm on a 14-blade wheel)

We are currently working with an electronics manufacturer to make a “converter box” that will convert this frequency output into a variable voltage output. By generating a 0-5V signal that is proportional to compressor wheel speed, we offer the end user the ability to easily log or display turbo speed. Also planned is a LCD screen dashboard display from this same supplier.

Orientation Features

The turbo was designed with easy orientation in mind. Particularly innovative is the actuator mounting for the wastegated turbos. By mounting the actuator bracket to the bearing housing, it allows us to contain the orientation within just one joint: the turbine to bearing housing joint. Mounting the actuator to the compressor cover (as has been done in the past on most internally-wastegated applications) ties the canister orientation to two joints. Mounting the actuator bracket to the turbine housing would have isolated it from any joints, but is not really practical given the exhaust gas temperatures of gasoline applications and the limitations of an actuator's diaphragm.

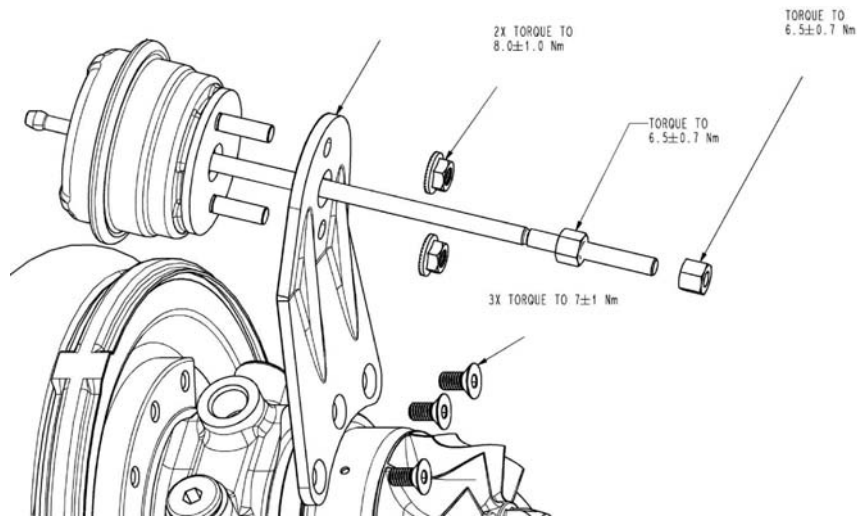


Figure 71: Actuator Must Be Re-Positioned on the Bearing Housing if the Turbine to Bearing Housing Orientation is Changed

The turbine housing is retained to the bearing housing through the use of clamp plates. There are four clamp plates on the small-frame turbos and five clamp plates on the large-frame turbos. It has been asked why we didn't use a v-band and the answer is simply that a turbine v-band can be risky when used at gasoline EGT's, especially if not properly tightened or if the vibration level is too high. Some small bands have been fortified to deal with these temperatures, but the common band is

not really capable from a long-term material strength perspective. Clamp plates are very robust and provide a lot of sealing load so that there is no leakage from the joint even under very high exhaust manifold pressures. The shape of the EFR clamp plates is innovative since the bolts can be loosened slightly, the clamps pivoted out of the way, and the bearing housing removed. There is no need to fully remove the bolts or the plates to get them out of the way for removal or re-installation. It is recommended to re-apply an anti-seize lubricant to the clamp plate bolt threads any time they are loosened. The torque specification on the clamp plate bolts is 13.5 N-m (10 ft-lb).



Figure 72: Turbine Clamp Plates Swiveled Out of the Way to Allow Bearing Housing Installation. Clamp Plates Face with Numbers Up.

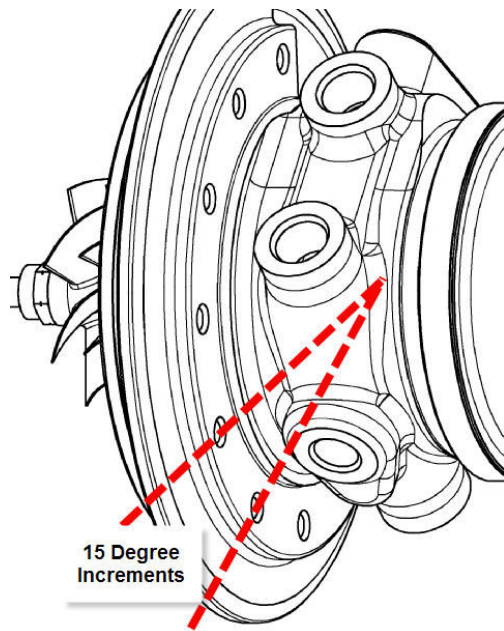


Figure 73: Actuator Bracket Can be Installed in 15 Degree Increments

When adjusting the orientation between the bearing housing and turbine housing, the actuator must also be moved. The bolt pattern on the bearing housing face is drilled in 15° increments which maximizes the canister mounting options. If the user reaches the end of the drilled pattern and needs to go just a little (15°) further, you can cheat the mounting by using only 2 of the 3 mounting screws and hanging the bracket off the flange. The bracket bolts have a M4 hex recess, and a long ball-end type is the tool of choice. If the turbine housing is still installed, a screwdriver set type of bit (4mm) can be used and turned either by a box end wrench or a small ratcheting device. With the turbine housing off, bolt access is easily achieved straight-on.



Figure 74: An Alternative to the Typical Angled Hex Wrench (in this example, only 2 of the 3 bolts are being used due to hanging the bracket off the mounting pad)



Figure 75: This is a Better Tool For Tightening the WG Bracket Bolts

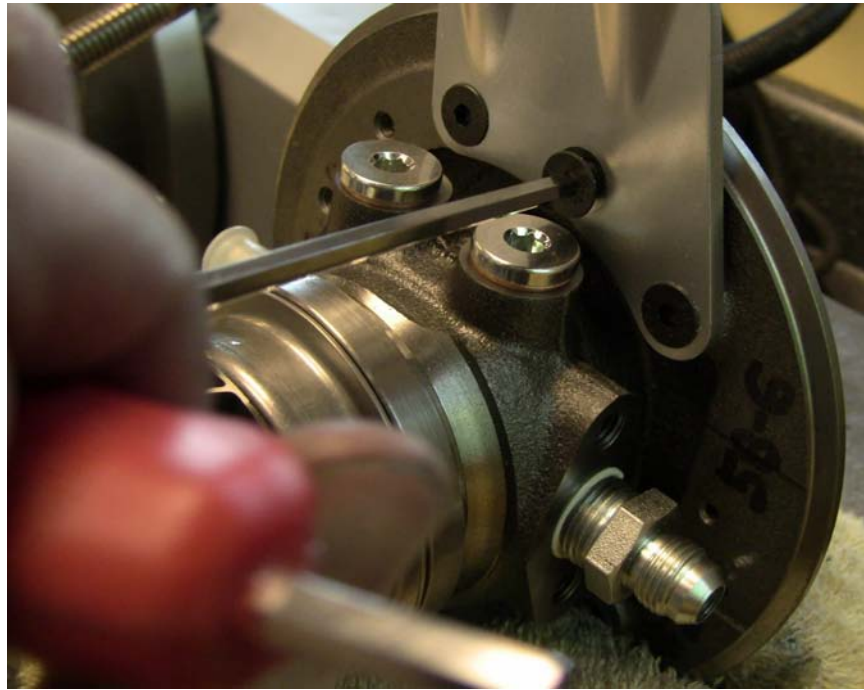


Figure 76: It is Easiest To Tighten the Bolts While the Turbine Housing is Removed

Oil Inlet Fitting

An oil inlet fitting has been provided that allows easy connection to a -4AN line. This fitting has been pre-installed into the bearing housing oil inlet port (M12x1.5) and is sealed with both a washer and an o-ring.



Figure 77: Oil Inlet Fitting With O-Ring and Washer (sealing contact on washer can be seen)

Additional oil restrictions should not be used. The required restriction to throttle the oil flow to the ball bearings is already integrated into the bearing housing. The oil supply line should be kept as short as possible. If a line of unusual length is required, we recommend a -6AN line especially for very cold climates. -3AN line is not recommended due to excessive oil supply delay times during cold start. We recommend that oil reaches the turbo in less than 4 seconds during a cold start cranking, and in under 1 second during hot-start conditions.

We often get questions about oil selection. The simplest answer is that turbos prefer warm (but not overly hot), high viscosity (e.g. 10W40), synthetic oil. Non-synthetic oils may of course be used but the user can expect a higher degree of laquering and coking. Users of thin oil (e.g. 5W20) can expect lesser bearing system robustness against harsh conditions or abuse, especially if the oil is very hot. Inlet oil pressure (gage) is recommended to be at least 1bar (15psi) and not more than 4bar (60psi) under all “fully warmed-up” conditions.

Oil Outlet

The oil drain flange on the bearing housing has been prepared for either a paper-type flange gasket (the bolt spread is 38mm or 1.5” and the bolts are M8x1.25) or a screw-in fitting. If the port thread is selected, a fitting with a 3/8-NPTF tapered thread should be used. We recommend the white liquid type of sealant instead of Teflon tape. The oil drain line should be at least -8AN (1/2” ID). The bearing housing oil drain should be pointed straight downward where possible, and at most 20 degrees tilted right or left. When routing the oil drain line, try to keep it running downhill all the time and avoid horizontal spots or sharp bends. The oil should drain to the block or pan in a low-pressure region above the level of the oil bath. It is not recommended to install the turbo considerably nose-up or nose-down. It was validation tested to be installed “flat” with respect to the ground.

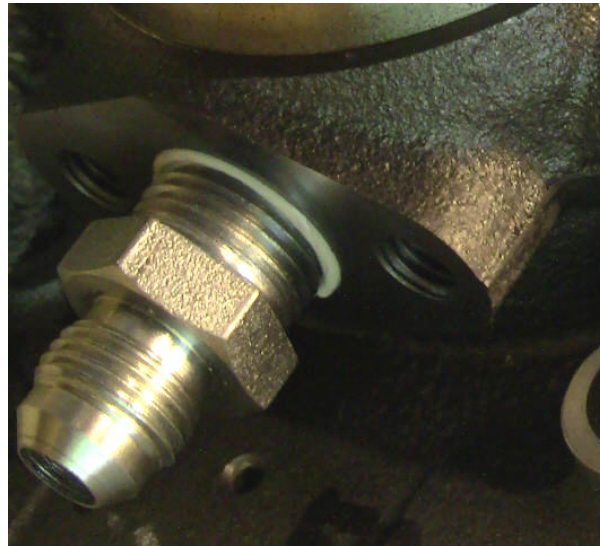


Figure 78: Another Picture of Dual-Machined Oil Outlet Flange (either for gasket or fitting)

Bearing Housing Water Ports

There are two M14x1.5 ports provided on each side of the bearing housing. This has been done for maximum installation flexibility. The water should enter into one of the two bottom ports, flow across the bearing housing from one side to the other, and then exit out of the top port. The two unused ports should be left plugged, which have been supplied with copper sealing washers. These ports are straight-thread, so a crush-washer type sealing arrangement is required for the line connections. Water cooling is highly recommended, wherever possible. In cases where it is not possible, turbo-compassionate cool down procedures (idle time) should be used. The BorgWarner ball bearing cartridge is made of the best materials available, but even it has limits during the heat soak condition.

Compressor Cover Connections

As mentioned in a prior section, there are three compressor cover types. The “small, A” cover is used with the 62mm and 67mm wheels and has a 2.5” inlet hose connection and a 2” outlet hose connection. The “medium, B” cover is used with the 70mm and 76mm wheels and has a 3.5” inlet hose connection and a 2” outlet hose. The “large, C” cover is used with the 83mm and 91mm wheels and has a 4” inlet hose connection and a 2.5” outlet hose. The “large” cover has a dual-machined outlet, both for a hose connection and a v-band connection. If the v-band feature is needed, the hose connection portion can be cut off and discarded.



Figure 79: Compressor Covers and Their Inlets and Outlets

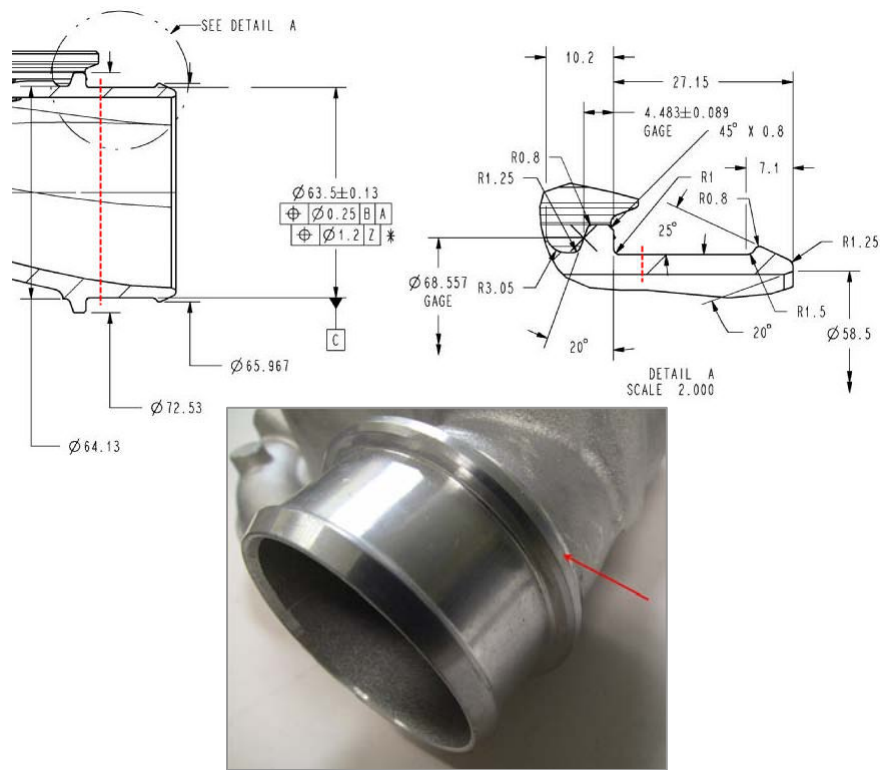


Figure 80: The Outlet of The Large "C" Comp Cover Can Be Cut Off for Use With a V-Band Connection. An O-Ring Can Be Placed In the Remaining Ditch. This V-Band Clamp is Supplied in the Hardware/Installation Kit.

Turbine Housing Connections

The turbine housings all have a v-band outlet that is designed for use with a 3" downpipe tube. The flange is half-marmon type, so the pipe connection must also have a half-marmon flange welded to it. These flange connections are very common and can be purchased through virtually any turbo distributor or dealer. BorgWarner offers a v-band to fit this flange, included within the optional hardware kit.

The turbine inlet flanges are of industry standard size and shape. The smallest turbine housing uses a "T25" flange, the larger single-scroll housing uses a "T3" flange, and the twin-scroll (divided) housings use a

“T4” flange.

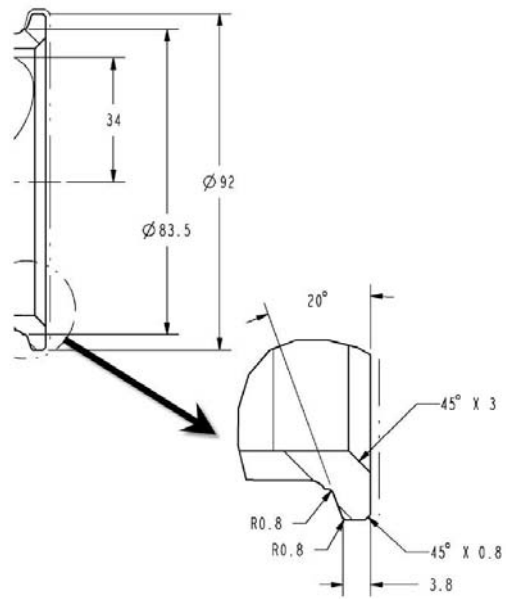


Figure 81: Turbine Outlet Flange Detail

Chapter 10: EFR Feature Summary

- The EFR product line is a wide range of all-new performance turbochargers from BorgWarner. They contain the highest level of technology currently available to aftermarket customers.
- Compressor sizes range from 62 to 91mm OD (50 to 68mm inducer) and support power levels up to 1000hp per turbo. The compressor stages are designed for the best possible combination of surge width, flow capacity, high boost pressure capability, and strength.
- Turbine sizes range from 55 to 80mm and the wheel material is titanium aluminide (Gamma-Ti). This material innovation is a major step forward for the performance user since it cuts turbine inertia by roughly 50% and hence dramatically improves turbo response.
- The EFR turbochargers use a premium dual-row ball bearing cartridge with ceramic balls, M50 races, and metal cages. This bearing system provides substantial friction reduction at low turbo speeds and in the process helps improve turbo response. The arrangement also provides a large thrust load capacity improvement over conventional systems.
- The turbine housings are constructed from durable 300-series stainless steel using an investment casting process. The result is a part with premium appearance and an extremely smooth internal flow channel. The part uses thin walls to reduce weight and thermal inertia.
- Turbine housings are available in both single-scroll and twin-scroll (divided) configurations. The twin-scroll housings offer optimized spool-up characteristics when used in conjunction with a divided manifold.
- The wastegated models feature very large port and valve sizes. Performance users are now able to make use of the elegance and cost reduction of an internal wastegate, in addition to simplifying the fabrication and installation task.

- The compressor stages feature an integrated compressor recirculation valve (CRV) to help avoid compressor surge and backflow during a throttle lift event. This further simplifies the installation task and lowers overall system cost.
- A boost control solenoid valve (BCSV) is included with every EFR turbo, making for a tidy mounting solution for the users of electronic boost control.
- Speed sensor mounting provisions are also pre-machined on every compressor cover. Speed sensors are available separately.

The BorgWarner EFR turbo is set to become the new world standard for performance turbocharging due to the high-technology feature package, unbeatable performance, and installation convenience. It has been designed and manufactured with only one purpose in mind: to dominate the street, track, and strip.

Chapter 11: EFR Installation Notes

- *Orientation Setting*

The oil inlet and drain ports need to be within 20 degrees of vertical as to encourage proper draining and avoid sealing problems. The actuator canister needs to be positioned so that the rod is centered leaving the can's opening hole. Any time the turbine housing clamp plate bolts are removed, fresh anti-seize compound should be applied.

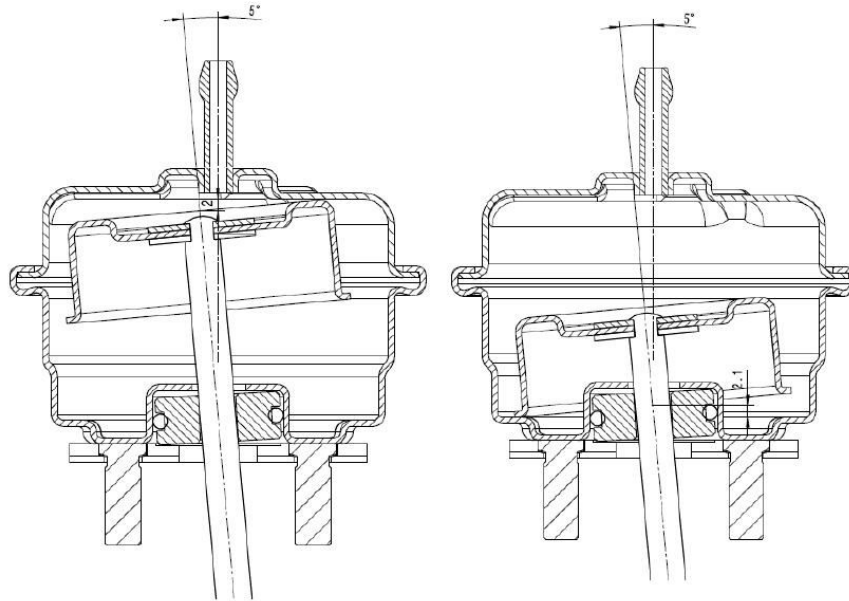


Figure 82: Schematic Showing 5 Degrees of Rod Misalignment Which Is a Damaging Amount (2 degrees = max allowable)

- *Wastegate Setting*

Avoid twisting the rod while tightening the adjustment nuts. Hold the rod steady while turning the nuts. The rod threads are 1mm pitch, so each turn of the nut equals a 1mm change in preload. We recommend at least 2mm of preload applied to the rod. This applies force to keep the wastegate valve held closed, and also prevents premature vibration wear of the canister internals.

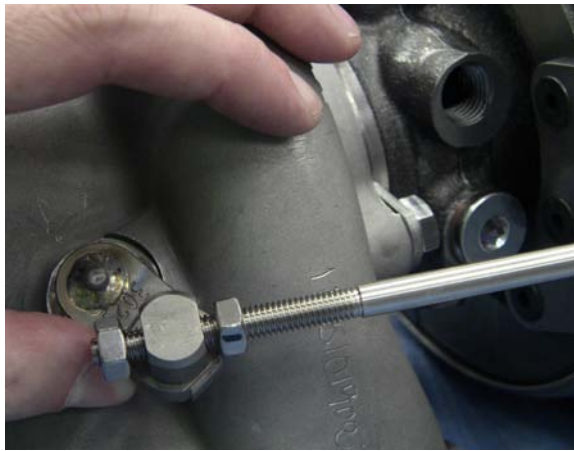


Figure 83: Holding Valve Closed with Nuts Loosened



*Figure 84: Line Drawn On Nut to More Easily Count Turns
(2mm Preload Added)*

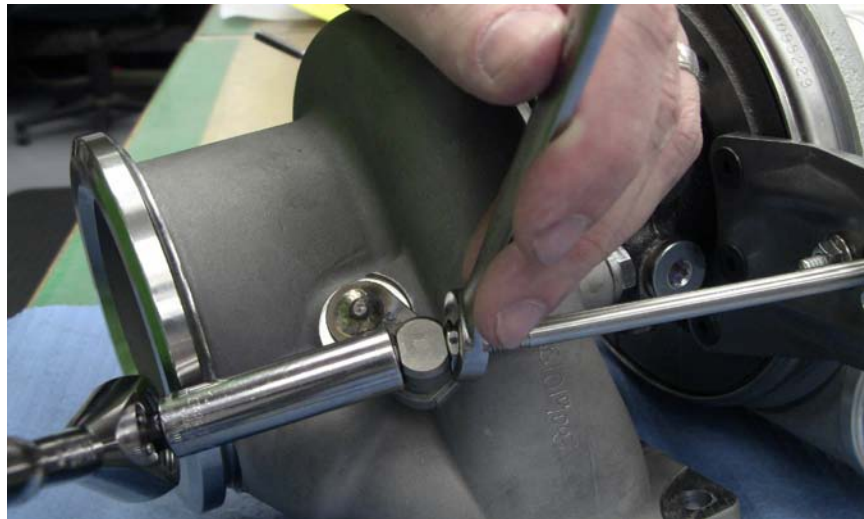


Figure 85: Tightening Nuts with Wrench and Ratchet (6.5 N-m)

- *Oil Supply and Drain*

Use a -4AN supply line that is less than 18" in length, especially in cold climates. This prevents excessively long delay times for getting oil to the turbo upon startup. It is highly recommended to pre-lube the turbo and lines before starting the engine with a fresh turbo installation. This can be achieved by cranking the engine with the ECU unplugged or some other starting-disable method. The oil drain line should be at least -8AN and should not have any sharp bends or kinks. The oil line should drain back to the block above the oil level in the pan and should avoid windage coming off of any crankshaft throws. Crankcase pressure should be as low as possible, via a well-functioning breather system.

- *0.64a/r Turbine Housing*

This turbine housing has limited access to one of the stud/nut locations due to the tight packaging constraints. This location must have a M8 stud or bolt protruding from the manifold, and this stud can be no longer than 18mm in height from the manifold flange. The nut must be tightened "on the way down" while the turbine housing is lowered onto

the stud and manifold.



Figure 86: This Stud Position When Used With the "A" (0.65a/r) Turbine Housing Should Protrude No More Than 18mm From the Manifold Surface. The Nut Needs To Be Tightened On the Way Down.

- *CRV Connection*

The CRV hose nipple should be connected to a source of intake manifold pressure/vacuum **DOWNSTREAM** of the throttle body. **IMPORTANT:** This signal hose to the CRV needs to see pressure while under boost, and manifold vacuum when the throttle body is closed. The CRV valve will leak while under boost if pressure is not applied to the nipple. This pressure acts upon the top side of the diaphragm and holds it closed while under boost. The hose nipple on the CRV plastic cover is 6mm OD, so select a suitable hose for connection and then route it to the intake manifold.

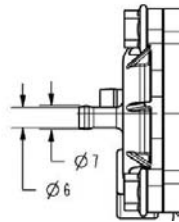
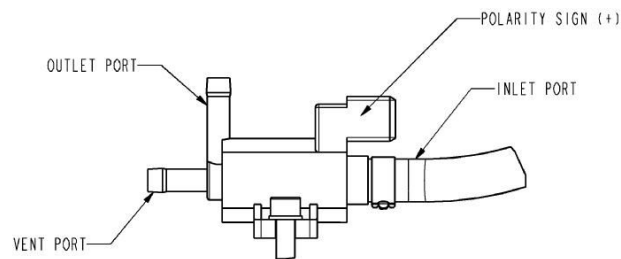


Figure 87: 6mm Hose Nipple On CRV

- *BCSV Connection*

The boost control solenoid valve accepts a PWM square wave signal of frequency less than or equal to 32Hz. The duty cycle controls the open-time of the valve. The +12V lead (polarity is marked on the BCSV connector) should be connected to a key-switched vehicle power supply. The ground wire is the one that is modulated by the ECU or some other device, and determines the PWM duty cycle.

The hose beneath the electrical connector is attached to the compressor cover source pressure. The control/outlet port faces upward, roughly in the same direction as the wastegate canister nipple it will be attached to. The third port is the vent and this one should be routed back to the air inlet tract or any other clean, ambient-pressure zone. This vent connection can be left disconnected, but it must be pointed downward in such a case so that water cannot intrude.



SOLENOID SPECIFICATIONS:

CONNECTOR:

EV1 INJECTOR TYPE
 E.G. DELPHI CONNECTION SYSTEMS:
 12196895: CONNECTOR BODY
 12157740: TERMINALS (X2)
 15324982: SEALS (X2)

ELECTRICAL DATA:

NOMINAL VOLTAGE: 12V
 CURRENT CONSUMPTION: $\leq 0.72A$ AT 12V, $-40^{\circ}C$ AND 100% DUTY CYCLE
 RESISTANCE: $23.0 \pm 1.2 \Omega$
 CYCLE FREQUENCY: $\leq 32Hz$ AT 13.5V
 OPERATING TEMPERATURE: -30 TO $130^{\circ}C$

Figure 88: Shown Again, the BCSV Connections

- *Turbine Outlet V-Band*

In the spirit of keeping the turbine housings as short as possible, some v-band clamps made for 3" tube flanges have been seen to be too wide and hence interfere with the turbine housing wastegate port casting wall. Other clamps are not too wide, such as the one provided in the optional BorgWarner EFR Hardware/Installation Kit.

Chapter 12: Acknowledgements

The EFR team would like to again thank BorgWarner upper management for approving and funding this project.

The team would also like to thank our supply base. Without their hard work and perseverance, the components used to build these turbos would not have been a success. In many cases, they share the same passion and excitement for the end product that we do.

And last but certainly not least, the team would like to thank our pre-production partners such as Full-Race Motorsports, Cosworth, Honda Performance Development, Sierra-Sierra Enterprises, Roush-Yates, and Ford Motor Company. By participating in the pre-production program, these companies were able to provide valuable feedback.

Appendix: Miscellaneous Pictures and Data

Accessory Kits	
179430	Speed Sensor Kit
179423	Hardware/Installation Kit
179424	Compressor Recirculation Valve Kit
179425	Boost Control Solenoid Valve Kit
179426	Wastegate Hose Kit

Figure 89: Optional Accessory Kits Available from BorgWarner

EFR Wastegate Canister Selection Guide			
Core Assy	0.64a/r TH	0.83a/r TH	0.92a/r TH
6255	179282, 179283, or 179284	N/A	N/A
6258	179282, 179283, or 179284	N/A	179420, 179421, or 179422
6758	179282, 179283, or 179284	N/A	179420, 179421, or 179422
7064	N/A	179285, 179286, or 179287	179285, 179286, or 179287
7670	N/A	179285, 179286, or 179287	179285, 179286, or 179287
8374	N/A	179285, 179286, or 179287	179285, 179286, or 179287
9180	N/A	179285, 179286, or 179287	179285, 179286, or 179287

Figure 90: WG Canister Selection Matrix Based on Spring Rate and Rod Length

EFR Wastegate Canister Bracket Kit Selection Guide			
Core Assy	0.64a/r TH	0.83a/r TH	0.92a/r TH
6255	179427	N/A	N/A
6258	179427	N/A	179428
6758	179427	N/A	179428
7064	N/A	179428	179428
7670	N/A	179428	179428
8374	N/A	179429	179429
9180	N/A	179429	179429

Each Wastegate Bracket Kit Includes:

- (1) Stainless Steel Bracket
- (3) Bracket to Bearing Housing Screws
- (2) Canister to Bracket Lock Nuts
- (1) Actuator Rod Nut (Outboard Side)
- (1) Long 410mm Wastegate Signal Hose
- (2) Hose Clamps

Figure 91: WG Bracket Kit Selection Matrix, and Contents

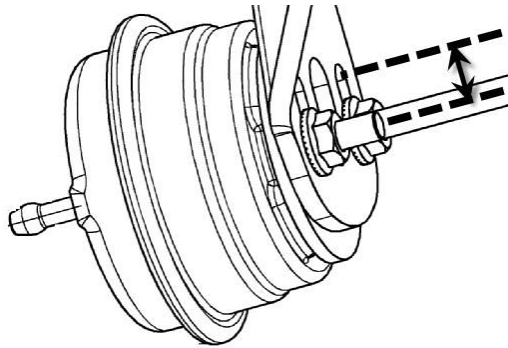
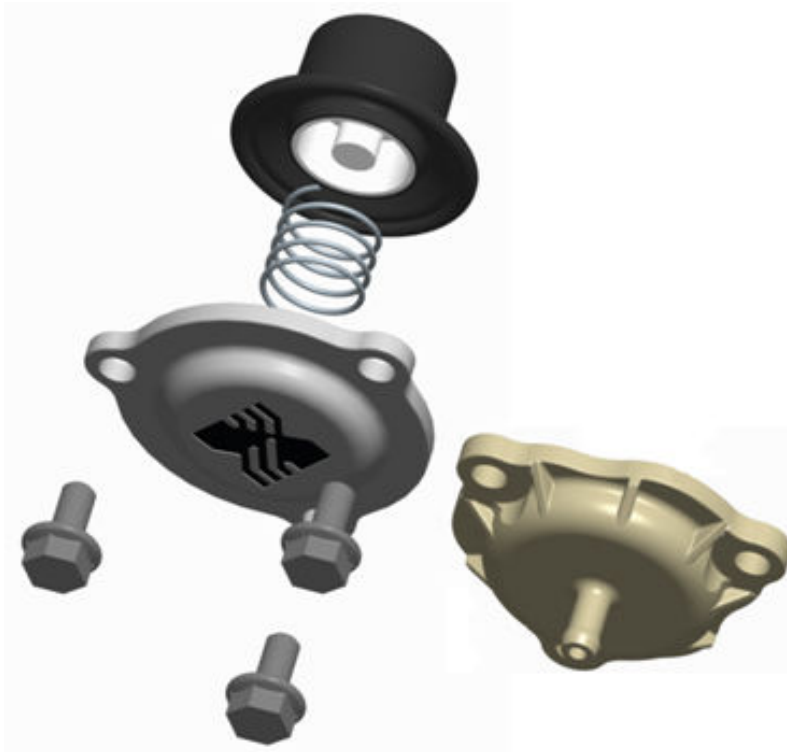


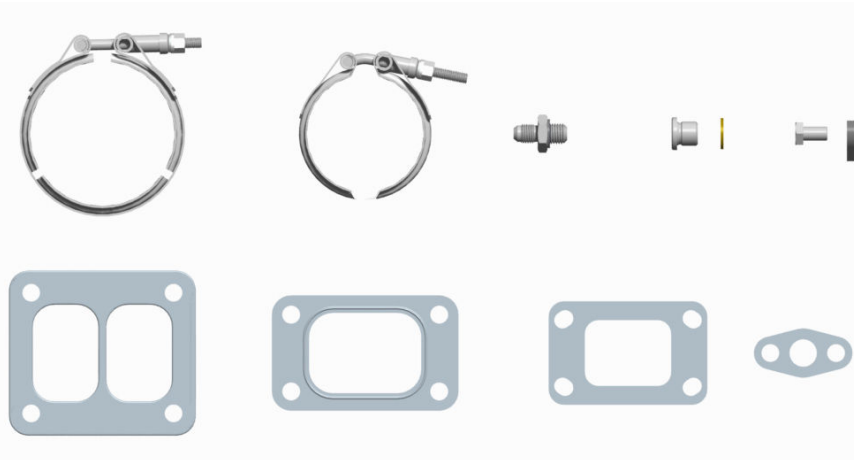
Figure 92: Bracket 179428 Has Slotted Holes For Adjustable Can Placement



The **179424** Compressor Recirculation Valve (CRV) Kit Includes:

- (1) CRV Plastic Cover w/ Hose Nipple*
- (1) CRV Disabling Block-Off Plate*
- (1) CRV Diaphragm/Piston Assembly*
- (1) CRV Spring*
- (3) Cover Plate Bolts w/ Locking Compound*

Figure 93: Contents of CRV Kit



The 179423 Hardware/Installation Kit Includes:

- (1) Turbine Housing Outlet V-Band Clamp*
- (2) V-Band Clamp Nuts*
- (2) Water Port Plugs*
- (6) Water Port Plug Sealing Washers*
- (2) Oil Drain Flange Gaskets*
- (1) Oil Inlet Fitting (-4AN) w/ Seal and Washer*
- (1) Compressor Cover Outlet V-Band Clamp for 83 & 91mm*
- (5) Turbine Housing to Bearing Housing Clamp Plates*
- (5) Clamp Plate Bolts*
- (1) Turbine Inlet Gasket for T25 Flange*
- (1) Turbine Inlet Gasket for T3 Flange*
- (1) Turbine Inlet Gasket for T4 Divided Flange*

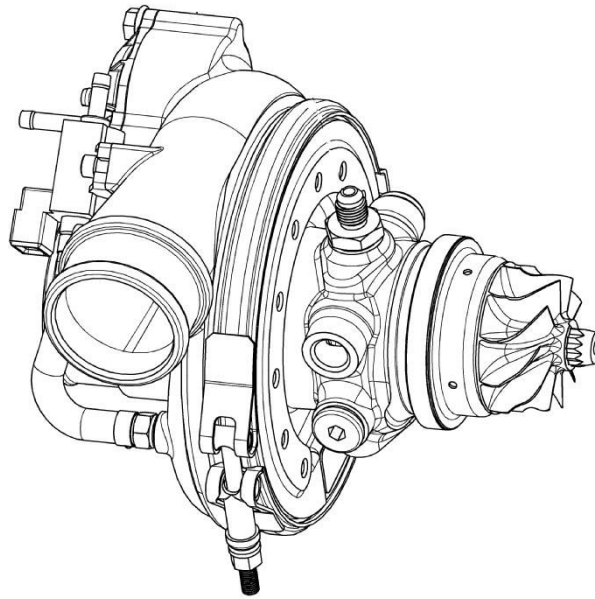
Figure 94: Contents of Hardware / Installation Kit



The **179425** Boost Control Solenoid Valve (BCSV) Kit Includes:

- (1) Boost Control Solenoid Valve
- (2) BCSV Screws
- (4) Hose Clamps
- (1) Compressor Cover Boost Port Fitting
- (1) Comp Cover Boost Port Washer
- (1) Wastegate Signal Hose, 110mm
- (1) Wastegate Signal Hose, 410mm

Figure 95: Contents of BCSV Kit



EFR Super-Core Product Selection Guide	
Rotors	Super-Core
6255	179139
6258	179140
6758	179375
7064	179354
7670	179350
8374	179257
9180	179356

Each Super-Core includes a fully assembled bearing and rotor system along with a complete compressor stage. This includes the compressor stage accessories such as the CRV and BCSV assembled to the comp cover.

Not included is the turbine housing assembly, turbine housing clamp plate hardware, or wastegate parts.

To build a complete turbo from scratch, the Super-Core must be mated with with a turbine housing, wastegate bracket kit, wastegate canister, and hardware/installation kit.

Figure 96: Super-Core Application List



The **179430** Speed Sensor Kit Includes:

- (1) Speed Sensor, Frequency Output
- (1) Speed Sensor Hold-Down Bolt

*** Note: Speed Sensor signal conversion and display accessories
can be purchased at: www.roadragegages.com

Figure 97: Contents of Speed Sensor Kit



The **179426** Wastegate Hose Kit Includes:

- (1) Wastegate Signal Hose, 410mm
- (2) Hose Clamps

Figure 98: Contents of Wastegate Hose Kit

Compressor Cover Boost Fitting	8 Nm
CRV Cover Screws	7 Nm
Boost Control Solenoid Valve Screws	3 Nm
V-Band Nut	17 Nm
Oil Inlet Fitting	23.5 Nm
Water Port Plugs	40 Nm
Actuator Bracket to Bearing Housing Screws	7.0 Nm
Actuator to Bracket Nuts	8.0 Nm
Actuator Rod-End Nuts	6.5 Nm
Turbine Housing Clamp Plate Screws (w/Anti-Seize)	13.5 Nm

Figure 99: EFR Fastener Torques

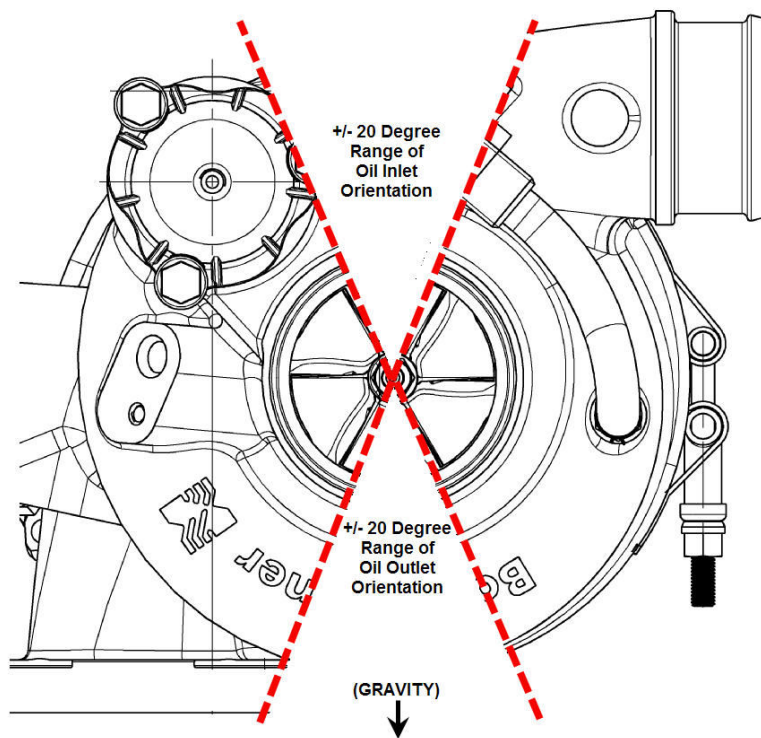


Figure 100: Explanation of Acceptable Oil Drain Angle

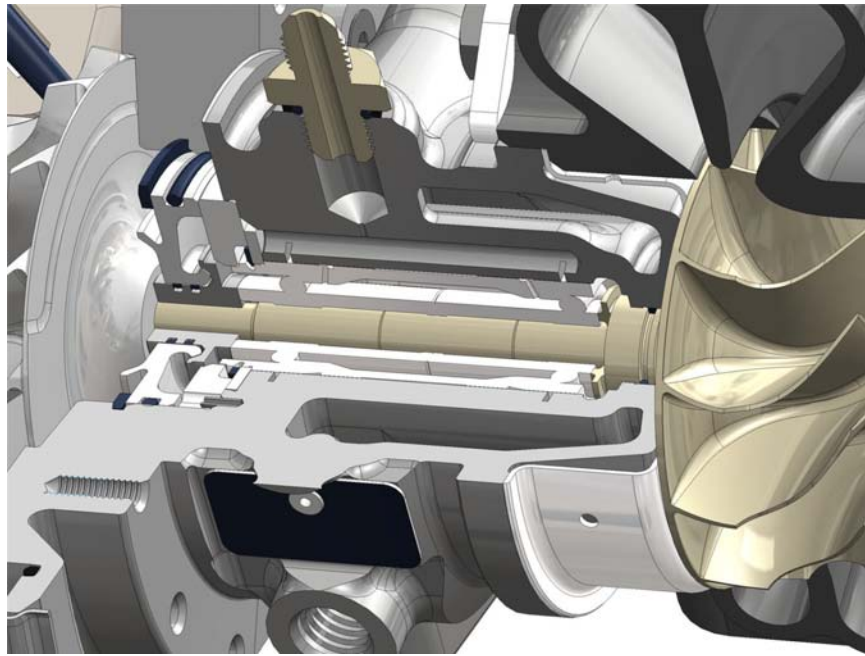


Figure 101: Bearing System Cross-Section Detail



Figure 102: Oil and Water Cavity Detail

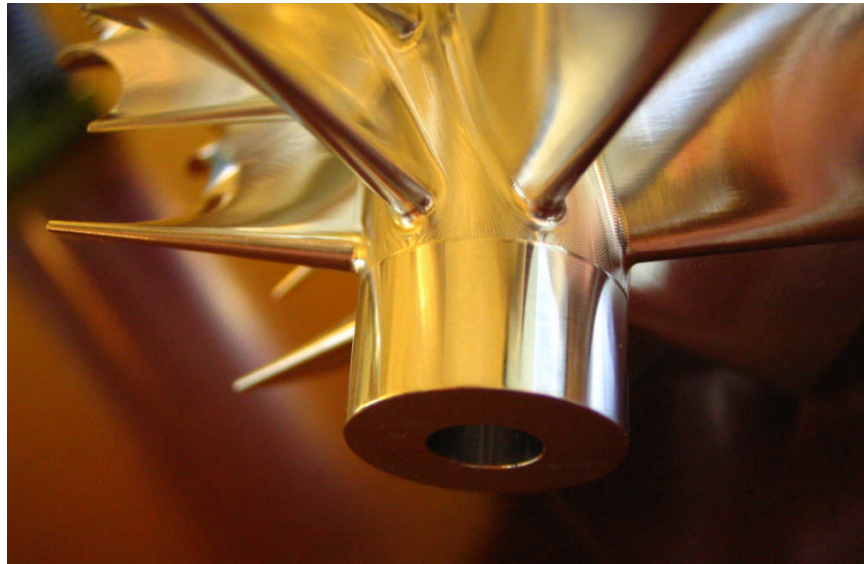


Figure 103: It's One Thing To Machine a Compressor Wheel; It's Another Thing For It To Be Durable Also

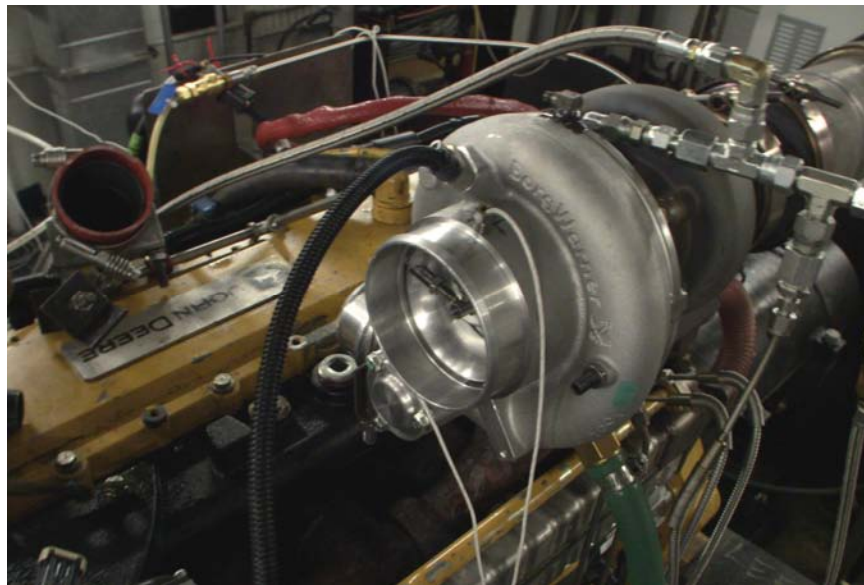


Figure 104: Shaft Motion Testing On a Heavy Duty Diesel Engine



Figure 105: A Very Large Amount of Gas Stand Testing Was Performed

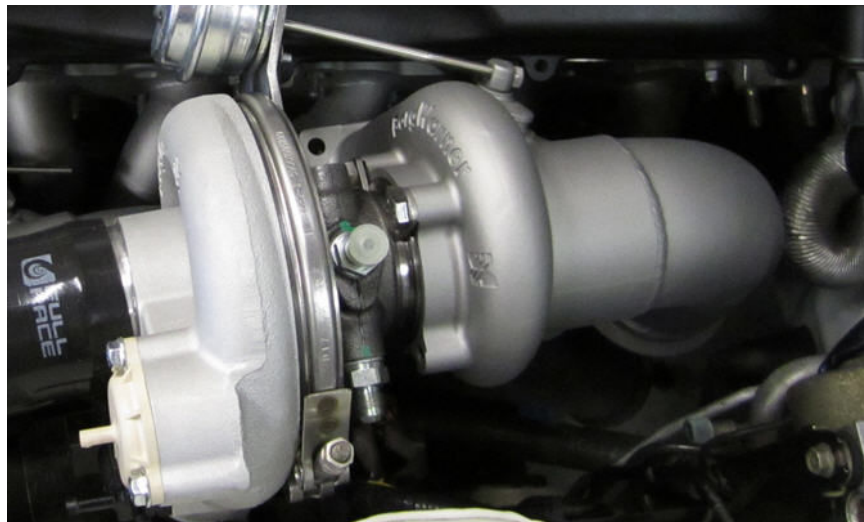


Figure 106: For Special Packaging Situations, a Stainless Downpipe Can be Welded Directly to the Turbine Housing (photo courtesy Full-Race Motorsports)





Figure 107: The First Two Cars to Receive EFR Turbos Were the Author's Porsche 911 and Fellow Employee Doug Erber's Mazda Miata. Accelerating our Product Observations Through the Installation Process Was a Key Early Step in the Program, Leading to Mid-Stream Improvements.




Figure 108: Also Known as the "Turbo Killer", the Sierra Sierra Time Attack EVO Should Prove to be a Very Good Field Test for EFR Turbos. We Intend to Put an End to Their Turbo-Killing Curse. (photos courtesy Sierra Sierra Enterprises)

Inputs - Click to Expand/Collapse







Enter Engine Information (Required)

Turbo Configuration Select One

Displacement (Liters) 3.0 (183.06 CID)

Ambient Air Temp (deg F) 75

Altitude (ft above sea level) 500 (14.456 psi barometric pressure)

Required Inputs	#1	#2	#3	#4	#5	#6
Engine Speed rpm	<input type="text" value="2000"/>	<input type="text" value="3000"/>	<input type="text" value="4000"/>	<input type="text" value="5000"/>	<input type="text" value="6000"/>	<input type="text" value="7000"/>
Volumetric Efficiency %	<input type="text" value="85"/>	<input type="text" value="95"/>	<input type="text" value="100"/>	<input type="text" value="110"/>	<input type="text" value="110"/>	<input type="text" value="105"/>
Boost Pressure (Gauge) psi	<input type="text" value="7"/>	<input type="text" value="10"/>	<input type="text" value="15"/>	<input type="text" value="17"/>	<input type="text" value="17"/>	<input type="text" value="17"/>
Intercooler Effectiveness %	<input type="text" value="99"/>	<input type="text" value="95"/>	<input type="text" value="95"/>	<input type="text" value="92"/>	<input type="text" value="90"/>	<input type="text" value="90"/>
Intercooler Pressure Drop psi	<input type="text" value="0.2"/>	<input type="text" value="0.2"/>	<input type="text" value="0.3"/>	<input type="text" value="0.4"/>	<input type="text" value="0.5"/>	<input type="text" value="0.6"/>
Air Filter Restriction psi	<input type="text" value="0.1"/>	<input type="text" value="0.1"/>	<input type="text" value="0.15"/>	<input type="text" value="0.15"/>	<input type="text" value="0.2"/>	<input type="text" value="0.2"/>
Muffler System Backpressure psi	<input type="text" value="0.5"/>	<input type="text" value="1"/>	<input type="text" value="1.5"/>	<input type="text" value="1.5"/>	<input type="text" value="2"/>	<input type="text" value="2"/>
Compressor Efficiency %	<input type="text" value="74"/>	<input type="text" value="74"/>	<input type="text" value="74"/>	<input type="text" value="74"/>	<input type="text" value="74"/>	<input type="text" value="74"/>
Turbine Efficiency %	<input type="text" value="72"/>	<input type="text" value="72"/>	<input type="text" value="72"/>	<input type="text" value="72"/>	<input type="text" value="72"/>	<input type="text" value="72"/>
Exhaust Gas Inlet Temperature deg F	<input type="text" value="1650"/>	<input type="text" value="1650"/>	<input type="text" value="1650"/>	<input type="text" value="1650"/>	<input type="text" value="1650"/>	<input type="text" value="1650"/>
Turbine Expansion Ratio ~	<input type="text" value="1.22"/> <input type="button" value="+"/> <input type="button" value="-"/>	<input type="text" value="1.36"/> <input type="button" value="+"/> <input type="button" value="-"/>	<input type="text" value="1.6"/> <input type="button" value="+"/> <input type="button" value="-"/>	<input type="text" value="1.85"/> <input type="button" value="+"/> <input type="button" value="-"/>	<input type="text" value="1.99"/> <input type="button" value="+"/> <input type="button" value="-"/>	<input type="text" value="2.13"/> <input type="button" value="+"/> <input type="button" value="-"/>
Calculated Percentage of Wastegating %	1	14	24	34	37	38
Optional Inputs						
BSFC lb/hp-hr	<input type="text" value="0.55"/>	<input type="text" value="0.55"/>	<input type="text" value="0.55"/>	<input type="text" value="0.55"/>	<input type="text" value="0.55"/>	<input type="text" value="0.55"/>
A/F Ratio ~	<input type="text" value="11.5"/>	<input type="text" value="11.5"/>	<input type="text" value="11.5"/>	<input type="text" value="11.5"/>	<input type="text" value="11.5"/>	<input type="text" value="11.5"/>

Figure 109: The Team at BorgWarner Has Developed An Interactive Turbo Matching Program That is Internet Based. Called "Match-Bot", the First Step is to Enter the Engine Input Data. Lots of Helpful Tips are Provided, Just Roll the Pointer Over the Question Marks.

Calculated Outputs - Click to Expand/Collapse

	#1	#2	#3	#4	#5	#6
Compressor Pressure Ratio ~	1.5	1.71	2.07	2.22	2.23	2.23
Compressor Outlet Temp deg F	163.19	193.68	240.33	257.23	259.03	259.84
Intake Manifold Air Temp deg F	75.88	80.93	83.27	85.62	85.4	83.48
Intake Manifold Air Density lb/in ³	0.00063	0.00071	0.00085	0.00089	0.00089	0.00089
Density Ratio (Intercooled) ~	1.48	1.67	2.01	2.12	2.1	2.1
Actual Flow Rate (Not Corrected) lb/min	5.74	18.44	31.04	45.05	53.69	55.78
Actual Flow Rate (Not Corrected) cfm	141.24	267.37	450.03	653.17	778.45	866.78
Correct Air Flow Rate lb/min	9.83	18.61	31.43	45.62	54.55	60.75
Correct Air Flow Rate kg/sec	0.074	0.14	0.237	0.344	0.412	0.459
Correct Air Flow Rate kg/hr	267	506	854	1240	1481	1651
Correct Air Flow Rate m ³ /sec	0.067	0.127	0.215	0.312	0.373	0.416
1/BSAC	9.4	9.4	9.4	9.4	9.3	9.3
Turbo Shaft Power Hp	4.9	12.49	29.23	46.97	56.38	63.05
Engine Power Hp	92.4	174.9	294.4	427.3	509.3	567.1
Torque lb-ft	242.64	306.22	386.57	448.85	445.78	425.46
Fuel Requirement lb/hr	50.8	96.2	161.9	235	280.1	311.9
Turbine Match Outputs						
Exhaust Manifold Pressure psi	3.8	6.6	11.1	15.1	18.3	20.6
Engine Delta Pressure (dP) psi	3	3	4	2	-1	-4
Turbine Swallowing Parameter PHI	0.021	0.03	0.039	0.042	0.041	0.039
Turbine Corrected Flow @ 51F lb/min	14.9	21.6	27.9	38.1	45.4	48.2
Is the Wastegate Flow Closed	No	No	No	No	Yes	Yes
Wastegate Flow Area @ CF=0.8 in ²	0.06	0.36	0.7	1.39	1.88	2.26
Port Diameter Requirement mm	7	17	24	34	39	43

Figure 110: Numerical Output is Provided as Well as Graphical Mapping

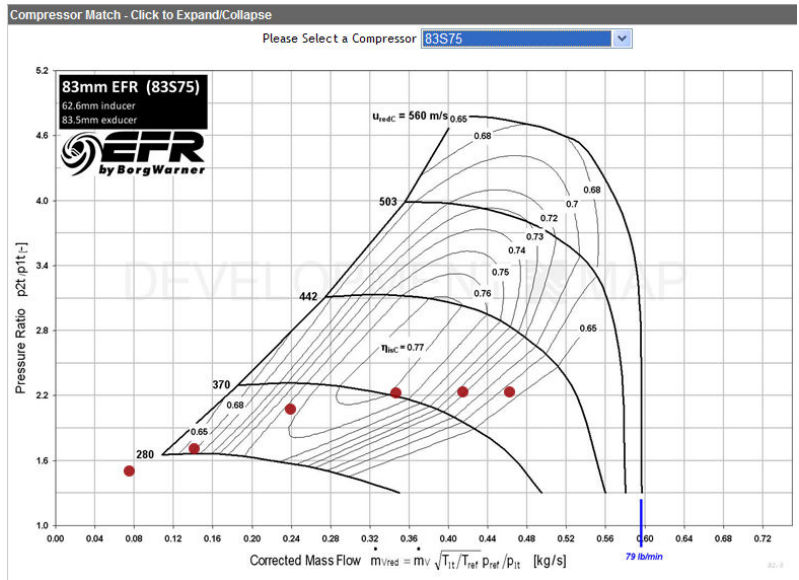


Figure 111: The User's Operating Points are Interactively Plotted onto Any Chosen Compressor Map

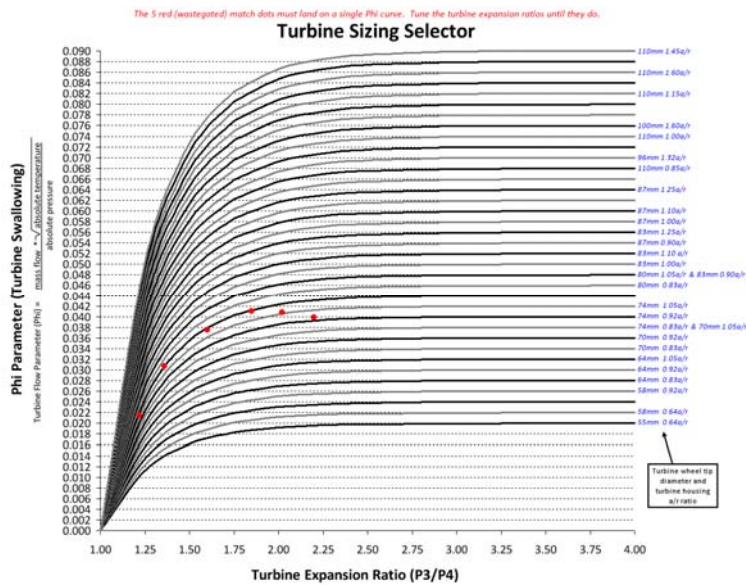


Figure 112: Turbine Matching is Also Performed. The User Dials In the Match Until All the Points Land on a Single Turbine Curve (the example above is not completed yet since the two right-most points droop below the chosen line)

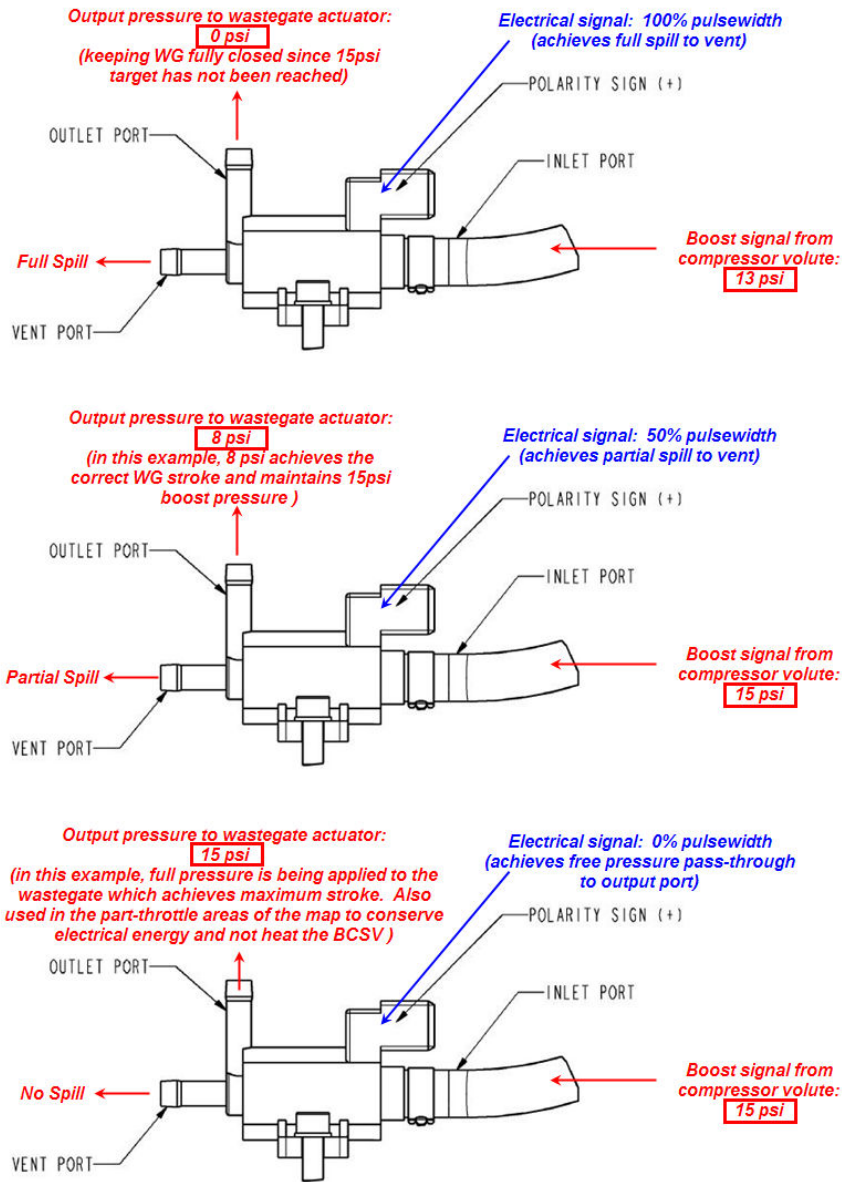


Figure 113: Three Examples of BCSV Operation

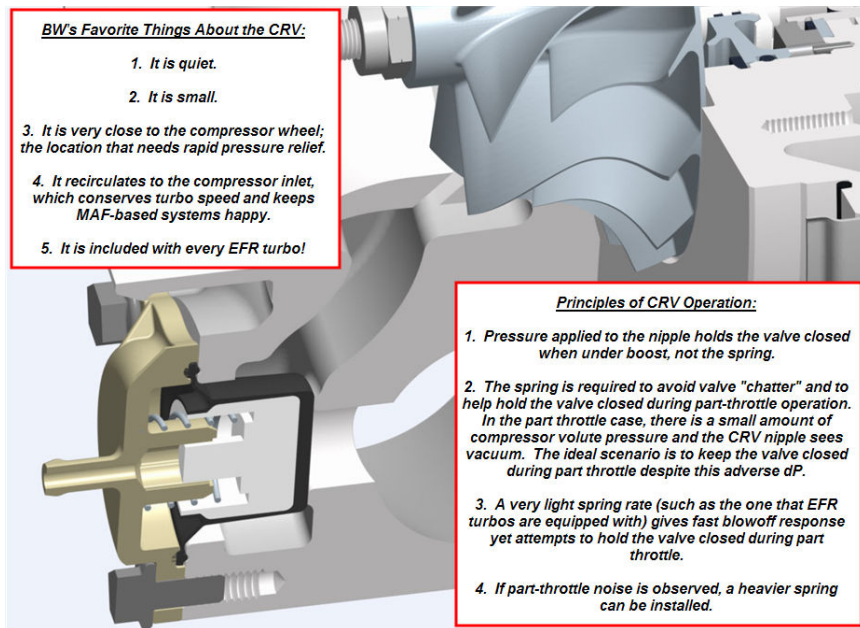


Figure 114: CRV Operation Principles and Advantages

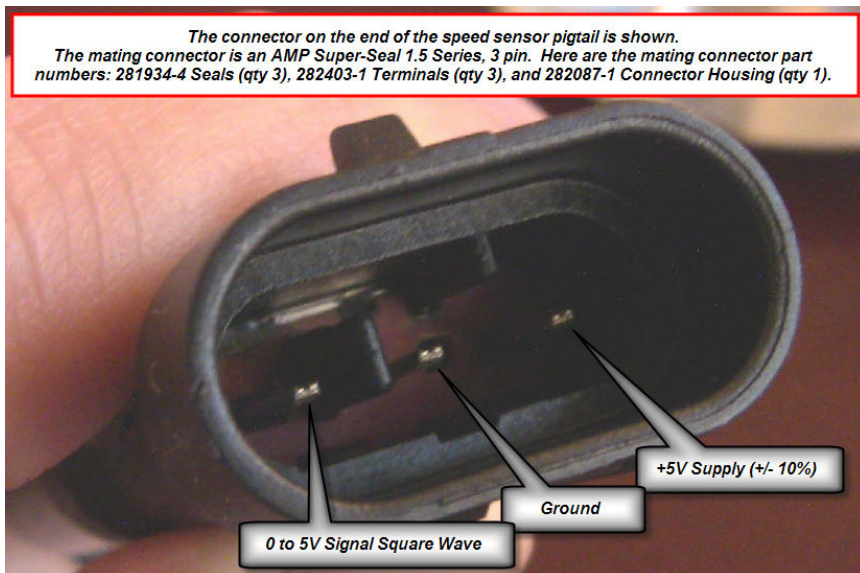


Figure 115: For Those Who May Want to Connect to the Speed Sensor Frequency Output Directly

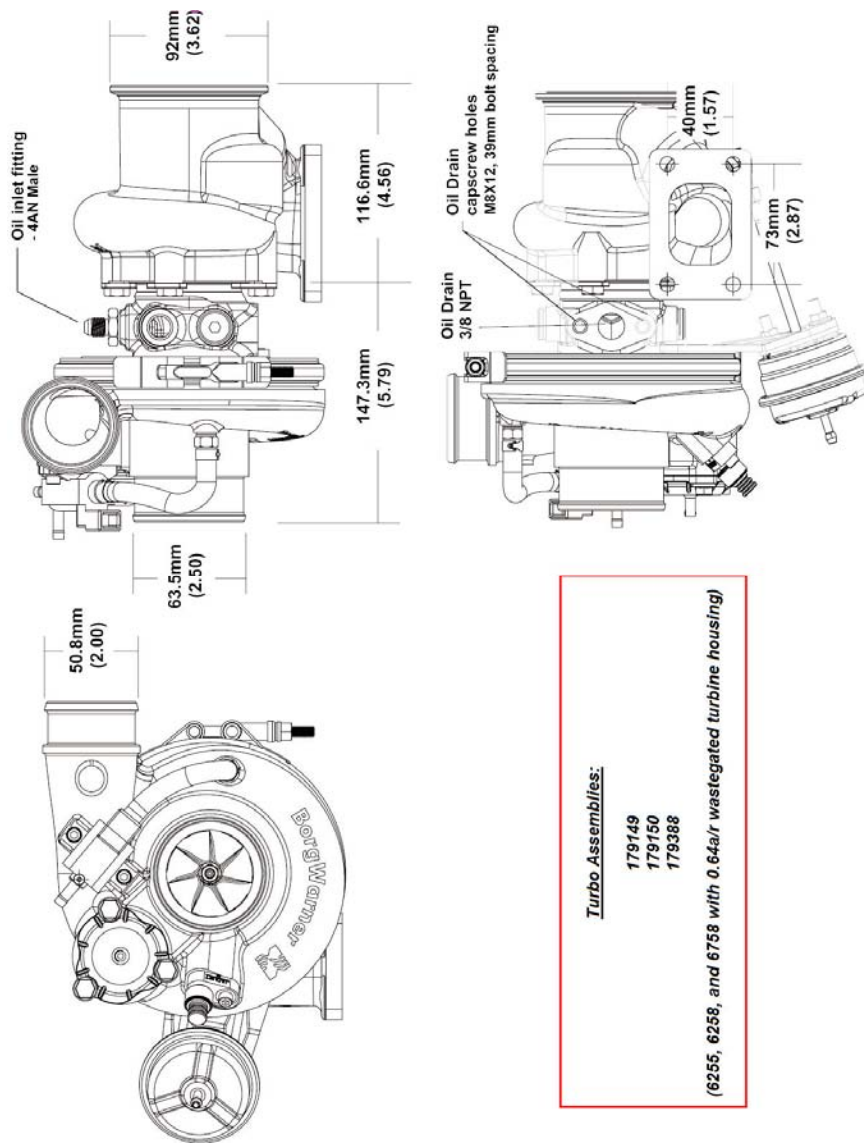


Figure 116: Outline Drawing #1

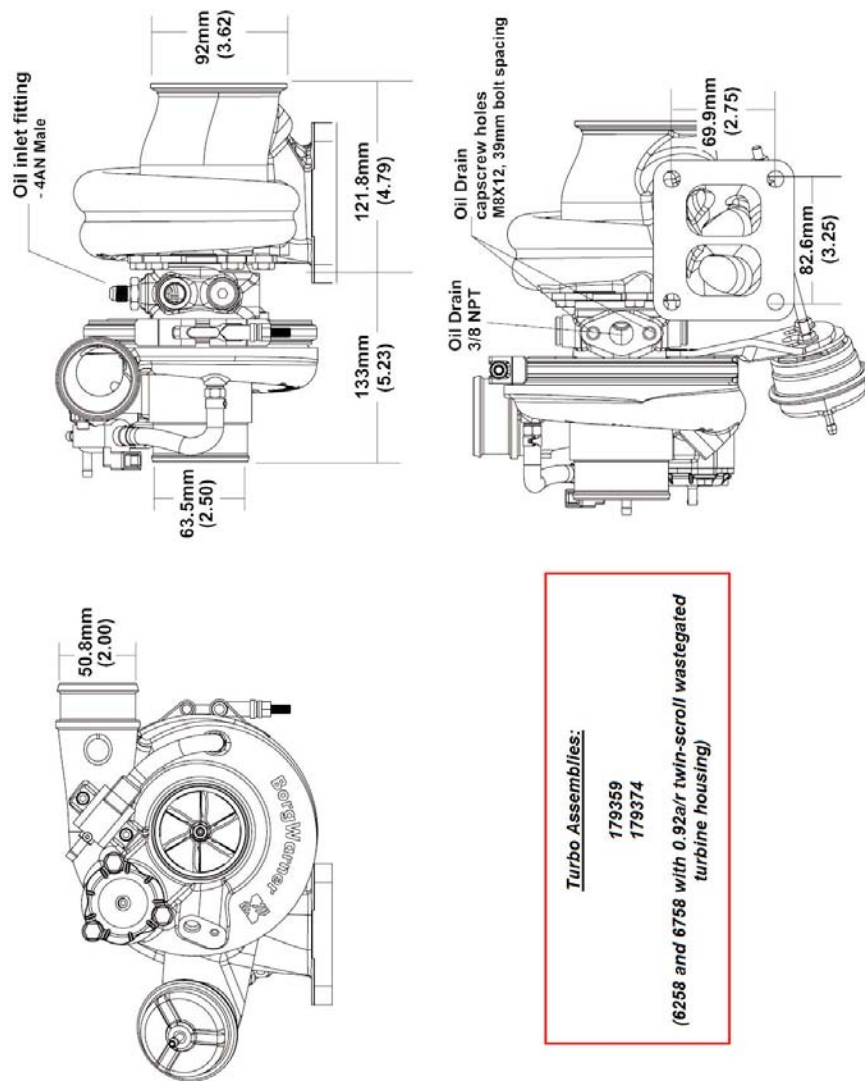


Figure 117: Outline Drawing #2

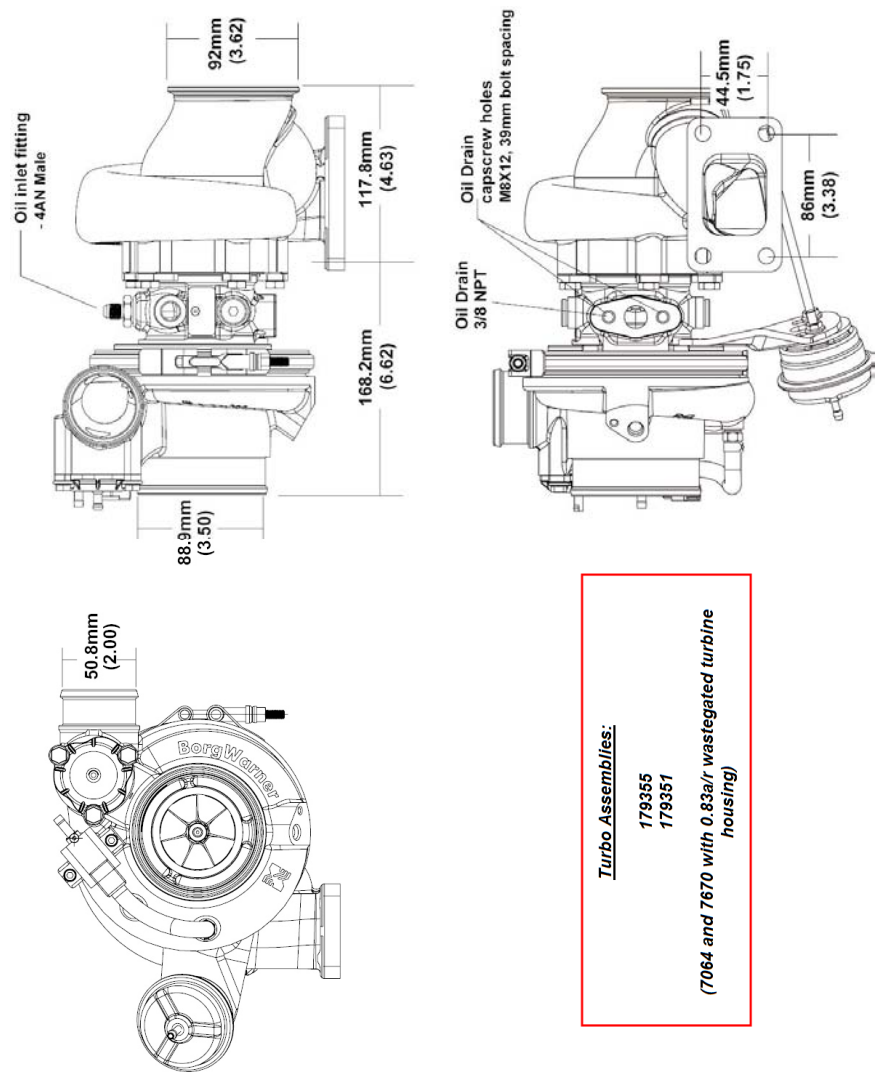


Figure 118: Outline Drawing #3

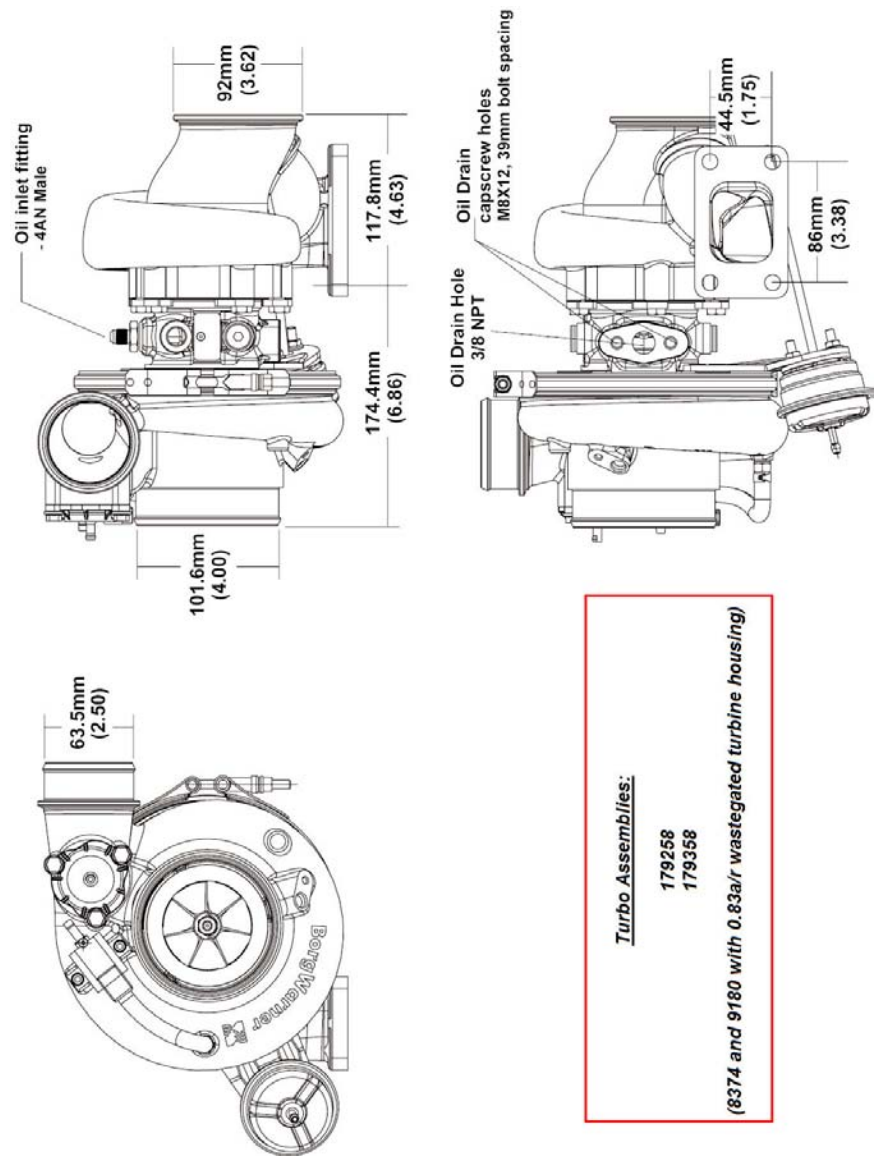


Figure 119: Outline Drawing #4

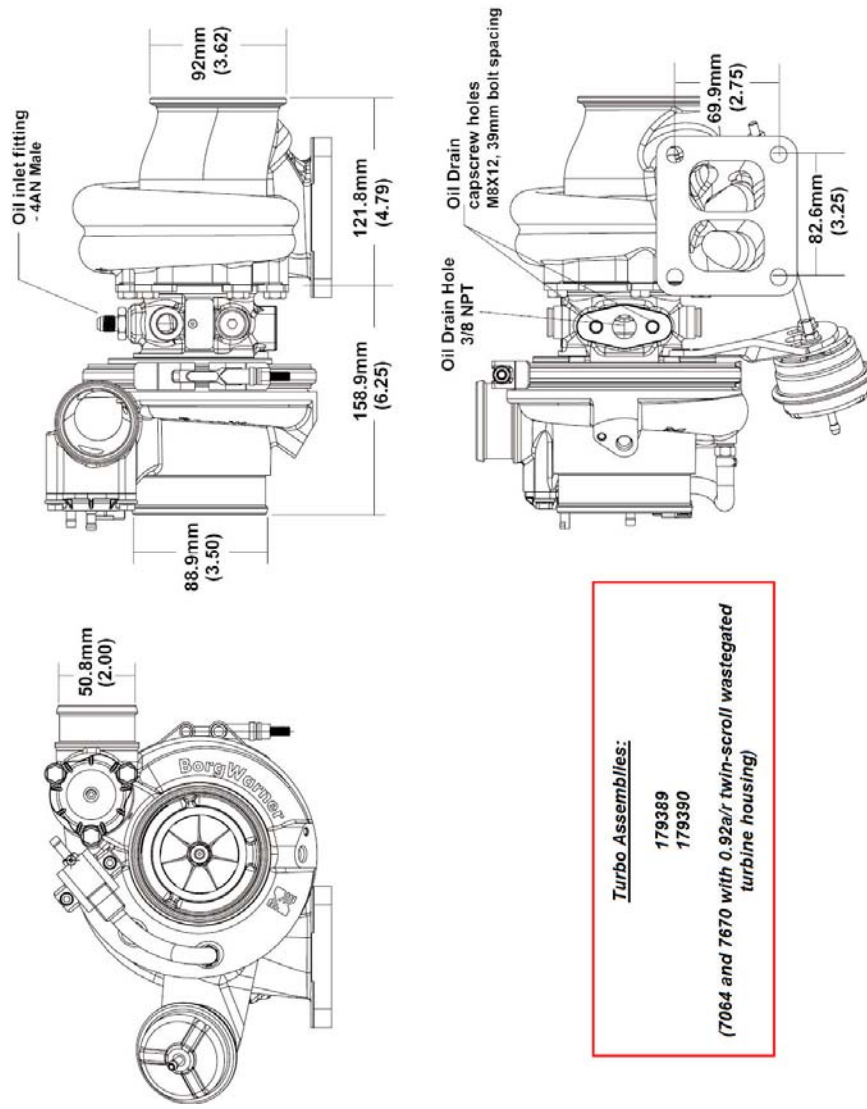


Figure 120: Outline Drawing #5

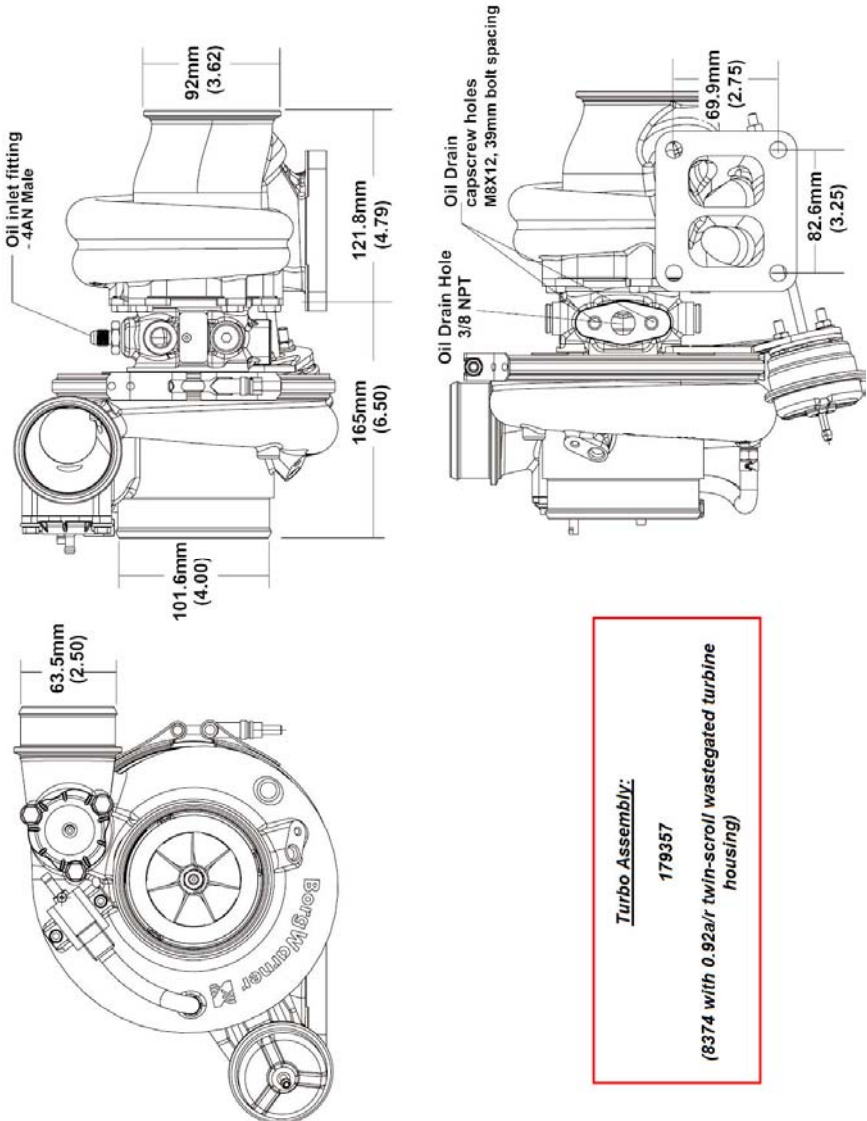


Figure 121: Outline Drawing #6

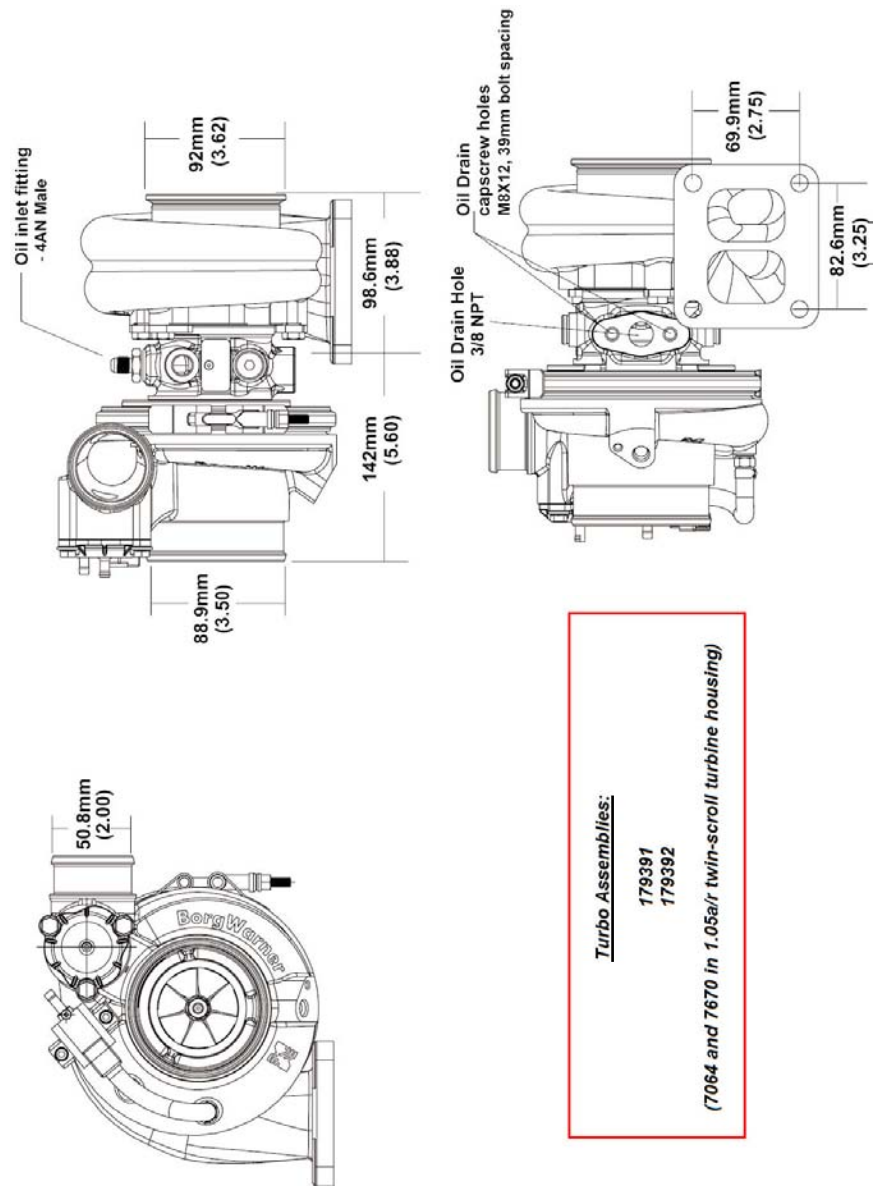


Figure 122: Outline Drawing #7

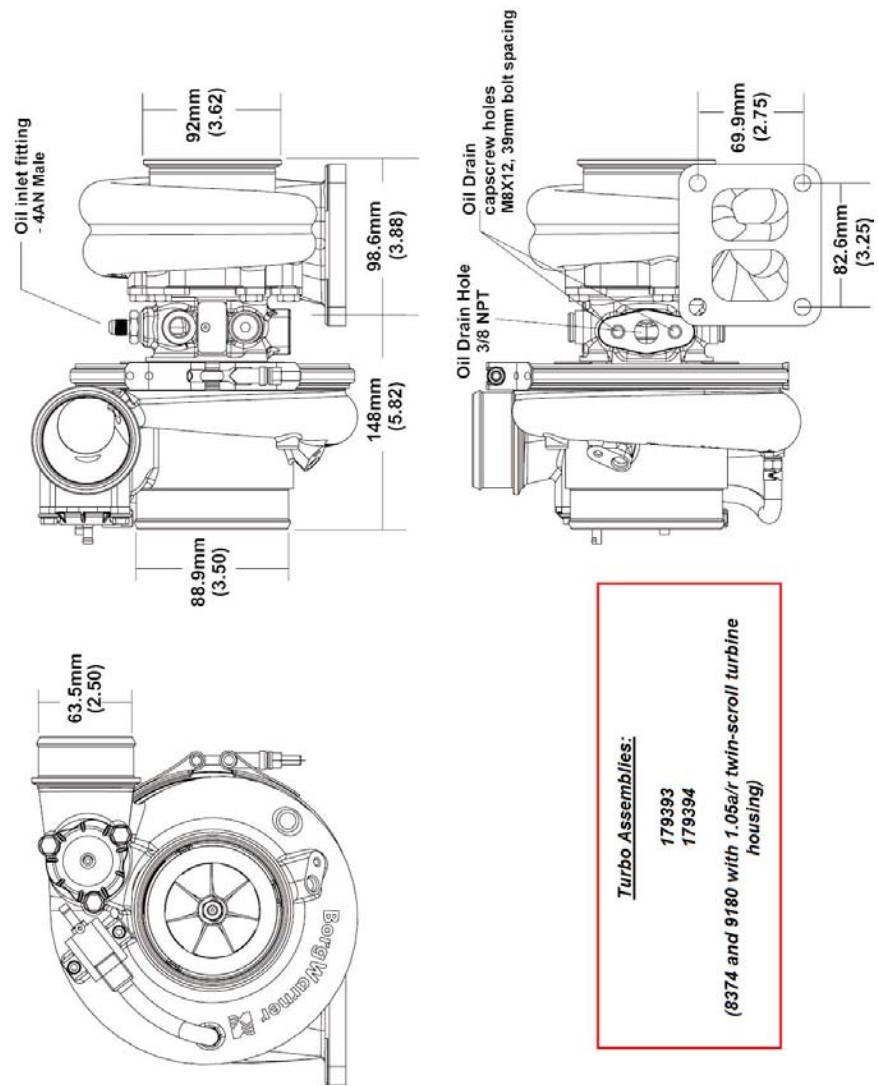


Figure 123: Outline Drawing #8

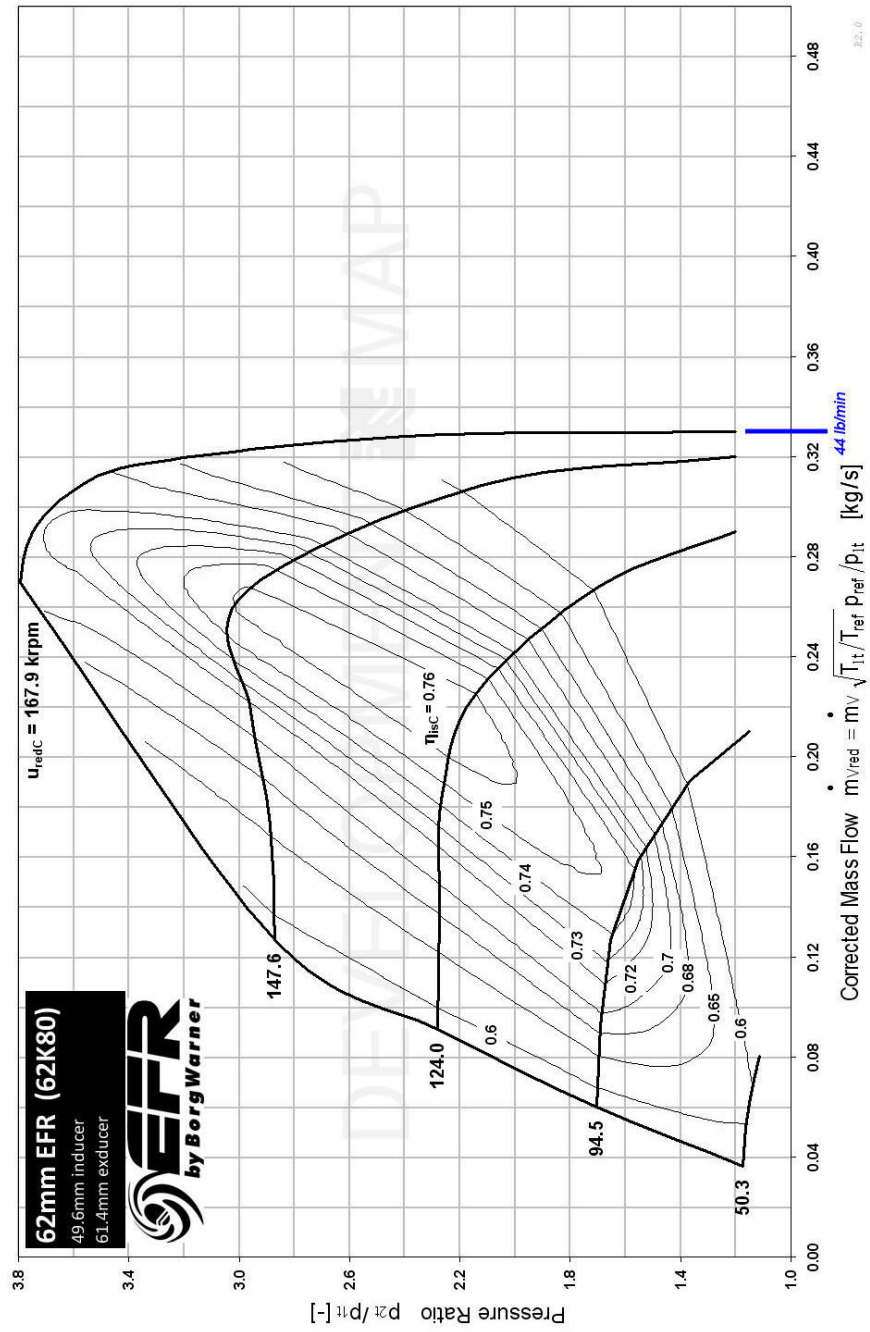


Figure 124: 62mm Compressor Map

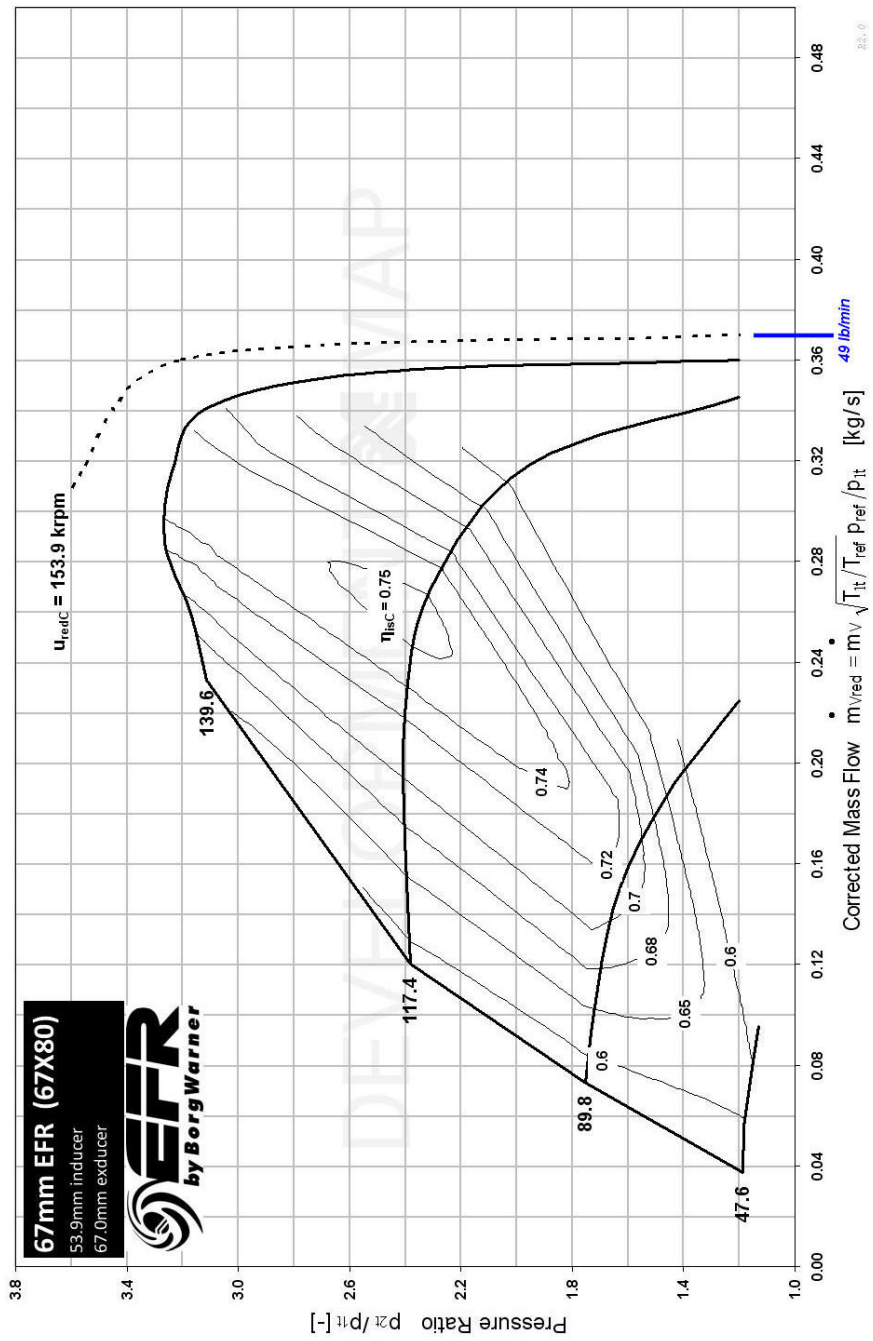


Figure 125: 67mm Compressor Map

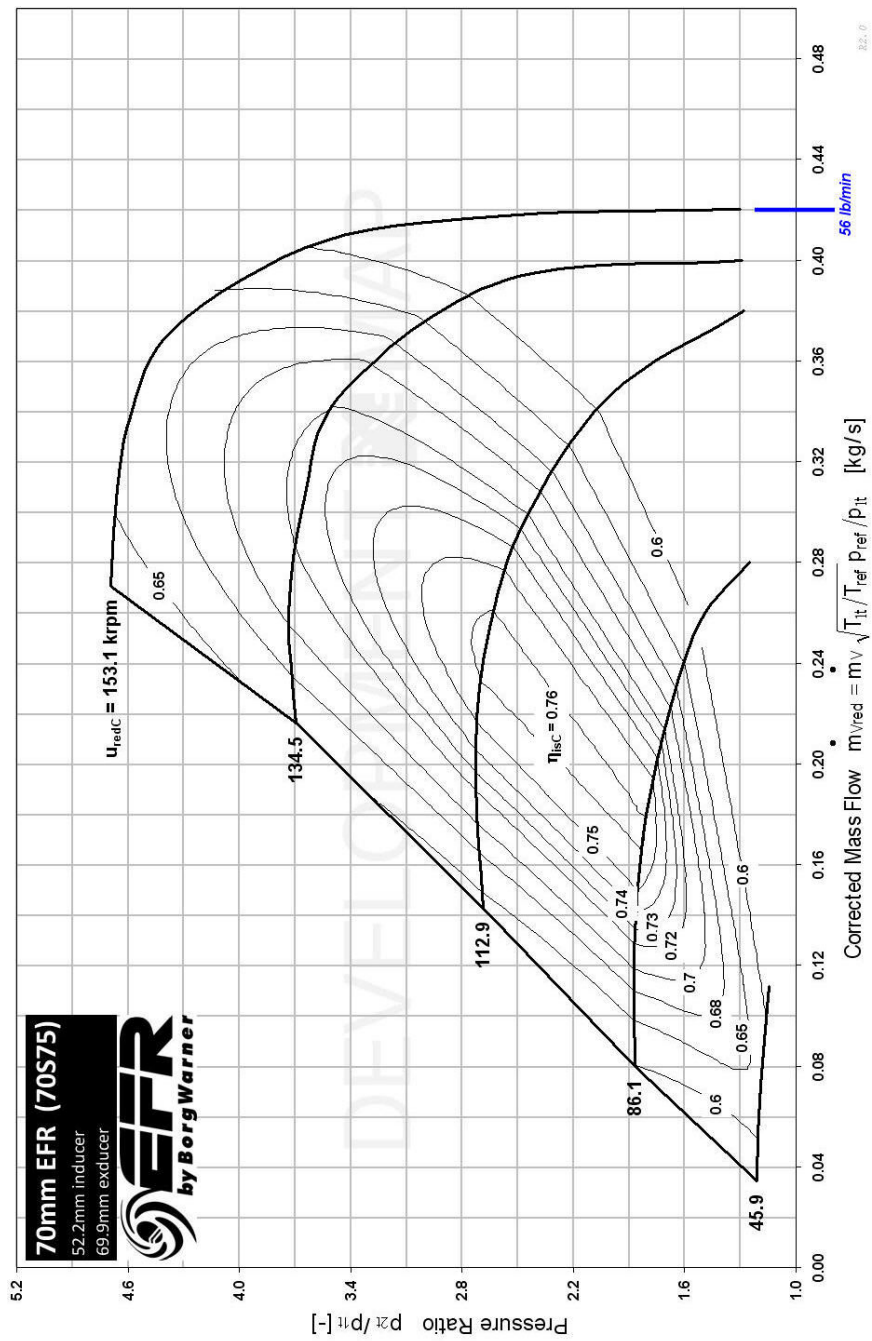


Figure 126: 70mm Compressor Map

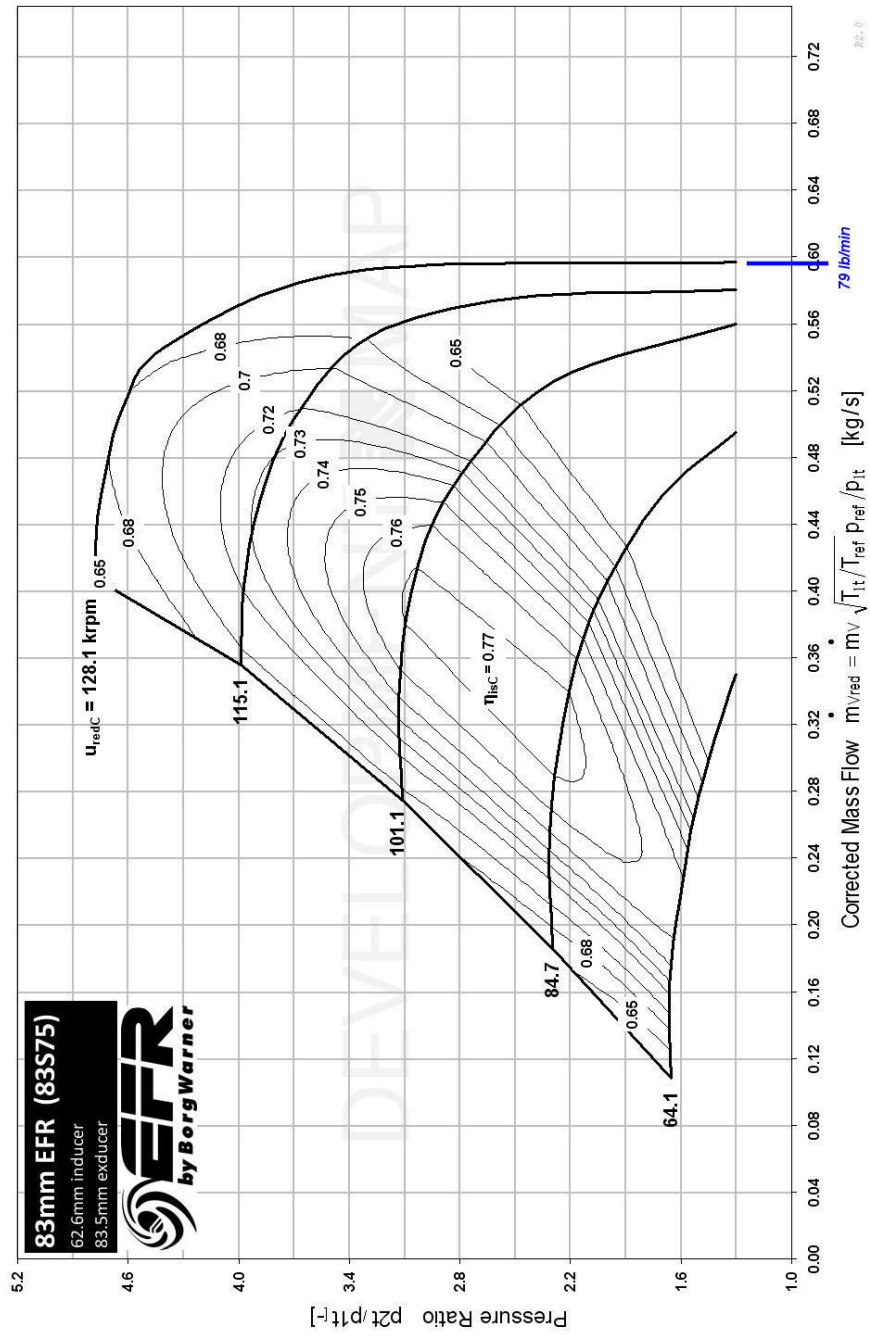


Figure 128: 83mm Compressor Map

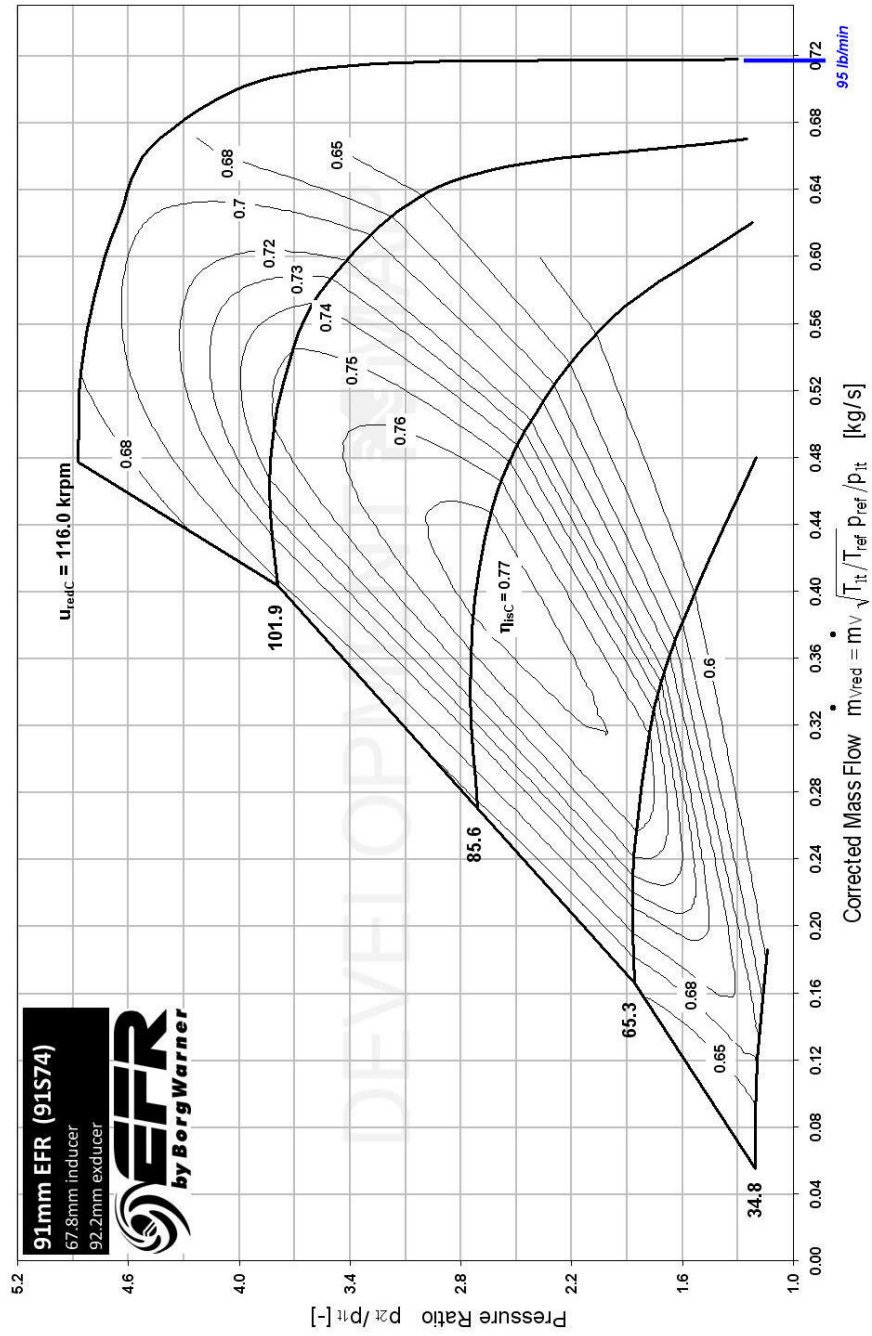


Figure 129: 91mm Compressor Map

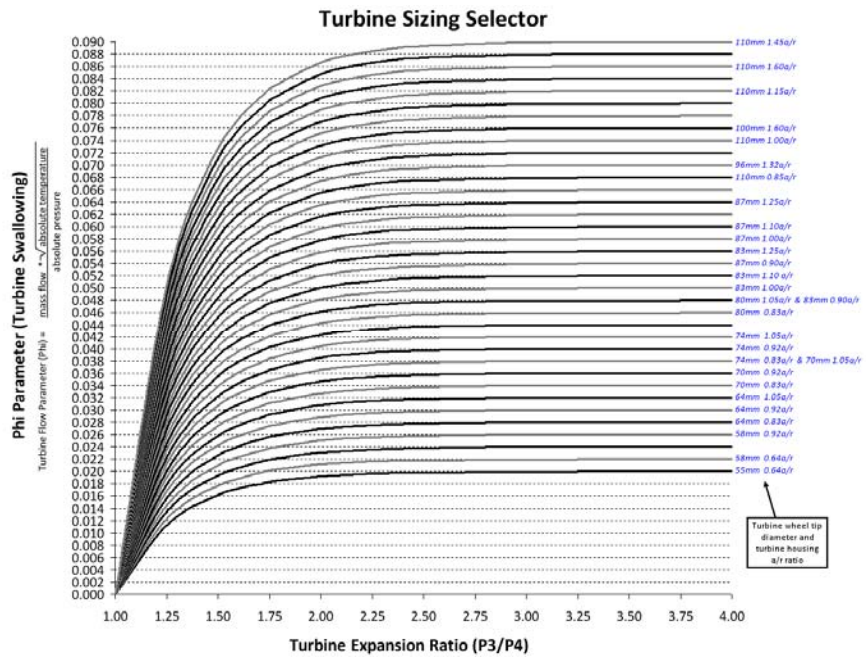


Figure 130: Turbine Sizing Chart for EFR and AirWerks (S400SX, S500SX)

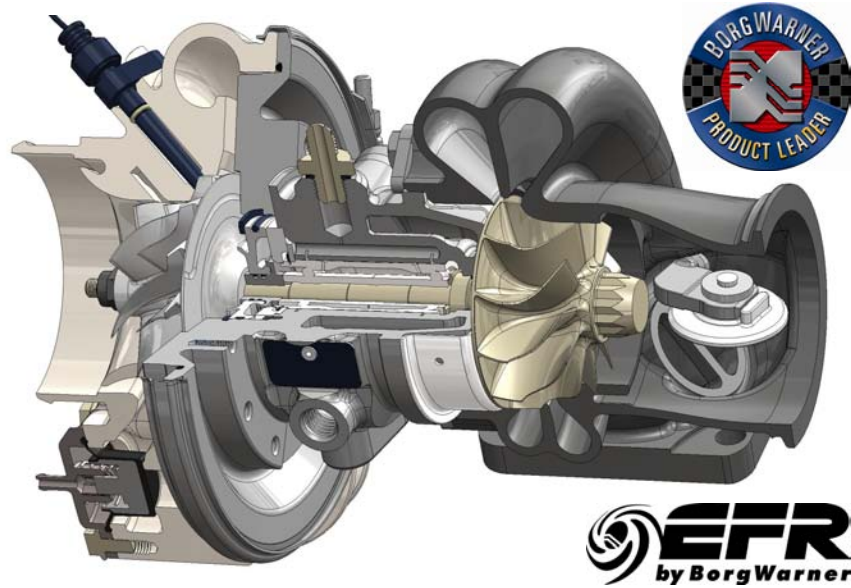


Figure 131: EFR Glamour Shot

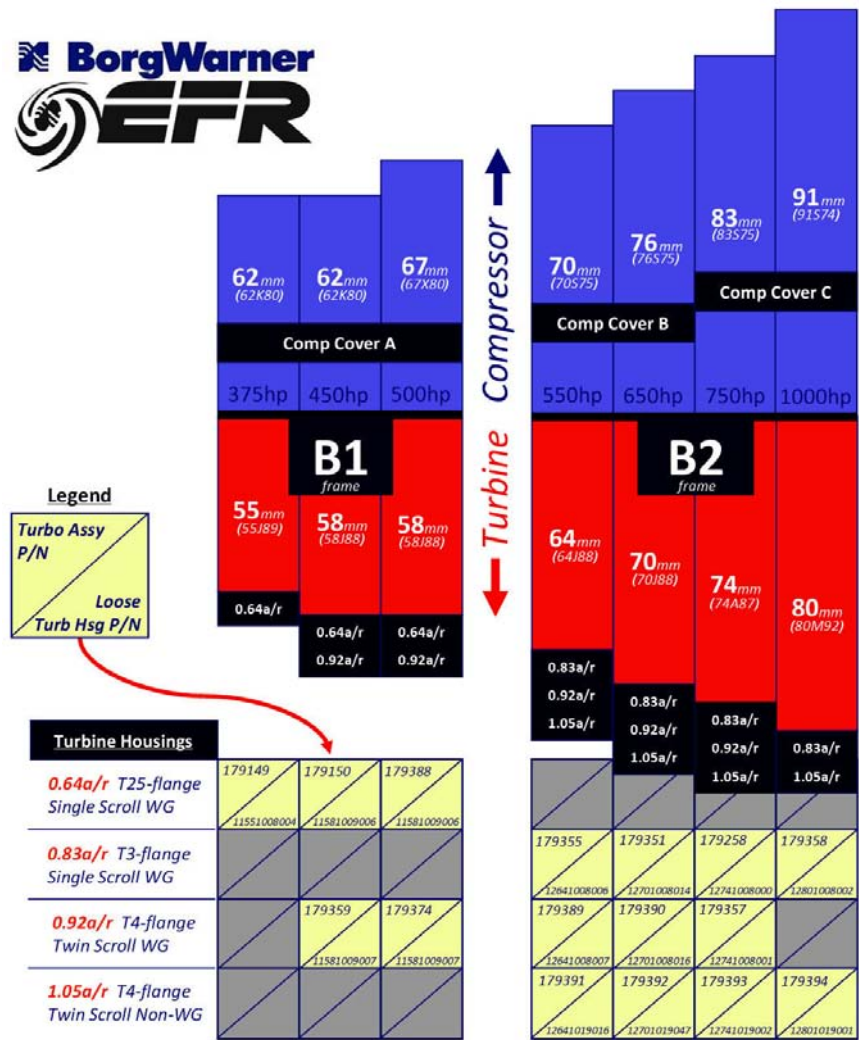


Figure 132: EFR Product Line Overview and Part Numbers

Notes

America

BorgWarner Turbo Systems

3800 Automation Avenue
Auburn Hills, MI 48326/USA
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Fax: ++1248 754 9397

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