

Garrett® Turbocharger System Optimization

by Honeywell

This Turbo Tech Section is intended to cover many of the auxiliary systems in a more complete and in-depth manner than what is originally covered in Turbo Tech 101, Turbo Tech 102, Turbo Tech 103 and Diesel Tech. With this additional section, you will better understand how to optimize your turbocharger system.

Turbo System Optimization will cover:

1. **TurboByGarrett.com**
2. **Application Information**
3. **Turbo Match**
4. **System Components**
 - **Air Filter**
 - **Oil Supply & Drain**
 - **Water Lines**
 - **Charge Tubing & Charge-Air-Cooler**
 - **BOV**
 - **Wastegate**
5. **Common Causes of Oil Leakage**
6. **System Testing/Monitoring**
7. **11-Point Checklist**

1. TurboByGarrett.com

The [TurboByGarrett.com](http://www.TurboByGarrett.com) website contains a lot of helpful information. It contains product information about turbos, intercoolers, and turbo kits. It explains Garrett's model nomenclature, it goes over Garrett's technology and product development as well as our involvement with OEM's and Motorsports. It contains tech tutorials written by the engineers from Basic, to Advanced, up to the Expert level where detailed formulas are used to plot operating points on compressor maps to help select the correct turbo. It also contains News and Events such as the GT ride of the month, the Garrett sponsored vehicles and what events we'll be at throughout the year as well as a distributor locator. The website has extensive information, both general and technical. No matter what your experience level, you'll find information that will help you with your specific application or simply increase your knowledge of turbos and turbos systems.

2. Application Information

The most important thing to understand before designing a system is the application. Is it going to be used for road racing, drag racing or drifting or maybe it will be primarily a street driven car. The intended use greatly affects the turbo selection as well as the system components. A turbo system that works well for a 9



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second drag car is most likely not going to work well for a drift car or road race car.

You need to have a target flywheel horsepower in mind.

The horsepower value will be used to help design the entire system.

Every time the horsepower value is used to help define a system component, I'm going to place a turbo indicator there. At the end of the section we'll see how many times we've used this horsepower value.



3. Turbo Match

- Go to www.TurboByGarrett.com
- Click on Turbo Tech
- Read Turbo Techs 101, 102 and 103.
- Using formulas in Turbo Tech 103, calculate mass flow and pressure ratio (PR) at redline for your specific application.
- Plot mass flow and PR on several compressor maps to determine the best fit.
- For the example in this presentation, the “application” will be a 400 flywheel hp street car using pump gas, therefore the estimated mass flow ~ 40 lbs/min



4. System Components

Air Filter

It is important to appropriately size the air filter for the maximum flow rate of the application. For our specific example, we are looking for target face velocity of ≤ 130 ft/min at redline to minimize restriction so as to provide the turbo with all the air necessary for it to function optimally.

If the turbo does not have access to the proper amount of air, excessive restriction can occur and cause:

- Oil leakage from the compressor side piston ring, which results in oil loss, a fouled CAC and potentially smoke out of the tailpipe.
- Increased pressure ratio, which can lead to turbo overspeed.
- Overspeed will reduce turbo durability and could result in an early turbo failure.

Determining the correct air filter size

Example:

Face Velocity = 130 ft/min

Mass Flow = 40 lbs/min

Air density = 0.076 lbs/ft³

Mass Flow (lbs/min) = Volumetric Flow Rate (CFM) x Air Density (lbs/ft³)

Volumetric Flow Rate (CFM) = Mass Flow (lbs/min)



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Air Density (lbs/ft3)

Volumetric Flow Rate = 526 CFM

**For twin turbo setups, simply divide the flow rate by two.

$$\text{Face Velocity (ft/min)} = \frac{\text{Volumetric Flow rate (CFM)}}{\text{Area (ft}^2\text{)}}$$

$$\text{Area (ft}^2\text{)} = \frac{\text{Volumetric Flow rate (CFM)}}{\text{Face Velocity (ft/min)}}$$

$$\text{Area (ft}^2\text{)} = 526 / 130 = 4.05$$

$$\text{Area (in}^2\text{)} = 4.05 \times 144$$

$$\text{Area} = 582 \text{ in}^2$$



Now that we know the required surface area that our air filter must have, we need to determine the correct air filter size using information provided by the filter manufacturer. We will need to know the following information about the filters we are considering:

- Pleat height
- Pleat depth
- Number of pleats

Example:

Pleat Height = 9.00 in.

Pleat Depth = 0.55 in.

of Pleats = 60

$$\text{Area (in}^2\text{)} = \text{pleat height} \times \text{pleat depth} \times \# \text{ of pleats} \times 2$$

$$\text{Area (in}^2\text{)} = 9.00 \times 0.55 \times 60 \times 2$$

$$\text{Area} = 594 \text{ in}^2$$

Actual Filter Area (594 in²) >

Calculated Area (582 in²)

Flow	526	ft ³ /min		
# of Pleats	Pleat Height	Pleat Depth	Area (in²)	Face Velocity (fpm)
50	8.00	0.55	440	172
60	9.00	0.55	594	128
60	10.00	0.55	660	115
60	10.50	0.55	693	109
	- input value			

Since the actual filter area (594 in²) is greater than the required area, this air filter will work for our application.

Oil Supply & Drainage

Journal Bearing Turbo

Journal-bearings function similarly to rod or crank bearings in an engine - oil pressure is required to keep components separated. An oil restrictor is generally not needed except for oil-pressure-induced leakage. The recommended oil feed for journal bearing turbochargers is -4AN or hose/tubing with an ID of approximately 0.25”.

Be sure to use an oil filter that meets or exceeds the OEM specifications.



Ball Bearing Turbo

An oil restrictor is recommended for optimal performance with ball bearing turbochargers. Oil pressure of 40 – 45 psi at maximum engine speed is recommended to prevent damage to the turbocharger’s internals. In order to achieve this pressure, a restrictor with a 0.040” orifice will normally suffice, but you should always verify the oil pressure entering the turbo after the restrictor in insure that the components are functioning properly.

Recommended oil feed is -3AN or -4AN line or hose/tubing with a similar ID.

As always, use an oil filter that meets or exceeds the OEM specifications.



OIL LEAKAGE SHOULD NOT OCCUR ON A PROPERLY FUNCTIONING SYSTEM IF RESTRICTOR IS NOT USED UNLESS THE SYSTEM PRESSURE IS EXCESSIVELY HIGH.

Oil Drain

In general, the larger the oil drain, the better. However, a -10AN is typically sufficient for proper oil drainage, but try not to have an inner diameter smaller than the drain hole in the housing as this will likely cause the oil to back up in the center housing. Speaking of oil backing up in the center housing, a gravity feed needs to be just that! The oil outlet should follow the direction of gravity +/-35° when installed in the vehicle on level ground. If a gravity feed is not possible, a scavenge pump should be used to insure that oil flows freely away from the center housing.

Avoid:

- Undulations in the line or extended lengths parallel to the ground
- Draining into oil pan below oil level
- Dead heading into a component behind the oil pan
- Area behind the oil pan (windage tray window) where oil sling occurs from crankshaft

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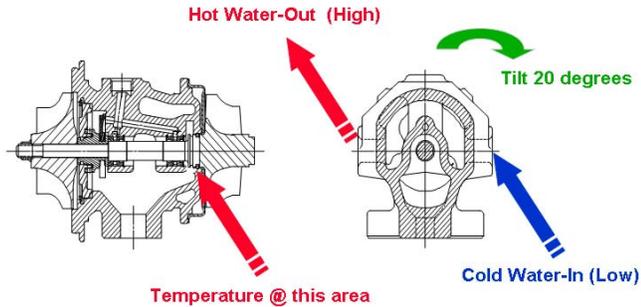
When installing your turbocharger, insure that the turbocharger axis of rotation is parallel to the level ground within +/- 15°. This means that the oil inlet/outlet should be within 15° of being perpendicular to level ground.

Water Lines

Water cooling is a key design feature for improved durability and we recommend that if your turbo has an allowance for water-cooling, hook up the water lines. Water cooling eliminates the destructive occurrence of oil coking by utilizing the Thermal Siphon Effect to reduce the Peak Heat Soak Back

Temperature on the turbine side piston after shut-down.

In order to get the greatest benefit from your water-cooling system, avoid undulations in the water lines to maximize the Thermal Siphon Effect.

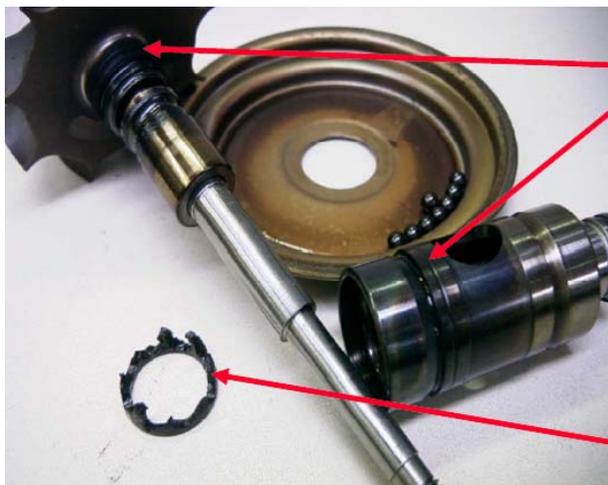
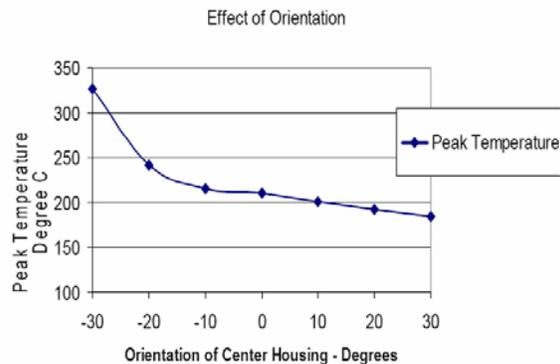


Negative degrees: water outlet of center housing is lower than water inlet

Positive degrees: water outlet of center housing is higher than water inlet

For best results, set the orientation of the center housing to 20°.

Significant damage to the turbo can occur from improper water line setups.



Bluing on the turbine wheel and turbine side of bearing from excessive heat

Bearing retainer melts and is damaged from heat soak back

Charge Tubing

The duct diameter should be sized with the capability to flow approximately 200 - 300 ft/sec. Selecting a flow diameter less than the calculated value results in the flow pressure dropping due to the restricted flow area. If the diameter is instead increased above the calculated value, the cooling flow expands to fill the larger diameter, which slows the transient response.

For bends in the tubing, a good design standard is to size the bend radius such that it is 1.5 times greater than the tubing diameter.

The flow area must be free of restrictive elements such as sharp transitions in size or configuration.

For our example:

- Tubing Diameter: velocity of 200 – 300 ft/sec is desirable. Too small a diameter will increase pressure drop, too large can slow transient response.
- Velocity (ft/min) = Volumetric Flow rate (CFM) / Area (ft²)



			Diameter (in)	Area (ft ²)	Flow Velocity (fps)
Flow (CFM)	526.00	ft ³ /min	1.50	0.012	714
			1.75	0.017	525
			2.00	0.022	402
			2.25	0.028	317
			2.50	0.034	257
			2.75	0.041	213
			3.00	0.049	179
			3.25	0.058	152
			3.50	0.067	131
			3.75	0.077	114
			4.00	0.087	100
	- input value				

Again, for twin turbo setups, divide the flow rate by (2).

Charge tubing design affects the overall performance, so there are a few points to keep in mind to get the best performance from your system.

- Duct bend radius:
 - Radius/diameter > 1.5
- Flow area:
 - Avoid area changes, sharp transitions, shape changes
- Available packaging space in the vehicle usually dictates certain designs

Selecting a Charge Air Cooler (aka intercooler) has been made simple with www.TurboByGarrett.com's intercooler core page. Each core is rated for horsepower, making it as easy as matching your desired power target to the core. In general, use the largest core that will fit within the packaging constraints of the application.

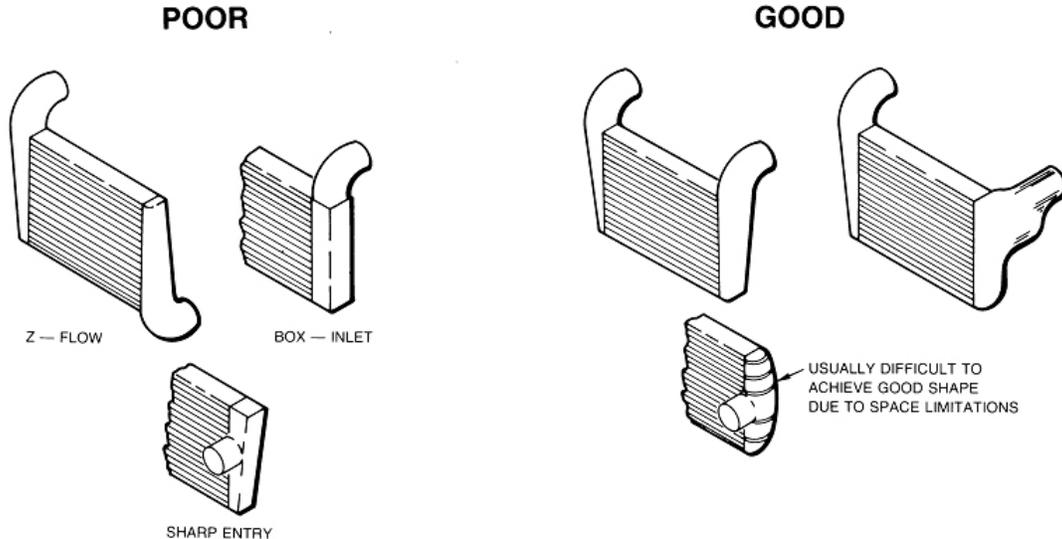
For our example:

AIR-AIR INTERCOOLER CORES

TF: Tube & Fin
BP: Bar & Plate

Part Number	Hot Flow Length (in)	No Flow Height (in)	Cold Flow Width (in)	Core Weight (lbs.)	* Horsepower	Type
703521-6001	6.0	12.0	4.5	9.0	180	BP
703517-6001	6.0	12.3	3.0	6.2	210	BP
703519-6002	8.0	12.4	3.5	8.8	275	BP
703518-6015	18.0	6.3	3.0	7.3	310	BP
753447-6001	22.0	6.3	2.3	7.6	320	BP
703517-6003	10.0	12.3	3.0	9.5	370	BP
703521-6003	10.0	12.0	4.5	13.1	375	BP
703520-6025	18.0	7.9	3.5	10.8	425	BP
703518-6018	24.0	6.3	3.0	9.9	475	BP
703518-6001	12.0	12.0	3.0	10.5	475	BP
703520-6009	24.0	6.3	3.5	11.6	500	BP
703518-6017	18.0	10.3	3.0	11.2	510	BP
753447-6004	22.0	10.3	2.3	11.8	530	BP
703520-6026	18.0	10.3	3.5	13.7	575	BP

Another important factor in selecting the correct intercooler is the end tank design. Proper manifold shape is critical in both minimizing charge air pressure drop and providing uniform flow distribution. Good manifold shapes minimize losses and provide fairly even flow distribution. The over-the-top design can starve the top tubes however. The side entry is ideal for both pressure drop and flow distribution, but it is usually not possible



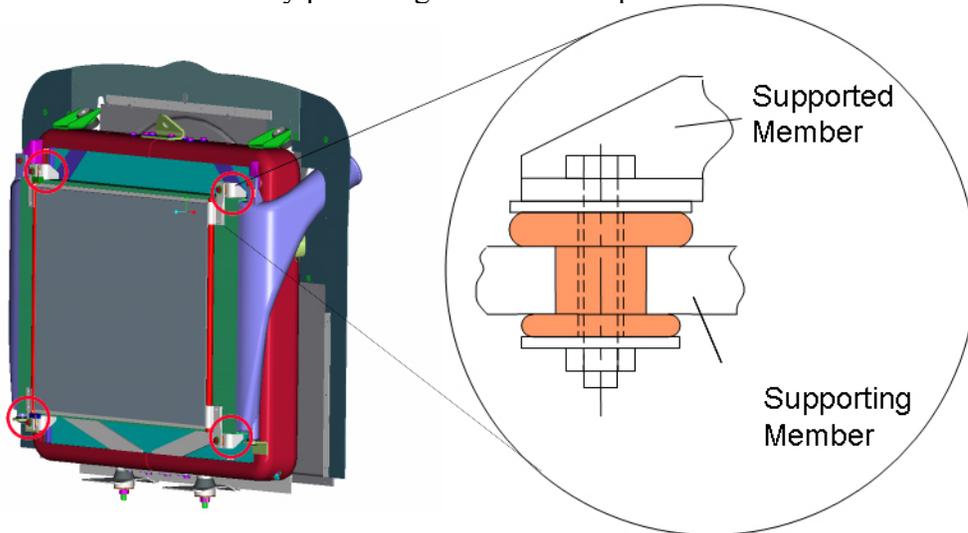
due to vehicle space limitations.

Proper mounting of the intercooler increases the durability of the system. Air to air charge air coolers are typically “soft-mounted”, meaning they use rubber isolation grommets. This type of mounting is also used for the entire cooling module. The design

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guards against vibration failure by providing dampening of vibration loads. It also reduces thermal loads by providing for thermal expansion.



Benefits of Isolation:

- Guards against vibration by damping loads
- Reduces thermal loading by providing for thermal expansion

Blow Off Valves (BOV)

Using the proper blow off valve (BOV) affects the system performance. There are two main types to consider.

MAP (Manifold Absolute Pressure) sensor uses either a vent-to-atmosphere valve or a recirculation valve.

- Connect signal line to manifold source
- Surge can occur if spring rate is too stiff



MAF (Mass Air Flow) sensor uses a recirculation (bypass) valve for best drivability.

- Connect signal line to manifold source
- Position valve close to the turbo outlet for best performance (if valve can handle high temp).
- Surge can occur if valve and/or outlet plumbing are restrictive.



Wastegates

Internal wastegates are part of the turbo and integrated into the turbine housing. Two connection possibilities exist for signal line. The first is to connect line from compressor outlet (not manifold - vacuum) to the actuator. The second is to connect a line from compressor outlet to boost controller (PWM valve) and then to the actuator.

Manifold pressure is limited by the spring rate of the actuator.



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Most OEM style actuators are not designed for vacuum, and thus, the diaphragm can be damaged resulting in excessive manifold pressure and engine damage.

External wastegates are separate from the turbo and integrated into the exhaust manifold rather than the turbine housing.

Connection to the manifold greatly affects flow capability, and correct orientation of the wastegate to the manifold is essential. For example, placing the wastegate at 90° to the manifold will reduce flow capacity by up to 50%! This greatly reduces the control that you have over the system and puts your entire drivetrain at risk. Instead, the ideal connection is at 45° with a smooth transition.



There are two connection possibilities for signal line:

- Connect a line from the compressor outlet (not manifold - vacuum) to the actuator
- Connect a line from the compressor outlet to a boost controller (PWM valve) and then to the actuator

Again, manifold pressure is limited by spring rate of actuator.

5. Common Causes of Oil Leakage

A properly installed turbo should NOT leak oil.

There are, however, instances where oil leaks occur. The most common causes, depending on the location of the leak, are:

Leakage from compressor and turbine seals

- Excessively high oil pressure
- Inadequate drain – drain is too small, does not go continuously downhill, or the location of the drain inside the oil pan is located in a section that has oil slung from the crank causing oil to back up in drain tube. Always place oil drain into oil pan in a location that oil from crank is blocked by windage tray.
- Improper venting of crankcase pressure.
- Excessive crankcase pressure.
- Oil drain rotated past the recommended 35°.

Leakage from compressor seal

Excessive pressure across the compressor housing inlet caused by:

- Air filter is too small.
- Charge air tubing too small or has too many bends between the air filter and compressor housing .
- Clogged air filter.

Leakage from Turbine seal

- Collapsed turbine piston ring from excessive EGT's.
- Turbo tilted back on its axis past recommended 15°.

6. System Testing and Monitoring

Testing

Many problems with turbo systems can be solved before the catastrophic happens through simple system testing.

Pressurize system to test for leaks

- Clamps
 - Check tightness
- Couplers
 - Check for holes or tears
- CAC core / end tanks
 - Check for voids in welds

Monitoring

The turbo system in your car should be monitored to insure that every aspect is functioning properly to give you trouble-free performance.

Instrumentation used to monitor / optimize system

1. Oil Pressure (Required to monitor engine operation)
 2. Oil Temperature (Required to monitor engine operation)
 3. Water Temperature (Required to monitor engine operation)
 4. A/F Ratio (such as a wideband sensor; required to monitor engine operation)
 5. Manifold Pressure
 6. Turbine Inlet Pressure
 7. Exhaust Gas Temperature
 8. Turbo Speed Sensor
- *The most accurate way to calibrate and optimize a system is through datalogging!*

Manifold Pressure

- Calibrate actuator setting to achieve manifold pressure required to meet hp target
- Detect over-boost condition
- Detect damaged actuator diaphragm



Back Pressure

- Monitor pressure changes in turbine housing inlet
- Affect of different turbine housing A/R's
- Increased back pressure decreases Volumetric Efficiency thus decreasing ultimate power



Pyrometer

- Monitor exhaust gas temperature (EGT) in manifold / turbine housing
- Adjust calibration based on temperature rating of turbine housing material or other exhaust components

Turbo Speed

- Determine operating points on compressor map





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- Determine if the current turbo is correct for the application and target hp
- Avoid turbo over-speed condition, which could damage turbo

7. 11 Point Checklist

1. **Application Information** – target horsepower, intended use of vehicle, etc.
2. **Air filter sizing** - determine size for application needs
3. **Oil Supply** - restrictor for ball-bearing turbo
4. **Oil Drain** – proper size and routing
5. **Water Lines** - set up for greatest thermal siphon effect
6. **Charge Tubing** – determine diameter for application needs
7. **Charge-Air-Cooler** - determine core size for application needs, design manifolds for optimal flow, mount for durability
8. **BOV** – VTA for MAP engines and by-pass for MAF engines
9. **Wastegate** – connect signal line to compressor outlet, smooth transition to external wastegate
10. **System Testing** – pressurize system to check for leakage, periodically check clamp tightness and the condition of couplers
11. **System Monitoring** – proper gauges/sensors to monitor engine for optimal performance and component durability