Mar Mediterráneo, 1 Nave 7
28830 San Fernando de Henares (Madrid)
T.+34 916 569 273 / F. +34 916 569 397
ventas@turbomaster.info
www.turbosbytm.com

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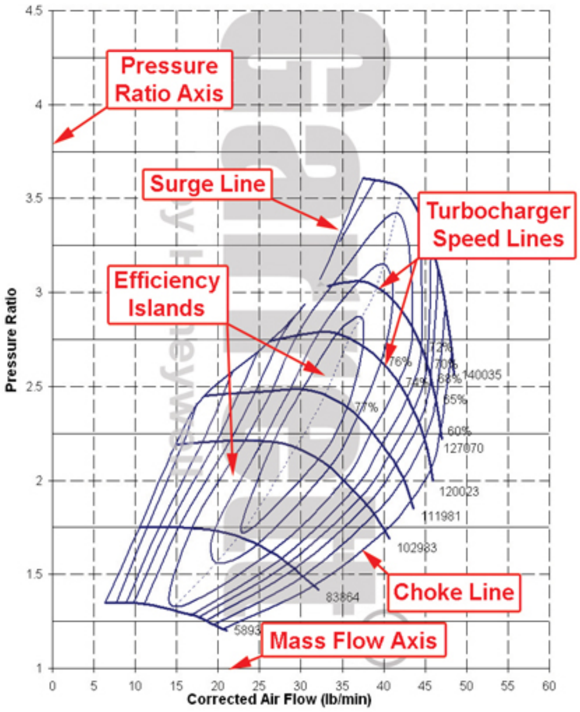
Compressor Maps



The compressor map is a graph that describes a particular compressor's performance characteristics, including efficiency, mass flow range, boost pressure capability, and turbo speed. Shown below is a figure that identifies aspects of a typical compressor map.

Parts of the Compressor Map:

Pressure Ratio

Pressure Ratio (Πc) is defined as the Absolute outlet pressure divided by the Absolute inlet pressure.

$$\Pi c = \frac{P_{2c}}{P_{1c}}$$

Where:

- Πc= Pressure Ratio
- P_{2c} = Compressor Discharge Pressure
- P_{1c} = Compressor Inlet Pressure

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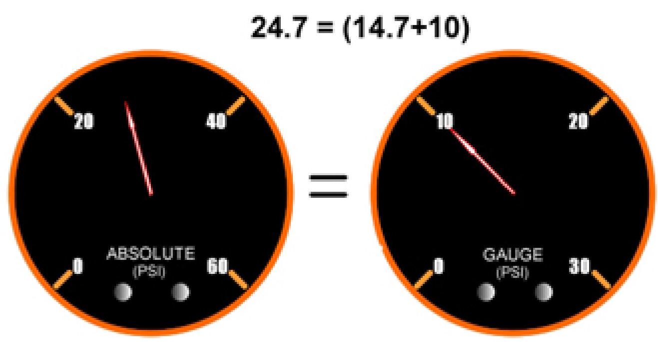
It is important to use units of Absolute Pressure for both P1c and P2c. Remember that Absolute Pressure at sea level is 14.7 psia (in units of psia, the a refers to "absolute"). This is referred to as standard atmospheric pressure at standard conditions.

Gauge Pressure (in units of psig, the g refers to "gauge") measures the pressure above atmospheric, so a gauge pressure reading at atmospheric conditions will read zero. Boost gauges measure the manifold pressure relative to atmospheric pressure, and thus are measuring Gauge Pressure. This is important when determining P2c. For example, a reading of 12 psig on a boost gauge means that the air pressure in the manifold is 12 psi above atmospheric pressure. For a day at standard atmospheric conditions,

12 psig + 14.7 psia = 26.7 psi absolute pressure in the manifold



The **pressure ratio** at this condition can now be calculated:

26.7 psia / 14.7 psia = **1.82**

However, this assumes there is no adverse impact of the air filter assembly at the compressor inlet.

In determining pressure ratio, the absolute pressure at the compressor inlet (P_{2c}) is often LESS than the ambient pressure, especially at high load. Why is this? Any restriction (caused by the air filter or restrictive ducting) will result in a "depression," or pressure loss, upstream of the compressor that needs to be accounted for when determining pressure ratio. This depression can be 1 psig or more on some intake systems. In this case P_{1c} on a standard day is:

14.7psia – 1 psig = 13.7 psia at compressor inlet

Taking into account the 1 psig intake depression, the **pressure ratio** is now:

(12 psig + 14.7 psia) / 13.7 psia = **1.95.**

That's great, but what if you're not at sea level? In this case, simply substitute the actual atmospheric pressure in place of the 14.7 psi in the equations above to give a more accurate calculation. At higher elevations, this can have a significant effect on pressure ratio.

For example, at Denver's 5000 feet elevation, the atmospheric pressure is typically around 12.4 psia. In this case, the pressure ratio calculation, taking into account the intake depression, is:

(12 psig + 12.4 psia) / (12.4 psia – 1 psig) = **2.14**

Compared to the 1.82 pressure ratio calculated originally, this is a big difference.

As you can see in the above examples, pressure ratio depends on a lot more than just boost.

Mass Flow Rate

Mass Flow Rate is the mass of air flowing through a compressor (and engine!) over a given period of time and is commonly expressed as lb/min (pounds per minute). Mass flow can be physically measured, but in many cases it is sufficient to estimate the mass flow for choosing the proper turbo.

Many people use Volumetric Flow Rate (expressed in cubic feet per minute, CFM or ft^3/min) instead of mass flow rate. Volumetric flow rate can be converted to mass flow by multiplying by the air density. Air density at sea level is 0.076lb/ft^3

What is my mass flow rate? As a very general rule, turbocharged gasoline engines will generate 9.5-10.5 horsepower (as measured at the flywheel) for each lb/min of airflow. So, an engine with a target peak horsepower of 400 Hp will require 36-44 lb/min of airflow to achieve that target. This is just a rough first approximation to help narrow the turbo selection options.

Surge line

Surge is the left hand boundary of the compressor map. Operation to the left of this line represents a region of flow instability. This region is characterized by mild flutter to wildly fluctuating boost and “barking” from the compressor. Continued operation within this region can lead to premature turbo failure due to heavy thrust loading.

Surge is most commonly experienced when one of two situations exist. The first and most damaging is surge under load. It can be an indication that your compressor is too large. Surge is also commonly experienced when the throttle is quickly closed after boosting. This occurs because mass flow is drastically reduced as the throttle is closed, but the turbo is still spinning and generating boost. This immediately drives the operating point to the far left of the compressor map, right into surge.

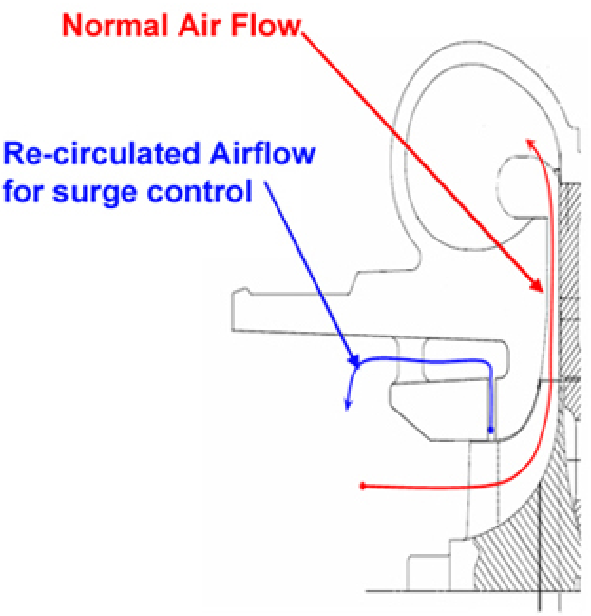


Figure 2

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ventas@turbomaster.info
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Surge will decay once the turbo speed finally slows enough to reduce the boost and move the operating point back into the stable region. This situation is commonly addressed by using a Blow-Off Valves (BOV) or bypass valve. A BOV functions to vent intake pressure to atmosphere so that the mass flow ramps down smoothly, keeping the compressor out of surge. In the case of a recirculating bypass valve, the airflow is recirculated back to the compressor inlet.

*A **Ported Shroud*** compressor *(see Fig. 2)* is a feature that is incorporated into the compressor housing. It functions to move the surge line further to the left *(see Fig. 3)* by allowing some airflow to exit the wheel through the port to keep surge from occurring. This provides additional useable range and allows a larger compressor to be used for higher flow requirements without risking running the compressor into a dangerous surge condition. The presence of the ported shroud usually has a minor negative impact on compressor efficiency.

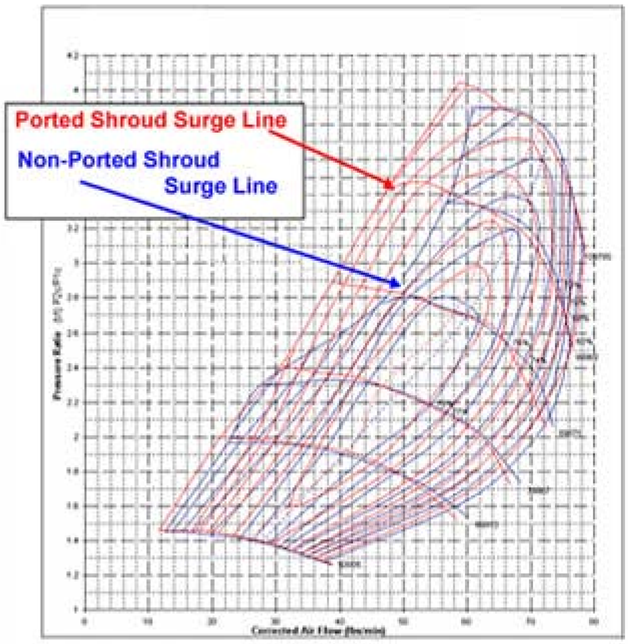

Figure 3

The Choke line

The Choke Line is the right hand boundary of the compressor map. For Garrett maps, the choke line is typically defined by the point where the efficiency drops below 58%. In addition to the rapid drop of compressor efficiency past this point, the turbo speed will also be approaching or exceeding the allowable limit. If your actual or predicted operation is beyond this limit, a larger compressor is necessary.

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The turbo speed lines

Turbo Speed Lines are lines of constant turbo speed. Turbo speed for points between these lines can be estimated by interpolation. As turbo speed increases, the pressure ratio increases and/or mass flow increases. As indicated above in the choke line description, the turbo speed lines are very close together at the far right edge of the map. Once a compressor is operating past the choke limit, turbo speed increases very quickly and a turbo over-speed condition is very likely.

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